G Model
JNC-25569; No. of Pages 11

ARTICLE IN PRESS

Journal for Nature Conservation xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.de/jnc

Review

Biodiversity in (the Natura 2000) forest habitats is not static: its conservation calls for an active management approach

Marko Kovac[a,*], David Hladnik[b], Lado Kutnar[c]

[a] Slovenian Forestry Institute, Department of Forest and Landscape Planning and Monitoring, Vecna pot 2, 1000 Ljubljana, Slovenia
[b] University of Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable Forest Resources, Vecna pot 83, 1000 Ljubljana, Slovenia
[c] Slovenian Forestry Institute, Department of Forest Ecology, Vecna pot 2, 1000 Ljubljana, Slovenia

ARTICLE INFO

Article history:
Received 14 January 2017
Received in revised form 2 June 2017
Accepted 14 July 2017

Keywords:
Disturbance
Succession
Dynamic approach
Sustainability
Management

ABSTRACT

Conservation of forest biodiversity means the managing of forest habitat types and the habitats of species in a sustainable manner. In forest habitat-type stewardship, the employment of suitable management approaches is critical. It is assumed that knowledge about the natural processes, and tree and forest habitat traits is integrated into these approaches. In addition to known techniques, forest science and practice are often recommended by diverse stakeholders to consider and introduce diverse management regimes into day-to-day management. While many of them are sound, being grounded in ecological science, some still need to be evaluated. This study was focused on the presentation of changes in the forest environment. Additionally, it addressed natural and man-made disturbances that play an important role in day-to-day management and attempted to describe differences between them from various points of view. The study also presented facts in regard to the static and dynamic approaches to biodiversity conservation (in the sense of the objective-setting process), management with forest habitat types and the assessment of their conservation status. The 91K0 – Illyrian *Fagus sylvatica* forest habitat types and 5130 – *Juniperus communis* formations on calcareous grasslands were used for exemplifying different approaches. The study revealed that the static approach to biodiversity conservation is mostly inappropriate. It also showed that unified management approaches to forest habitat types do not work because they provide different outcomes in different habitat types with different tree-species compositions.

Contents

* Corresponding author.
E-mail address: marko.kovac@gozdis.si (M. Kovac).

http://dx.doi.org/10.1016/j.jnc.2017.07.004
1617-1381/

Please cite this article in press as: Kovac, M., et al. Biodiversity in (the Natura 2000) forest habitats is not static: its conservation calls for an active management approach. *Journal for Nature Conservation* (2017), http://dx.doi.org/10.1016/j.jnc.2017.07.004

1. Introduction

Natura 2000, the most significant nature conservation effort in the European Union (EU), is a coherent ecological network of special areas. Its designation was based on the EU Birds (OJEC, 1979) and Habitats Directives (HDirective; OJEC, 1992). Since its establishment, this network has assisted in meeting the objectives of the Convention on Biological Diversity (Convention; UN, 1992a) by sustaining biodiversity in ecosystems and habitats of species. At the same time, both directives form an integrated framework for the identification, maintenance, and protection of sites of high biodiversity value. Finally, they enable Member States to implement biodiversity policy commitments requested by the convention (UN, 1992a) and legally binding biodiversity assessment, reporting, and monitoring (Bock et al., 2005).

Biodiversity has been thoroughly investigated since the mid-1950s. Its early explorations have encompassed fundamental evolutionary topics, such as food chains and their interrelations (Hutchinson, 1959), successions and their seral stages (Odum, 1969), as well as attempts to shape a general theory of diversity (Brown, 1981). In the search for new knowledge and efficient conservation management techniques, recent research has delved into the examination of i) different biodiversity spheres, namely composition, function, and structure; ii) their functioning at different organizational and spatial scales such as species genes, individual species, forest ecosystems and landscapes (Crow, Haney, Waller, Hathaway, & Trower, 1994; Franklin, 1993; Noss, 1990) and; iii) biodiversity assessment and productivity (Bengtsson, Nilsson, Franc, & Menozzi, 2000). Several studies also cover the development of indicators for biodiversity assessment (Angelstam, Breuss, & Mikusinski, 2001; Chirici et al., 2012; Marchetti, 2005; Noss, 1999).

The importance of biodiversity for sustainable forest management (SFM; Forest Europe, 2017) is the primary cause for the inclusion of ca. 23% of all EU forests (EC, 2017) into the Natura 2000 network in which they represent ca. 50% of habitats. Its inclusion (along with other goods and services) into forest management planning naturally has not been without consequences. Not only has the goal-setting process become more intricate, aiming at finding trade-offs among diverse goods and services, the evaluation of the effects of different management regimes on forest biodiversity has also become demanding. Despite its unpopularity, this step is inevitable as it helps mitigate disputes among stakeholders often advocating different interests and views on whether and in what way applied management regimes do or do not affect forest habitats' biodiversity or their species (Bouwma, Van Apeldoorn, & Kamphorst, 2010; Niemelä et al., 2005). Furthermore, even though the HDirective requires the assessment of the conservation status of the forest habitat types, studies addressing this topic are rare. Usually, they deal with the development of indicators and the means of their assessment (Cantarello & Newton, 2008; Kovač, Kutnar, & Hladnik, 2016) and with the development of methods for the overall assessment of the conservation status (Hernando, Tejera, Velázquez, & Núñez, 2010).

A proper understanding of disturbances and their relations to ecosystem diversity is crucial for forest biodiversity conservation. Contemporary biological and forest sciences agree that natural and man-made disturbances are the main agents of ecosystem diversity (Bengtsson, Nilsson, Franc, & Menozzi, 2000; Bergeron & Harvey, 1997). Disturbance-diversity theories are generally classified into equilibrium and non-equilibrium groups (Connell, 1978). Among the latter, it is worth noting the intermediate disturbance hypothesis, which works well in temperate, boreal, and Mediterranean forests (Torras & Saura, 2008). This hypothesis postulates that forest biodiversity is highest at intermediate scales of disturbances, whereby the scale represents the intensity of management and the length of time between two successive disturbances (Roberts & Gilliam, 1995). Such theories also play a significant role in forest management. Silviculture, the art and science of managing forests to obtain a variety of goods and services without undermining forest integrity (Fujimori, 2001; Graham & Jain, 1998), more or less completely resembles the effects of the previously mentioned disturbances (Mitchell, Palik, & Hunter, 2002; Schütz, 2001; Schütz, 2002). However, despite the long-term use of silvicultural techniques, little is known regarding the extent to which they affect the biodiversity aspects of forest ecosystem stability (Bengtsson, Nilsson, Franc, & Menozzi, 2000; Decocq et al., 2005) and the lives of different animal species (Paillet et al., 2010).

SFM is the most important and sophisticated paradigm of modern forestry. Although sustainability itself has a long historical record (Von Carlowitz, 1713), this paradigm is recent and dates back to the Rio Conference (UN, 1992b). However, unlike biodiversity conservation, SFM is more complex as it promotes the sustainable use and provision of all forest goods and services (Schmithüsen, 2013), multiple uses of forestlands (Schmithüsen, 2007) and nature-based (syn. ecosystem) forest management (Diaci, 2006a; Franklin, 1997; Pommerening & Murphy, 2004; Pukkala & von Gadow, 2011; Schütz, 1999).

In pursuing SFM, forest management traditionally employs diverse management regimes developed through long-term field experiments. With the inclusion of biodiversity into SFM and raised environmental awareness, these regimes are occasionally rejected with the argument that they do not support biodiversity conservation. To alleviate differences between forest and nature conservation management approaches, this article first aimed to address two contrasting groups of approaches to biodiversity, i.e.: i) static vs. dynamic and ii) non-management vs. management approaches. In the first group, we engaged with the problems of forest naturalness, successions, and perpetual stand development. These processes not only characterize many Natura 2000 habitat types, but they also blur general views on the naturalness of forest ecosystems and reopen the problems of habitat conservation status assessments. In the second group of approaches, we focused on the differences between the non-management and management approaches. Additionally, an independent section addressed the problems linked to forest monitoring, reporting, and SFM. Finally, in the conclusions, we proposed suggestions for improvements, better management, and future work.

Forest management problems and dilemmas were exemplified by the 91K0 – Illyrian *Fagus sylvatica (Aremonio-Fagion)* forest habitat type (Kutnar, Matijašič, & Pisek, 2011), the old-growth (syn. pristine) forest remnant of Pečka (belonging to the same habitat type) and the 5130 – *Juniperus communis* formations on calcareous grasslands. Both are suitable due to their heterogeneity and capability of forming successional seral stages (EC, 2007). Especially important is the first forest habitat type because it covers a significant share of national forestlands (ca. 50%) and provides many goods and services. It is mostly managed with nature-based techniques, whereby the intensity of management is to a great extent adjusted to site conditions (Boncina et al., 2014).

