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Concept note

Forest-food nexus: a topical opportunity for human well-being and silviculture

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Abstract - As population will reach over 9 billion by 2050, interest in the forest-food nexus is rising. Forests play an important role in food production and nutrition. Forests can provide nutritionally-balanced diets, woodfuel for cooking and a broad set of ecosystem services. A large body of evidence recommends multi-functional and integrated landscape approaches to reimagine forestry and agriculture systems. Here, after an in-depth commented discussion of the literature produced in the last decade about the role for forests with respect to the food security global emergency, we summarize the state of the art in Italy as a country-case-study. This commentary aims to increase awareness about the potential of silviculture in Italy for combining ecological resilience with economic resilience, and for reasonably increasing non-wood products supply by means of a sustainable intensification of forest management at national level. Chain-supply fragmentation, landowner inertia, and lack of governance and cooperation may hamper an effective exploitation of non-wood products. The strategies to guarantee an effective supply of non-wood products require appropriate business skills and the presence of a structured business service. A transparent market is also essential; therefore, the introduction of standards (e.g. grading rules and forest certification schemes) is important since they can add value to products and services, and emphasize the importance and complexity of the forest sector. However, the implementation of sustainable forest management for an effective supply of non-wood products is affected by the availability of appropriate planning tools, and the public officers need a new mindset to stimulate and support the business capacity of forest owners.

Keywords - Forest, Food, Silviculture, Security, Safety

Introduction

Up to 805 million people are undernourished worldwide (FAO, 2014) and malnutrition affects nearly every country on a global scale (IFPRI, 2014). As the world population was 7.2 billion in 2013 and is projected to reach over 9 billion by 2050 (Roberts, 2011), the demand for food, feed, fibre and energy will increase, while per-capita land availability will decline. Therefore, the issues of food security and nutrition are now strategical in policy debates. In 2012, the UN Secretary General proposed to eliminate global hunger by 2025 – the so-called "Zero Hunger Challenge". In parallel, interest in the role of forests and tree-based systems in complementing agricultural production has been rising (Vira et al. 2015).

Forests provide food for one billion people, e.g. by providing ≈20% of proteins in the diet in 62 countries (FAO, 2013). However, the forest-food nexus is complex with many and strong connections. Forests produce carbohydrates, proteins, fats, vitamins, fuels, medicinals, wood for construction, fencing and furniture, as well as essential ecosystem services such as water control and protection of biodiversity, soil, and quality of water and air. The intensity by which forests are managed affects forest structure (Vilén et al., 2012), soils (Jandl et al., 2007), biogeochemical cycles (Luyssaert et al., 2007), biodiversity (Paillet et al., 2010), and other ecosystem services provisioning (Gamfeldt et al., 2013). Growing demand for food, energy and land is increasing the pressure over forests. Loss and degradation of forests worsen food insecurity both directly – by affecting the availability of fruits, wildlife, mushrooms and other products of use in the food industry (tannins, cork, truffles, aromatic herbs, honey, etc.) – and indirectly – by modifying the factors that are important for crop and livestock production (van Noordwijk et al., 2014).

A recent Global Assessment Report prepared by the International Union of Forest Research Organizations (Vira et al. 2015) highlights that the complex processes linking tree products and services to food security and nutrition are currently not adequately incorporated into global and national strategies. Although the focus is mostly on those parts of the world that are characterized by extensive hunger

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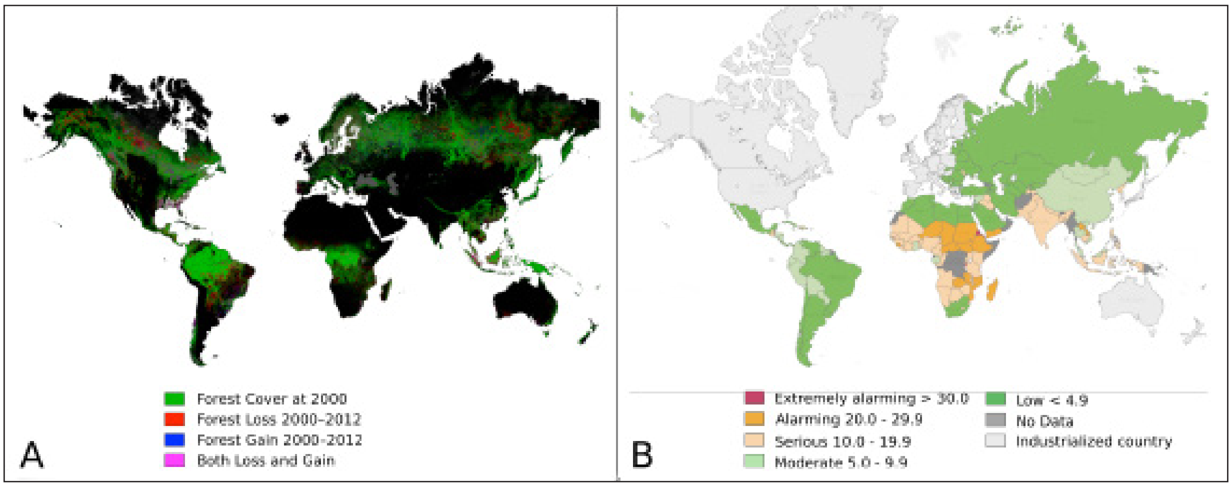

Figure 1 - A, Global forest cover change from 2000 to 2012 (Hansen et al., 2013). Green marks, no change; red marks, loss; blue marks, new forests; purple marks, areas with both losses and gains. B, Global Hunger Index 2014 (Von Grebner et al., 2014).

and malnutrition, primarily in poorer nations and in the tropics (Figure 1), also the most industrialized countries can contribute to a sustainable use of their own forests for improving global food security.

After an in-depth commented discussion of recent scientific literature about forest contribution to food production and the main drivers of forest systems for food nutrition, this commentary addresses the state of the art in Italy as a country-case-study, that is representative of the situation in developed countries. The aim is to increase awareness about the potential of silviculture in Italy by means of a sustainable intensification of forest management for combining ecological resilience with economic resilience.

How forests contribute to food production and nutrition

Non-wood and non-timber products (NWFP and NTFP) are defined as products of biological origin other than wood derived from forests, other wooded land and trees outside forests" (FAO 1999) and as "all biological materials other than timber which are extracted from forest for human use" (De Beer and McDermott 1989), respectively. Therefore NWFPs include animal products (bush meat, trophy, skin, fish, insects), soil (litter, clay, chalk, sand), fungi (mushroom, truffle, spawn), and plants (trees, shrubs, herbs, grasses), which are further subdivided into flowers and fruits (food, oil, spices, honey), leaves (forage, fodder), stem and bark (latex, gum, resin, fibre, dye, sap, cork, bark pieces), while NTFPs include also wood in forms of fuelwood, poles, derivatives (Vidale et al., 2015). All these products may have either a direct or an indirect use in the food industry.

Natural forests, agroforestry systems, single-species tree crop systems and orchards support food production and contribute to dietary diversity and quality. They are a vital source of food to millions of people on the planet, although this service is not well recognized yet. Around one out of every six persons in the world directly depends on forests, with food being one essential aspect of this dependence (Agrawal et al., 2013; Vira et al. 2015).

Much attention is nowadays on agroforestry systems that involve the cultivation and management of trees and/or shrubs for food and/or non-food values (such as soil conservation or providing shelter for crops), generally in combination with agricultural crops. A geospatial analysis by Zomer et al. (2014) estimated extent and recent changes in agroforestry practices at a global scale, based on remote sensing-derived global datasets of land use, tree cover and population: agroforestry systems (defined in this study as agricultural lands with > 10 % tree cover) were 43 % (over 1 billion ha) of global agricultural land in 2010. Globally, the amount of tree cover on agricultural land increased substantially between 2000 and 2010, with the agroforestry area increasing by 3 % (+82.8 million ha). The proportions of agroforestry lands and of people living in these landscapes in Europe were 45 and 46 %, respectively, that basically correspond to the averages at world level.

All forest-based systems represent a steady supply of fruits, vegetables, seeds, nuts, oils, roots, fungi, herbs and animal protein. For instance, around 50 % of the fruit consumed globally comes from trees (Powell et al., 2013): most of these fruits are from fully-domesticated, cultivated sources, but native forests are important genetic resources for the improvement of planted stock (Dawson et al., 2014). A limited number of plant species (20-30) is nowadays used in conventional agriculture all over the world (Ducci et al., 2015), while natural forests and agroforestry systems often harbour high biodiversity and can deliver a wide array of tree foods. As an example, Mediterranean forests include 25,000 plant species (Myers et al., 2000).

Wild meat, fish and insects are other important food sources from forest systems. In Europe, wild ungulate populations of roe deer, red deer, wild boar and alpine chamois have been expanding in recent years (Ramanzin et al., 2010). At present, there are 20 ungulate species in Europe, with an estimated total number of 18 millions heads and a total biomass of about 770 000 tons (Apollonio et al., 2010). The growth of ungulates in many areas has turned into overabundance, originating conflicts with human activities and biodiversity. Marketing of meat from hunted wild ungulates is already a practice in various European countries (Winkelmayer and Paulsen, 2008), and has been proposed as a way of counteracting overabundance (Thogmartin, 2006). Game meat production as alone was estimated over 23,000 tons in EU-28, corresponding to a total value of above 321 M € (FOREST EUROPE 2015). Safety requirements of game meats have been addressed by Regulations (EC) No. 853/2004, 854/2004 and 178/2002. The value of fish as a nutritious food is well established (Kawarazuka and Béné, 2011). In many tropical forests, wild fish represents the main source of animal protein in the diet (daSilva and Begossi, 2009). The importance of insects as a source of food and livestock feed has recently gained momentum (FAO, 2013). Insects are a cheap, available source of proteins, fats, and, to a lesser degree, carbohydrates. Some species are also considered good sources of vitamins and minerals (FAO, 2013; Schabel, 2010).

Trees also provide fodder, green fertiliser and fuel that are essential to food production. Animal fodder enables communities to keep livestock that provides them with nutritionally important products, such as milk and meat. Trees also provide green manure that replenishes soil fertility and supports crop production (Jamnadass et al., 2013). Many forest products are also used in ethnoveterinary treatments that support animal health and hence human food production (Dharani et al., 2014).

In developing countries, 2.4 billion households still use conventional biofuels for cooking and heating. Firewood is the most important rural domestic biofuel in the world, and is expected to further increase (IEA, 2006).

Forest products are also an important source of revenue, which can contribute to food supply. A multitude of NTFPs harvested from natural and cultivated forests and woodlands provide a range of resources that are used directly, or are sold for income that can be used to purchase a variety of products, including food. As NWFP consumption is rarely reported by the national statistical agencies, an estimation of their economic value is complex.

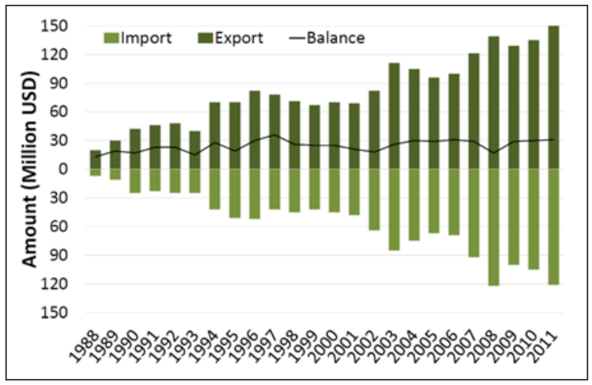

Figure 2 - EU-World trade balance for non-wood forest products (Vidale et al., 2015).

According to UN (2000) and FAO (2010), however, the market in Europe is rising, as it totaled 1.10 billion € in 1995 and 4.53 billion € in 2005. Both import and export of European NWFPs have been considerably increasing in the last 25 years, with a net balance of more than 30 million USD in 2011 (Figure 2). When there is availability but relatively low NTFP food use in areas of dietary need, reasons can include high labour costs, low yields, high phenotypic variability (with large proportions of non-preferred products), and lack of knowledge on appropriate tree management (Jamnadass et al., 2011).

Apart from these direct roles, forests provide ecosystem services which underpin the agricultural production and support the diversification of livelihoods. Forests, agroforests and, within certain conditions, plantations provide important ecosystem services, including water provision, soil protection, nutrient cycling, climate regulation, clean air and water, biodiversity conservation, and pollination, all of which are essential for crop production and ultimately affect food and nutritional security (Figure 3). Here below, we summarize the major links between food security and these forest ecosystem services.

Forests, woodlands and trees play a vital role in controlling water flows and in supplying farmers with water (Malmer et al., 2010). If rainfall does not provide sufficient water supply, households depend on sources of groundwater that are often found in or near the forest. Moreover, forests play a basic role in the quality of groundwater since they act as filters and remove pollution from water and air, with benefits for human and crop health. Trees also prevent soil erosion and nutrient leaching, both of which are critical functions for food production systems. At the same time, green manures and forest litter maintain and enhance soil fertility, supporting crop yields when external fertiliser inputs are not available (Garrity et al., 2010). Nitrogen-fixing trees have received considerable attention for their ability

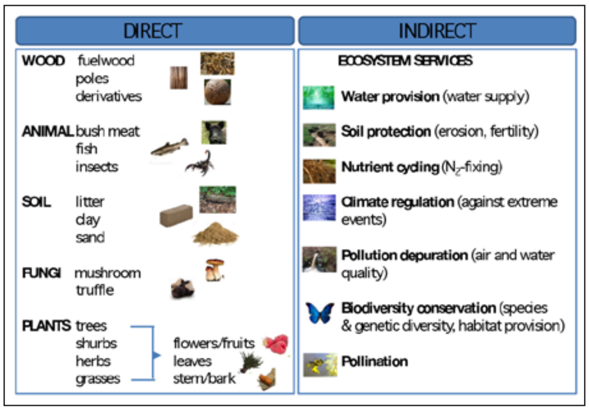

Figure 3 - Effects of forest-based systems to support agricultural production.

to cycle atmospheric nitrogen in cropping systems (Sileshi et al., 2012). Climate regulation by trees can promote more resilient and productive food-cropping systems, such as through the provision of a canopy that protects crops from direct exposure to the sun, extreme rainfall events and high temperatures (Pramova et al., 2012). Forests are centres of plant and animal biodiversity, protecting species and their genetic variation, which may be essential for human food security (Dawson et al., 2014). Pollination is one of the most studied ecosystem services (Klein et al. 2007). A diversity of trees can support populations of pollinator species such as insects and birds (Garibaldi et al., 2013). In addition, forests provide important habitat for a range of other fauna that include the natural predators of crop pests, although forests may also host the crop pests themselves.

Drivers of forests and tree-based systems for food security and nutrition

Interconnected environmental, social, economic and governance factors affecting forests and tree-based systems for food security and nutrition have been classified into the following major drivers: population growth, urbanisation, governance shifts, climate change, commercialization of agriculture, industrialisation of forest resources, gender imbalances, conflicts, formalisation of tenure rights, rising food prices and increasing per capita income (Kleinschmit et al. 2015).

The shift from forests and tree-based systems towards agriculture is among the many inter-related factors that continue to drive deforestation and forest degradation. Deforestation and forest degradation interact with food security and nutrition by affecting both the direct and indirect provision of goods and services. During the past decade, deforestation rates have decreased globally, while some countries are showing increasing rates of reforestation (Meyfroidt and Lambin, 2011). However, deforestation continues unabated in many parts of the world, and is in large part the result of agricultural expansion, cattle ranching (FAO, 2010), urbanization, and globalization of agricultural trade (De Fries et al., 2010). Recent trends show that agriculture is the biggest driver accounting for 73 % of deforestation worldwide, while mining accounts for 7 %, infrastructure for 10 % and urban expansion for 10 % (Hosonuma et al., 2012). Agri-businesses such as cattle ranching, soybean farming and oil palm plantations are now the most important drivers of forest loss globally (Boucher et al., 2011).

Further, an increasing proportion of the world forests have been degraded both structurally and functionally. Forest degradation is the long-term decline in forest ecosystem function and productivity caused by disturbances from which land cannot recover without human intervention. Land degradation currently affects hundreds of millions of hectares of agricultural lands and forests, and an estimated 1.5 billion people who live in these landscapes (Zomer et al., 2009). Land degradation is the long-term result primarily of poor agricultural management, associated with the expansion of extensive and intensive agricultural production practices into lands that are only marginally suitable for such activities. Without adequate organic or fossil fuel-derived fertilisers or other agricultural inputs (e.g. irrigation, pesticides, etc.), agricultural productivity typically declines in such areas. The drivers of forest degradation include unsustainable forest management for timber, fuelwood, wildlife and other NTFPs, air pollution, and human-induced fires, exacerbated in many regions by a number of factors, including climate change (Chazdon, 2014) and changing rural demographics (Uriarte et al., 2012).

As already stressed, deforestation and forest degradation interact with food security and nutrition. For instance, they affect forest carbon stocks and have implications for the governance and local use of forests (Phelps et al., 2010). Studies have shown that there is a direct relationship between tree cover, tree species diversity and food security especially of vulnerable groups (van Noordwijk et al., 2014). Changes in the extent and type of forests have implications for food provisioning, and for food security and nutrition of local and distant human populations (Sunderland et al., 2015). Habitat loss, largely driven by agricultural expansion, has been identified as the single largest threat to biodiversity worldwide (Newbold et al., 2014). Agricultural activities are intensifying, particularly in the tropics (Shackelford et al., 2015). The tropics host the majority of biodiversity-rich areas on the planet.

Consequently tropical land is increasingly subject to competing claims (Giller et al., 2008). A range of concepts and frameworks for implementation are now being discussed which aim to consider land-use change in forested landscapes in such a way that competing demands for food, commodities and forest services may be, hopefully, reconciled (Pirard and Treyer, 2010).

In a world characterized by increasing resource and land scarcity, the traditional conflicts between farming and foresting are aggravated by the increased demands for land to allow for the expansion of urban settlements, industrial development and resource extraction. Under such increasing pressures, hard choices have to be made about land and forest management. Sustainable multi-functional integrated landscape approaches aim at balancing livelihood security and nutritional needs of people with other land management goals (Vira et al. 2015). The contribution of forests to these approaches is of high significance for the implementation of existing international commitments. Forests and tree-based systems are embedded within a mosaic of food production systems and other land uses. An integrated governance is thus needed for securing these multi-functional landscapes.

Present pressures on forests, including climate change, population growth, urbanisation, deforestation, are often interrelated. Thus, designing appropriate responses requires multiple, nested-scales approaches. Managing resilient and climate-smart landscapes on a multi-functional basis that combines food production, biodiversity conservation, other land uses and the overall maintenance of ecosystem services should be at the forefront of efforts to achieve global food security (Vira et al. 2015). Applying an integrated landscape approach provides a unique opportunity for forestry and agriculture to coordinate efforts. Not all tree commodities are, however, amenable to production in diversified systems; for example, oil palm is not well suited (Donald, 2004).

Greater attention from the scientific and policy communities is required for reimagining forests for food security. In particular, a supportive policy framework needs to be developed that considers both the forestry and agriculture sectors in tandem. A better quantification of the benefits received by rural communities from different tree production categories is required (de Foresta et al., 2013): in many tropical countries, laws for timber extraction were largely designed around large-scale export-oriented forestry operations rather than to sustain healthy small-scale domestic markets (Cerutti et al., 2013).

Non-wood forest products in Italy

FOREST EUROPE (2015) estimated that a marketed value of around 2.3 billion €/year is provided by plant (73%) and animal (27%) products from European forests, but the statistics may be incomplete. With respect to the total, 1.7 billion €/year is from plant products (73%), with the main part represented by decorative and ornamental plants (47%), while the value of animal products is around 0.6 billion €/year, mainly due to wild meat (51%) and wild honey (45%). Overall, NWFPs trade is increasing in Europe (Figure 4), where raw NWFPs account for ~20% of timber trade (Vidale et al., 2015). Italy is first in Europe as ratio of annual NWFP value to annual value of industrial roundwood (Figure 4).

Recent results from the COST Action StarTree (Vidale et al., 2015) show that Italy is among the four top European exporters of cork stoppers, is one of the three top countries for chestnut seed processing, and is among the leading exporters of wild mushroom, while it is the only European country among the top five global importers of tannins.

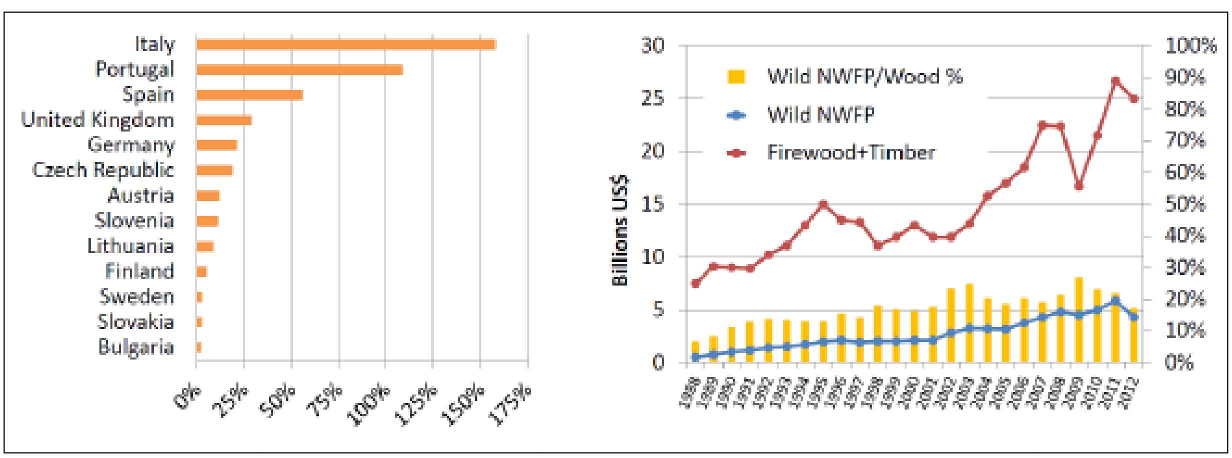

Figure 4 - Ratio of annual non-wood forest product (NWFP) production to industrial roundwood (left), and trade of NWFP and wood in Europe (right) (Vidale et al., 2015; FOREST EUROPE 2011).

The annual value of marketed NWFP in Italy is estimated around 100 M €, but the statistics may be largely incomplete (FOREST EUROPE, 2015). Among NWFPs, food products are also relatively relevant. For instance, Italy is the second largest European chestnut (*Castanea sativa*) producer for fresh and dry products and flour; walnut (*Juglans regia*) production is 10,500 tons per year (Ducci et al. 2015). The market for pine (*Pinus pinea* and *Pinus cembra*) fruits in shell represents over 208,000 tons per year, 80 % absorbed by the industry. Collecting mushrooms and truffles has considerable importance in the economy of rural mountainous and hilly areas: reliable statistics are not available for mushrooms while Italy is the 3rd European producer of truffles, with a turnover of over 19 M €/year (Ducci et al., 2015).

Game meat market trend observed at European level is similar even in Italy, where the increase of total forest coverage and a cautious approach in forest harvesting have enhanced the expansion of ungulates. This trend involved mainly roe deer (*Capreolus capreolus* L.), wild boar (*Sus scrofa* L.) and red deer (*Cervus elaphus* L.), whose populations are estimated to be over 400,000, 1,000,000 and 65,000 heads, respectively, with increasing pressure on agricultural crops and forests in many areas (Chianucci et al., 2013). Roe deer, wild boar and red deer represents over 80% of total ungulates biomass and contribute to the market of wild meat with important economic revenues, which are estimated around 25 M €/year just for Tuscany, a region in Central Italy (Cutini et al., 2015).

The Italian trade of honey is estimated in 38 M €: transhumance of hives to the woods affects honey quality and organoleptic traits determined by the forest species that provide pollen and nectar. Another important example of high value production at local level is that of *manna*, a natural product, at high content of mannithol harvested by the incision of the bark from two species of Ash (*Fraxinus* spp) trees: Italy is the first world producer of manna, with 3200 kg per year (Ducci et al., 2015).

Grounds for intensifying silviculture and food products from forests in Italy

Albeit trade-offs between wood and NWFPs cannot be excluded as it is often the case in developing countries (Chakravarty et al., 2015), in Italy an effective joint impulse for exploitation of wood and NWFPs may come from a sustainable intensification of forest management, with a reasonable increase of the marketed NWFPs too: currently these products are, in many cases, excluded from the market and fostering payments for them would encourage landowners to sustainably manage their forests on the whole (Prokofieva et al., 2012).

Chain-supply fragmentation, ownership fragmentation (Paletto et al., 2013), landowner inertia, and lack of governance and cooperation may hamper an effective exploitation of food products from Italian forests. However, these issues impact all the product chains from forestry in Italy. Generally, the increase of forest service demand and the gradual abandonment of mountainous land have caused a decrease of forestry and significant changes in land management. Only in the case of coppice, wood production has remained relatively high. The wood harvesting rate of Italian forests is ~14 Mm^3/yr, i.e. 1.5 m^3/ha yr (Gasparini and Tabacchi, 2011) and is among the lowest rates in Europe. As a consequence, also the mean value of marketed roundwood (74 €/ha) is much lower than in the neighbouring countries (FOREST EUROPE, 2015). In contrast, the current increment of wood volume is around 36 Mm^3/yr (Gasparini and Tabacchi, 2011), and thus the harvesting rate (≈40 %) is largely lower than in the EU-28 and Europe (71 % and 66 %, respectively, FOREST EUROPE, 2015).

To develop Italy's forest sustainability and resilience and favour forest bioeconomy, an intensification of forest management is the possible solution to the conundrum that increasing demand for conservation areas and increasing pressure for good production have created, similarly to what is happening in Europe (Carnus et al., 2012) and other world areas (e.g. Canada, Mathey et al., 2008). An improved awareness of policy makers and the general public may translate these unexploited Italian forest assets into employment (e.g. a gradual and sustainable increase of the wood harvesting rate up to a sustainable threshold of 20-21 Mm^3/y would translate into ~35,000 new jobs) and gross domestic product.

Developing measures targeted at increasing wood and non-wood supply from forests requires policy decisions and expert knowledge. A forest management map of European forests has been recently developed (Hengeveld et al., 2012): approaches of this kind may greatly help in selecting the areas suitable for intensification. Moreover, the implementation of sustainable forest management for an effective supply of wood and non-wood products is conditioned by an appropriate use of planning tools, and the public officers need to develop a new mindset for stimulating and supporting the business capacity of forest owners.

As concerns distinctively the NWFPs, it should be stressed that they can be effectively exploited under the broader perspective of territorial marketing (Pettenella and Secco, 2006): well known success cases are those of the Road of Porcino mushroom (http://www.stradadelfungo.it) and the Road of Truffle and Chestnut (http://www.tartufoe-castagna.it). Under such a perspective, the strategies to guarantee an effective supply of NWFPs require appropriate business skills and the presence of structured business services. A transparent market is also essential: the introduction of standards (such as grading rules and forest certification schemes) is important since they can also add value to products and services, and emphasize the importance and complexity of the forest sector.

Conclusions

Policy processes towards a bio-based economy should seek to produce decisions that are evidence-based (Corona, 2014). Contextually, the use of scientific knowledge to support evidence-based decisions requires suitable communication of figures and key findings: this paper has been targeted to contribute to this end.

The adoption of large-scale industrial agriculture has resulted in negative impacts on the environment (Cassman, 2012), public health (Bandara et al., 2010) and even nutrition (Ellis et al., 2015), suggesting the paradigm itself needs to be challenged (Tilman and Clark, 2014). This approach was appropriate to the context of the 1960s and 1970s, when water and nutrients were abundant, energy was cheap, and ecosystems were able to detoxify pollutants. The global context today is very different with growing scarcity of cheap energy (Day et al., 2009), water (Wallace, 2000) and nutrients (e.g. phosphorus, Cordell et al., 2009).

The development of crop agriculture and animal husbandry over the past few centuries, and particularly since the early 20th century, has diminished dependence on forests for food security and nutrition in many societies. Nonetheless, forests continue to play a very important role, often complementing other food production systems, and, on a global level, can contribute to the "Zero Hunger Challenge" (Vira et al. 2015). While forests are not a solution for global hunger in themselves, in many circumstances they play a vital supplementary role, especially during periods of unpredictability (such as long drought spells), as they complement conventional staple diets derived from agricultural production systems. To do this efficiently, an improved knowledge of the most effective management of landscapes and the role of forests in the provision of nutritious diets is required.

Evolving strategies to respond to the "Zero Hunger Challenge" primarily focus on achieving a sustainable intensification, by improving the productivity of agricultural and forest systems without causing ecological harm or compromising biodiversity and other ecosystem services (FAO, 2011; Garnett et al., 2013). Paradigms for forest and tree management have evolved considerably in the last 50 years, away from a state-controlled, production-centric approach to more collaborative systems which prioritise the needs of local people, and value the provision of ecosystem services (Mace, 2014). Landscapes are now managed for a much more diverse (often non-local) set of purposes (Ribot et al., 2006). It is time to develop a vision where economic resilience is joint with ecological resilience towards actual sustainability.

Managing landscapes on a multi-functional basis that combines local and global scales, food production, forest conservation and the maintenance of ecosystem services will help to achieve food security (Godfray, 2011). This provides a unique opportunity for silviculture and agriculture to coordinate efforts at the conceptual and implementation levels and achieve more sustainable systems.

Italian forests are well suited for a sustainable intensification of forest management, i.e. for suitably increasing the intensity of forest harvesting while maximizing the provision of forest ecosystem services and products. Ultimately, national production of wood and non-wood goods, including food products, may reduce the pressure on global forests, in particular in the areas at higher risk of deforestation and hunger.

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Research paper

Long-term development of experimental mixtures of Scots pine (*Pinus sylvestris* L.) and silver birch (*Betula pendula* Roth.) in northern Britain

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Abstract - The Caledonian pinewoods of northern Scotland are a priority conservation habitat in Europe which are dominated by Scots pine (*Pinus sylvestris*), but varying proportions of a number of broadleaved species such as silver birch (*Betula pendula*) can occur in these forests. Better understanding of the dynamics of mixed Scots pine-birch stands would be helpful in informing current initiatives to restore and increase the area of the pinewood ecosystem. Some evidence is provided by two experiments established in the 1960s which compared plots of pure Scots pine and pure birch with two treatments where the two species were mixed in 3:1 and 1:1 ratios. Some fifty years later, Scots pine was the more vigorous of the two species in these experiments, being both taller and significantly larger in diameter. The highest basal area was generally found in the pure Scots pine plots and the values in the mixed plots tended to be intermediate between those of the two component species. Examination of the growth in the mixed plots showed a slight, but non-significant, tendency towards overyielding. This appeared to be due to Scots pine growth being better than predicted, while that of birch was slightly less than predicted. These results suggest that in these mixtures, which are composed of two light demanding species, the main mechanism driving long-term performance is inter species competition and there is little evidence of any complementary interaction. These results suggest that any strategy seeking to increase the long-term representation of broadleaves such as birch in the Caledonian pinewoods will need to create discrete blocks that are large enough to withstand the competitive pressures exerted by the pine.

Keywords - Mixtures, Pinus sylvestris, Betula pendula, competition

Introduction

There has been increasing interest in growing tree species in mixed stands for reasons such as adapting forests to climate change, providing greater biodiversity, and enhancing the visual attractiveness of forests (Quine et al. 2013). However, successful establishment and management of mixed species forests depends on understanding the characteristics of the component species (e.g. growth habit, shade tolerance) and the way in which their mutual interactions change over time (Pretzsch 2009, chapter 9). Paquette and Messier (2011) suggested that beneficial interactions between tree species may be more important in stressful environments such as the boreal forests while reviews of facilitation in wider plant communities have also highlighted the need for taking environmental gradients into account (Brooker et al. 2008). The complexity of these interactions suggests that, despite recent reports of the benefits of mixed stands for the provision of a range of ecosystem services including productivity (Felton et al. 2010, Zhang et al. 2012, Gamfeldt et al. 2013), it may be problematic to extrapolate potential performance of mixtures from one climatic region or site type to another.

Forests of the British Isles and adjoining regions of Atlantic Europe are mostly characterised by single species plantations of fast growing non-native conifers grown on relatively short rotations (Mason 2007, Mason and Perks 2011). Recent data (Forestry Commission 2003) suggest that the total area of mixed-species stands (defined as where no single species occupies more than 80 per cent of the stand) was only around 200,000 ha or about 8 per cent of the forest area of Great Britain. In the last decade there has been increasing recognition of the potential role of growing tree species in mixture as part of a strategy of adapting British forests to projected climate change (Read et al. 2009, p. 174-175). The UK Forestry Standard, which sets out the national basis for sustainable forest management, encourages forestry practices which promote greater species diversity such as fostering of mixed stands (Anon. 2011, p. 96). In addition, recent guidance in Wales and Scotland supports the wider use of a range of

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species mixtures (Anon. 2010, Grant et al. 2012). Nevertheless, the limited experience of the creation and management of mixtures in British forestry makes it difficult to be certain about the regions of the British Isles where mixtures may be most effective, the particular species combinations that should be deployed, and the interactions between management practice and mixture development over time.

One forest type where the role of mixtures has been discussed for several decades is the Caledonian pinewoods of northern Scotland, which are recognised by the European Union Habitats Directive as being of special conservation value (Mason et al. 2004). These forests are dominated by Scots pine (*Pinus sylvestris* L.) at all stages of stand development, but some stands can contain variable amounts of several broadleaved species including birches (*Betula pendula* and *B. pubescens*), aspen (*Populus tremula*) and rowan (*Sorbus aucuparia*) (Edwards and Mason 2006). In broad terms, these pinewoods can be divided into two categories: the remnants of genuinely native pinewoods amounting to about 17,800 ha and a more extensive area of Scots pine dominated plantations amounting to about 101,000 ha (Mason et al. 2004). The remnant pinewoods are managed primarily for biodiversity and landscape while the plantations are managed for a range of ecosystem services including timber production (of sawlogs and small roundwood) on a rotation of 70-100 years. However, the considerable age of many trees in the remnant pinewoods (Edwards and Mason, 2006) plus concerns over regeneration failure in these stands means that sensitive management of the plantations will be important for the long-term continuity of the pinewood ecosystem in northern Scotland. Given earlier studies showing beneficial effects of birch species on soil properties of acid heathland soils (Dimbleby 1952, Gardiner 1968, Miles 1981), it has been proposed that incorporating a proportion of birch into Scots pine plantation stands would improve soil and tree nutrition with consequent benefits for stand productivity, and possibly other ecosystem services. However, there is little published evidence that can be used to examine this proposition.

A study in south-eastern Norway compared productivity of nine paired plots of pure Scots pine with that found in mixtures of Scots pine and birch (Frivold and Frank 2002). Volume growth in the mixtures was less than that in pure stands, although the differences were not significant. Hynynen et al. (2011) investigated performance of mixed Scots pine and silver birch stands of mid rotation age on 14 sites in eastern Finland. Over a 19 year period, they found that volume increment decreased with increasing amounts of birch. However, an earlier report from Finland had suggested 10-14% increases in productivity from Scots pine/birch mixtures over the respective pure stands (Mielikäinen 1980). Models suggested that this increase appeared to diminish between 30 and 70 years of age with an optimum proportion of birch of no more than 20 per cent (Mielikäinen 1996). In an overview of the theory and performance of two species mixtures in Europe, Pretzsch (2005) also suggested that the performance of mixtures of light demanding species such as Scots pine and birch could be strongly affected by site conditions, noting an apparent loss of increment in birch in more oceanic conditions.

The only relevant British study described two experiments with Scots pine-birch mixtures where basal area declined with increasing proportion of birch (Malcolm and Mason 1999). The authors suggested that Scots pine appeared to be benefitting in mixture at the expense of birch. These results were obtained in 30-years-old stands that had only recently closed canopy while the studies by Frivold and Frank (2002) and Hynynen et al. (2011) also involved stands that were mostly under 50 years of age. Given that relative productivity of species can change with age (Pretzsch 2005), it would be dangerous to extrapolate long-term performance of two species mixtures from growth in the early stem exclusion phase (*sensu* Oliver and Larson 1996). In this paper, we report on the further development of Scots pine-silver birch mixtures in the two experiments previously examined by Malcolm and Mason (1999) when the trees were about 50 years of age, which is about two-thirds of normal rotation age for Scots pine in Britain (Mason et al. 2004).

Materials and Methods

The two experiments described in this paper were located at Ceannacroc in north-west Scotland (57° 7' N, 4° 45' W) and at Hambleton in north-east England (54° 15' N, 0° 30' W). The Ceannacroc experiment was planted on a peaty podsol on undulating terrain at 150 m elevation with annual rainfall of 1500 mm while the Hambleton experiment was sited on a podsolic ironpan soil on level ground at an elevation of 210 m with an annual rainfall of 810 mm. Both sites were used for sheep grazing before planting in 1960 (Ceannacroc) and 1961 (Hambleton). At time of planting, both sites were characterised by heathland vegetation with heather (*Calluna vulgaris* L.) being the dominant species. Soil fertility of both experiments would be classed as 'very poor' using the Ecological Site Classification (ESC) (Pyatt et al. 2001), but soil moisture would be classed as 'very moist' at Ceannacroc and 'slightly dry' at Hambleton.

Both sites were cultivated before planting to reduce vegetation competition using a shallow (c. 20 cm deep) single mouldboard plough. The same experimental design was used at both locations with 4 treatments being compared, namely pure Scots pine, pure silver birch, a 1:1 mixture of both species, and a 3:1 mixture of Scots pine and silver birch. These treatments were laid out in a randomised block design with three replications of each treatment using a plot size of 0.2 ha with 900 plants per plot at a spacing of 1.5 m between and within rows. The mixture treatments were achieved by planting alternative 25 plant plots (5 by 5 trees) of each species in a chequer-board pattern. This design would be considered as a 'replacement series' (Sackville Hamilton 1994) since the focus of investigation is on the effect of contrasting species proportions at a constant spacing.

All replicates were located in close proximity to one another at the Hambleton site, but at Ceannacroc one block was located 900 m to the east on a similar site type. At Ceannacroc, all birch trees were fertilised in 1962 at a rate equivalent to 8 kg P ha^{-1}, but no other remedial treatments were undertaken at either site during the establishment phase. At Ceannacroc there was an unauthorised thinning in 2002 which removed a number of Scots pine trees from all plots where this species was present. There has been windblow of isolated trees within this experiment since 2002. The Hambleton experiment was thinned in 1998 and in 2003. These were thinnings from below which removed suppressed and sub-dominant trees, amounting to between 5 and 15 per cent of the basal area in each treatment.

The early assessment history was described by Malcolm and Mason (1999), but essentially involved measurements of height growth at 3, 6 and 10 years after planting, and estimates of basal area and standing volume at around 31-32 years of age. Subsequent assessments at 40, 45 and 55 years (Ceannacroc) and 38, 43 and 48 years (Hambleton) measured dbh of all trees in an internal 0.09 ha assessment plot to calculate basal area plus also providing estimates of top height. The only exception was at Ceannacroc where inspection of the 32 year data revealed very poor growth in one plot of the 3:1 mixture in block two which had been planted on a wet peaty soil: this plot was excluded in the later measurements. The variable thinning history described above with no precise measure of material removed has meant that we have had to use current basal area as a measure of productivity in these experiments.

Analysis of the data followed procedures used recently in examination of results from the long-term mixtures experiment at Gisburn (Mason and Connolly 2014). In brief, this involved comparing species performance pure and in mixture assuming that performance of an individual species in a mixed plot could be treated as an independent value. We then compared the overall performance of the pure species and the two mixed treatments using standard analysis of variance procedures. This was extended to compare the performance of the mixture treatments with what would have been expected from the growth of the species in the pure plots. For this purpose we calculated a *delta* statistic which is derived as (*actual basal area – predicted basal area*) where the *actual* value is the observed performance in mixture while the *predicted* value is based on the species performance in the pure plots. A delta statistic of zero implies that mixed stand performance conforms to the predictions derived from that of the component species in pure stands, a negative value indicates that performance in mixture is less than would be predicted, while a positive value is a sign of enhanced productivity in the mixed stand. We calculated the delta statistic for each mixture combination in each replicate and analysed the results with ANOVA. We also examined the results of the various mixture combinations using methods for presenting results from a replacement series (Kelty 1992).

Positive mixing effects can be shown when the productivity of a mixture is greater than that of pure stands of the individual component species. Such effects are classed either as 'overyielding' where the productivity of the mixture is more than the average of the pure stands or 'transgressive overyielding' where the mixture outyields the most productive of the pure species (Pretzsch 2009).

Results

At both sites, and when averaged over all treatments, there were major difference between the growth of Scots pine and silver birch, with trees of the first species generally being significantly taller and larger at most ages of assessment (Table 1). The only exception was in the first decade after planting when birch trees tended to be taller than the pines. Based upon top height measurements at the last assessment, productivity was similar at both sites being 10 m^3 ha^{-1} yr^{1} for Scots pine and 4 m^3 ha^{-1} yr^{1} for birch (Edwards and Christie 1981).

In contrast to the major difference found between the species at most ages, there were relatively few interactions between species and mixture treatments (Table 2). Those that occurred were due to birch trees growing in one or both of the mixture treatments being appreciably taller than those growing in the pure birch plots (e.g. at Hambleton in year 32). At the time of the last assessment, the density of

Table 1 - Comparative growth of Scots pine (SP) and silver birch (BI) planted pure and in varying mixture proportions at different ages of stand development in two separate experiments in Scotland and northern England. Results are averaged over all treatments.

Parameter		Height (m)							Diameter (cm)			
Age (years)		3	6	10	32	40/38	45/43	55/48	32	40/38	45/43	55/48
Experiment	Treatment											
Ceannacroc	SP	0.2	1.1	2.6	13.5	-	-	18.9	14.5	17.8	21.4	22.3
	BI	0.3	0.9	1.9	13.5	-	-	17.6	12.9	11.5	15.1	15.4
	Significance	***	**	***	ns	-	-	ns	**	***	***	*
	SED	0.01	0.04	0.1	0.4	-	-	0.8	0.5	1.1	1.0	3.1
	5%LSD	0.02	0.09	0.2	0.9	-	-	1.8	1.2	2.5	2.2	6.9
Hambleton	SP	0.5	1.3	3.1	13.4	15.3	16.1	17.2	13.9	16.7	17.0	19.2
	BI	0.9	1.7	3.0	11.8	14.6	15.6	16.1	8.3	10.5	10.9	12.0
	Significance	***	***	ns	***	*	ns	**	***	***	***	***
	SED	0.02	0.05	0.1	0.2	0.3	0.2	0.2	0.3	0.5	0.7	0.7
	5%LSD	0.04	0.1	0.2	0.4	0.6	0.5	0.5	0.6	1.0	1.6	1.4

Notes:
1. Where two ages are given for an assessment, the first refers to the Ceannacroc experiment and the second to the Hambleton one.
2. Significance is defined as: ***= $p<0.001$, **= $p<0.01$, *=$p<0.05$, ns=non-significant.

Table 2 - Height and diameter growth of Scots pine (SP) and silver birch (BI) planted pure and in varying mixture proportions at different ages of stand development in two separate experiments in Scotland and northern England. Also stand density at the last assessment.

Parameter		Height (m)							Diameter (cm)				Density (stems ha^{-1})
Age (years)		3	6	10	32	40/38	45/43	55/48	32	40/38	45/43	55/48	55/48
Experiment	Treatment												
Ceannacroc	SP pure	0.2	1.0	2.5	13.0	-	-	18.6	13.6	16.4	20.7	24.0	807
	SP3:BI1	0.2	1.1	2.6	13.5	-	-	18.3	14.8	18.1	21.1	25.2	467
	SP1:BI1	0.3	1.1	2.7	14.1	-	-	19.7	15.1	18.5	22.4	26.1	459
	BI pure	0.4	0.9	1.7	12.4	-	-	18.6	12.4	13.0	14.6	16.8	1374
	BI1:SP3	0.3	0.8	1.8	14.2	-	-	16.1	14.4	9.4	16.4	19.1	194
	BI1:SP1	0.3	1.0	2.1	14.0	-	-	18.2	11.9	12.2	14.3	16.8	364
	Significance	**	ns	ns	ns	-	-	ns	ns	ns	ns	ns	-
	SED	0.01	0.1	0.2	0.8	-	-	1.5	1.0	2.2	1.9	5.4	-
	5%LSD	0.03	0.2	0.3	1.7	-	-	3.5	2,3	5.0	4.3	11.9	-
Hambleton	SP pure	0.5	1.3	3.0	13.3	15.4	16.5	17.6	13.3	15.9	16.7	18.6	1585
	SP3:BI1	0.5	1.3	3.0	13.4	15.4	16.0	17.4	13.6	16.4	17.3	19.0	1261
	SP1:BI1	0.4	1.3	3.1	13.4	15.2	15.7	16.7	14.8	17.7	16.8	20.1	922
	BI pure	0.9	1.7	3.0	10.4	13.8	15.0	15.9	7.9	10.4	10.8	11.9	1931
	BI1:SP3	0.9	1.7	3.0	12.1	15.0	16.0	15.9	8.2	10.7	10.7	12.1	305
	BI1:SP1	0.9	1.7	3.1	12.7	15.0	15.8	16.5	8.9	10.5	11.1	12.1	663
	Significance	ns	ns	ns	**	ns	*	*	ns	ns	ns	ns	-
	SED	0.03	0.1	0.1	0.3	0.5	0.4	0.4	0.5	0.8	1.3	1.1	-
	5%LSD	0.07	0.2	0.3	0.6	1.1	0.9	0.9	1.1	1.7	2.8	2.5	-

Notes:
1. In mixed plots, the value shown in a given row is for the first species listed, i.e. in SP3:BI1 the value refers to the Scots pine component of the mixture.
2. Where two ages are given for an assessment, the first refers to the Ceannacroc experiment and the second to the Hambleton one.
3. Height measure is a mean height for years 3-10 and a top height measure thereafter.
4. Significance is defined as: **= $p<0.01$, *=$p<0.05$, ns=non-significant.

the pure birch treatment at both sites was appreciably higher than that of the pure pine plots (Table 2). The overall density of the mixture plots was similar to that found in the pure Scots pine, but the pine was the dominant component of the mixture. Thus at the last assessment date, the percentage of Scots pine stems per mixture was 71 per cent (3:1 mixture) and 56 per cent (1:1 mixture) at Ceannacroc: equivalent figures for Hambleton were 81 per cent and 58 per cent (Table 2).

In the Hambleton experiment, basal area production was significantly higher in pure Scots pine than in pure birch at all ages of assessment (Table 3). The values for the two mixtures were intermediate between the two pure plots, but were never significantly different from each other. The 1:1 mixture always had a significantly lower production than the pure Scots pine treatment, but the differences between the latter and the 3:1 treatment were smaller. However, production in the two mixture treatments was always higher than in the pure birch treatment. Results at Ceannacroc were much more variable, reflecting the impact of the unauthorised thinning when the trees were 42-years-old. Until that time, results reflected those from Hambleton with highest values in the pure Scots pine, lowest in the pure birch, and the two mixtures intermediate between the two pure plots. However, at the two later dates, there was little difference between any of the treatments, reflecting the preferential removal of the

Table 3 - Basal area production of Scots pine (SP) and birch (BI) grown pure and in varying proportions in mixture in two different experiments in Scotland and northern England.