2. Dynamic vs. static approach to biodiversity

2.1. Natural dynamics and naturalness

The static approach to biodiversity in nature conservation is common. The main reason for its use is simplicity in dealing with biodiversity assessment, management, monitoring, and reporting, as well as in defining the habitats of species (Van Dyck, 2012). Such a view is also promoted by the HDirective (Mergeay & Santamaria, 2012) which has presumed the establishment of the network of a more or less fixed number of sites whose biodiversity is expected to be sustained over an undefined period. Regardless of its practicability, this approach to nature conservation is inappropriate because it views forest landscape and ecosystem dynamics (Campagnaro, Frate, Carranza, & Sitzia, 2017), unfolding changes in the forest environment (Kobler, Cunder, & Pirnat, 2005), and the longevity of tree species (Pretzsch, 2009) in an entirely static manner.

Closely associated with forest dynamics is the concept of forest naturalness, which is defined as the degree of similarity between the present and natural ecosystem conditions (Winter, 2012; Winter, Vrška, & Begehold, 2013). Accordingly, an ecosystem in a natural state should be free of any long-lasting human impact. It is worth noting, however, that science argues whether natural forests presently exist at all (Peterken, 1996; Remmert, 2013). Because all forests on Earth are exposed to direct or indirect human impacts, their naturalness continues to decrease. Investigations show that all forest uses and management regimes affect forest biodiversity, either positively or negatively (Gibson et al., 2011; Götmark, 2013; Paillet et al., 2010). Notwithstanding their long-lasting effects that may blur the differences between the natural and managed ecosystems, the gradient of naturalness, spanning from the most simplified forests such as plantations to the most natural ones as possible under current conditions, is still evident and is clearly linked to the forest biodiversity formation (Winter, Fischer, & Fischer, 2010).

2.2. Successions and seral stages

Another fundamental concept in vegetation ecology is succession. The term "dynamics of vegetation succession" means temporal changes in the vegetation structure (Glenn-Lewin & Van der Maarel, 1992; Odum, 1969), a change in species composition or in the three-dimensional architecture of the plant cover in a specific place through time (Pickett & Cadenasso, 2005). In his seminal paper, dealing with the first codification of vegetation dynamics, Clements (1916) focuses on three key features: i) a discrete starting point; ii) a clear directional trajectory; and iii) an unambiguous end. These three assumptions have ever since been associated with the notion of succession.

The succession trajectory of a complex forest ecosystem is influenced by a set of factors, including forest management, human alterations, disturbances, and changing climate. All of them slowly modify the ultimate portrayals of successions. However, because a variety of possible forest development trajectories exist, there nevertheless remain open questions such as "Which, out of many biodiversity portrayals, is the correct one?", "How long do forest management planning horizons last?" and "How to define which conservation status is favourable?"

After a natural disturbance, the forest vegetation continues to develop until it arrives into a new temporary stable state. Among the many processes shaping forest ecosystem development, cyclical population fluctuations, patch dynamics, secondary, primary and secular successions (also called vegetation history), and long-term vegetation changes in response to (global) changes and climate are best known. The time scale of these processes varies from less than a year to thousands of years. Additionally, the duration of successional stages at the plant community level also spans from less than a year in early secondary stages in the tropics to ca. 1000 years in late temperate forest stages (Van der Maarel, 2005).

In view of the Natura 2000 forest habitat type conservation status assessments, different time scales should not be ignored. Similarly to the changing conditions and conservation statuses of forest habitat types, the values of indicators (i.e. stand density index, basal area, diversity indices) assisting in assessing their biodiversity also vary over time. Consequently, the status of habitat types cannot be considered static.

Fig. 1 depicts changes in the Slovene part of the 91K0 – Illyrian *Fagus sylvatica* habitat type between the mid-1940s and present times. Only between the late 1950s and early 1970s, when the first nation-wide forest vegetation mapping took place (Košir et al., 1974), did forest cover increase from 43% to 60% (UrL RS, 2007) due to secondary succession (a combination of the post-agricultural and post-disturbance establishment of forests in forestlands). At the occasion of mapping, as much as 33% of the present habitat type area was in different seral stages or was not mapped as this habitat type (Fig. 1, in yellow). According to reports, secondary successions pose problems globally (Sitzia, Semenzato, & Trentanovi, 2010).

A different view of successions enabled a regeneration experiment in three test sites in the 91K0 – Illyrian *Fagus sylvatica* forest habitat type that triggered the development of early vegetation successions (Kutnar, Eler, & Marinšek, 2015). In this experiment, nine 0.4 ha-large plots (three in each test site), installed in mature fir-beech stands (standing volume in range from 390 to 628 m^3 ha^{-1}), were subjected to regeneration felling with three intensities: i) control plot – no felling; ii) medium cut plot – ca. 50% of the standing volume removed; iii) fully cut plot – 100% of the standing volume removed. Significant changes in the plant species compositions and vegetation structures occurred two years after felling. Undoubtedly, the most significant finding was the detection of 105 new plant species, which enriched the species composition by ca. 40% (151 plant species before and 250 species after treatment). The majority of new species initiated in the fully felled gaps and they belonged to the early successional, non-typical forest plants (Fig. 2).

Depending on different influential factors, the directions of further successional development (Prach et al., 2014) of the 91K0 – Illyrian *Fagus sylvatica* habitat type (see Fig. 2, options 2 and 3) are expected. Notwithstanding all possible developmental trajectories, this experiment unambiguously demonstrated that light plays a decisive role in the forest regeneration process and in sustaining and enriching habitat types' species compositions. To sustain their species richness, regenerating them with a wide array of regeneration patterns ranging from small-sized gaps to large-sized openings is inevitable. A larger amount of tree species also secures the existence of the habitat type in the long run by providing the opportunity to develop more development strategies (insurance hypothesis; Bengtsson, Nilsson, Franc, & Menozzi, 2000; Mitchell, 2005). This is especially important when unexpected hazards (i.e. large-scale infestations, climate change) undermine the integrity of the existing habitat type to such a degree that the development of a new trajectory is inevitable.

Also challenging in view of habitat type management and assessment are forest habitat types that belong to certain seral stages of a secondary or even primary forest succession. A typical example is the 5130 – *Juniperus communis* formations on calcareous grasslands. This habitat type is native to the Karst area (S and SW part of Slovenia) and represents an early successional stage of bushland, developing toward a forest formation (Fig. 3). Its importance is due to its diverse flora and rare, endangered, and protected plant and animal species. To ensure its favourable conservation status, proper management and restoration actions need to be implemented regularly, despite its temporary biodiversity portrayals. As Fig. 3 shows, the course of natural development transforms this habitat type through several successional seral stages into downy oak forest (*Quercus pubescens*). In optimal conditions, the transformation may even end with the stage of sessile oak (*Quercus petraea*).

As assumed, the conservation approach to such habitat types should respect the natural dynamics in time and space. Furthermore, the strategy of nature conservation in such sites still must be broadly discussed due to many open questions such as: "What is the length of the conservation horizon?", "How should the dynamic goals be set and implemented?", and "Wouldn't floating areas, sup-

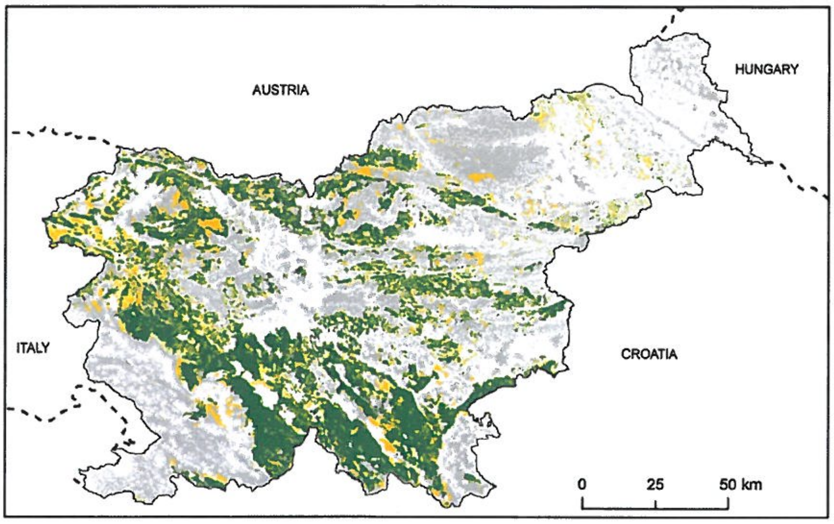


Fig. 1. Changes in the potential zone of the 91K0 – Illyrian *Fagus sylvatica* forest habitat type in Slovenia. The spatial distribution of the habitat type over 50 years ago is indicated in green (Košir et al., 1974; Košir et al., 2003), while its newer patches are shown in yellow (Kovač et al., 2016). Other woodlands are indicated in grey.

porting succession theory, be more convenient for conservation than permanent plots in the case of these habitats?"

2.3. Perpetual forest stand development

Forests differ from other land ecosystems in almost every aspect such as the biogeochemical cycles, climate regimes and vegetation and its organization at the community and population levels. Also very different are their biodiversity features, which require a dynamic approach to biodiversity conservation. Unlike other land habitats, whose biodiversity portrayals vary mostly seasonally, the biodiversity portrayals of forest stands change over time and space. The changes are due to the longevity of trees, their growth dynamics (Pretzsch, 2009; White & Walker, 1997), and fluctuating environmental conditions and disturbances, including forest management (Bergeron & Harvey, 1997; Decocq et al., 2004; Decocq et al., 2005; Mitchell, Palik, & Hunter, 2002; Pressey, Cabeza, Watts, Cowling, & Wilson, 2007). Specifically, a mature forest stand (i.e. a group of large trees with diameter at breast height >50 cm) with its own biodiversity portrayal (e.g. prevalent shade, only a few tree species, specific animal species, little ground vegetation) inherently develops toward a young forest grove, whose biodiversity portrayal will be more similar to open spaces than to closed forests (Fig. 2). This simple statement asserts that neither a stand in particular development phase nor its biodiversity portrayal can be conserved over time on the same site but only in a wider area. This fact should be respected when setting up the network and assessing its habitat types.

3. Non-management vs. regular management approach

3.1. Disturbances as silvicultural tools

Despite sparse knowledge about the ancient portrayals of Europe's natural forests, people's imaginations usually portray these forests as fully stocked landscapes with closed tree canopies. Conversely, recent theories suggest that the ancient old-growth forests were much more open than today because of a variety of disturbances including human encroachments and grazing by large herbivores (Bengtsson, Nilsson, Franc, & Menozzi, 2000; Mitchell, 2005). Regardless, the remnants of old-growth forests are vital for modern forest and nature conservation management as they bring information and knowledge for understanding natural processes and the improvement of silvicultural techniques.

Studies dealing with biodiversity in pristine and managed mature forests reveal many differences. While the compositional traits of both forest types are similar (i.e. species richness of vascular plants), their structural traits differ significantly (Hale, Pastor, & Rusterholz, 1999; Sitzia et al., 2012). Old-growth forests, for instance, produce rather homogeneous forest structures, characterized by a lower number of tree-species, and less structured developmental phases and vertical layers (Schütz, Saniga, Diaci, & Vrška, 2016). Additionally, much longer life cycles produce diverse structures, such as hollow and decayed trees along with large amounts of deadwood being home to plant, fungi, and highly specialized animal species, commonly found only in unmanaged forests (Commarmot et al., 2005; Moning & Müller, 2009; Müller, Hothorn, & Pretzsch, 2007; Sitzia, Campagnaro, Gatti, Sommacal, & Kotze, 2015). Another important feature of old-growth forests is regeneration. In contrast to managed forests, in which it is normally planned, regeneration in pristine forests mostly occurs accidentally as a consequence of more or less frequent disturbances. The disturbances with turnovers between 200 and 460 years (Nagel, Svoboda, & Kobal, 2014) commonly produce between 0.01–0.5 ha large gaps and open spaces (Nagel & Svoboda, 2008) which are regenerated afterwards.

Studies also reveal that unevenness rarely occurs in the forests (natural and managed) of the central temperate vegetation belt (Schütz et al., 2016) due to its unsustainability in the long run (Schütz, 2001). If it does occur, the structure is due to the presence of more shade-tolerant tree species.

Slovenia's old-growth forests are scarce and small. Despite this, these forests exhibit very similar traits, such as long generation cycles and the tendency to accumulate large amounts of biomass. Additionally, the forests are also bereft of all kinds of unevenness, such as rich species compositions and fine-grained horizontal and vertical structures (Boncina, 2000).

Because of their significance, compositional and structural traits should be at the centre of research when dealing with disturbances in old-growth and managed forests. Especially, because the investigations of processes in the forests allow the conclusions that nature-based forest practices, mimicking natural ecological processes, seem to be more likely to sustain the forest environment and its goods and services (North & Keeton, 2008) than the nature

Please cite this article in press as: Kovac, M., et al. Biodiversity in (the Natura 2000) forest habitats is not static: its conservation calls for an active management approach. *Journal for Nature Conservation* (2017), http://dx.doi.org/10.1016/j.jnc.2017.07.004

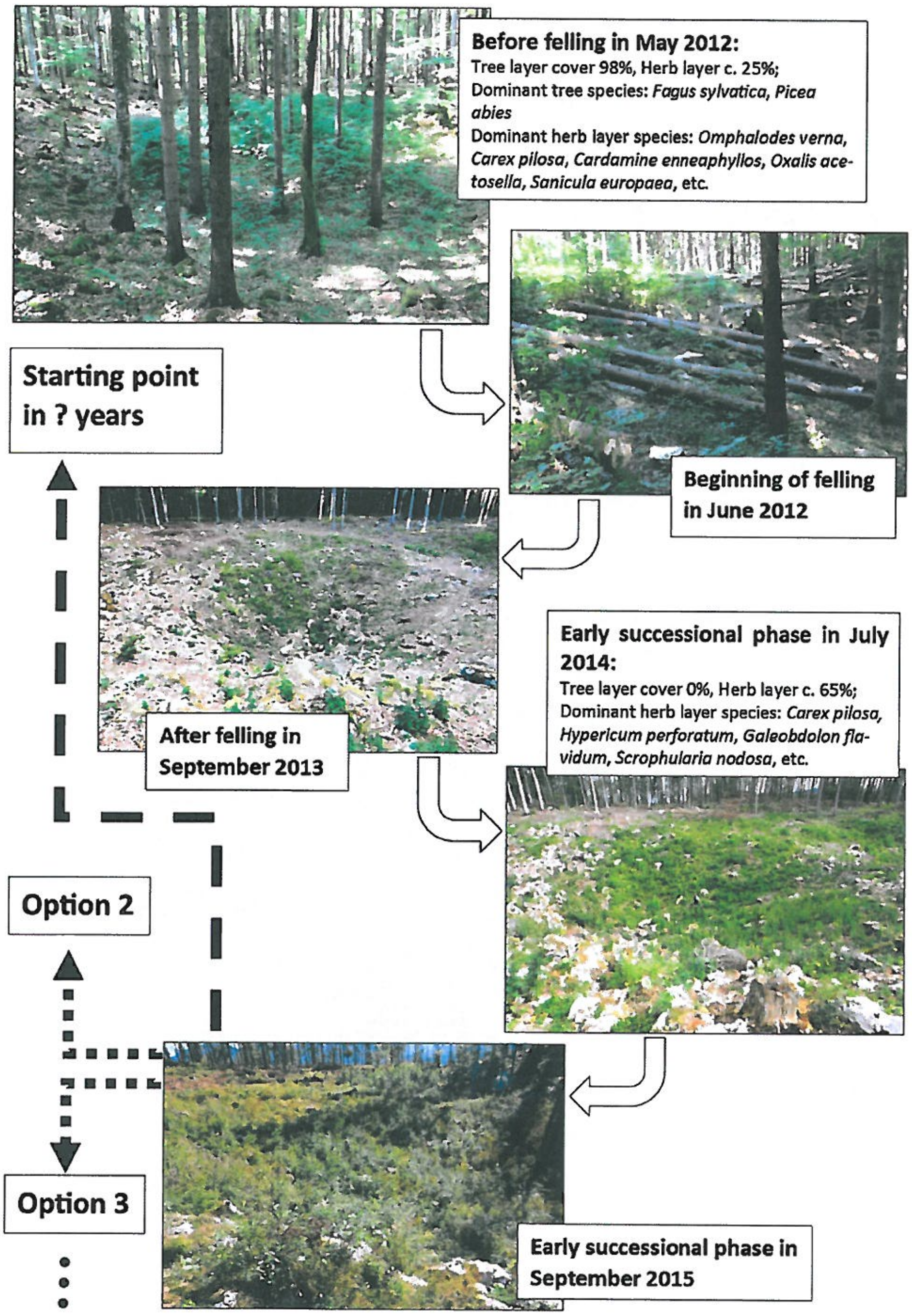


Fig. 2. Development of forest succession in the 91K0 – Illyrian *Fagus sylvatica* habitat type after intensive (100% removal of trees) regeneration felling (Kutnar, Eler, & Marinšek, 2015).

unfriendly ones. Notwithstanding the regional differences in the concepts of SFM and their imperfections, silvicultural treatments in the stands continue to remain the most important tool for emulating natural disturbance dynamics (Adamic, Diaci, Rozman, & Hladnik, 2016; Mitchell, Palik, & Hunter, 2002; Raymond, Bédard, Roy, Larouche, & Tremblay, 2009; Schütz, 1999). In this context, it is also worth noting that the natural processes in Central European old-growth forests largely behave in accordance with the intermediate diversity hypothesis; because of long time intervals between successive disturbances and the competitiveness of the shade-tolerant beech, they mostly produce homogeneous forests.