Parameter		Basal area (m^2 ha^{-1})			
Age (years)		32	40/38	45/43	55/48
Experiment	Treatment				
Ceannacroc	SP pure	41.0	49.7	29.0	34.9
	SP3:BI1	41.9	33.6	32.4	28.8
	SP1:BI1	34.2	42.3	32.1	32.8
	BI pure	19.8	27.5	30.7	33.3
	Significance	**	ns	ns	ns
	SED	2.6	9.5	3.6	7.1
	5%LSD	6.7	22.4	9.1	16.2
Hambleton	SP pure	42.3	42.0	44.9	44.8
	SP3:BI1	36.2	38.3	41.0	41.3
	SP1:BI1	34.2	35.6	30.0	38.5
	BI pure	24.4	23.0	24.7	24.6
	Significance	**	***	*	***
	SED	2.9	1.4	5.6	1.3
	5%LSD	7.1	3.2	13.8	3.1

Notes:
1. Where two ages are given for an assessment, the first refers to the Ceannacroc experiment and the second to the Hambleton one.
2. Significance is defined as: ***= p<0.001, **= p<0.01, *=p<0.05, ns=non-significant.

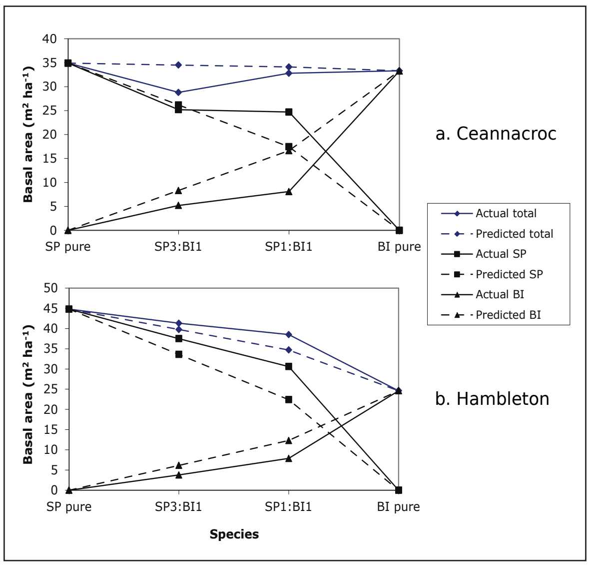

Figure 2 - Graphs of the basal area (m^2 ha^{-1}) at 55 years at Ceannacroc (Fig. 2a) and 48 years (Hambleton) (Fig. 2b) in two Scots pine-birch mixtures compared with the performance in pure plots of these species. Solid lines show the actual productivity in each treatment while the broken lines indicate the expected outturn if intra- and inter-specific interactions were equivalent.

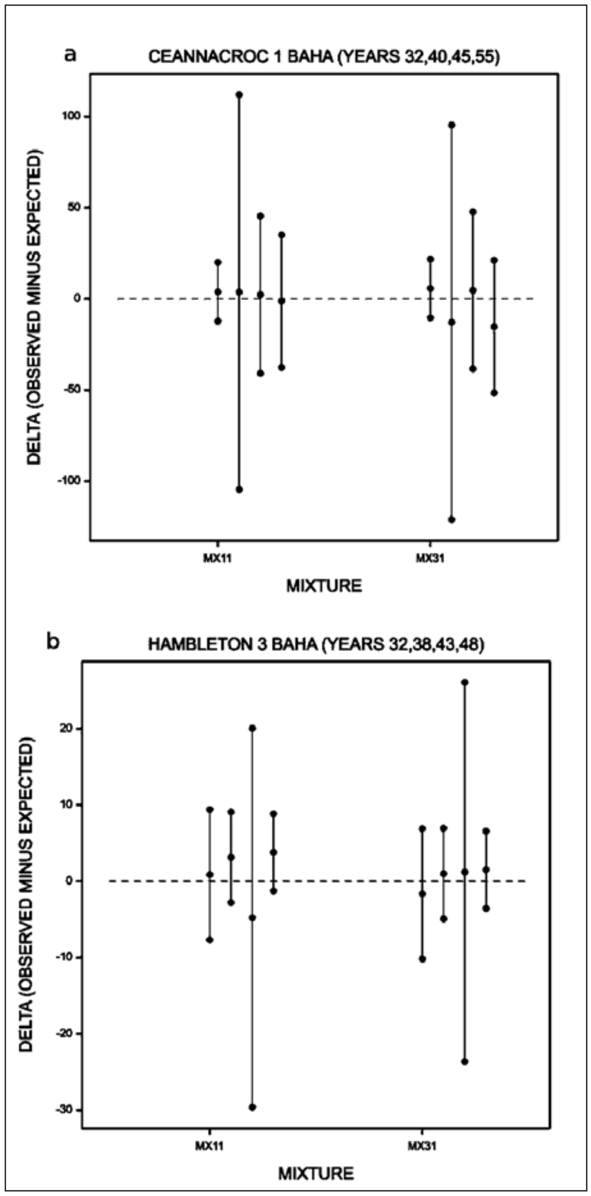

Figure 1 - Graphs showing the values of the delta statistic for differences in basal area (m^2 ha^{-1}) between the two Scots pine-birch mixture treatments and expected values based on the performance of the pure species plots in the experiments at Ceannacroc (Fig 1a) and Hambleton (Fig. 1b). Values are shown for the 1:1 and 3:1 Scots pine: birch mixture combinations in four different years covering tree ages 32-55 (Ceannacroc) and 32-48(Hambleton). At each age of assessment, the mean delta value and the 95 per cent confidence interval is presented.

pine in the thinning. At both sites, Scots pine had the highest proportion of basal area in the mixtures, comprising 83 per cent (3:1 mixture) and 75 per cent (1:1 mixture) at Ceannacroc, compared to 91 per cent and 80 per cent respectively at Hambleton.

Examination of the growth of the mixed plots compared to predictions based on performance of Scots pine and silver birch in the pure plots (Fig. 1a and 1b) revealed a general tendency for performance of the mixed plots to be slightly better than predicted (i.e. delta statistic >0), but these differences were never significant. There was also little evidence of any difference between the two mixture proportions. There were a couple of assessments where there was substantial variation around the predictions, namely year 40 at Ceannacroc and year 43 at Hambleton. The latter almost certainly reflects the thinning carried out in 2003, but the cause of the former is unclear. In both experiments the Scots pine component was more productive in mixture than predicted whereas the reverse applied to the birch (Fig. 2). This differential performance between the species was most apparent in the 1:1 mixture.

Discussion

Although both Scots pine and birches are widely distributed in northern Europe and are often found growing in mixture (Hynynen et al. 2010), there is a surprising lack of long-term experimental evidence to indicate how stands composed of these two light-demanding, pioneer species might interact. These two experiments were planted in parts of Britain which experience different climates, with annual rainfall at Ceannacroc being at least twice that recorded for Hambleton, yet there was relatively little difference in tree growth and productivity between the two sites. This suggests that, despite the variation caused by the unauthorised removal of Scots pine in the Ceannacroc experiment, the pattern of growth in the mixtures would have been quite similar at both locations. For the rest of this discussion, we mainly focus upon the Hambleton experiment to try to understand the processes influencing the patterns of growth and development in these mixtures.

After the initial establishment phase, Scots pine was taller and larger than birch throughout the life of these stands, and so came to dominate the mixed plots (Table 2). There was a period around years 30-40 at Hambleton where birch appeared to grow taller in mixture as also reported from Scandinavian studies (Mielikäinen 1980, Kaitaniemi and Lintunen 2010) but this trend did not persist in the later years. As a result of this differential growth between the species, there was a slight suggestion of overyielding in mixture (Fig. 2 - Hambleton) due to the greater productivity in the Scots pine more than offsetting the lower production in the birch. The poorer performance of birch in mixture is also evident at Ceannacroc (Fig. 2) despite the likelihood that the removal of the pine in thinning would have reduced the amount of inter-specific competition. However, as yet the overall improved performance in mixture has been small and not significantly different from what would have been expected based on the performance of the pure plots (Fig. 1). At Hambleton, there was also evidence that overall basal area production in mixture declined with increasing proportion of birch (Table 3), in line with results recorded in Scandinavia (Frivold and Frank 2002, Hynynen et al. 2011). The slower rate of self-thinning in the pure birch plots (Table 2) will also have influenced the smaller diameters and lower heights recorded for this species compared to Scots pine (Table 1).

Examination of tree species' interactions in mixed stands typically distinguishes three types of response, namely 'competition', 'competitive reduction' and 'facilitation' (Forrester 2014). The first of these responses occurs when one species has a negative impact on the growth or survival of another. The second arises where competition between species is less intense than competition within species, normally because of differential resource use by the component species of the mixture. Facilitation arises when the species interact in such a way that the growth of at least one of the species is positively affected. The second and third response can be difficult to distinguish and therefore the combined response is sometimes referred to as 'complementarity' (Forrester 2014). Although previous reports had shown slight changes in soil properties (e.g. a small increase in pH) with increasing proportions of birch (Malcolm and Mason 1999), the lack of any significant overyielding effect in the mixtures suggests that facilitation is unlikely to have occurred in these experiments.

Therefore, it seems likely that the response observed in the mixtures in these experiments represents a balance between competition between the two species, and competitive reduction in that the Scots pine appears to benefit from reduced intra-species competition due to the presence of birch in the mixtures. A further indication of the latter process is provided by the densities observed in the mixed stands at Hambleton, where there was negligible difference between the combined species density in the pure Scots pine and in the two mixed plots (Table 2) whereas stocking of the pure birch was some 20 per cent higher. The slower rate of self-thinning and lower vigour recorded in the pure silver birch plots would accord with the view that this species performs less well in oceanic Europe (Pretzsch 2005) and reflects the recommendation that dense birch stands should be heavily thinned to maintain vigour and improve timber quality (Cameron 1996). Site quality could also have influenced the outcome if the sites were too nutrient poor for good birch growth, since Scandinavian experience is that typical pine sites are too poor for silver birch (Hynynen et al. 2010). However, evaluation of species potential on these sites using the British ESC system (Pyatt et al. 2001) suggests that growth of both Scots pine and silver birch would be less than optimal (grading of 'suitable' in ESC), with limitations imposed either by lack of soil nutrients or excessive soil moisture.

These mixture experiments are now of an age that is close to two-thirds of that found in a standard rotation for Scots pine in Britain, yet there is no evidence that the magnitude of the limited positive interaction in the mixed plots has altered over time (Fig. 1). This may reflect the fact that the two species are both light demanding and have other similar functional traits which mean that they have limited ecological combining ability (Kelty 2006). The pattern of mixing used in the design may also have influenced the development of the mixtures and the extent of any overyielding since the 'chequerboard' layout will have resulted in small pockets of intense within-species competition alternating with less intense areas of between species competition along the edges of the species groups. Thus, analysis of a similar chequerboard mixture experiment with Norway spruce (*Picea abies* L. (Karst.)) and Scots pine, showed that diameter growth of individual Norway spruce trees was negatively affected by increasing numbers of Scots pine, but there was no effect of increasing numbers of Norway spruce (Yanai, 1992).

Conclusion

As noted earlier, one practical benefit from these experiments is to help improve understanding of the dynamics of the Scots pine-birch mixtures that can develop within the Caledonian pinewoods of northern Scotland, especially in the more oceanic western part of the pinewood zone (Edwards and Mason 2006). The results presented here do not suggest that there is much likelihood of a long-term coexistence of Scots pine and birch in intimate single storeyed mixtures, but rather that the more vigorous growth of the pine will tend to progressively eliminate the admixed broadleaved species. Any plan to enhance the proportion of birch in the Caledonian pinewoods would seemingly need to develop small blocks of birch within a pine matrix that were large enough to withstand the competitive pressure exerted by the pine and which could act as a future seed source.

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Research paper

Assessing the bibliometric productivity of forest scientists in Italy

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Abstract - Since 2010, the Italian Ministry of University and Research issued new evaluation protocols to select candidates for University professorships and assess the bibliometric productivity of Universities and Research Institutes based on bibliometric indicators, i.e. scientific paper and citation numbers and the h-index. Under this framework, the objective of this study was to quantify the bibliometric productivity of the Italian forest research community during the 2002-2012 period. We examined the following issues: (i) the bibliometric productivity under the Forestry subject category at the global level; (ii) compared the aggregated bibliometric productivity of Italian forest scientists with scientists from other countries; (iii) analyzed publication and citation temporal trends of Italian forest scientists and their international collaborations; and (iv) characterized productivity distribution among Italian forest scientists at different career levels. Results indicated that: (i) UK is the most efficient country based on the ratio between Gross Domestic Spending on Research and Development and bibliometric productivity under the Forestry subject category, followed by Italy; (ii) Italian forest scientist productivity has a significant positive time trend, but is characterized by high inequality across authors; (iii) one-half of the Italian forest scientist publications are written in collaboration with foreign scientists; (iv) a strong relationship exists between bibliometric indicators calculated by WOS and SCOPUS, suggesting that these two databases have the same potential to evaluate the forestry research community; and (v) self-citations do not significantly affect the rank of Italian forest scientists.

Keywords - Scientometrics, Forestry, Web of Science, SCOPUS, SCImago

Introduction

In the last few decades, increased attention has been paid to the scientific productivity of researchers and research institutions (Abramo & D'Angelo 2014; Adams 1990; Griliches 1998). Science policy increasingly includes productivity as a key factor in determining the financial budgets for research projects and scientists' careers (Bouyssou and Marchant 2010; Buela-Casal et al. 2010).

Chirici (2012) reported two main approaches applied to evaluate scientific productivity: (i) peer-review, where panels of appointed experts perform a qualitative evaluation; and (ii) bibliometrics, where a quantitative analysis of publications and citations is performed. In the last two decades, evaluation of researchers' work and careers has increasingly transitioned from peer-review to bibliometric evaluation (e.g. Seglen 1997b; Rogers 2002; Cameron 2005). Several studies were conducted that confirmed the use of bibliometric indicators as a suitable evaluation method (e.g. Falagas et al. 2006; Kumari 2006, Li & Zhao 2015). A measure of the publication and citation numbers provides an assessment of the respective quantity and quality of the research within a given field of science. For example, Vergidis et al. (2005) generated an analysis of microbiology researcher productivity; Falgas et al. (2006) examined global trends of research productivity in tropical medicine; Kumari (2006) compared the trends in different countries regarding synthetic organic chemistry research; Chirici (2012) analyzed Italian research productivity in forestry; and Li and Zao (2015) published a bibliometric assessment of global environmental research.

Measuring research strength is considered essential for a modern country's ongoing innovative and competitive capacity at the global level. A country's success in science, technology, and research determines its ability to compete for increasingly mobile resources and investment capital and to participate in global knowledge-sharing networks (The Council of Canadian Academies 2006). Monitoring research achievements in a specific field is crucial to measure a country's vitality in a specific research sector. The number of research publications in a certain scientific field reflects a country's commitment to science and is a reasonable indicator of its research

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and development (R&D) efforts in that field (Li & Zhao 2015; Falgas et al. 2006; Rajendram et al. 2006). Moreover, Hagen (2015) reported that participation in top-level international research is an indicator of national competitive ability and academic achievement. Multi-national teams has generated more than one-quarter of all publications in the world (Royal Society UK 2011). Collaboration has many benefits and is considered essential for groundbreaking research (Bidault & Hildebrand 2014; Sonnenwald, 2007).

The scientific output of a country is evaluated by assessing institutions or individual scientists. Two important parameters are examined, including overall production and impact of scientific publications (Bornmann 2011; Cronin 1984; Franceschini et al. 2007). The following three approaches are applied to evaluate these parameters using bibliometric indicators: i) counting the publication number; ii) counting the citation number; or iii) combining the first two counts to create hybrid indicators. Publication and citation counts are traditionally employed to indicate the influence or impact an author has within the research community (Adams 1990; Abramo & D'Angelo 2011, Wildegaard 2015). Hybrid indicators, such as the Hirsh index (h-index), provide a productivity measure and its impact using a single numerical value (Hirsch 2005; Jacso 2009; Alonso et al. 2009). An approach that offers an alternative to the combination of absolute output count and citation weight is to adjust citation measures directly for a range of factors, most commonly research age. For instance, the age-weighted citation rate (AWCR) adjusts citations by a given publication age (Jin 2007; Fedderke 2013).

A direct relationship exists between research and the overall development of a country (UNESCO, 2010). A viable approach to provide evidence of research productivity is to compare bibliometric indicators with Gross Domestic Spending (GDS) on research and experimental development (R&D) of a country (Meo et al. 2013; Leydesdorffa et al. 2009, Matthew et al. 2006). For example, the perfomance of a country in a specific field can be expressed as the number of scientific papers published or the number of citations received per 1 million USD investment in R&D (Clarke et al. 2007, Tarkowski 2007).

Another important performance aspect to analyze in a country or institution within specific scientific fields is productivity distributions among authors. Inequality indicators are applied to understand if productivity rates in a specific area are due to the efforts of a few or many authors (Cole & Eales 1917; Fuyuki et al. 2003; Bornmann et al. 2008).

Glänzel and Thjis (2004) has stressed the influence of self-citations in calculating bibliometric indicators. In fact, where citations are used as a proxy to evaluate impact on the scientific community, self-citations are problematic, as they do not represent the influence of the work on other researchers, and therefore might distort citation rates (Asknes 2003; Glänzel et al. 2006).

In the present study, these issues of individual and institutional productivity were examined with reference to Italy, and specifically to the Forestry subject category. Italy is a suitable case study: since 2010, the Ministry of University and Research introduced new evaluation protocols to select candidates under the National Scientific Habilitation (ASN – Abilitazione Scientifica Nazionale) and University and Research Institute productivity is assessed under the Evaluation of Research Quality (VQR – Valutazione della Qualità della Ricerca). Both evaluations are based on bibliometric indicators, i.e. number of scientific papers, citations and h-index (MIUR 2012). The assessments are also used to determine fund allocations to Universities.

Citation databases are employed to calculate bibliometric indicators. Comparisons of existing citation databases have been performed to assess scientific productivity of authors or organizations using Thomson Reuters Web of Science (WOS), Elsevier SciVerse Scopus (SCOPUS), and Google Scholar (Chirici 2012; Abrizah et al. 2013; Bartol et al. 2014). Franchescet (2010) completed a detailed literature review and demonstrated a moderate to high correlation between h-indexes produced by WOS and SCOPUS. In Italy, the National Agency for the Evaluation of Italian Universities and Research Institutes (ANVUR, Agenzia Nazionale per la Valutazione del Sistema Universitario e della Ricerca) recommended calculating bibliometric indicators on the basis of either WOS or SCOPUS.

The aim of the present study was to conduct a quantitative assessment of the bibliometric productivity of the Italian forest research community for the 2002-2012 publication period. Specific objectives were targeted to: (i) assess the global aggregated bibliometric productivity of Italian forest scientists using SCOPUS data available from the SCImago Journal & Country Rank (SCImago) systems; (ii) compare aggregated bibliometric productivity of Italian forest scientists with the most productive countries in Forestry on a global level (USA, UK, China, Germany, and France) on the basis of GDS on R&D; (iii) show publication and citation temporal trends by Italian forest scientists; (iv) analyze international collaborations by Italian forest scientists; (v) investigate inequality of bibliometric productivity among Italian forest scientists; (vi) show main subject categories of publications by Italian forest scientists; and (vii) compare productivity of Italian forest scientists at different career levels.

2. Materials and methods

2.1 Time frame and indicators

The 2002-2012 time period was analyzed, the same officially adopted by the Italian Ministry of University and Research for the last ASN evaluation.

The following bibliometric indicators were obtained from WOS and SCOPUS databases: i) number of publications (NP); ii) number of citations, including self-citations (NC) and without self-citations (NCws); and iii) h-index. NP is the number of scientific papers published by a given author; authorship sequence and journal ranking were not factored into the analysis. NC is the number of times papers written by an author were cited by other papers; the journal ranking where the citation was referenced was not considered; self-citations, defined as citations from papers authored or co-authored by the individual were either included or excluded. The last indicator was the well known Hirsch or h-index (Hirsch 2005). The h-index is defined by how many h of a researcher's publications have at least h citations each. The h-index requires the following: the total number of papers published by an author (NP) and the total citation number (here NC and NCws).

We also evaluated the following two additional bibliometric indicators useful in analyzing author efficiency: (i) mean citation number per paper, i.e. CPP (with self-citations) or CPPws (without self-citations); and (ii) age-weighted citation rate (AWCR), which enhances contributions from early stage researchers (Jin 2007; Fedderke 2013).

2.2 Global level analysis

Global comparisons of aggregated bibliometric productivity under the Forestry subject category were conducted on the basis of the SCImago database (SCImago 2007). For each year, NP, NCws, and AWCR were queried to determine the most productive countries of those included in the analysis, i.e. USA, France, Germany, China, UK, and Italy. The perfomance of a country was evaluated by calculating the GDS Index-NP as the ratio between GDS on R&D (GDS, in millions $USD); and NP and the GDS Index-NC as the ratio between GDS and NC. GDS was defined as the total expenditure (current and capital) on R&D conducted by all resident companies, research institutes, universities, and government laboratories in a country; it included R&D funded entities from abroad, but excluded domestic funds for R&D spent outside the domestic economy; this indicator was measured in millions USD and as a percentage of Gross Domestic Product (OECD 2015). The data on GDS were acquired from OECD (2015) as an mean over the 2002-2012 period.

The aggregated bibliometric productivity in Forestry of Western Europe was also compared with the USA and Italy based on NP, NC, and CPP. We integrated the definition adopted in SCIMAGO (SCImago, 2007) for Western Europe.

The international collaboration rate of a country was calculated as the percentage of publications whose affiliations of the authors include other countries on the total publications of the considered country.

2.3 Italian level analysis

An Italian forest scientist database including individuals with permanent positions was created from an official list of professors and researchers at Italian Universities and the Agricultural Research Council (CRA). The database included two different subject subcategories: forest management and silviculture (coded AGR05 for VQR and ASN), and wood technology and forest operations (coded AGR06 for VQR and ASN). As concerns the researchers at the National Research Council (CNR), who were not included in the list, we selected individuals officially affiliated with the Italian Society of Silviculture and Forest Ecology. The final database resulted in a total of 144 authors.

For each author, the following indicators were obtained: NP, NC, NCws, and h-index derived from WOS and SCOPUS, and h-index, excluding self-citations (NC), from SCOPUS only. We extracted author publications from 2002-2012 and citations attributed to those publications until the end of 2014. Differences in indicator means were tested for statistical significance using Wilcoxon's signed ranks test (Wilcoxon 1945). Statistical association among indicators derived from the two databases was calculated using the methodology of González-Pereira et al. (2010) and further developed by Chirici (2012).

We also analyzed NP, NC, and CPP temporal trends of the 144 authors during 2002-2012, the authors' international collaborations, and the specific subject categories where the papers were published. The international collaboration rate was calculated as the percentage of publications with international co-authors based on the total publication number (Morel et al. 2009). Co-author country affiliations were used to analyze the international co-authorship network (ICN) (Leydesdorff et al., 2014).

The Lorenz curve displays statistical distributions and the dimension of production unevenness or inequality. The approach was applied to conduct an in-depth investigation of differences between NP and NC among authors. The information in the Lorenz curve was also examined using the Gini coef-

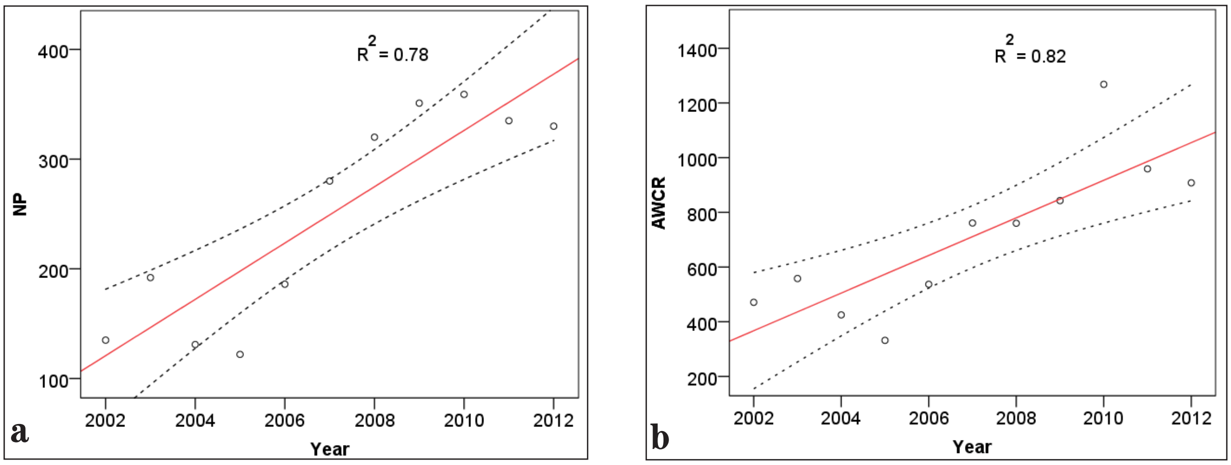

Figure 1 - Time trend of number of publications (a) and AWCR (age-weighted citation rate) (b) in Italy under the subject category Forestry in the period 2002-2012. Dotted lines are the 95% confidence interval of the linear regression. Data source: SCImago database.

ficient, a measure of statistical dispersion (Allison & Stewart 1974), similarly to Dundar and Lewis (1998) and Hagen (2015).

Self-citation relevance was analyzed to determine the rank position of individual authors in terms of citations and h-index. We chose the SCOPUS database and calculated Spearman's correlation coefficient (Spearman 1904) between each indicator determined with and without self-citations.

In Italy, scientists of Universities (UNI), the National Research Council (CNR), and the Agricultural Research Council (CRA) achieve three career levels: A-level (UNI: full professor; CNR: executive researcher; CRA: executive researcher); B-level (UNI: associate professor; CNR: first researcher; CRA: first researcher); C-level (UNI, CNR, CRA: researcher). Forest scientist productivity at different career levels (A-level, B-level, C-level) was analyzed using Wilcoxon signed-rank test; the mean, median, variance, maximum and minimum values, and standard deviation of each indicator were generated. We also compared CPP temporal trends per author per year among scientists at different career levels. The Gini coefficient was employed to quantify productivity inequality among authors at the same career level.

3. Results

3.1 Global results

Throughout 2002-2012, the cumulative bibliometric productivity of forest scientists at the global level was 0.60% of the total productivity of scientists for NP (118,561 vs. 20,117,441) and NC (1,503,622 vs. 249,752,677). The cumulative bibliometric productivity of Italian forest scientists (NP = 2824; NC = 49,214) was 0.013% NP and 0.015% NC in global bibliometric productivity and 2.3% NP and 2.6% NC in Forestry global bibliometric productivity. On a national level, the cumulative bibliometric productivity of Italian forest scientists was 0.44% of the total number of Italian scientific publications and 0.27% of the total citations received by Italian scientists.

Globally, the four scientific subject areas with the highest bibliometric productivity were Medicine (30% NP and 35% NC); Biochemistry, Genetics, and Molecular Biology (12% NP and 24% NC); and Engineering (19% NP and 9% NC). Agriculture and Biological Sciences, which include Forestry, represented 6.8% NP and 7.8% NC. The results from Italy were similar. The highest bibliometric productivity was represented by Medicine (35% NC and 41% NC); Biochemistry, Genetics, and Molecular Biology were consistent with global results (15% NP and 21% NC); and Engineering (15% NP and 9% NC). Results indicated Agriculture and Biological Sciences produced 6.6% of total NP and 6.9% of total NC in Italy.

In the Forestry subject category, the USA was the most productive country, with 32,032 total publications (35% of the total at the global level) and 71,808 citations (40% of the total), resulting in an h-index = 241. In 2012, Italy was ranked 9th based on its h-index (97); and 13th and 10th respectively from NP (2782), and NC and NCws (2722); and 8th from average citations per publication (CPP). While NP and AWCR increased from 2002-2012 (Fig. 1), Italy's h-index and NC rank remained stable over the examined period (Fig. 2).

On a global level, France, Germany, and the United Kingdom, which traditionally publish the largest number of European forestry papers, were respectively 2nd (142), 3rd (136), and 4th (133) in h-index results; and respectively 6th (5124), 4th (5931), and 5th (5280) in NP; and 5th (16015), 3rd (5732), and 2nd (17233) in NC, respectively.

The country demonstrating the highest improvement during the 2002-2012 period was the P.R. China, with results showing increased NP (from 7th position in 2002 to 2nd in 2006) and NC (from the 18th position in 2002 to 5th in 2012).

Among the countries examined, China had the

Figure 2 - Trend of number of publications (NP), number of citations with self-citations (NC) and without self-citations (NCws), mean citations per publication (CPP) and h-index of Italian authors under the subject category Forestry in the period 2002-2012. Bold numbers mark the position of Italy in the annual international ranking. Data source: SCImago database.

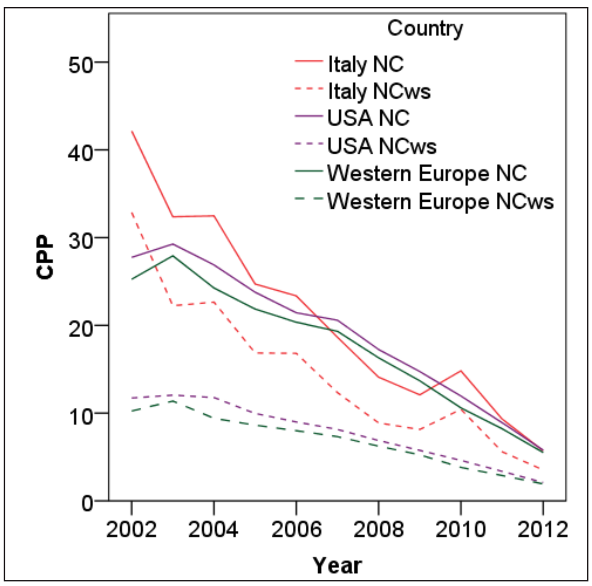

Figure 3 - Trend of CPP (mean citations per paper) with (solid lines) and without self-citations (dotted lines) for USA, Western Europe and Italy under the subject category Forestry. Data source: SCImago.

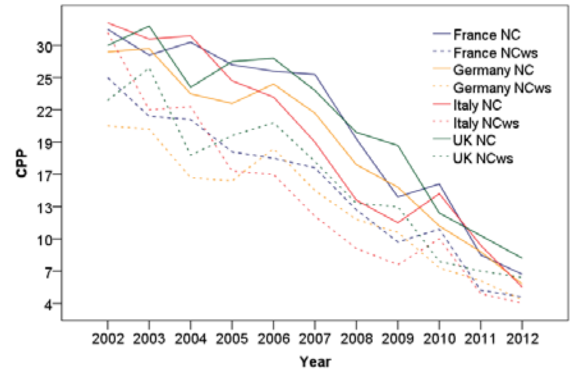

Figure 4 - Trend of CPP (mean citations per paper), with (solid lines) and without (dotted lines) self-citations, as concerns scientific papers from France, UK, Germany and Italy under the subject category Forestry.

lowest pro-capita GDS (106 USD), followed by Italy (392 USD) (Table 1). The UK was the most efficient in terms of total expenditure per article and per citation, followed by Italy. On average, Italy spent 32% less than China, 17% less than the USA, 23% less than Germany, 5% less than France, and 9% more than the UK to publish a paper. Italy spent 72% less than China, 22% less than Germany, 15% less than the USA, the same as France, and 13% more than the UK to generate a citation.

From 2002-2006 and 2010-2012, Italy demonstrated higher CPP values than the USA and Western Europe. Furthermore, Italy showed higher CPPws values than the USA and Western Europe over the entire period (2002-2012) (Fig. 3).

Italy's CCP was comparable to the three European countries with the most productive h-indices (France, UK, Germany). Italy ranked first in 2002 and 2004 and second in 2010 and 2011 (Fig. 4).

Italy demonstrated active international collaboration, evidenced by at least one co-author from a different country, always for at least 42% of the papers (minimum value in 2008) and the highest result was observed in 2002 with 64% of the papers (Fig. 5). Italy was more active than the USA with its international co-authorship.

Table 1 - Comparison of the efficiency of bibliometric productivity with respect to the gross domestic spending on research and experimental development (GDS). Data source: GDS: OECD (2015); NP and NC: SCImago.

	OECD data			Productivity		Productivity in Forestry				GDS Indices in Forestry	
Country	GDS (Million USD)	Population (Millions)	GDS pro capita (USD)	Total number of publications	Total number of citations	Number of publications (NP)	Number of citations (NC)	% of total number of publications	% of total number of citations	GDS Index-NP (Million USD per publication)	GDS Index-NC (Million USD per citation)
United Kingdom	36632	63.70	575	1526627	44011201	5344	102236	0.35	0.23	6.86	0.36
France	48185	65.63	734	984010	24700140	5248	103566	0.53	0.42	9.18	0.47
United States	381343	314.11	1214	5494335	177434935	32452	594488	0.59	0.34	11.75	0.64
Germany	80159	80.42	997	1141980	35721869	5977	107474	0.52	0.30	13.41	0.75
Italy	23316	59.53	392	648963	18019464	2824	49214	0.46	0.27	8.26	0.47
PR China	143672	1350.69	106	2482078	19110353	8882	48494	0.36	0.25	16.18	2.96

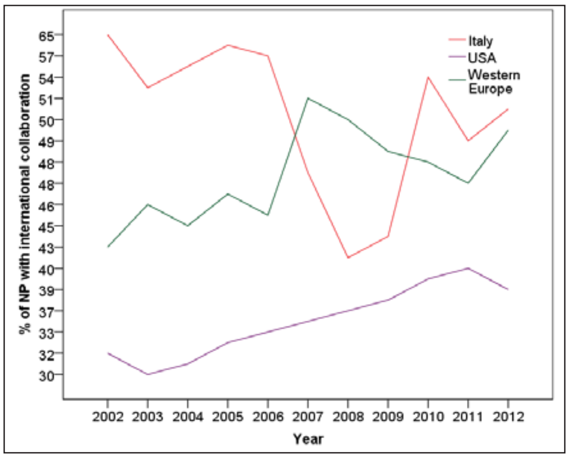

Figure 5 - Trend of the percentage of papers with international coauthorship under the subject category Forestry as concerns USA, Western Europe and Italy. Data source: SCImago

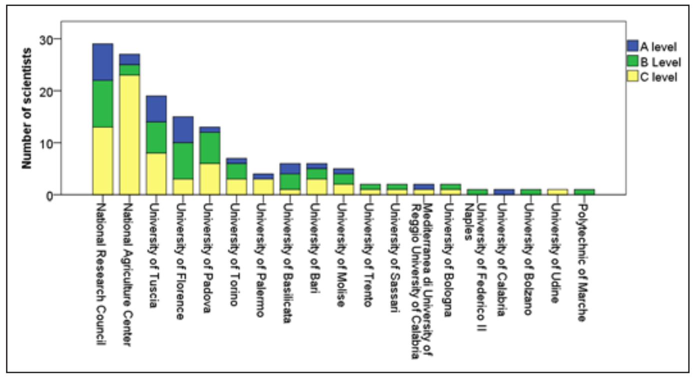

Figure 6 - Number of Italian forest scientists with a permanent position in the period 2002-2012, reported by Institution (National Research Council – CNR, Agricultural Research Council – CRA, and several universities - UNI) and career level.

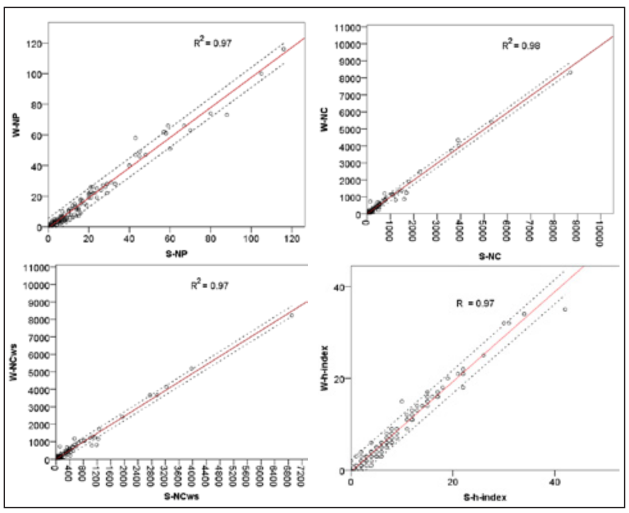

Figure 7 - Linear regressions between the WOS and SCOPUS values concerning: (a) NP - number of publications; (b) NC - number of citations with self-citations; (c) NCws - number of citations without self-citations; (d) h-index. Dotted lines are the 95% confidence interval of the linear regression. Data source: SCOPUS and WOS.

3.2 Italian forest scientist results

One hundred forty-four Italian forest scientists with permanent positions at 19 Italian research institutions (17 Universities [UNI]; the National Research Council [NRC]; and the Agricultural Research Council [CRA]) were analyzed. The forest scientists were classified as 28 A-level scientists, 46 B-level scientists, and 70 C-level scientists (Fig. 6).

NP per author ranged from 0 to 116 using both databases (WOS and SCOPUS) (Table 2). WOS results indicated NC per author was between 0 and 8323 (8227 excluding self-citations) and SCOPUS queries resulted in 0 to 8697 NP (6903 excluding self-citations). The h-index ranged between 0 and 42 using SCOPUS and 0 and 35 using WOS.

The Wilcoxon signed ranks test found no significant differences among mean values for the three indicators following WOS and SCOPUS bibliometric queries (NP: Z = 0.274, P = 0.073; NC: Z = 0.323, P = 0.342; NCws: Z = 0.267, P = 0.0789; h-index: Z = 0.765, P = 0.393). Correlation analyses showed strong atatistical association ($P < 0.001$) between WOS and SCOPUS for all the three indicators: R = 0.98 for NP; R = 0.99 for NC and NCws; R = 0.98 for h-index (see also Fig. 7). These results confirm that SCOPUS and WOS produce comparable and closely related bibliometric data.

The notable differences between mean and median values for NP and NC (Table 2) were due to variability in productivity among scientists. The Gini coefficient for NP (Gini = 0.84 SCOPUS; Gini = 0.85 WOS) and NC (Gini = 0.81 SCOPUS; Gini = 0.80 WOS) provided support for these observations. Among Italian forest scientists, we found the absence of publications for 9.1% of them in WOS and

Table 2 - Bibliometric indicators of Italian forest scientists over the period 2002-2012. Values refer to individual scientists. Data source: SCOPUS and WOS.

	Number of publications		Number of citations		Number of citations without self-citations		h-index		h-index without self-citations
	SCOPUS	WOS	SCOPUS	WOS	SCOPUS	WOS	SCOPUS	WOS	SCOPUS
Average	15	14	421	423	320	402	7	7	6
Maximum	116	116	8697	8323	6903	8227	42	35	37
Median	8	6	75	70	52	61	5	4	4
Minimum	0	0	0	0	0	0	0	0	0
Standard Deviation	20	20	1040	1039	813	1005	7	7	6

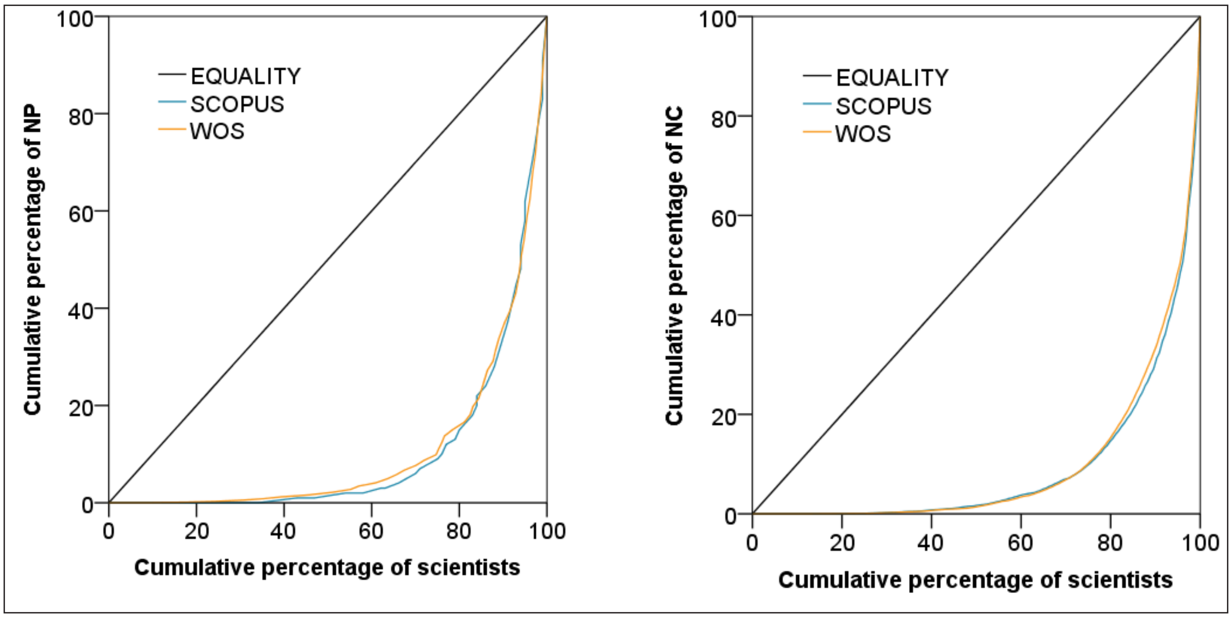

Figure 8 - The Lorenz line plots the cumulative percentage of authors vs. (a) the cumulative percentage of number of publications (NP) and (b) the cumulative percentage of number of citations. The Gini coefficient represents the area between the equality line (dotted) and the Lorenz curves: the larger the area, the higher the inequality indicator.

Table 3 - Classification by subject areas of the publications by the Italian forest scientists in the period 2002-2012. Data source: SCOPUS.

Subject Area	Number of publications
Agricultural and Biological Sciences	995
Environmental Science	619
Biochemistry Genetics and Molecular Biology	234
Earth and Planetary Sciences	231
Social Sciences	64
Medicine	61
Engineering	53
Mathematics	34
Materials Science	30
Immunology and Microbiology	27
Energy	26
Physics and Astronomy	25
Pharmacology Toxicology and Pharmaceutics	22
Chemistry	19
Computer Science	17
Arts and Humanities	16
Multidisciplinary	14
Business Management and Accounting	13
Chemical Engineering	11
Economics Econometrics and Finance	11
Decision Sciences	7
Neuroscience	3
Veterinary	2
Health Professions	1

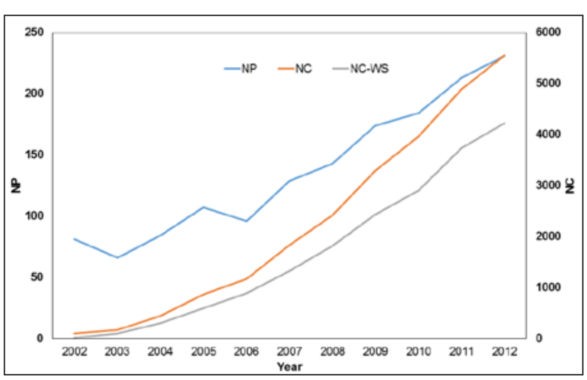

Figure 9 - Trend of number of publications (NP), number of citations with self-citations (NC) and number of citations without self-citations (NCws) of the Italian forest scientists. Data source: SCOPUS.

SCOPUS, while 35% of them represented over 90% of the total NP and NC (Fig. 8).

Following analysis of SCOPUS data over the 2002-2012 period, papers published by the Italian scientists totaled 1508, with 38723 citations (29318 NCws) and h-index = 91 (h-index ws = 80). The papers were classified under a wide range of subject areas in SCOPUS and some were classified in more than one subject area. Agricultural and Biological Science (66%) was the most common subject area, which include the subject category Forestry. However, a large number of publications were also included in Environmental Science (41%), Biochemistry, Genetics, and Molecular Biology (15%), Earth and Planetary Science (15%), and other subject areas (20%) (Table 3).

The annual figures for total NP, NC, and NCws for the Italian forest scientists strongly increased from 2002-2012. In terms of publications, 81 were found in 2002 and 231 in 2012 (Fig. 9).

More than 42% of the publications had one or more international co-authors. The level of international collaboration remained stable over the considered time period (Fig. 10).

INC, calculated on the basis of SCOPUS data in the period 2002-2012, reported Italian forest scientists co-authored publications with 64 different countries, including the USA (co-authorship number = 459), France (380), Germany (236), and the UK (182) (Fig.11). Interestingly, these countries are those with the highest h-indices in Forestry during the analyzed time period.

Author rank was not influenced by self-citations; in fact, author position with and without self-citation

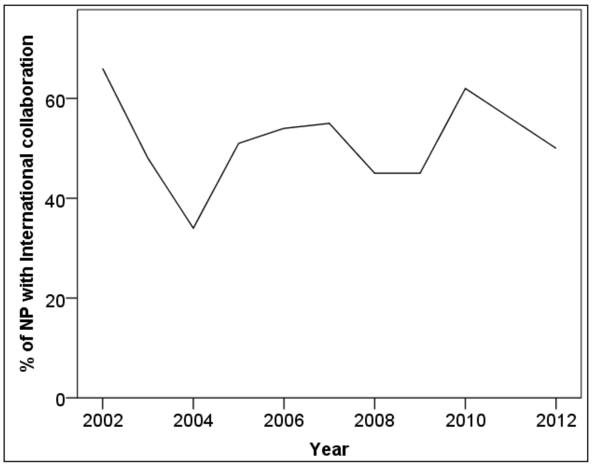

Figure10 - Temporal trend of percentage of papers written by Italian forest scientists in collaboration with foreign scientists. Data source: SCOPUS.

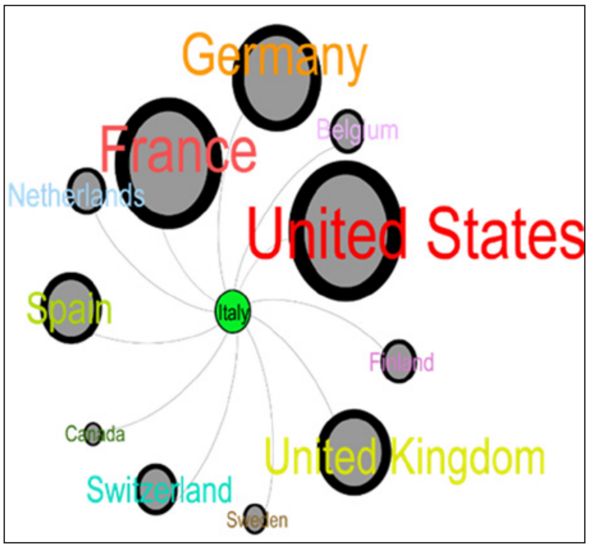

Figure 11 - International collaboration network showing the top 11 countries linked with Italy under the Forestry subject category. The circle size is proportional to the number of collaborative papers.

showed a high linear relationship based on NC and h-index (Fig. 12).