3.2. Alternation of species due to natural and man-made disturbances – the case of mixed fir-beech forests

Alternation is the process of the trees of one species being succeeding by another tree species (Fox, 1977). It may occur in managed and unmanaged forests (Mölder, Streit, & Schmidt, 2014) and may be triggered by natural, man-made or combined processes. It occasionally poses a threat to the conservation of forest habitat types.

For a considerable period, this process has also been experienced by the unevenly aged fir-beech forests (Boncina, Gaspersic, &

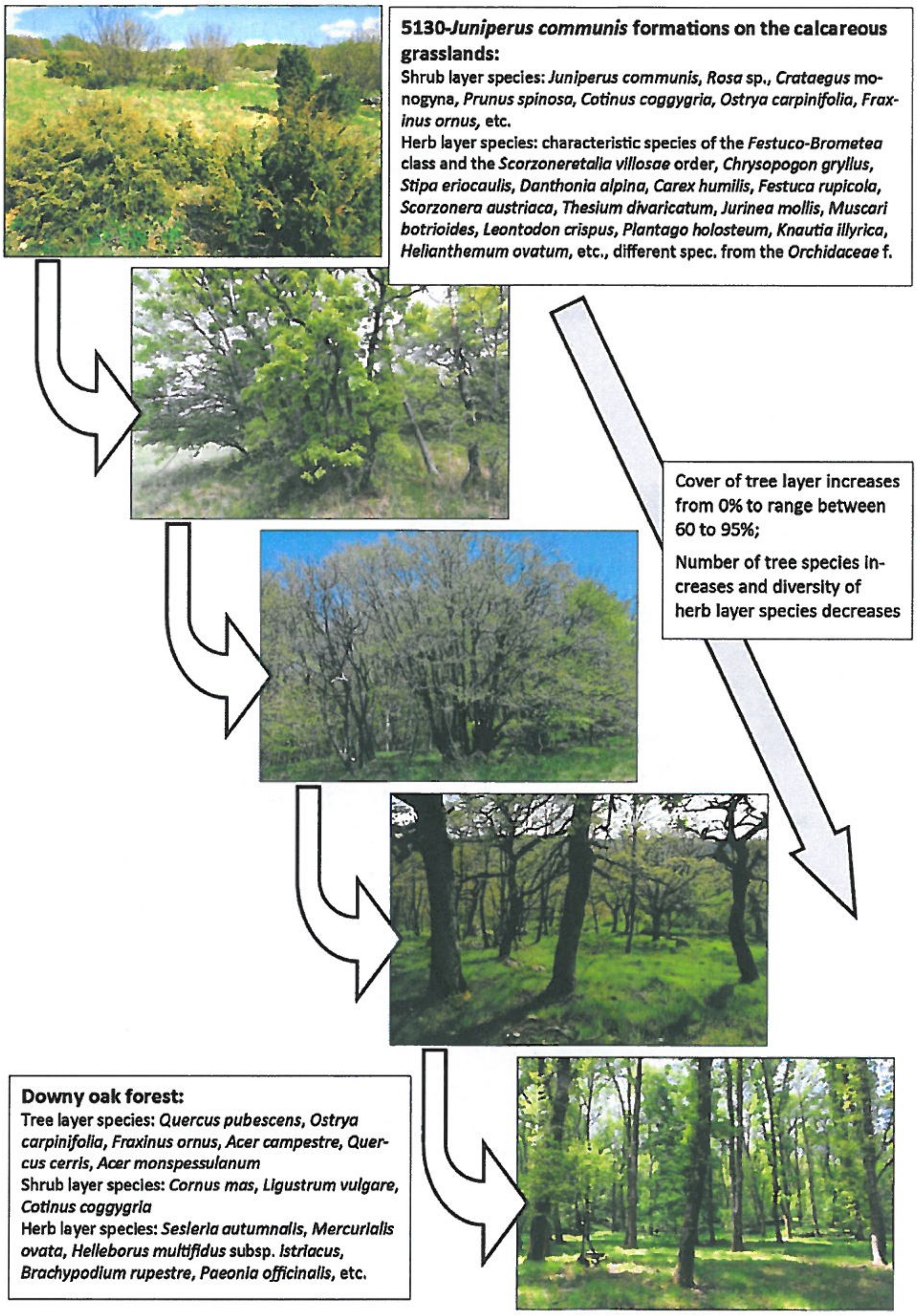


Fig. 3. One possible development alternative: seral stages spanning from the 5130 – *Juniperus communis* formations on calcareous grasslands (top) (Kaligarič & Trčak, 2004) to downy oak forest (*Quercus pubescens*) (bottom).

Diaci, 2003), belonging to the forest association of *Omphalodo Fagetum*. According to the Natura 2000 nomenclature and classification, these forests are the subtype of the 91K0 – Illyrian *Fagus sylvatica* forest habitat type (Kovač et al., 2016). The forests originate from mature fir-beech forests that underwent large-scale shelter-wood felling in the 19th century and were afterwards naturally regenerated by fir. After the period of intensive and unsuppressed growth of fir, a single tree and group-selection management systems were introduced. The great variability of their structures, created over the last 60 years, is thus very likely attributed to the interactions among factors such as alternated different management regimes, deer herbivory, and the decline of fir from the 1980s onward (Boncina, Gaspersic, & Diaci, 2003).

As assumed, the major problem of these forests is declining fir which is being replaced by beech. In managed forests, alternation is monitored with the research forest yield plots established some 60 years ago (Kobal & Hladnik, 2009) and with the periodical forest inventorying of forest management units (ZGS, 2014). The same process also unfolds in the pristine forest of Pecka (Fig. 4) in which the shares of fir and beech have been significantly changed over the last hundred years (ZGS, 2014).

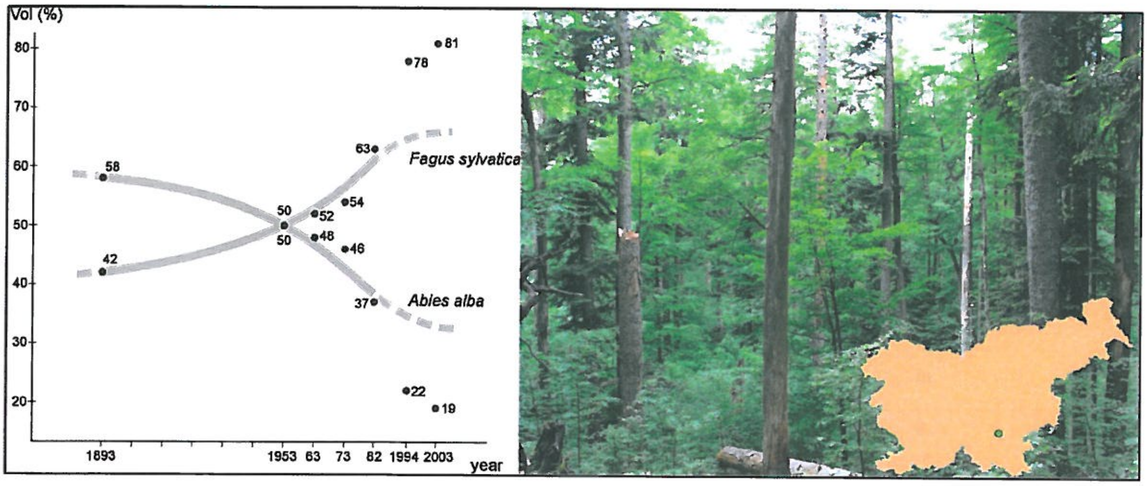


Fig. 4. Left – alternating shares of fir and beech in the old-growth remnant of Pečka in the previous century. From the late 1950s onwards, the data have been collected via full callipering at the occasions of revisions of the Forest Management Unit of Soteska (ZGS, 2014). Right: The remnant of old-growth Pečka; Location: Forest Management Unit of Soteska, SE Slovenia; Latitude = 45°45′23.5″; Longitude = 14°59′26.4″; Area: 59.50 ha; Set aside:1893; Forest habitat subtype: *Omphalodo Fagetum*; Mean standing volume: 712 m^3 ha^{-1}; Mean increment: 11 m^3 ha^{-1}; Share of conifers in standing volume = 12.7% (fir 12.5%, spruce 0.2%); Share of broadleaves in standing volume = 87.3% (beech 87.2%; other 0.1%) (ZGS, 2014).