The comparison of scientists at different career levels (A, B, C) showed that A-level scientists exhibited higher mean values than B- and C-levels for NP, NC, and h-index (Table 4). However, A-level authors showed the highest variability relative to the other two groups for all three indicators. In fact, within the A-level group, 70% of the total NP were authored by only 20% of the A-group scientists (Gini SCOPUS = 0.62; Gini WOS = 0.63), 10% of the A-group had not published any paper (NP = 0), and 90% of the total NC, including NCws (Gini SCOPUS and WOS=0.79), were represented by 10% of the authors.

Results showed 40% of the B-level group authors published 80% of the total NP (Gini SCOPUS = 0.53; Gini WOS = 0.57); and 4% of authors did not have any publications (NP = 0). Eighty percent of NC was attributed to 20% of the B-level scientists (Gini SCOPUS = 0.72; Gini WOS = 0.74). Analysis results indicated 90% of the C-level group publications were authored by 40% of the scientists (Gini SCOPUS = 0.57; Gini WOS = 0.61), publications were not detected in the databases for 13% of the authors (NP = 0), and 80% of NC were attributed to 80% of C-level authors (Gini SCOPUS = 0.77; Gini WOS=0.78).

Analyzing the mean CPP per author, we found C-level scientists exhibited the lowest values during the 2002-2012 analysis period (Fig. 13).

Discussion and conclusions

At the global level, the Forestry subject category represented 0.6% of the total number of scientific publications and citations, and in Italy the subject category was detected in 0.4% of NP and 0.3% of NC. Italy published fewer scientific papers in Forestry compared with the USA, China, France, Germany and UK, which were the most productive countries in terms of NP during the analysis period (2002-2012). However, if the economic investments in research (on the basis of GDS in R&D) are considered, then Italy becomes the most productive country following UK. These results are consistent with global research efficiency analysis conducted by the Royal Society of UK (2011), reported by Nature (2013). China and the USA, the most productive countries per NP were last in terms of CPP (mean citation per paper), emphasizing these two countries produce a high number of publications with fewer citations compared to Italy, UK, France, and Germany. Based on aggregated bibliometric productivity under the Forestry subject category, results showed Western Europe exceeded the USA in terms of NP. Comparable results are reported for other scientific fields, including Parasitology (Falagas et al. 2006) and Microbiology (Vergidis et al. 2005).

Overall, our study identified the following essential bibliographic results to assess scientific performance of forest scientists in Italy.

(i) Bibliometric indicators (number of publications; number of citations; h-index) shows a strong relationship between WOS and SCOPUS, suggesting the two databases have the same potential to evaluate the Italian forestry research community.

(ii) Self-citations do not significantly affect author rank under the Forestry subject category, therefore evaluation of individual productivity can be conducted using indicators with or without self-citations.

(iii) Bibliometric productivity under the Forestry subject category in Italy increased rapidly over the evaluated time period. This trend was also observed for other subject categories in Italy (Aspen Report 2012; Dario & Moed 2011).

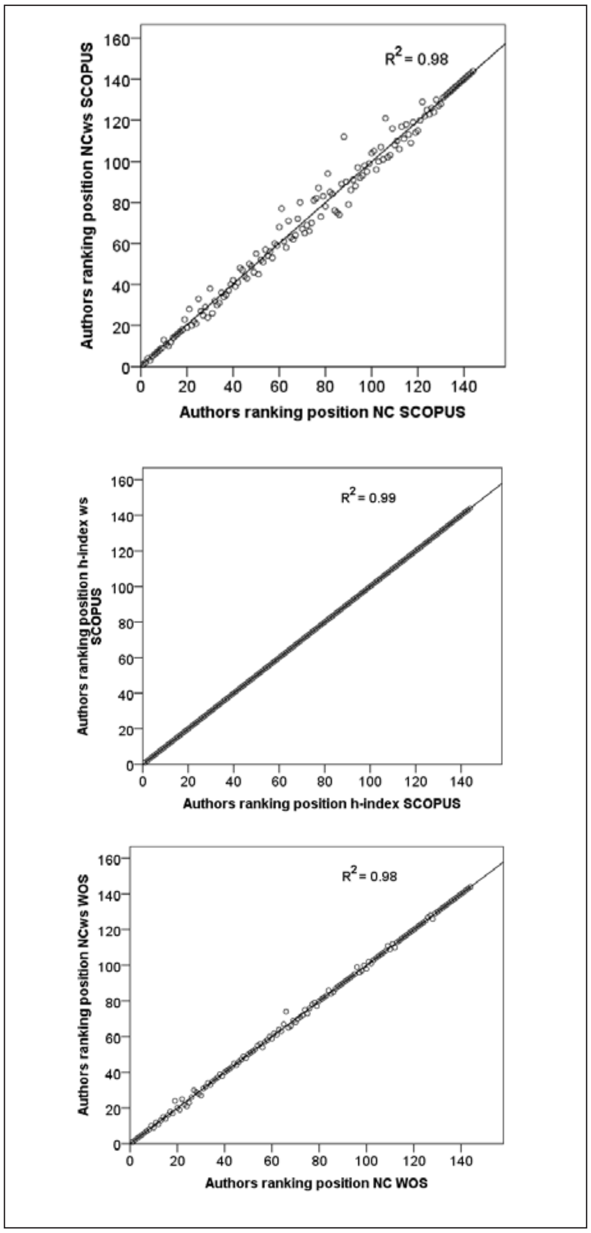

Figure 12 - Correlation between the ranks of Italian forest scientists calculated with and without self-citations: (a) SCOPUS citations, (b) WOS citations, (c) SCOPUS h-index.

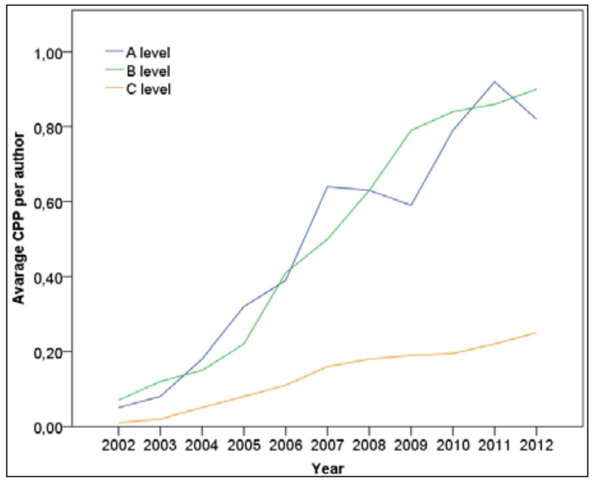

Figure 13 - Trend of mean CPP (NC/NP) of the Italian forest scientists by career level.

(iv) The productivity of Italian forest scientists is not equitable; a small number of active researchers produces the largest number of scientific publications, while a small number of forest scientists are inactive (with no publications registered on WOS or SCOPUS during the 2002-2012 period). This variability is even higher for scientists at top career levels (A-level). These results are consistent with Paulina and Francesconi (2007) for other subject categories in Agricultural and Biological Sciences in Italy.

(v) A high number of publications by the Italian forest research community (50% of the total) is written in collaboration with one or more foreign scientists. This result reflects the global internationalization trend of Italian research emphasized by Glänzel and Schlemmer (2007). Elsevier (2013) reported on a global level the rate of co-authorship among different countries increased from 14% in 2003 to 17% in 2011. The countries exhibiting more co-authorship with the Italian forest

Table 4 - Bibliometric indicators of the Italian forest scientists by career level. Means are calculated per author.

Career level		Number of publications		Number of citations		Number of citations without self-citations		h-index		h-index without self-citations
		SCOPUS	WOS	SCOPUS	WOS	SCOPUS	WOS	SCOPUS	WOS	SCOPUS
A	Average	24	23	891	900	698	864	10	10	9
	Maximum	116	116	8697	8323	6903	8227	42	35	37
	Median	7	7	55	80	38	75	6	5	5
	Minimum	0	0	0	0	0	0	0	0	0
	Standard Deviation	32	32	1848	1822	1468	1771	11	11	9
B	Average	17	16	423	408	322	387	8	7	7
	Maximum	80	74	3620	3709	2749	3665	22	22	19
	Median	11	8	109	95	81	92	7	5	6
	Minimum	0	0	0	0	0	0	0	0	0
	Standard Deviation	18	18	707	711	548	689	6	6	5
C	Average	11	10	232	242	169	228	6	5	5
	Maximum	67	66	5317	5410	3966	5190	31	32	28
	Median	7	5	58	48	39	46	4	3	3
	Minimum	0	0	0	0	0	0	0	0	0
	Standard Deviation	14	14	675	695	501	662	6	6	5

research community (USA, France, Germany, UK) are also the most productive on a global level under the Forestry subject category.

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Indicators of sustainable forest management: application and assessment

Project reporting

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

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Indicators of sustainable forest management: a European overview

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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[1]) 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 Forum 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

[1] CNR-IBAF, National Research Council of Italy, Institute for Agro-environmental and Forest Biology, Monterotondo (RM), Italy
[2] CNBF National Centre for the Study and Conservation of Forest Biodiversity 'Bosco Fontana', Marmirolo (MN), Italy

[1] United Nations Agenda 21: Rio Declaration an Forest Principles. Post-Rio Edition (United Nations, New York, 1993)

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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 (Lammertsvan 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.

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

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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 CO2 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 managed 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

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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 welled 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.

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

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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.

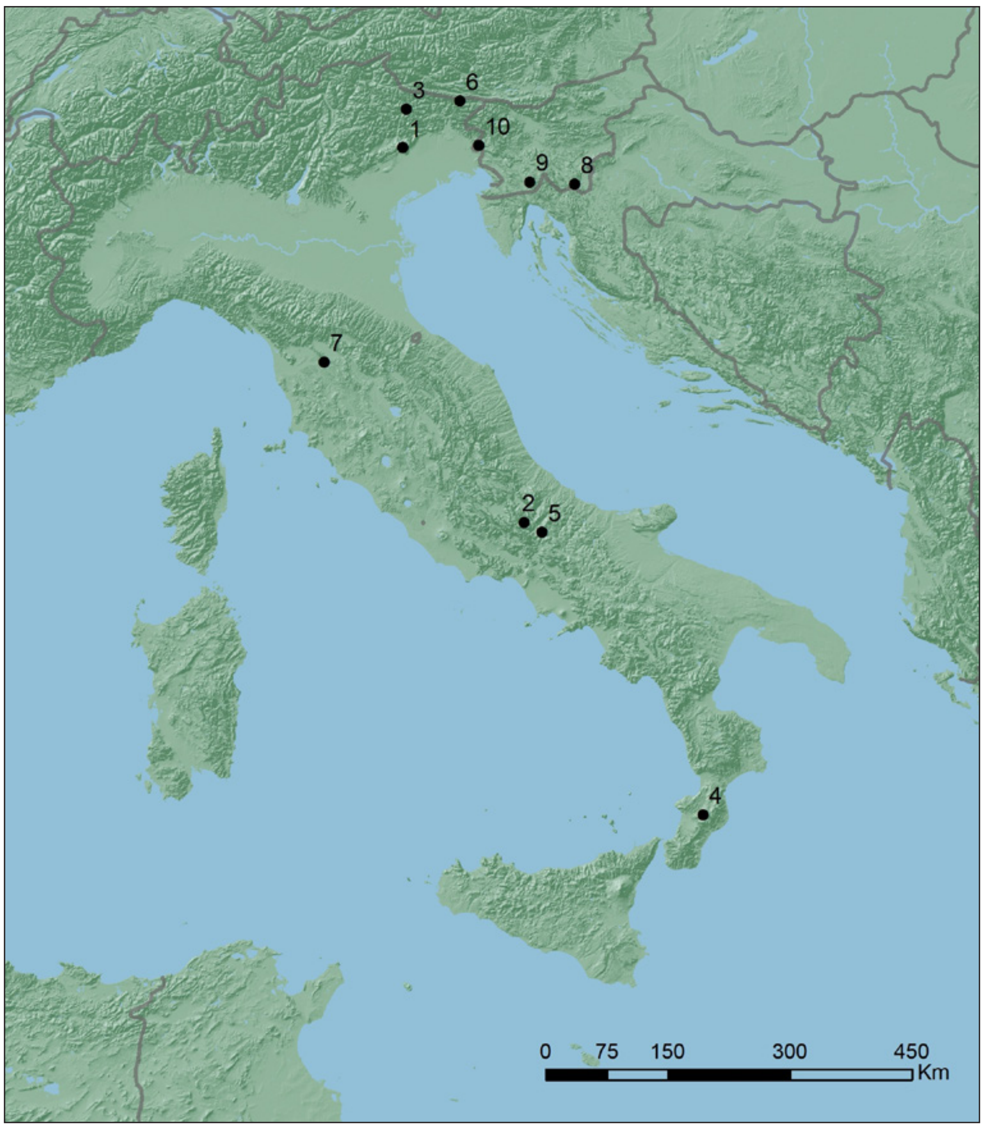

Figure 1 - Location of the study sites: 1. Cansiglio, 2. Chiarano Sparvera, 3. Lorenzago di Cadore, 4. Mongiana, 5. Montedimezzo-Pennataro, 6. Tarvisio, 7. Vallombrosa, 8. Kočevski Rog, 9. Snežnik, 10. Trnovo.

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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^3 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 Foret 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 consisted 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 micro-habitats, 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^3 (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 of Cadore and Comelico") and contains two Sites of Community.

Total area of Foret 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^2 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 (Garfì 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 (Femmelschlag) 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^3 ha^{-1}, the increment 4.58 m^3 ha^{-1} yr^1. Annual cuttings are about 30’000 m^3. 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 submitted 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 responsibles 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^3, 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 reafforestation 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 matching 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^3 ha^{-1} and the increment is 9.4 m^3 ha^{-1} yr^1. 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 (Sl)

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^3 ha^{-1} and the increment is 8.3 m^3 ha^{-1} yr^1. 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 (Sl)

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 spruceas main tree species. Elm and Sycamore are also present. The average growing stock is 292.0 m^3 ha^{-1} and the increment is 6.2 m^3 ha^{-1} yr^1. 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.

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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).

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

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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 7th 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 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

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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

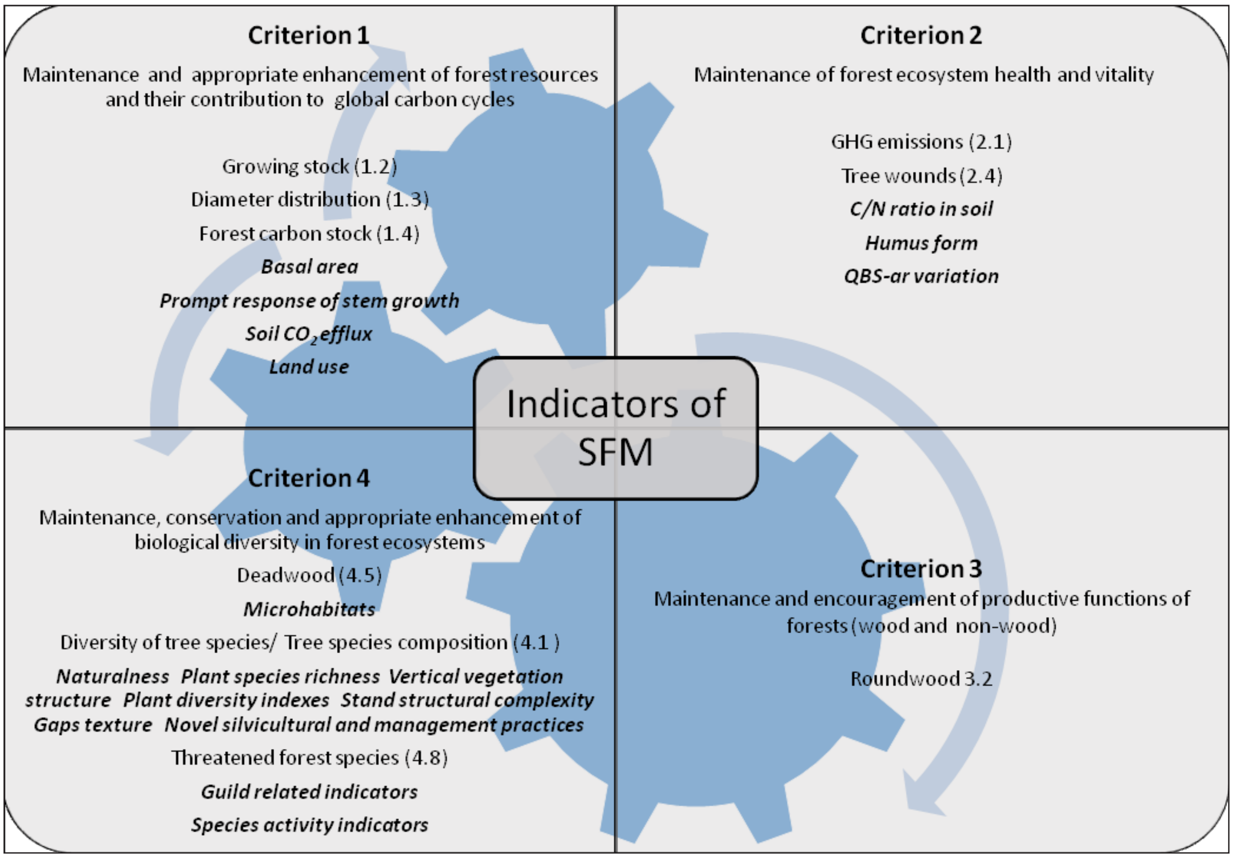
A fundamental goal of sustainable forest management is the maintenance of forest biodiversity. This criterion includes all forest life forms, the ecological roles they perform and the genetic diversity they hold. It includes the following indicators:

- 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 selvicultural 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.

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http://ojs-cra.cilea.it/index.php/asr

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

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

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

[1] Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, Forestry Research Centre (CREA-SEL), Arezzo, Italy
[2] CNR-IBAF, National Research Council of Italy, Institute for Agro-environmental and Forest Biology, Monterotondo (RM), Italy
[3] Department of Yield and Silviculture, Slovenian Forestry Institute, Ljubljana, Slovenia
[4] CNR-ISAFOM, National Research Council of Italy, Institute for Agriculture and Forest Mediterranean Systems, Rende(CS), Italy
[5] Department of Forest and Landscape Planning and Monitoring, Slovenian Forestry Institute, Ljubljana, Slovenia
[6] UNIMOL, Dipartimento di Bio-scienze e Territorio, Università degli Studi del Molise, Pesche (IS), Italy

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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^{-1}
- Changes: Diameter class n ha^{-1} per yr.

Measurement time

Before [Y]

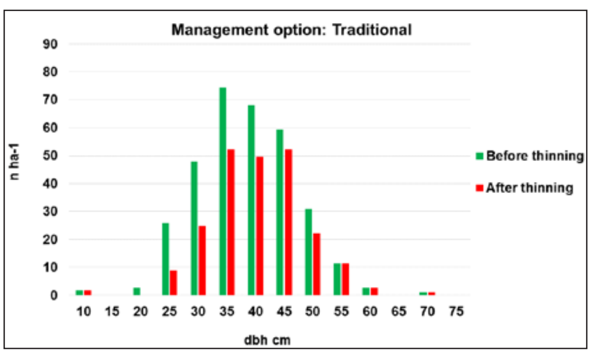
After [Y]

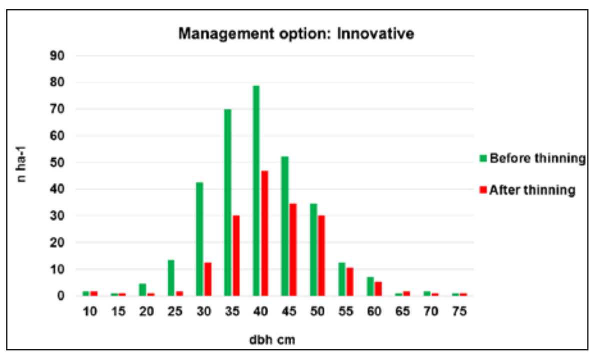
Feasibility

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

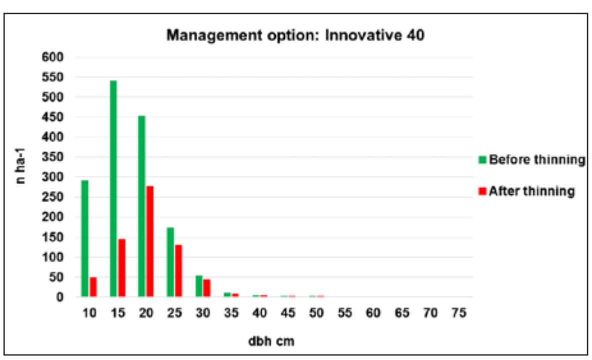
Results from ManFor C.BD.

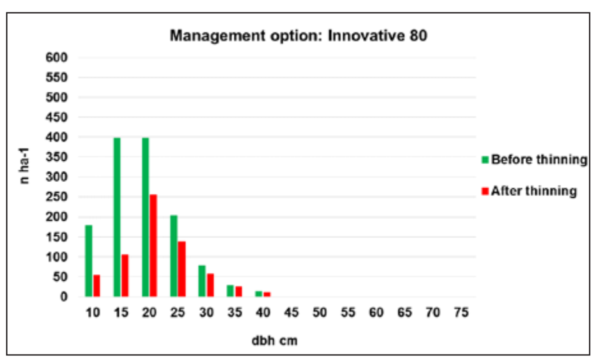
Cansiglio

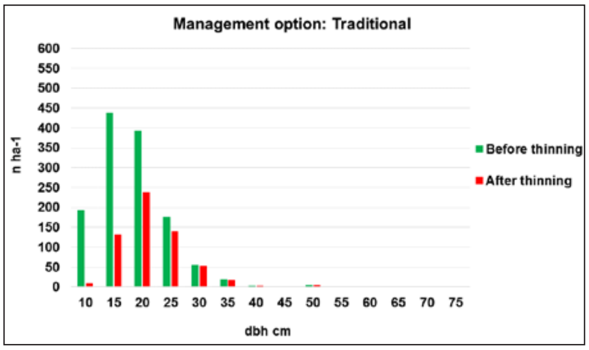




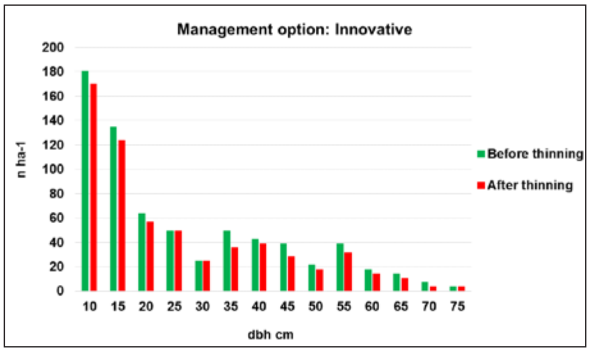
Chiarano

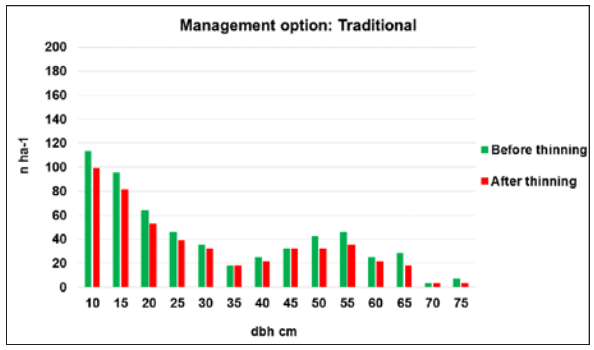




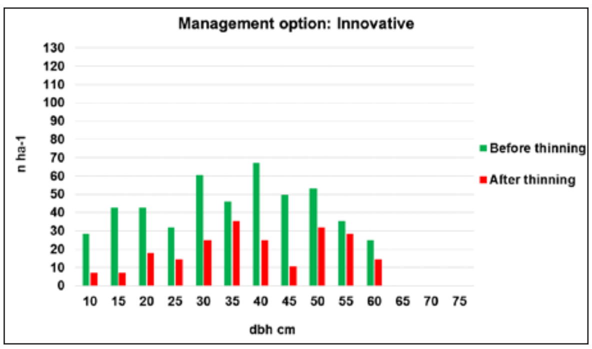


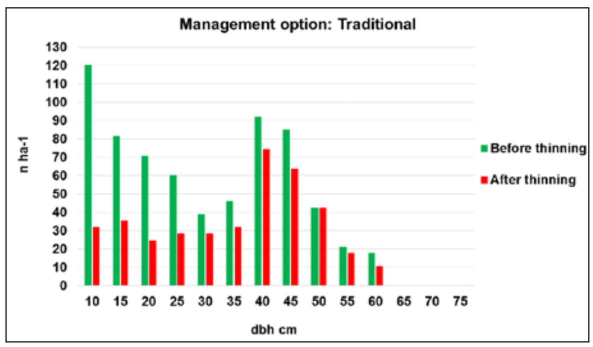
Lorenzago 1



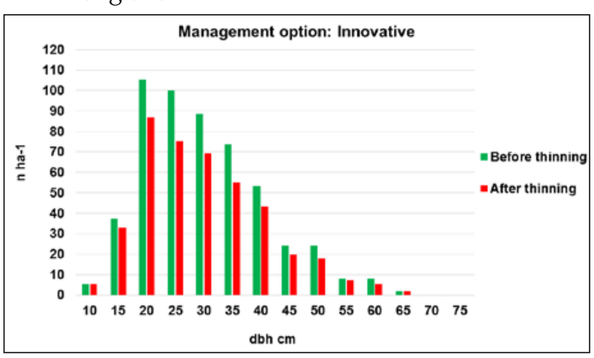


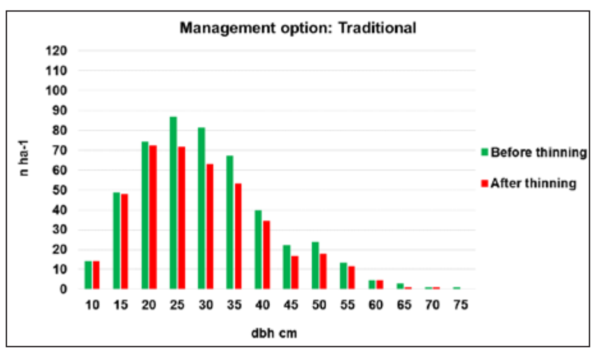
Lorenzago 2



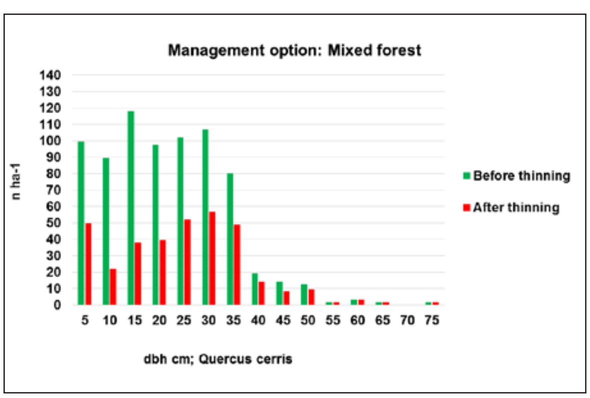


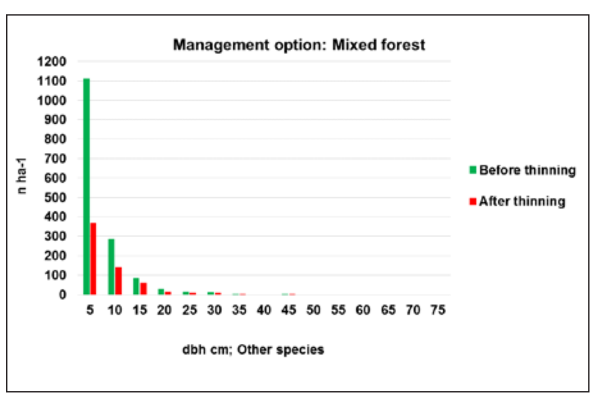
Mongiana

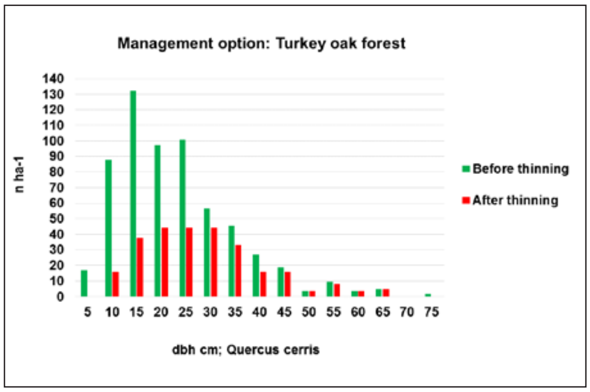


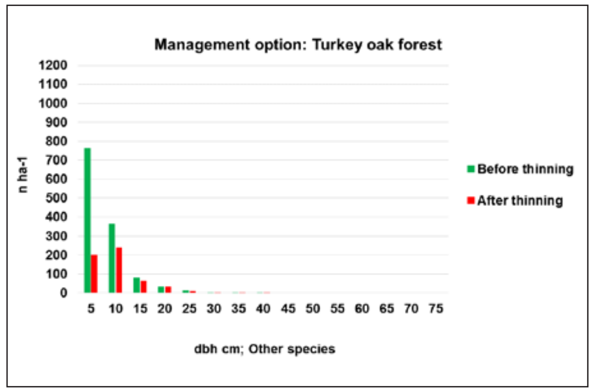


Pennataro

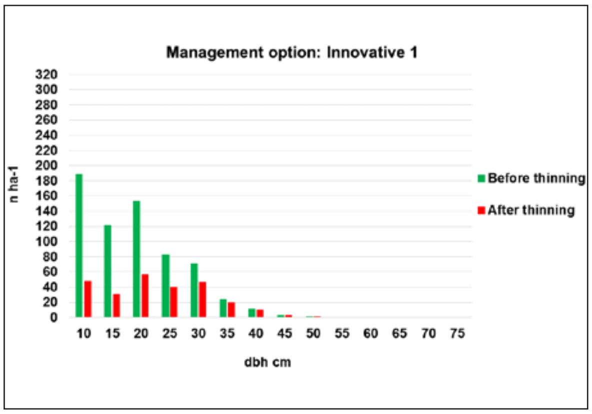


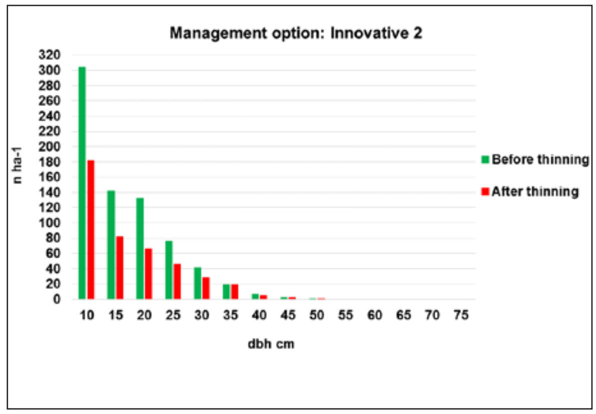


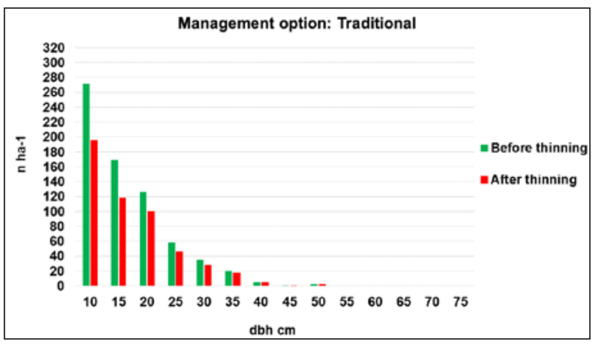




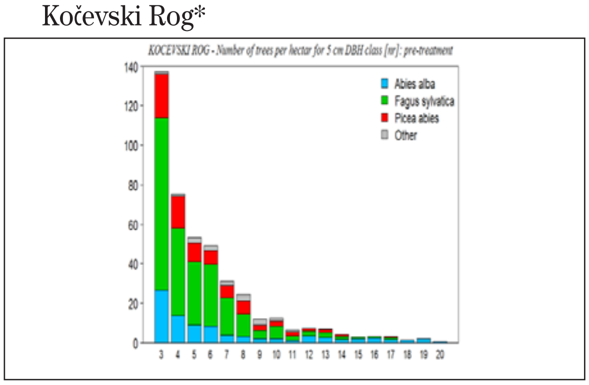
Tarvisio

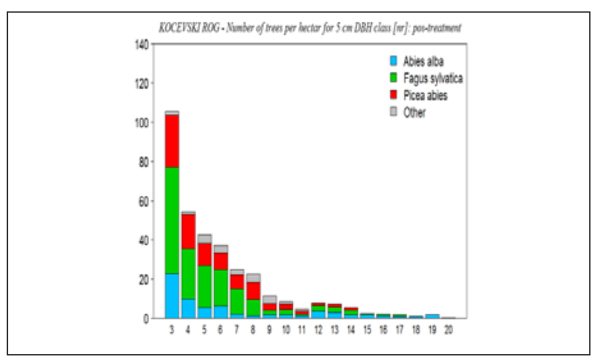




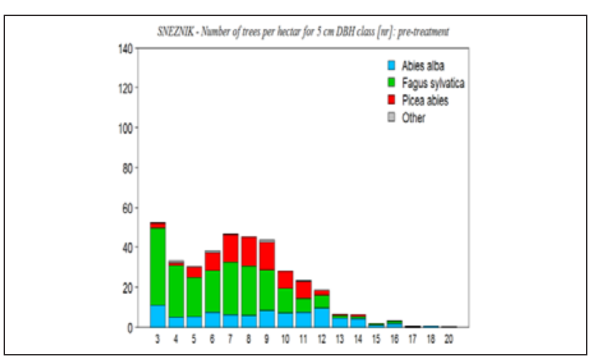


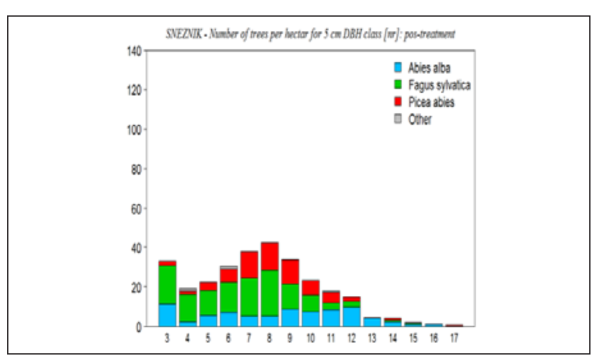
Kočevski Rog*



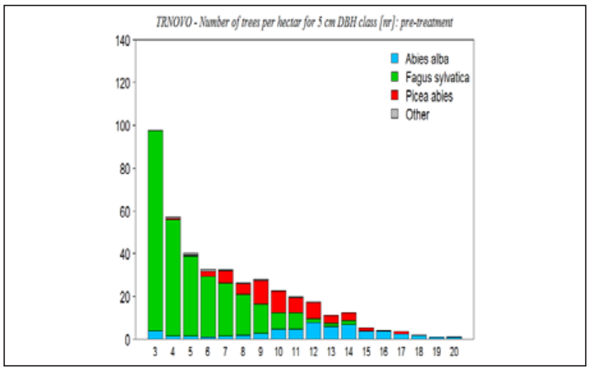


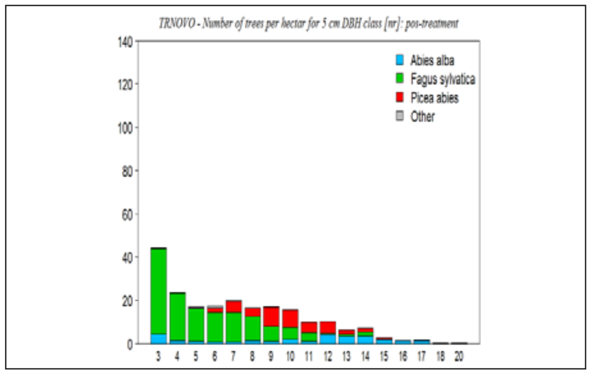
Snežnik*





Trnovo*





*In Slovenian sites, diametric classes of 5 cm were reported on x axis and frequencies (number of trees ha-1) 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 CO2 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^{-1}

Changes: MgC ha^{-1}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^2
Changes: m^2 per yr.
Status: $m^2 ha^{-1}$
Changes: $m^2 ha^{-1}$ 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^2 ha^{-1})	Cansiglio Innovative	41.9	26.6
Basal area (m^2 ha^{-1})	Cansiglio Traditional	39.6	29.8
Basal area (m^2 ha^{-1})	Chiarano Traditional	36.7	23.1
Basal area (m^2 ha^{-1})	Chiarano I80	40.4	24.8
Basal area (m^2 ha^{-1})	Chiarano I40	40.2	23.0
Basal area (m^2 ha^{-1})	Lorenzago Area 1 Innovative	53.3	43.1
Basal area (m^2 ha^{-1})	Lorenzago Area 1 Traditional	58.8	46.4
Basal area (m^2 ha^{-1})	Lorenzago Area 2 Innovative	54.6	28.1
Basal area (m^2 ha^{-1})	Lorenzago Area 2 Traditional	58.0	43.2
Basal area (m^2 ha^{-1})	Mongiana Innovative	41.6	32.6
Basal area (m^2 ha^{-1})	Mongiana Traditional	38.7	31.4
Basal area (m^2 ha^{-1})	Pennataro Mixed forest	38.6	24.9
Basal area (m^2 ha^{-1})	Pennataro Turkey oak forest	43.7	25.3
Basal area (m^2 ha^{-1})	Tarvisio Innovative 1	47.7	25.8
Basal area (m^2 ha^{-1})	Tarvisio Innovative 2	37.9	24.7
Basal area (m^2 ha^{-1})	Tarvisio Traditional	35.7	28.5
Basal area (m^2 ha^{-1})	Vallombrosa Innovative	56.9	36.7
Basal area (m^2 ha^{-1})	Vallombrosa Traditional	54.3	53.2
Basal area (m^2 ha^{-1})	Kočevski Rog 100	30.9	0
Basal area (m^2 ha^{-1})	Kočevski Rog 50	31.1	17.9
Basal area (m^2 ha^{-1})	Snežnik 100	41.0	0
Basal area (m^2 ha^{-1})	Snežnik 50	45.5	25.7
Basal area (m^2 ha^{-1})	Trnovo 100	43.8	0
Basal area (m^2 ha^{-1})	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_2 efflux from forests soils.

Rationale CO_2 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_2 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 ($\mu mol\ CO_2 m^2/sec$)	Trnovo (beech stand with 100% logged growing stock)		2.1
Soil respiration ($\mu mol\ CO_2 m^2/sec$)	Trnovo (control beech stand)		2.3
Soil respiration ($\mu mol\ CO_2 m^2/sec$)	Chiarano Innovative 80		3.44
Soil respiration ($\mu mol\ CO_2 m^2/sec$)	Chiarano Innovative 40		2.82
Soil respiration ($\mu mol\ CO_2 m^2/sec$)	Chiarano Control		4.34
Soil respiration ($\mu mol\ CO_2 m^2/sec$)	Mongiana Innovative		2.69
Soil respiration ($\mu mol\ CO_2 m^2/sec$)	Mongiana Traditional		2.39
Soil respiration ($\mu mol\ CO_2 m^2/sec$)	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 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

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Landscape [2]/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 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

[2] Landscape of Italian and Slovenian sites refers to a squared area of 100 km^2 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

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Assessing indicators of forest ecosystem health

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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_2 and N_2).

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"

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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 (≤ 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 characterize by slow (2-7 years) decomposition and carbon is stored in both horizons organic (humic components) than in those organic-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 characterize by very slow (> 7 years) decomposition and SOC is stored in both horizons organic (humic components) than in those organic-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 umid 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 decompositor fauna of the soil (i.e. arthropodos).

Indicator name	Site	Time	EUMULL	MESOMULL	OLIGOMULL	DYSMULL	LEPTOAMPHI	EUMACROAMPHI	HEMIMODER	EUMODER	DYSMODER	HEMIMOR	HUMIMOR
Humus	Cansiglio	Before				7	1	1					
form	Innovative	After			5	2		2					
Humus	Cansiglio	Before				3		6					
form	Control	After		1		3	1	4					
Humus	Cansiglio	Before			1	2		6					
form	Traditional	After		2	5	1		1					
Humus	Chiarano	Before		2	3	2	1	1					
form	Traditional	After	2		3	4							
Humus	Chiarano	Before	2		2	4		1					
form	I80	After	1	2	1	4	1						
Humus	Chiarano	Before	2	2		5							
form	I40	After		3	3	3							
Humus	Mongiana	Before							8				
form	Innovative	After							7	2			
Humus	Mongiana	Before							4	4	1		
form	Control	After							5	2	2		
Humus	Mongiana	Before							6		1		2
form	Traditional	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 CO2eq.

Measurement units

Status: g

Changes: g per m^3

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
CO2eq (g m^{-3})	Cansiglio Traditional	54000
CO2eq (g m^{-3})	Cansiglio Innovative 1	51000
CO2eq (g m^{-3})	Chiarano Traditional	13500
CO2eq (g m^{-3})	Chiarano Innovative 1	12900
CO2eq (g m^{-3})	Chiarano Innovative 2	13100
CO2eq (g m^{-3})	Mongiana Traditional	75000
CO2eq (g m^{-3})	Mongiana Innovative 1	78000
CO2eq (g m^{-3})	Tarvisio Traditional	98100
CO2eq (g m^{-3})	Tarvisio Innovative 1	94800
CO2eq (g m^{-3})	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 figures of after harvesting evaluation and useful for various purposes.

Methods

For the microarthropods extraction and QBS-ar index application, three soil cores 100 cm^2 and 10 cm deep were sampled in each soil typology. Microarthropods were extracted using a Berlese-Tüllgren 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

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 presented here, but without testing them to avoid the creation of misleading data.

Recruitment

Full text Recruitment of forest habitat type (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 ≥ X 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

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 m < h < 1.3 m.

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 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

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Assessing indicators of forest productive functions

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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 influenced 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%

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Real roundwood

Site	Structural timber	Sawlog	Roundwood % Log	Pallet parquet	Wood biomass	Fuelwood
Cansiglio						
Total	-	-	-	11.7	-	88.3
Vallombrosa	not available					
Chiarano						
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

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

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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^2)/ Cover (in %) per hectare (or surface in m^2).

Changes: Number per hectare (or surface in m^2) /Cover (in %) per hectare (or surface in m^2)

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^2 plot (min: 3 species; max: 10 species)	6.2 species per 400m^2 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: *Fagus sylvatica:* 38.9% *Abies alba:* 14.5% *Picea abies:*10.1%	Upper tree layer: *Fagus sylvatica:* 18.1% *Abies alba:* 5.3% *Picea abies:* 5.2%
Tree species composition (Mean cover of main tree species)	8-Kočevski Rog; 9-Snežnik; 10-Trnovo	Lower tree layer: *Fagus sylvatica:* 29.2% *Abies alba:* 3.5% *Picea abies:* 1.6%	Lower tree layer: *Fagus sylvatica:* 14.0% *Abies alba:* 1.0% *Picea abies:*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.

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

Methods

Permanent plots were estabilished 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^2).

Changes: Number per hectare (or surface in m^2).

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 400m² plot (min: 29 species; max: 68 species)	70.4 species per 400m² plot (min: 41 species; max: 106 species)
Plant species richness (mean, minimun and maximum number of herb species*)	8-Kočevski Rog; 9-Snežnik; 10-Trnovo	37.2 species per 400 m² plot (min: 21 species; max: 51 species)	57.0 species per 400 m² 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:

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

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

Haegyi [Hg] (Haegyi 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

Haegyi 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^2, m

Changes: number, m^2, 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

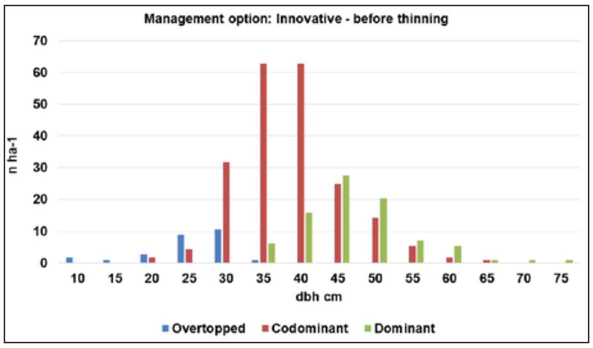
Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2 (inventory technician)	2	Carbon stock, Basal Area, Diameter distribution

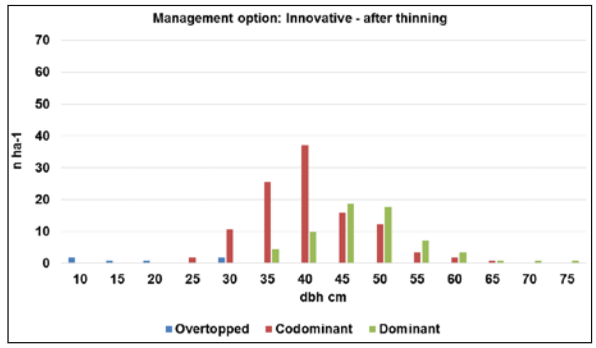
Results from ManForC.BD.