3.3. Regeneration and recruitment

Insufficient natural regeneration and recruitment of dominant tree species are two more causes that need to be considered prior to set strategies for the conservation of forest habitat types and subtypes. Similar to alternation, both these processes are wide-spread in the unevenly aged fir-beech forests in the Slovene part of the Dinaric ridge and beyond (Diaci et al., 2008). Investigations show that the fir recruitment rate into higher DBH classes has steadily declined over the years (Klopcic & Boncina, 2011). This practically means that small fir trees, residing in shadowed understory (although shade-tolerant and capable of reacting to light after being released from the quasi-stationary stage; Schütz, 2001), have not fully exploited their potential. Although the data from the permanent sample plots reveal that the current shares of fir in the share of the stand basal area of the thickest trees remain large (Fig. 5; *Omphalodo Fagetum*), this share tends to decline in all classes with the DBH smaller than 30 cm (Boncina, Gaspersic, & Diaci, 2003). Because observations and measurements of stand structures suggest that fir will also decline in the future, it is likely that a more courageous regeneration felling will have to be implemented in order to sustain these forest habitat subtypes (Kovač & Fabbio, 2016).

Unlike fir, which has the potential to regenerate in small gaps, human interventions are crucial for maintaining the shares of sessile oak in the 91K0 – Illyrian *Fagus sylvatica* forest habitat type subtypes (Fig. 5). The results of the previous Forest and Forest Ecosystem Condition Survey (Kovač et al., 2016) showed that the stocking indicators (i.e. share of species in basal area, growing stock) of shade-intolerant tree-species are unfavourable. Furthermore, observations in oak forests suggest that the successful recruitment of sessile oak depends on the amount of light. In old-growth forests, sessile oak cannot recruit as long as the structures of mature forests are sufficiently crashed, thus allowing a new tree regeneration to develop unimpeded. In managed forests, natural oak regeneration works well by combining medium-sized gaps with diffusely opened neighbouring stands. According to observations, their minimum sizes should span between at least 0.25 ha at the initial stage to at least 0.5 ha at the pole stage (Schütz et al., 2016).

Within the Natura 2000 system, regeneration (i.e. natural, artificial, and combined) silvicultural actions, composed of small (0.1–0.25 ha) and medium-sized (0.25–1 ha) regeneration gaps and larger areas (1–3 ha) and variable life cycles (i.e. shortening and prolonging rotation periods), seem to be a good approach for sustaining the biodiversity of all forest habitat types.

Furthermore, to support animal species, forest management is recommended to avoid abrupt transitions from mature to young stands. Smooth transitions in several steps are especially beneficial for birdlife and saproxylic beetles (e.g. De Groot et al., 2016). In the case of low shares of mature stands in the neighbourhood, rich with bird and beetle populations, it is convenient to shorten the rotation periods on the areas to be regenerated and to accelerate the regeneration process. Moreover, in large regeneration areas, undergoing final cuts, it would also be convenient to leave a certain amount of retention trees (e.g. 10–20 trees/ha of low wood and economic quality, with DBH > 20 cm) to natural ageing, to become new habitats for bird and other species (Pasinelli, 2003; Mason et al., 2016). When the ecology of tree species allows, and the regeneration areas are sufficiently large, tree groups and habitat retentions are perhaps better options (Gustafsson et al., 2012).

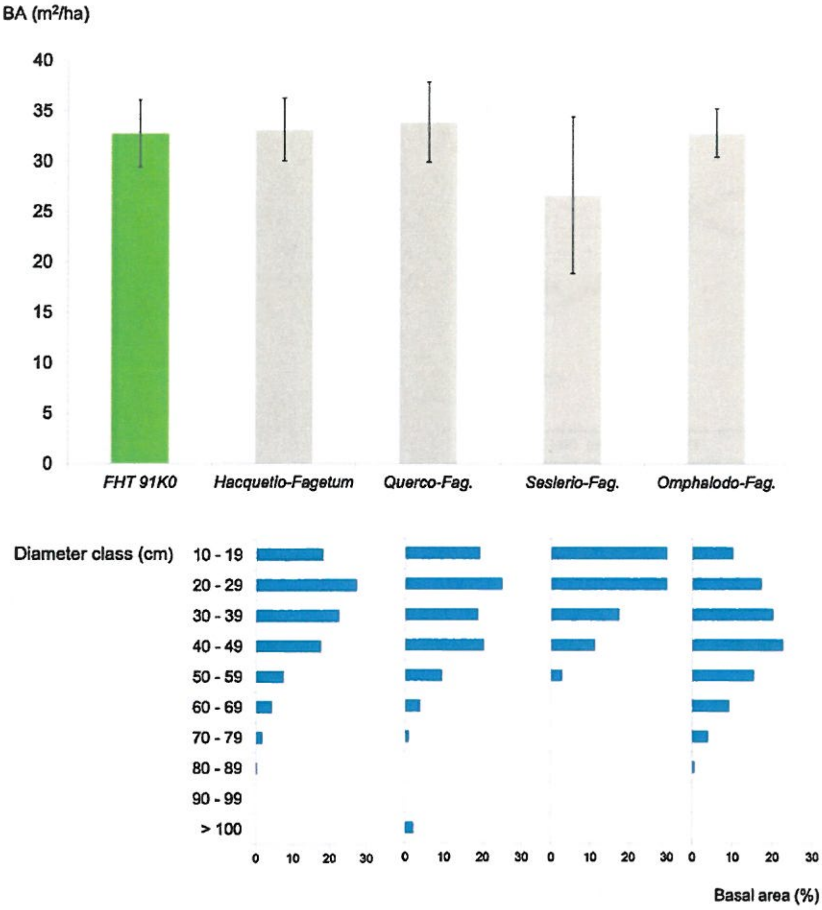
4. Monitoring, reporting, and sustainable management in view of the dynamic approach to forest biodiversity

4.1. Toward reliable monitoring and reporting

In accordance with the HDirective and its supplementary documents, the assessment of the conservation status must refer to the forest habitat type (EC, 2015; OJEC, 1992). A forest habitat type is defined as a vegetation system composed of two or more interacting forest habitat subtypes (Kovač et al., 2016). Consequently, a habitat type is considered a mosaic of different forest stands in different developmental phases (e.g. young, pole, mature stand), belonging to different forest habitat subtypes and often consisting of more forest associations. Furthermore, because the planning process (Williams, 2011) operates only within known land boundaries, all forest sites that are subject to monitoring and assessment must first be identified in the field and afterwards assessed in order to produce valid overall estimates for habitat subtypes and types.

Such an understanding of the concept of forest habitat type is especially meaningful for biodiversity conservation at the forested landscape (Kovač et al., 2016) and forest ecosystem scales. Specifically, if the forest habitat subtypes are well managed by using

Please cite this article in press as: Kovac, M., et al. Biodiversity in (the Natura 2000) forest habitats is not static: its conservation calls for an active management approach. *Journal for Nature Conservation* (2017), http://dx.doi.org/10.1016/j.jnc.2017.07.004



Tree species composition in % of standing basal area

Picea abies	25	19	3	25
Abies alba	3	2		25
Pinus sylvestris	7	1	12	
Fagus sylvatica	37	48	57	39
Quercus petraea	6	9	5	
Acer pseudoplatanus	4	2	2	6
Carpinus betulus	2	8	2	
Ostrya carpinifolia	3		4	

Fig. 5. Estimates of basal area and its structure by dominant tree species and DBH classes in four vegetation units of the 91K0 – Illyrian *Fagus sylvatica* forest habitat type. The estimates come from the 2012 Forest and Forest Ecosystem Condition Survey (Kovač et al., 2016).

different silvicultural strategies, they (as the constituent elements of forest landscapes) help prevent the homogenization of forest landscapes. The same holds at the forest ecosystem level where these strategies assist in sustaining the tree species diversity of forest associations and prevent them from amalgamating with the neighbouring ones.