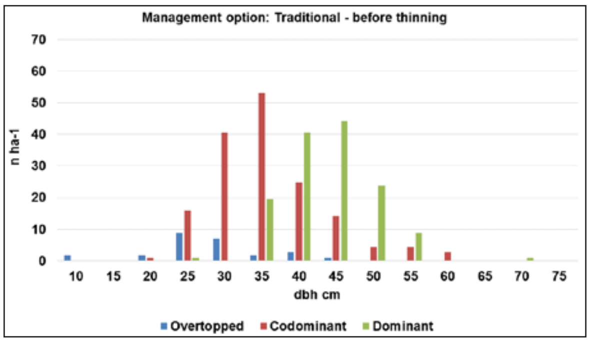
Indicator name	Site	Layer	Before	After
Tree density per layer	Cansiglio	Dominant	85	64
(n ha^{-1})	Innovative	Codominant	210	110
		Overtopped	26	5
Tree density per layer	Cansiglio	Dominant	139	112
(n ha^{-1})	Traditional	Codominant	161	105
		Overtopped	25	9
Tree density per layer	Chiarano	Dominant	241	218
(n ha^{-1})	Traditiona	Codominant	686	341
		Overtopped	350	36
Tree density per layer	Chiarano	Dominant	303	234
(n ha^{-1})	Innovative 80	Codominant	603	314
		Overtopped	391	96
Tree density per layer	Chiarano	Dominant	272	207
(n ha^{-1})	Innovative 40	Codominant	866	379
		Overtopped	391	73
Tree density per layer	Lorenzago	Dominant	131	103
(n ha^{-1})	Area 1	Codominant	110	95
	Innovative	Overtopped	446	400
Tree density per layer	Lorenzago	Dominant	120	95
(n ha^{-1})	Area 1	Codominant	88	67
	Traditional	Overtopped	371	325
Tree density per layer	Lorenzago	Dominant	131	81
(n ha^{-1})	Area 2	Codominant	180	74
	Innovative	Overtopped	170	60
Tree density per layer	Lorenzago	Dominant	95	81
(n ha^{-1})	Area 2	Codominant	255	191
	Traditional	Overtopped	325	117
Tree density per layer	Mongiana	Dominant	302	234
(n ha^{-1})	Innovative	Codominant	150	118
		Overtopped	75	66
Tree density per layer	Mongiana	Dominant	219	184
(n ha^{-1})	Traditional	Codominant	157	126
		Overtopped	103	98
Tree density per layer	Pennataro	Dominant	254	184
(n ha^{-1})	Mixed	Codominant	145	91
	forest	Overtopped	1285	542
Tree density per layer	Pennataro	Dominant	310	171
(n ha^{-1})	Turkey oak	Codominant	192	96
	forest	Overtopped	1779	676
Tree density per layer	Tarvisio	Dominant	357	226
(n ha^{-1})	Innovative 1	Codominant	645	241
		Overtopped	500	124
Tree density per layer	Tarvisio	Dominant	234	170
(n ha^{-1})	Innovative 2	Codominant	984	590
		Overtopped	295	144
Tree density per layer	Tarvisio	Dominant	213	188
(n ha^{-1})	Traditional	Codominant	841	640
		Overtopped	383	245
Tree density per layer	Vallombrosa	Dominant	242	157
(n ha^{-1})	Innovative	Codominant	178	88
		Overtopped	88	71
Tree density per layer	Vallombrosa	Dominant	266	261
(n ha^{-1})	Traditional	Codominant	215	211
		Overtopped	107	101

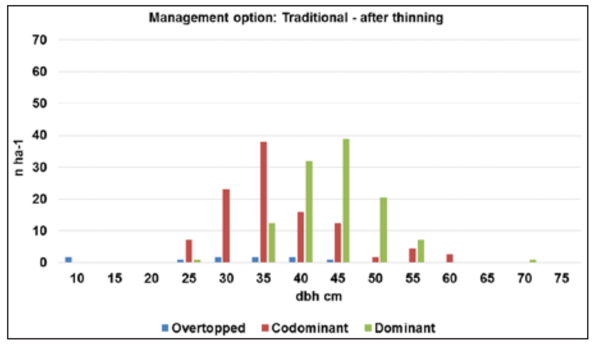
Indicator name	Site	Layer	Before	After
Basal area	Cansiglio	Dominant	15.1	11.7
per layer (m^2 ha^{-1})	Innovative	Codominant	25.3	14.6
Basal area	Cansiglio	Dominant	21.0	17.3
per layer (m^2 ha^{-1})	Traditional	Codominant	17.0	11.9
		Overtopped	1.6	1.7
Basal area per layer	Chiarano	Dominant	12.5	11.6
(m^2 ha^{-1})	Traditional	Codominant	19.0	10.9
		Overtopped	5.1	0.6
Basal area	Chiarano	Dominant	17.0	13.5
per layer (m^2 ha^{-1})	Innovative 80	Codominant	18.0	9.9
		Overtopped	5.4	1.4
Basal area	Chiarano	Dominant	13.6	10.6
per layer (m^2 ha^{-1})	Innovative 40	Codominant	21.8	11.4
		Overtopped	4.8	1.0
Basal area	Lorenzago	Dominant	30.6	23.7
per layer (m^2 ha^{-1})	Area 1	Codominant	12.6	11.0
	Innovative	Overtopped	10.0	8.5
Basal area	Lorenzago	Dominant	31.1	24.3
per layer (m^2 ha^{-1})	Area 1	Codominant	15.7	11.2
	Traditional	Overtopped	12.0	10.9
Basal area	Lorenzago	Dominant	25.0	16.2
per layer (m^2 ha^{-1})	Area 2	Codominant	11.9	8.6
	Innovative	Overtopped	6.7	3.3
Basal area	Lorenzago	Dominant	16.8	14.7
per layer (m^2 ha^{-1})	Area 2	Codominant	33.2	25.0
	Traditional	Overtopped	8.0	3.5
Basal area	Mongiana	Dominant	30.0	23.5
per layer (m^2 ha^{-1})	Innovative	Codominant	9.0	6.9
		Overtopped	2.6	2.2
Basal area	Mongiana	Dominant	25.5	21.1
per layer (m^2 ha^{-1})	Traditional	Codominant	10.3	7.6
		Overtopped	3.0	2.8
Basal area	Pennataro	Dominant	23.8	16.8
per layer (m^2 ha^{-1})	Mixed	Codominant	5.9	3.8
	forest	Overtopped	8.9	4.4
Basal area	Pennataro	Dominant	24.6	15.9
per layer (m^2 ha^{-1})	Turkey oak	Codominant	9.1	4.8
	forest	Overtopped	9.9	4.5
Basal area	Tarvisio	Dominant	21.2	16.5
per layer (m^2 ha^{-1})	Innovative 1	Codominant	19.3	7.6
		Overtopped	7.3	1.8
Basal area	Tarvisio	Dominant	13.5	11.5
per layer (m^2 ha^{-1})	Innovative 2	Codominant	21.8	12.2
		Overtopped	2.7	1.1
Basal area	Tarvisio	Dominant	14.0	12.6
per layer (m^2 ha^{-1})	Traditional	Codominant	18.0	13.6
		Overtopped	3.7	2.3
Basal area	Vallombrosa	Dominant	34.9	23.9
per layer (m^2 ha^{-1})	Innovative	Codominant	17.5	9.3
		Overtopped	4.6	3.4
Basal area	Vallombrosa	Dominant	30.9	30.3
per layer (m^2 ha^{-1})	Traditional	Codominant	18.8	18.4
		Overtopped	4.6	4.4

Cansiglio

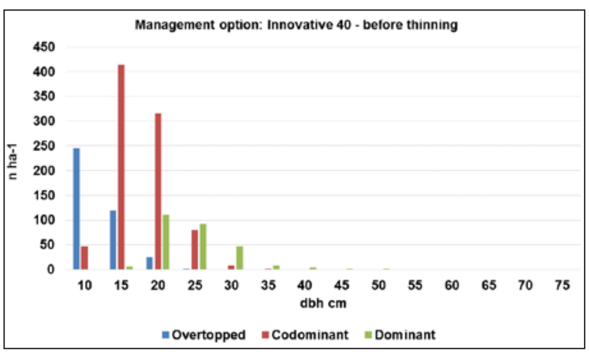


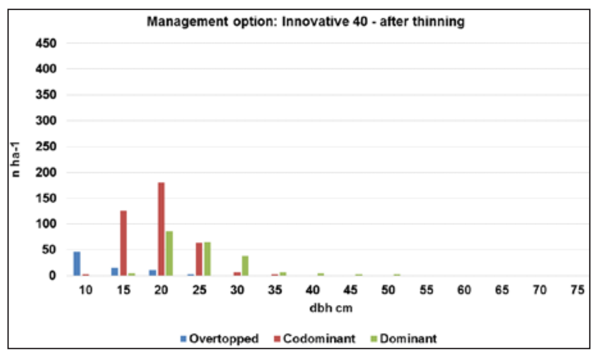


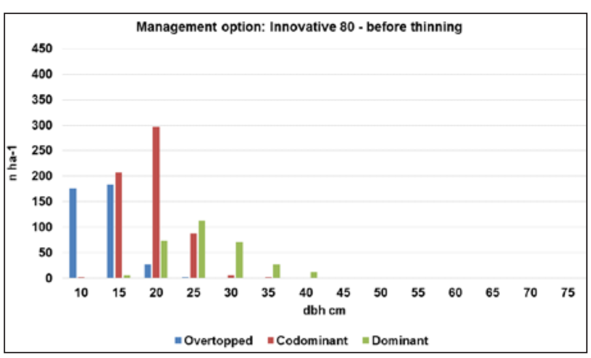


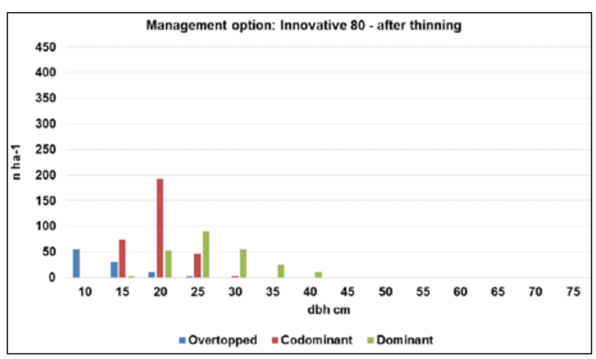


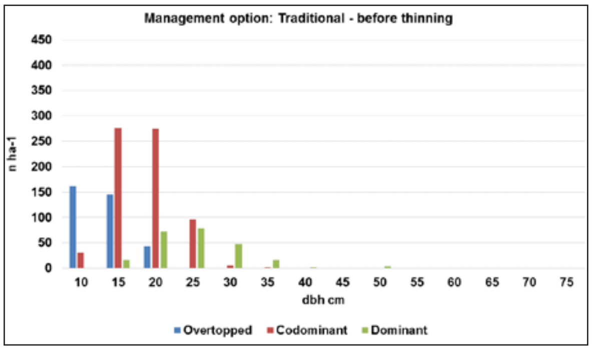
Chiarano

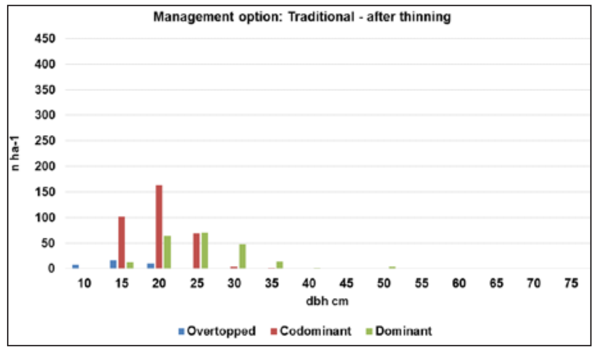




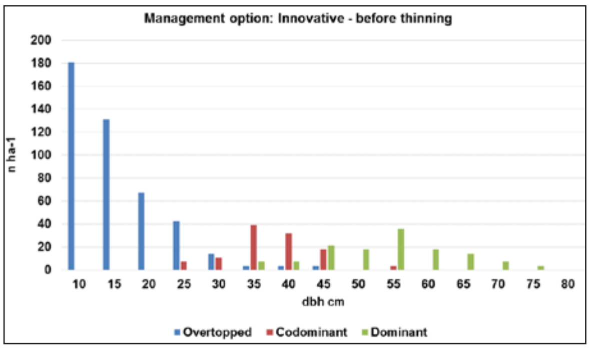


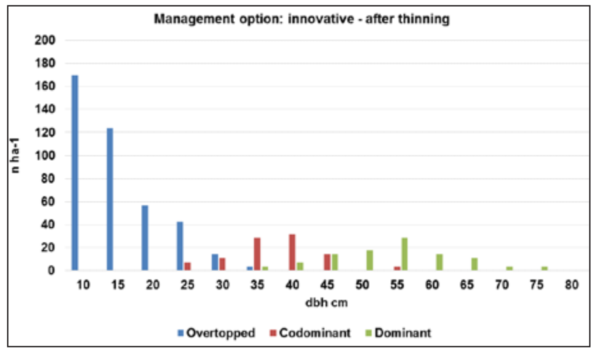


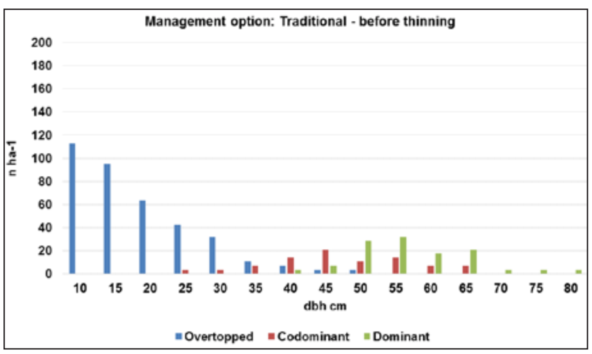


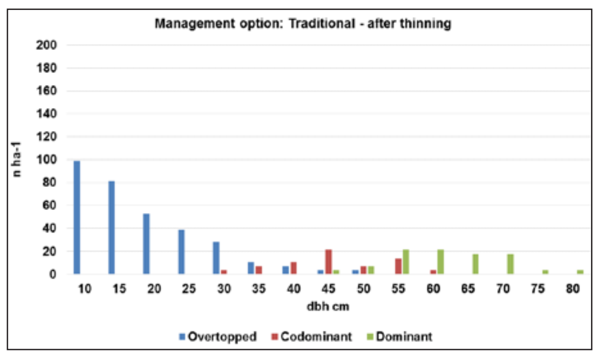


Lorenzago 1

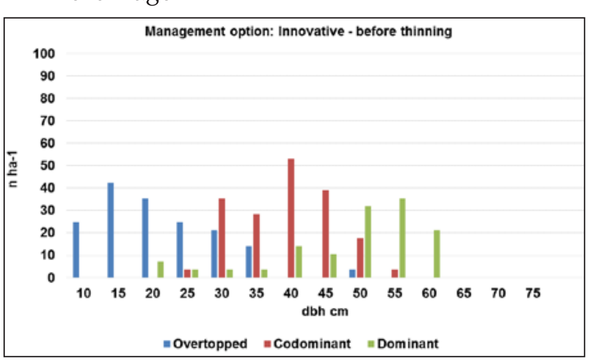


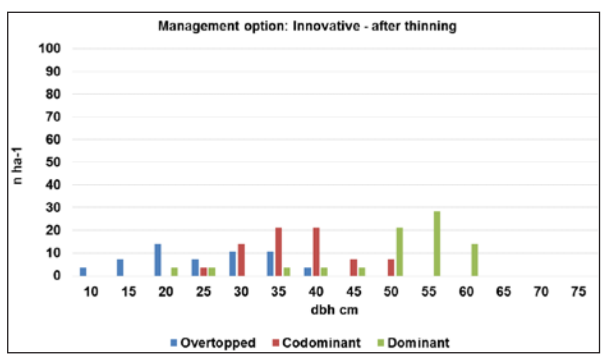


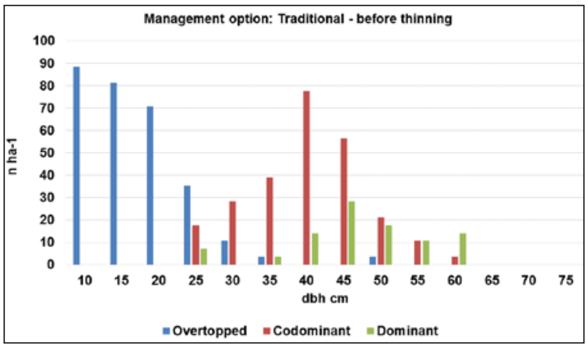


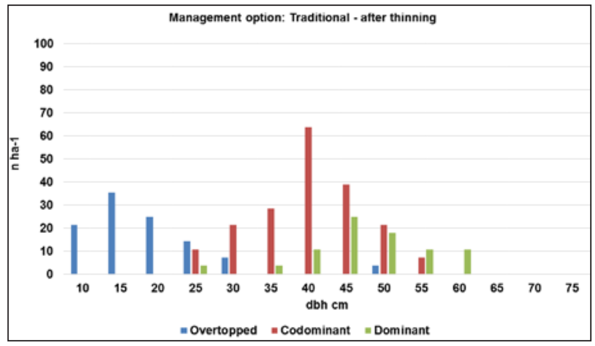


Lorenzago 2

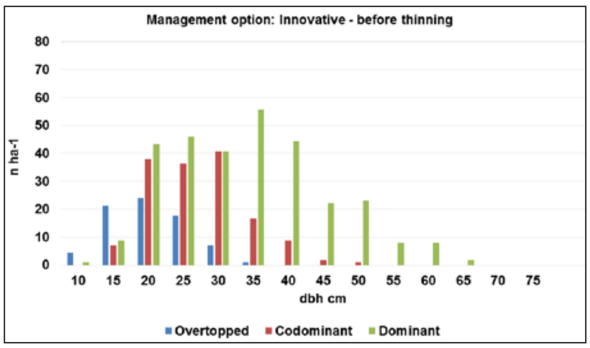


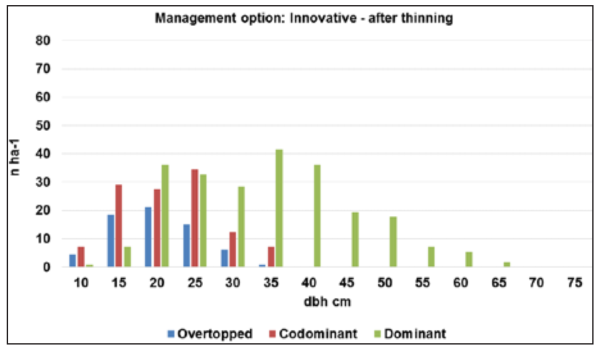


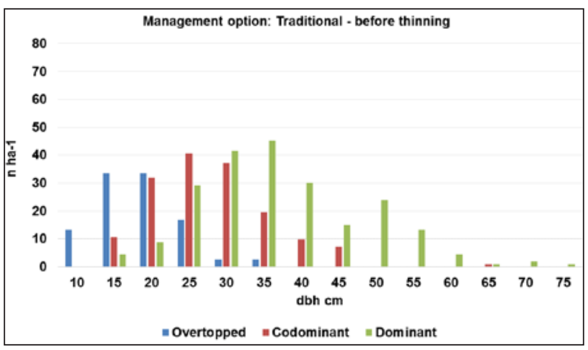


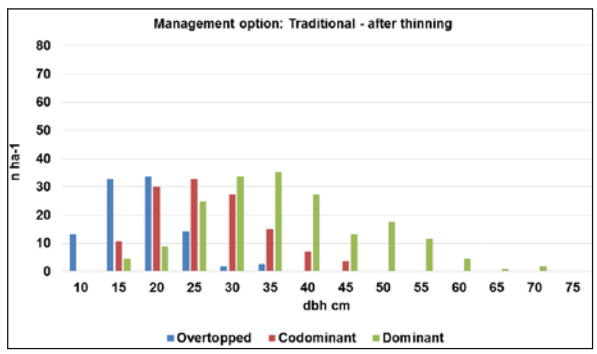


Mongiana

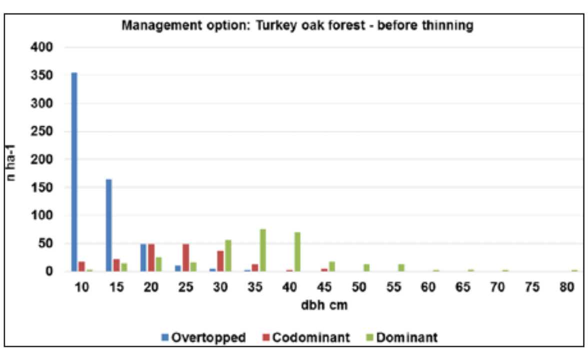


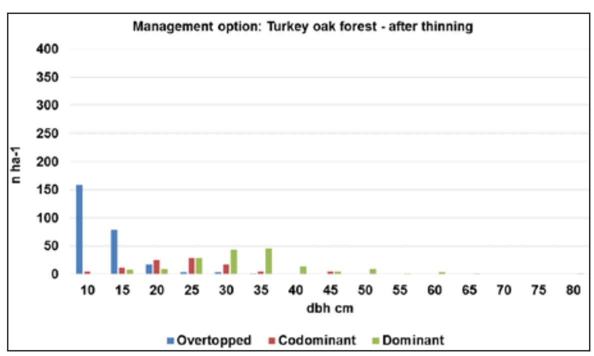


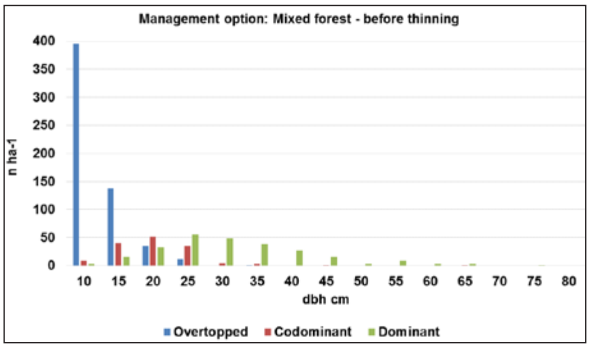




Pennataro



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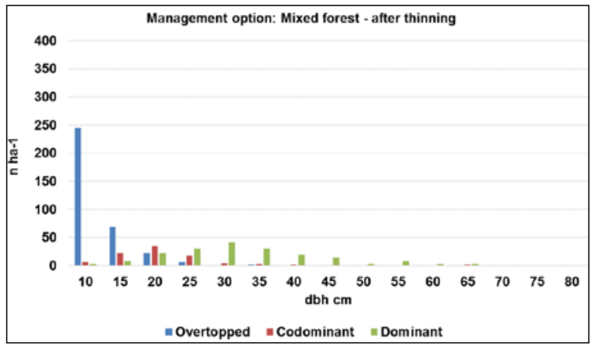
n ha-1
dbh cm
Overtopped
Codominant
Dominant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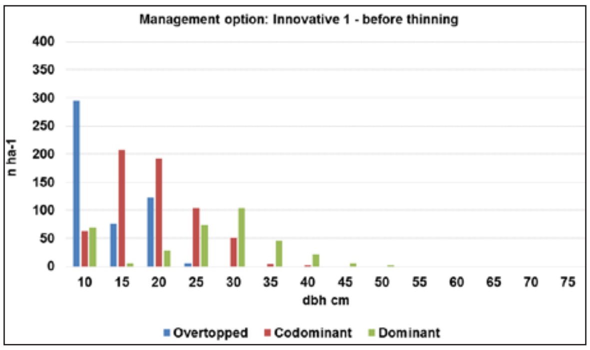
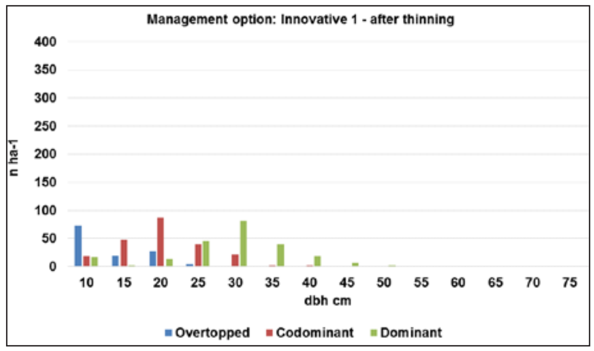
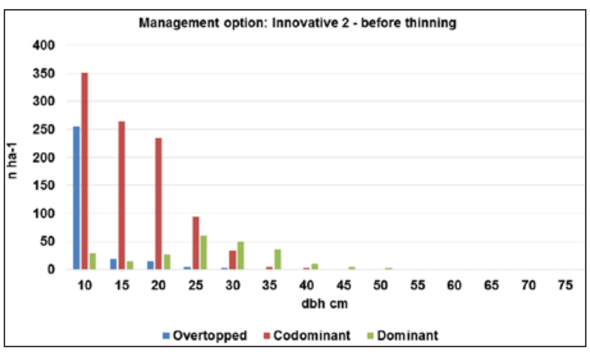
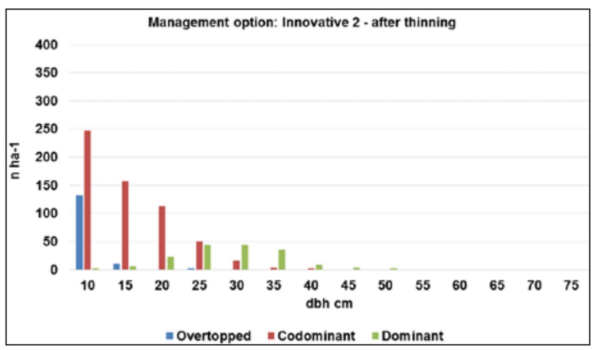
n ha-1
dbh cm
Overtopped
Codominant
Dominant

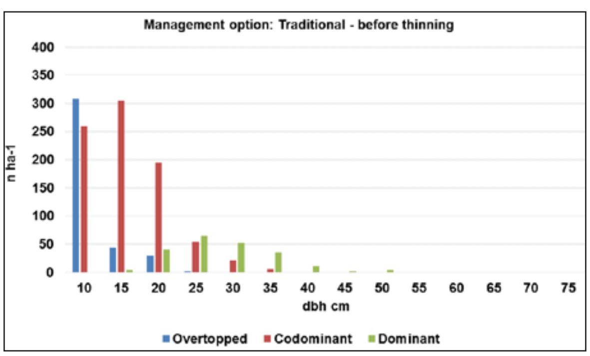
Tarvisio

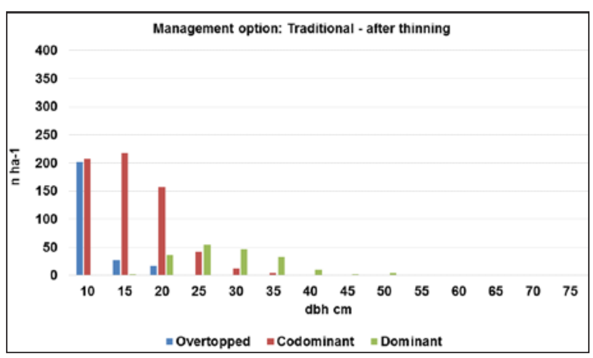

Management option: Innovative 1 - before thinning
n ha-1
dbh cm
Overtopped
Codominant
Dominant


Management option: Innovative 1 - after thinning
n ha-1
dbh cm
Overtopped
Codominant
Dominant

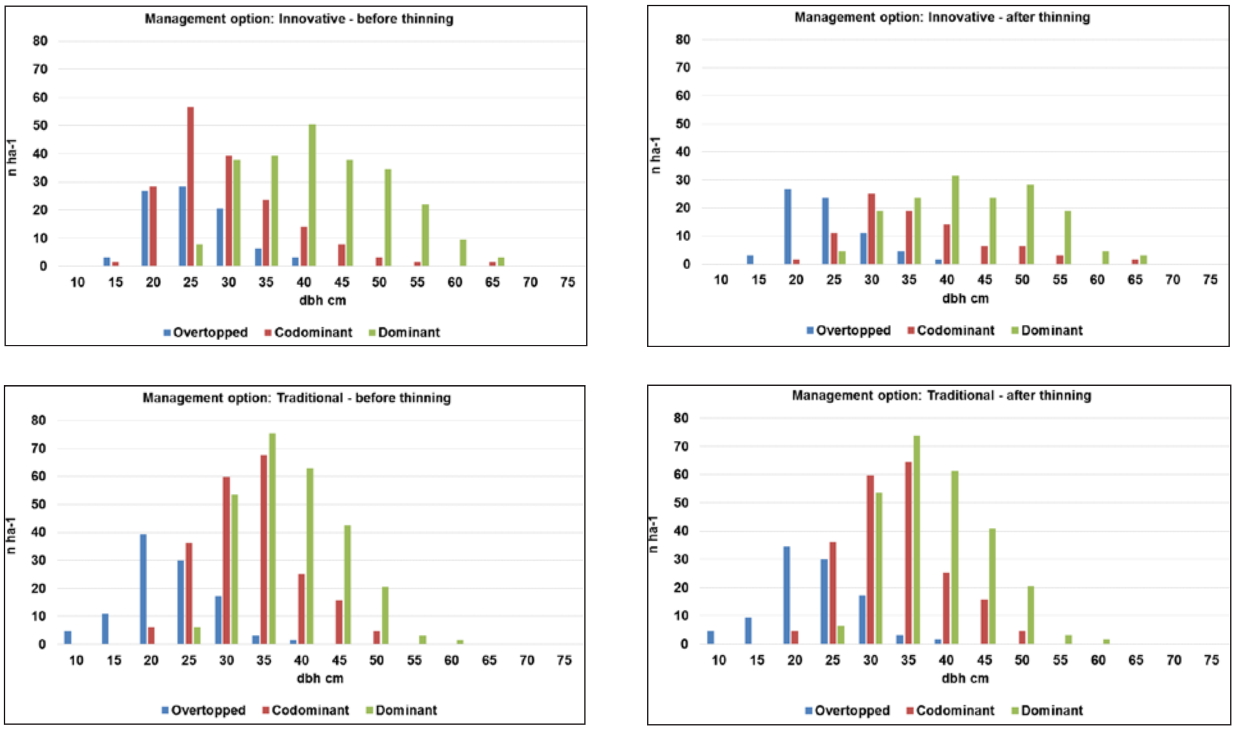

Management option: Innovative 2 - before thinning
n ha-1
dbh cm
Overtopped
Codominant
Dominant


Management option: Innovative 2 - after thinning
n ha-1
dbh cm
Overtopped
Codominant
Dominant


Management option: Traditional - before thinning
n ha-1
dbh cm
Overtopped
Codominant
Dominant


Management option: Traditional - after thinning
n ha-1
dbh cm
Overtopped
Codominant
Dominant

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 Raunkiær's life forms (e.g. share of Phanerophyte, Chamaephytes, Hemicryptophyte, Geophytes, Therophyte)(Raunkiær 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.

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Assessing indicators of deadwood and microhabitats

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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 ≥ 5 cm and height ≥ 1,30 m were included. Coarse woody debris was sampled if its minimum diameter was ≥ 5 cm and length ≥100 cm. Stumps threshold were: top diameter ≥ 5 cm and height ≤ 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	Saproxylic 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 censed 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.

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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 examination 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	

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Assessing indicators of animal diversity

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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]

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[2] CNBF National Centre for the Study and Conservation of Forest Biodiversity 'Bosco Fontana', Marmirolo (MN), Italy
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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.% 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.40 3.5%; Innov.80 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 1.5%; Innov.2 5.9%
Threatened beetle species	Vallombrosa	4.8%	NA

The number of threatened species varied in the plots where the different selvicultural 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 knowlwdge	Costs	Interaction with other indicators
Stand	2	2	Vertical vegetation structure, Plant species richness

Results from ManFor C.BD.

Indicator name	Site	Control	Treatement 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 Encountery 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 saproxilic 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% logging 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 stuctural 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%
Saproxylichoverfly 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 selvicultural 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.

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Applying indicators of vegetation diversity

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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, Søgaard 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 20O7, 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 CO2 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-

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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 overstory trees and understory 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 understory 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^2 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 communitiesand 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 pi 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 α = 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	Fagus sylvatica- UPPER TREE LAYER (%)	3.12	0.0162	*
	Fagus sylvatica - LOWER TREE LAYER (%)	3.40	0.0104	*
	Fagus sylvatica - SHRUB LAYER (%)	1.82	0.1270	ns
	Fagus sylvatica - HERB LAYER (%)	0.97	0.4439	ns
	Abies alba - UPPER TREE LAYER (%)	1.31	0.2772	ns
	Abies alba - LOWER TREE LAYER (%)	0.84	0.5271	ns
	Abies alba - SHRUB LAYER (%)	0.30	0.9101	ns
	Abies alba - HERB LAYER (%)	0.94	0.4637	ns
	Picea abies - UPPER TREE LAYER (%)	1.13	0.3567	ns
	Picea abies - LOWER TREE LAYER (%)	1.52	0.2027	ns
	Picea abies - SHRUB TREE LAYER (%)	0.85	0.5186	ns
	Picea abies - HERB LAYER (%)	1.09	0.3782	ns
SPECIES RICHNESS	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
	NUMBER OF HERB LAYER SPECIES	27.97	0.0000	***
BIODIVERSITY INDEX	EVENNESS index	6.46	0.0001	***
	SHANNON index H	9.71	0.0000	***
	SIMPSON index D`	4.00	0.0041	**

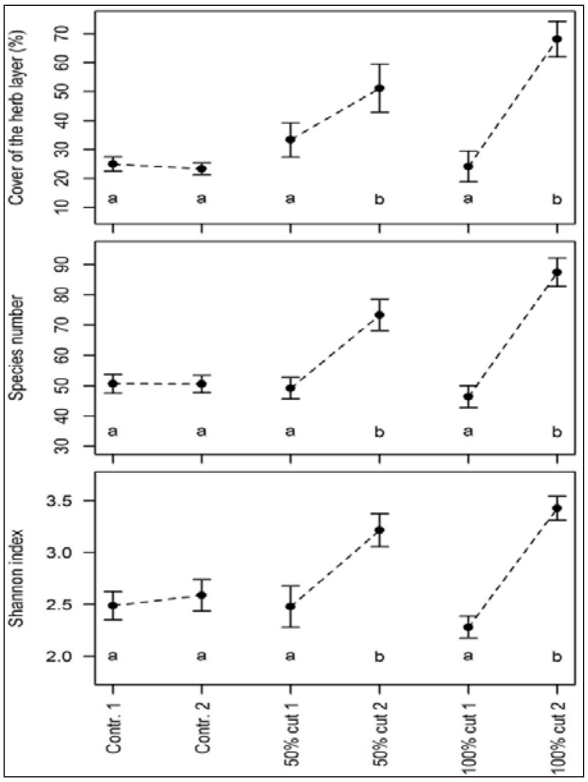


Figure 1 - Comparison of selected indicators; mean cover of the herb layer, the vascular species number and the Shannon index for three silvicultural measures before (1) and two years after the logging (2) in the study plots at three test sites in Slovenia (Kutnar et al. 2015).
The error bars represent 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.

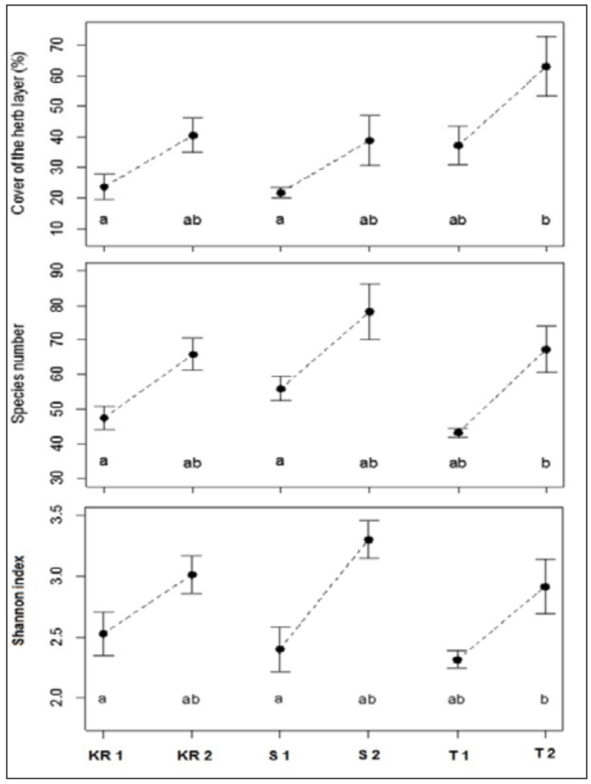
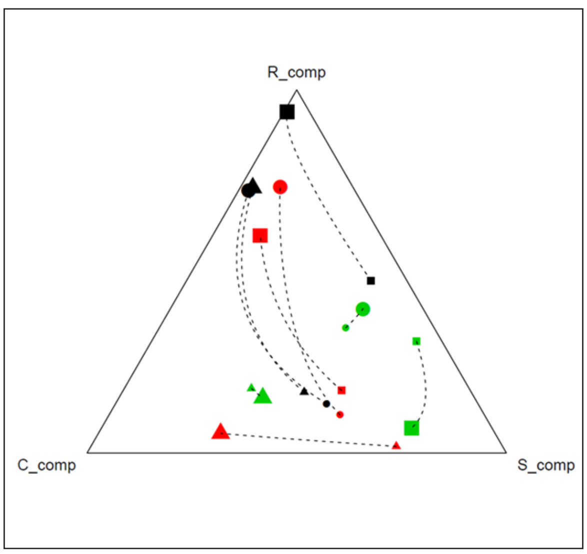


Figure 2 - Comparison of selected indicators;mean cover of the herb layer, the vascular species number and the Shannon for three test sites (Kočevski Rog - KR, Snežnik - S and Trnovo - T). A comparison between the states before (1) and after (2) logging is presented.
The error bars represent standard 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.



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.

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.

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Technical note

Volume function for the tree farming English oak plantations of the Valdarno (Tuscany, Italy)

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Abstract - In the past centuries, a notable reduction of lowland forests in Italy was detected as a result of the expansion of intensive agriculture and deforestation activities. According to the National Forest Inventory (INFC 2005), the English oak (*Quercus robur* L.) is mainly a scattered species distributed across 146,000 hectares of mixed forests. This species has been used in many national programs to recreate woods in the lowlands as well as tree in farming plantations. In the 1980s, within the restoration program of the Santa Barbara mining area in the Municipality of Cavriglia (Valdarno, Tuscany), about 172 hectares of tree farming plantations were created with English oak. Due to the shortage of specific volume equations for Italian plantations, a sampling campaign was carried out. The volume of 299 sample trees was measured using the Heyer formula and a volume equation was studied as a polynomial function of DBH and total height of trees. The final equation demonstrated to be quite robust with a RMSE of 0.0176 m3 corresponding to a relative RMSE of 10%.

Keywords - volume equation, tree farming plantation, English oak, Valdarno

Introduction

The English oak (*Quercus robur* L.) together with Sessile oak (*Quercus petraea* (Matt.) Liebl.), Common walnut (*Juglans regia* L. 1753) and Wild cherry (*Prunus avium* (L.) L. 1755) is one of the most commonly and widely used tree species in planting forestry for valuable timber production (Kenk 1993; Kerr 1996, Loginov 2012, Saha et al. 2012). These species were used across the whole Europe according to climatic conditions and managed by a specific silvicultural model (Lamaire 2010, Nubout 2006, Perin and Claessens 2009).

The distribution of the English oak in Italy is nowadays strictly connected to tree farming systems and mixed forests. In fact, its spatial distribution has been gradually reduced due to the intense land uses and the socio-economical changes occurred over the past centuries. The deforestation activities, due to the expansion of intensive agricultural crops, have caused a heavy reduction of the forests dominated by this oak species (Pividori et al. 2015). According to the last National Forest Inventory (Tabacchi et al. 2007), English oak is mainly a scattered species distributed across 146,000 hectares of mixed forest. On the opposite, it has been used for timber production because of reforestation programs financed by the EU since the 1980s, and many plantations were created in the floodplains. As a consequence, the species was reintroduced in the Italian framework in many lowland forests and in almost all the Italian Regions, even if mainly as tree farming plantation. These typical tree farming plantations have been managed with periodical geometrical or selective thinning (Ravagni et al. 2015) and a rotation age of 40 years was commonly adopted. Unfortunately, specific volume equations for English oak growing into tree farming plantations are missing in Italy, the only volume table for this species regarding natural forests (Castellani 1970, Castellani 1972, Castellani 1980, Castellani et al. 1984).

Aim of the paper is to set up a specific volume equation for pure plantations with English oak. At this purpose, a sample of trees felled in the course of thinning operations conducted between 1996 and 2014 was measured and analyzed.

Materials and Methods

The restoration program of Santa Barbara's mining area (Valdarno - Arezzo Province) represents first examples of English oak tree farming plantations in Italy. It was established in the '70s and '80s of 1900 reforesting 172 hectares with English oak seedlings (Buresti 1984, Ravagni et al. 2015). During thinning operation, undertaken in different plantations of

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the Santa Barbara area (43.5737 N, 11.4912 E), 299 trees were cut and fully measured to determine the volume. For each sampled tree, the following parameters were measured:

- diameter at breast height (DBH) above bark;
- stem circumference at intervals of one meter from 0.5 meters up to the top diameter of 3 centimeters;
- total height of the tree.

The collected data were first scanned to evaluate the quality of the dataset. Stem volume was calculated by the Heyer formula determining the volume of each section (La Marca 1999). The regression model was calculated using a stepwise analysis based on the Akaike's information criterion (AIC, Akaike 1974) of backward type starting from the "maximum model" [1] (Del Favero 1978, Del Favero and Hellrigl 1978, Mancino and Verrastro 2002, Nosenzo 2008). Following this procedure, the stem volume (expressed in m^3) was calculated as a function of a polynomial equation using the DBH (expressed in centimeters) and the total height of the tree (expressed in meters).

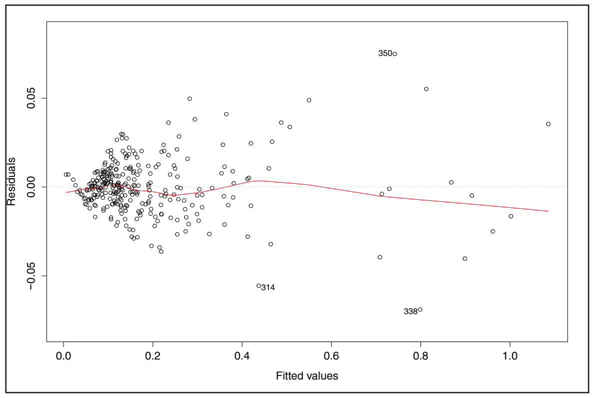

Figure 1 - Distribution of regression's residuals.

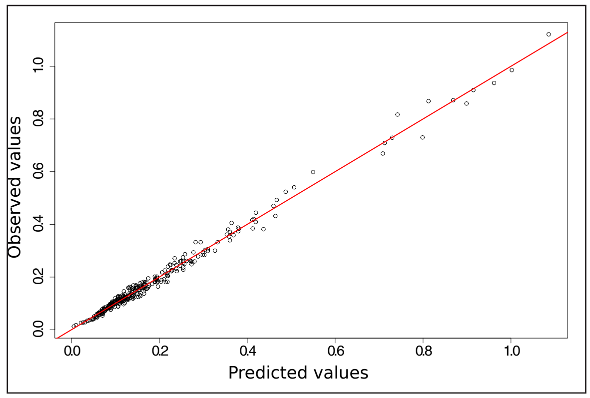

Figure 2 - Predicted vs. observed values of the sampled trees' Volumes.

$$V= a+b\,D+c\,D^2+d\,D^3+eH+f\,H^2+g\,D\,H+h\,D\,H^2+i\,D^2H+l\,D^2\,H^2+m\,B^3\,H+n\,D^3\,H^2$$

The Durbin-Watson test (Durbin and Watson 1971) was used to test the autocorrelation of disturbances of the regressive model. Root Mean Squared Error (RMSE) and relative RMSE (rRMSE) were calculated using a cross-validation procedure with the leave-one-out approach. All the calculations and statistical analyses were conducted on R software (R CoreTeam, 2015) using the *stats* and the *ipred* (Peters and Hothorn 2015) packages.

The tree sampling was limited only to same plantations without following complex schemes and was configured as not probabilistic but according a reasoned choice type (Mancino and Verrastro 2002).

Results

The main statistics of the 299 sampled trees are reported in Table 1, while the regression coefficients of the final equation with the statistical significance of coefficients are shown in Table 2. The Residual Standard Error was 0.01631 with an adjusted R^2 of 0.9907. The Durbin-Watson test showed a p-value of 0.2785 highlighting an absence of autocorrelation of residuals. These values are plotted Fig. 1, while predicted values versus observed values are reported in Fig. 2. The cross-validation procedure calculated a very low RMSE of 0.0176 m^3 and the rRMSE was lower than 10% (9.33%).

Table 1 - Main statistics of all the collected mensurational variables.

		n.observ.	minimum	maximum	average	st. dev.
d	cm	299	4.5	41.0	17.9	0.155
H	m	299	4.9	24.0	13.2	0.166
V	m3	299	0.006	1.121	0.174	0.177

Table 2 - Regression coefficients and their significance for the two-entry stem volume table. Significance of parameters is reported with the following legend: p<0.1 (.), p<0.05 (*), p<0.01 (**), p<0.001 (***).

Coefficients	Estimate	Std.	Error	t value	Pr(>ltl)
(Intercept)	-0.3641	0.0980	-3.716	0.0002	***
D	0.0504	0.0146	3.456	0.0006	***
I(D^2)	-0.0011	0.0006	-2.178	0.0302	*
H	0.0535	0.0154	3.469	0.0006	***
I(H^2)	-0.0018	0.0008	-2.334	0.0202	*
I(D*H)	-0.0076	0.0016	-4.714	0.0000	***
I(D*H^2)	0.0003	0.0001	5.700	2.95E-008	***
I(D^2*H)	0.0002	0.0001	3.936	0.0001	***
I(D^2*H^2)	-0.0001	0.0001	-5.169	0.0000	***

In Table 3 the trend of stem form factor per DBH and tree height classes are reported. A part for the DBH 5 class, in all the other DBH classes the form factor increase with the tree height.

Discussion and conclusions

The use of trees collected from thinning activi-

Table 3 - Expected value of stem form factor per dbh and tree height classes.

dbh 10		dbh 15		dbh 20		dbh 25		dbh 30		dbh 35		dbh 40	
H (m)	f	H (m)	f	H (m)	f	H (m)	f	H (m)	f	H (m)	f	H (m)	f
8	0.492	8	0.537	9	0.450	12	0.391	20	0.429	20	0.399	20	0.376
9	0.493	9	0.487	10	0.425	13	0.393	21	0.438	21	0.402	21	0.374
10	0.503	10	0.457	11	0.411	14	0.398	22	0.447	22	0.404	22	0.371
11	0.520	11	0.443	12	0.407	15	0.406	23	0.456			23	0.368
12	0.541	12	0.441	13	0.409	16	0.416						
13	0.566	13	0.447	14	0.417	17	0.428						
		14	0.460	15	0.429	18	0.441						
		15	0.479	16	0.444	19	0.455						
				17	0.463	20	0.471						
				18	0.483								

ties demonstrated to be a fair choice, not limiting the calculation neither the growth of the species (Kerr 1996, Jobling and Pearce 1977). The study produced a local volume equation ready to use after a preliminary analysis of DBH distribution and DBH-tree height relationship. The physical attributes of sampling area (Valdarno), even if localized as compared to the overall distribution of the species, makes the area a good “reference site” because of the mild climate, the average rate of precipitations during summer and an average temperature of 11°C, all of this representing fair conditions for the species autoecology .

The database was highly representative of the full life-span of a typical English oak plantation and the volume function demonstrated a close fit with a low RMSE.

According to the literature, this equation represents the first calculated for English oak tree farming plantations in Italy and is an useful tool to evaluate the oak stem volume growing in tree farming plantations undergoing a regular thinning regime. An adequate analysis of ranges (diameter and tree height) is anyway needed prior to using this function in other geographical locations.

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