To obtain proper assessments, which spatial units are subject to conservation, monitoring and reporting should also be known. For all the three phases, it is vital to know whether a single forest area with a specific tree-species composition at a specific site (i.e. a single forest stand, belonging to a forest association), a group of such stands in a larger forest complex, or all such stands in the region or country is considered as a reporting and conservation unit. To demonstrate this problem, consider the small-sized forest habitat subtypes or forest associations (i.e. *Querco petraeae-Fagetum, Ostryo-Fagetum, Seslerio autumnalis-Fagetum, Omphalodo-Fagetum*) that belong to the heterogeneous 91K0 – *Illyrian Fagus sylvatica* forest habitat type. If the stands belonging to habitat subtypes and forest associations alone are considered conservation units, and their biodiversity portrayals need to be sustained, only a free-style silvicultural system (Diaci, 2006b) can be implemented. The same areas must also be subject to monitoring and reporting. Conversely, if these stands are considered part of the forest habitat types in the landscape, region or nation, several management options, ranging from free-style to shelter-wood techniques can be implemented, less intensive monitoring can be introduced, and only one report can be prepared.

4.2. Sustainable forest management vs. biodiversity

Dynamic changes in forest habitat types and subtypes make management for biodiversity challenging. Unlike the biodiversity portrayal of non-forest habitats, which can be considered static over time, the biodiversity portrayals of forest habitat types and subtypes must be always considered dynamic and temporary. However, to steward the forest habitat types toward the desired conditions (Kovač et al., 2016), the portrayals within the transition periods of developmental phases or sub-phases (e.g. young forest stand consists of seedling, thicket, and sapling phases) can be considered static, whereby each of them may last only a limited length of time, e.g. 5-10 years.

SFM is about seeking trade-offs among different forest goods and services (including biodiversity) while assuring their sustainable provision and use over time by means of nature-based management (Montréal Process, 2017; Forest Europe, 2015). Sustainably managed forests that can only provide balanced services thus need to be managed in a way to fit the habitat-type demographic, standing volume, and sometimes even economic equilibriums. In view of SFM, biodiversity is only one relatively important forest habitat-type trait, which should not be favoured over all other goods and services. A similar approach should also be applied within biodiversity itself when more species share the same environment (i.e. woodpecker vs. other birds; beech vs. long-horn beetle).

However, in day-to-day management, biodiversity conservation is often interpreted too rigidly and does not support sustainable forest development. Typical examples come from the conservation guidelines, which often command i) such high shares of mature stand phases that do not match the normal shares, defined by sustainability models (i.e. normal forest model; von Gadow, 2005) and ii) site-unsuitable free tree-species compositions of the habitat types that cannot be achieved due to all sorts of infestations or long-term presence of foreign/invasive species. In the latter case, persevering with only site-suitable tree-species compositions would be in contradiction with the ecosystem management principles (Schlaepfer, Gorgerat, & Bütler, 2004), ecosystem stewardship (Chapin et al., 2010), and the insurance hypothesis (Bengtsson, Nilsson, Franc, & Menozzi, 2000).

Finally, in addition to the respect of natural dynamics, biodiversity conservation as part of SFM strongly depends on the amount of stewardship capacity. This should be grounded on mutual trust and understanding among stakeholders, willingness, preparedness for joint-fact finding, collaboration and dealing with conflict as well as for sharing the responsibility. Naturally, a sufficient operational capability to carry out the tasks should also exist.

5. Conclusions

To better conserve biodiversity, forest habitat types, and their species, much effort has recently been expended on the exploration of new (Di Salvatore et al., 2016) and the justification of existing approaches to forest management. While the majority of these approaches are solidly grounded in ecological science, some of them are suggested to be used in day-to-day management without prior considerations of the nature of the environments in which they would supposedly work well. Similar conclusions may be drawn from the Natura 2000 system, which also has built-in flaws and conundrums that should be openly discussed, resolved, and changed.

An essential message, summarized from the explored natural processes, is, that biodiversity, as one of the many traits of forest habitat types or ecosystems, is to be understood dynamically in time and space. Both the biodiversity portrayal and the naturalness of forest habitat types are transitory, and they can neither always be considered correct (Kovač et al., 2016; Noss, 1999), nor can they be conserved over a longer period (Fig. 4). Moreover, the system of desired conditions, assisting in achieving naturalness, is often misused. This is especially true when it is considered as a rigid, unchangeable statement, instead of an avenue leading toward likely future conditions. Much less rigidness should also be reflected by the Natura 2000 network itself. For many reasons (i.e. mistakes in databases, among other reasons) the system should be occasionally updated (i.e. unsuitable areas out, suitable areas in) and open for the replacement of permanent sites with floating ones when needed.

The next message is that natural structures and regeneration patterns are not directly transferable to managed forests. While old-growth forests are strongly shaped by the hazardous events that may wipe out a part or the whole population, the structures and species of managed forests are likely to be sustainable. As such, they also host many shade-tolerant and –intolerant plants species and in such a way complete the habitats with resting and foraging spots for permanent and migratory animal species (Connelly, Schroeder, Sands, & Braun, 2000; Graf, Bollmann, Bugmann, & Suter, 2007). The introduction of the regeneration patterns of various sizes (i.e. 0.10–3.00 ha) should also work well. In doing so, especially important is the rule that regeneration patterns and sizes must always correspond to the ecology of species. Many studies (Mölder et al., 2014) and examples in the field reveal that the relation between them is underestimated, as many forest types of the central temperate vegetation belt suffer the loss of species diversity. On the basis of the stocking indicator trends of the dominant tree species in the 91K0 forest habitat subtypes, it is possible to predict that shade-tolerant beech will likely prevail over time if the regeneration patterns do not change and deer herbivory does not diminish. In addition to fir, especially endangered species seem to be admixed shade-intolerant species, such as sycamore maple, hornbeam, whitebeam (*Sorbus aria*), mountain ash (*Sorbus aucuparia*), which all need larger open spaces to regenerate. Similarly, sessile oak, the dominant species of the small-sized *Querco petraeae-Fagetum* forest habitat subtype, also needs larger regeneration gaps.

European forests have been influenced by man for several hundreds of years (Fabbio, Merlo, & Tosi, 2003; Peterken, 1996). In the course of events, they have changed their pristine character in terms of tree-species compositions and fine-grained structures. Being adapted to natural and man-made disturbances, they harbour the prevalent majority of forest biodiversity and provide numerous goods and services to society. To assure their proper functioning in the future, further investigations should primarily address the development of i) suitable management regimes, based on ecological science, ii) common sets of indicators to be used for assessments of their conservation status in biogeographical regions, and iii) models for valuing the conservation status of habitat types and making trade-offs between biodiversity and other services.

Acknowledgements

This research paper was funded by the i) The Public Forest Service Task 4, financed by the Ministry of Agriculture, Forestry and Food of the Republic of Slovenia; and ii) Research Program P4-0107, financed by the Slovenian Research Agency. Our special thanks go to our colleague Dr. Tommaso Sitzia from the Università degli Studi di Padova, who kindly gave us an opportunity to present the topic at the occasion of the event "Forest management and Natura 2000 in the Alpine and Continental biogeographical regions" in Padua, Italy, in June 2016 and to contribute with the paper. Additionally, we would like to thank Andrej Kotnik and Dusan Rozenberger, who provided us the material for Fig. 4 (graph, photo), Jure Zlogar, who designed it, Ana M. Kovac, who proofread an earlier version of the manuscript, and Terry Jackson, who proofread this manuscript. Finally, our sincere thanks go to two anonymous reviewers for their critical comments and support in improving the earlier version of the manuscript.

References

Adamic, M., Diaci, J., Rozman, A., & Hladnik, D. (2016). Long-term use of uneven-aged silviculture in mixed mountain Dinaric forests: a comparison of

old-growth and managed stands. *Forestry*, *90*, 1–13. http://dx.doi.org/10.1093/forestry/cpw052
Angelstam, P., Breuss, M., & Mikusinski, G. (2001). Toward the assessment of forest biodiversity at the scale of forest management units—a European landscape perspective. Criteria and indicators for sustainable forest management at the forest management unit level. *EFI Proceedings*, *38*, 59–74.
Bengtsson, J., Nilsson, S. G., Franc, A., & Menozzi, P. (2000). Biodiversity, disturbances, ecosystem function and management of European forests. *Forest Ecology and Management*, *132*, 39–50.
Bergeron, Y., & Harvey, B. (1997). Basing silviculture on natural ecosystem dynamics: an approach applied to the southern boreal mixedwood forest of Quebec. *Forest Ecology and Management*, *92*, 235–242.
Bock, M., Rossner, G., Wissen, M., Remm, K., Langanke, T., Lang, S., ... & Vrščaj, B. (2005). Spatial indicators for nature conservation from European to local scale. *Ecological Indicators*, *5*, 322–338. http://dx.doi.org/10.1016/j.ecolind.2005.03.018
Boncina, A., Gaspersic, F., & Diaci, J. (2003). Long-term changes in tree species composition in the Dinaric mountain forests of Slovenia. *The Forestry Chronicle*, *79*, 227–232.
Boncina, A., Cavlovic, J., Curovic, M., Govedar, Z., Klopcic, M., & Medarevic, M. (2014). A comparative analysis of recent changes in Dinaric uneven-aged forests of the NW Balkans. *Forestry*, *87*, 71–84. http://dx.doi.org/10.1093/forestry/cpt038
Boncina, A. (2000). Comparison of structure and biodiversity in the Rajhenav old-growth forest remnant and managed forest in the Dinaric region of Slovenia. *Global Ecology and Biogeography*, *9*, 201–211.
Bouwma, I. M., van Apeldoorn, R., & Kamphorst, D. A. (2010). *Current practices in solving multiple use issues of Natura 2000 sites: conflict management strategies and participatory approaches*. Wageningen: Alterra.
Brown, J. H. (1981). Two decades of homage to Santa Rosalia: toward a general theory of diversity. *American Zoologist*, *21*, 877–888.
Campagnaro, T., Frate, L., Carranza, M. L., & Sitzia, T. (2017). Multi-scale analysis of alpine landscapes with different intensities of abandonment reveals similar spatial pattern changes: implications for habitat conservation. *Ecological Indicators*, *74*, 147–159. http://dx.doi.org/10.1016/j.ecolind.2016.11.017
Cantarello, E., & Newton, A. C. (2008). Identifying cost-effective indicators to assess the conservation status of forested habitats in Natura 2000 sites. *Forest Ecology and Management*, *256*, 815–826. http://dx.doi.org/10.1016/j.foreco.2008.05.031
Chapin, F. S., Carpenter, S. R., Kofinas, G. P., Folke, C., Abel, N., Clark, W. C., ... & Young, O. R. (2010). Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in Ecology & Evolution*, *25*, 241–249. http://dx.doi.org/10.1016/j.tree.2009.10.008
Chirici, G., McRoberts, R. E., Winter, S., Bertini, R., Brändli, U.-B., Asensio, I. A., ... & Marchetti, M. (2012). National forest inventory contributions to forest biodiversity monitoring. *Forest Science*, *58*, 257–268. http://dx.doi.org/10.5849/forsci.12-003
Clements, F. E. (1916). *Plant succession: an analysis of the development of vegetation. Publication No. 242*. Washington: Carnegie Institution of Washington.
Commarmot, B., Bachofen, H., Bundziak, Y., Bürgi, A., Ramp, B., Shparyk, Y., ... & Zingg, A. (2005). Structures of virgin and managed beech forests in Uholka (Ukraine) and Sihlwald (Switzerland): a comparative study. *Forest Snow and Landscape Research*, *79*, 45–56.
Connell, J. H. (1978). Diversity in tropical rain forests and coral reefs. *Science*, *199*, 1302–1310.
Connelly, J. W., Schroeder, M. A., Sands, A. R., & Braun, C. E. (2000). Guidelines to manage sage grouse populations and their habitats. *Wildlife Society Bulletin*, *28*, 967–985. http://www.jstor.org/stable/3783856
Crow, T., Haney, A., Waller, D., Hathaway, M., & Trower, J. (1994). *Report on the scientific roundtable on biological diversity convened by the Chequamegon and Nicolet National Forests. General Technical Report NC-166*. St. Paul: USDA Forest Service, North Central Experiment Station.
De Groot, M., Eler, K., Flajšman, K., Grebenc, T., Marinšek, A., & Kutnar, L. (2016). Differential short-term response of functional groups to a change in forest management in a temperate forest. *Forest Ecology and Management*, *376*, 256–264. http://dx.doi.org/10.1016/j.foreco.2016.06.025
Decocq, G., Aubert, M., Dupont, F., Alard, D., Saguez, R., Wattez-Franger, A., ... & Bardat, J. (2004). Plant diversity in a managed temperate deciduous forest: understorey response to two silvicultural systems. *Journal of Applied Ecology*, *41*, 1065–1079. http://dx.doi.org/10.1111/j.0021-8901.2004.00960.x
Decocq, G., Aubert, M., Dupont, F., Bardat, J., Wattez-Franger, A., Saguez, R., ... & Delelis-Dusollier, A. (2005). Silviculture-driven vegetation change in a European temperate deciduous forest. *Annals of Forest Science*, *62*, 313–323. http://dx.doi.org/10.1051/forest:2005026
Di Salvatore, U., Tonti, D., Bascietto, M., Chiavetta, U., Cantiani, P., Fabbio, G., ... & Ferretti, F. (2016). ManFor C.BD sites and the drivers of forest functions. *Italian Journal of Agronomy*, *11*, 64–95.
Diaci, J., Roženbergar, D., Mikac, S., Anić, I., Hartman, T., & Bončina, A. (2008). Long-term changes in tree species composition in old-growth Dinaric beech-fir forest. *Glasnik za sumske pokuse*, *42*, 13–28.
Diaci, J. (2006a). Nature-based forestry in Central Europe: alternatives to industrial forestry and strict preservation. *Studia Forestalia Slovenica*, 126. https://prosilvaeurope.files.wordpress.com/2013/01/diaci_nature_based_forestry-2_0.pdf/. [Accessed 31 May 2017].
Diaci, J. (2006b). *Gojenje gozdov: pragozdovi, sestoji, zvrsti, načrtovanje, izbrana poglavja*. Ljubljana: Biotehniška fakulteta, Oddelek za gozdarstvo in obnovljive gozdne vire.
EC – European Commission (2007). Interpretation Manual of European Union Habitats – EUR27, European Commission, DG Environment.
EC – European Commission (2015). Natura 2000 and forests Part I-II. Technical report 2015, 88, European Commission, DG Environment.
EC – European Commission (2017). EU forests and forest related policies, European Commission, DG Environment. http://ec.europa.eu/environment/forests/index_en.htm/. [Accessed 12 January 2017].
Fabbio, G., Merlo, M., & Tosi, V. (2003). Silvicultural management in maintaining biodiversity and resistance of forests in Europe—the Mediterranean region. *Journal of Environmental Management*, *67*, 67–76. http://dx.doi.org/10.1016/S0301-4797(02)00189-5
Forest Europe (2017). Forest Europe home page. http://foresteurope.org/. [Accessed 12 January 2017].
Fox, J. F. (1977). Alternation and coexistence of tree species. *The American Naturalist*, *111*, 69–89. http://www.jstor.org/stable/2459979
Franklin, J. F. (1993). Preserving biodiversity: species, ecosystems, or landscapes? *Ecological Applications*, *3*, 202–205. http://dx.doi.org/10.2307/1941820
Franklin, J. F. (1997). Ecosystem management: an overview. In M. S. Boyce, & A. Haney (Eds.), *Ecosystem management: applications for sustainable forest and wildlife resources* (pp. 21–53). New Haven: Yale University Press.
Fujimori, T. (2001). *Ecological and silvicultural strategies for sustainable forest management*. Amsterdam, London, New York, Tokyo: Elsevier.
Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., ... & Sodhi, N. J. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, *478*, 378–381. http://dx.doi.org/10.1038/nature10425
Glenn-Lewin, D. C., & Van der Maarel, E. (1992). Patterns and processes of vegetation dynamics. In D. C. Glenn-Lewin, R. K. Peet, & T. T. Veblen (Eds.), *Plant succession: theory and prediction* (pp. 11–59). London: Chapman & Hall.
Götmark, F. (2013). Habitat management alternatives for conservation forests in the temperate zone: review, synthesis, and implications. *Forest Ecology and Management*, *306*, 292–307. http://dx.doi.org/10.1016/j.foreco.2013.06.014
Graf, R. F., Bollmann, K., Bugmann, H., & Suter, W. (2007). Forest and landscape structure as predictors of capercaillie occurrence. *The Journal of Wildlife Management*, *71*, 356–365. http://dx.doi.org/10.2193/2005-629
Graham, R. T., & Jain, T. B. (1998). Silviculture's role in managing boreal forests. *Conservation Ecology*, 2. http://hdl.handle.net/10535/3366.
Gustafsson, L., Baker, S. C., Bauhus, J., Beese, W. J., Brodie, A., Kouki, J., ... & Franklin, J. F. (2012). Retention forestry to maintain multifunctional forests: a world perspective. *BioScience*, *62*, 633–645.
Hale, C., Pastor, J., & Rusterholz, K. (1999). Comparison of structural and compositional characteristics in old-growth and mature, managed hardwood forests of Minnesota, USA. *Canadian Journal of Forest Research*, *29*, 1479–1489. http://dx.doi.org/10.1139/x99-076
Hernando, A., Tejera, R., Velázquez, J., & Núñez, M. V. (2010). Quantitatively defining the conservation status of Natura 2000 forest habitats and improving management options for enhancing biodiversity. *Biodiversity and Conservation*, *19*, 2221–2233. http://dx.doi.org/10.1007/s10531-010-9835-8
Hutchinson, G. E. (1959). Homage to Santa Rosalia or why are there so many kinds of animals? *The American Naturalist*, *93*, 145–159. http://www.jstor.org/stable/2458768
Kaligarič, M., & Trčak, B. (2004). Vzhodna submediteranska suha travišča (*Scorzoneretalia villosae*) (62A0). In Jogan N., Kotarac M. and Lešnik A. (Eds.), *Opredelitev območij evropsko pomembnih negozdnih habitatnih tipov s pomočjo razširjenosti značilnih rastlinskih vrst: končno poročilo*. Miklavž na Dravskem polju: Center za kartografijo favne in flore.
Klopcic, M., & Boncina, A. (2011). Stand dynamics of silver fir (*Abies alba* Mill.)-European beech (*Fagus sylvatica* L.) forests during the past century: a decline of silver fir? *Forestry*, *84*, 259–271. http://dx.doi.org/10.1093/forestry/cpr011
Kobal, M., & Hladnik, D. (2009). Stand diversity in the Dinaric fir-beech forests. *Zbornik gozdarstva in lesarstva*, *90*, 25–42.
Kobler, A., Cunder, T., & Pirnat, J. (2005). Modelling spontaneous afforestation in Postojna area: Slovenia. *Journal for Nature Conservation*, *13*, 127–135.
Košir, Ž., Zorn-Pogorelc, M., Kalan, J., Marinček, L., Smole, I., Čampa, L., ..Šolar, M. (1974). Gozdnovegetacijska karta Slovenije M 1:100.000. Ljubljana: Biro za gozdarsko načrtovanje, Gozdarski inštitut Slovenije.
Košir, Ž., Zorn-Pogorelc, M., Kalan, J., Marinček, L., Smole, I., Čampa, L., ... & Kralj, T. (2003). Gozdnovegetacijska karta Slovenije, digitalna verzija. In I. Tavčar, L. Kutnar, & A. Kralj (Eds.), *Digitalna priredba*. Ljubljana: Biro za gozdarsko načrtovanje, Gozdarski inštitut Slovenije.
Kovač, M., & Fabbio, G. (2016). Wood production. Hereditary management systems and practices in wood-production forests. *Italian Journal of Agronomy*, *11*, 27–31.
Kovač, M., Kutnar, L., & Hladnik, D. (2016). Assessing biodiversity and conservation status of the Natura 2000 forest habitat types: tools for designated forestlands stewardship. *Forest Ecology and Management*, *359*, 256–267. http://dx.doi.org/10.1016/j.foreco.2015.10.011
Kutnar, L., Matijašič, D., & Pisek, R. (2011). Conservation status and potential threats to Natura 2000 forest habitats in Slovenia. *Šumarski list*, *135*, 215–230. http://hrcak.srce.hr/71628
Kutnar, L., Eler, K., & Marinšek, A. (2015). Effects of different silvicultural measures on plant diversity – the case of the Illyrian *Fagus sylvatica* habitat type (Natura 2000). *iForest – Biogeosciences and Forestry*, *9*, 318–324. http://dx.doi.org/10.3832/ifor1587-008
Marchetti, M. (2005). Monitoring and indicators of forest biodiversity in Europe: from ideas to operationality. *EFI Proceedings*, *51*.

Mason, F., Zapponi, L., Di Salvatore, U., Cantiani, P., De Cinti, B., & Ferretti, F. (2016). Îlots de senescence in the ManFor C.BD sites. *Italian Journal of Agronomy*, *11*, 135–140.

Mergeay, J., & Santamaria, L. (2012). Evolution and biodiversity: the evolutionary basis of biodiversity and its potential for adaptation to global change. *Evolutionary applications*, *5*, 103–106. http://dx.doi.org/10.1111/j.1752-4571.2011.00232.x

Mitchell, R. J., Palik, B. J., & Hunter, M. L. (2002). Natural disturbance as a guide to silviculture. *Forest Ecology and Management*, *155*, 315–317.

Mitchell, F. J. G. (2005). How open were European primeval forests? Hypothesis testing using palaeoecological data. *Journal of Ecology*, *93*, 168–177. http://dx.doi.org/10.1111/j.1365-2745.2004.00964.x

Moning, C., & Müller, J. (2009). Critical forest age thresholds for the diversity of lichens, molluscs and birds in beech (*Fagus sylvatica* L.) dominated forests. *Ecological Indicators*, *9*, 922–932. http://dx.doi.org/10.1016/j.ecolind.2008.11.002

Montréal Process (2017). The Montréal Process. https://www.montrealprocess.org/. [Accessed 12 January 2017].

Mölder, A., Streit, M., & Schmidt, W. (2014). When beech strikes back: how strict nature conservation reduces herb-layer diversity and productivity in Central European deciduous forests. *Forest Ecology and Management*, *319*, 51–61.

Müller, J., Hothorn, T., & Pretzsch, H. (2007). Long-term effects of logging intensity on structures, birds, saproxylic beetles and wood-inhabiting fungi in stands of European beech *Fagus sylvatica* L. *Forest Ecology and Management*, *242*, 297–305. http://dx.doi.org/10.1016/j.foreco.2007.01.046

Nagel, T. A., & Svoboda, M. (2008). Gap disturbance regime in an old-growth *Fagus-Abies* forest in the Dinaric Mountains, Bosnia-Herzegovina. *Canadian Journal of Forest Research*, *38*, 2728–2737. http://dx.doi.org/10.1139/X08-110

Nagel, T. A., Svoboda, M., & Kobal, M. (2014). Disturbance, life history traits, and dynamics in an old-growth forest landscape of southeastern Europe. *Ecological Applications*, *24*, 663–679. http://dx.doi.org/10.1890/13-0632.1

Niemelä, J., Young, J., Alard, D., Askasibar, M., Henle, K., Johnson, R., . . . & Nowicki, P. (2005). Identifying, managing and monitoring conflicts between forest biodiversity conservation and other human interests in Europe. *Forest Policy and Economics*, *7*, 877–890. http://dx.doi.org/10.1016/j.forpol.2004.04.005

North, M. P., & Keeton, W. S. (2008). Emulating natural disturbance regimes: an emerging approach for sustainable forest management. In R. Lafortezza, J. Chen, G. Sanesi, & T. R. Crow (Eds.), *Patterns and processes in forest landscapes* (pp. 341–372). Springer Science + Business Media B.V.

Noss, R. F. (1990). Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*, *4*, 355–364. http://dx.doi.org/10.1111/j.1523-1739.1990.tb00309.x

Noss, R. F. (1999). Assessing and monitoring forest biodiversity: a suggested framework and indicators. *Forest Ecology and Management*, *115*, 135–146. http://dx.doi.org/10.1016/S0378-1127(98)00394-6

Odum, E. P. (1969). The strategy of ecosystem development. *Science*, *164*, 262–270.

OJEC (1979). Council Directive 79/409/EC of 2 April 1979 on the conservation of the wild birds. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0147/. [Accessed 12 January 2017].

OJEC (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, 1992. http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm/. [Accessed 12 January 2017].

Paillet, Y., Bergès, L., Hjältén, J., Ódor, P., Avon, C., Bernhardt-Römermann, M., . . . & Grandin, U. (2010). Biodiversity differences between managed and unmanaged forests: meta-analysis of species richness in Europe. *Conservation biology*, *24*, 101–112. http://dx.doi.org/10.1111/j.1523-1739.2009.01399.x

Pasinelli, G. (2003). *Dendrocopos medius* middle spotted woodpecker. *BWP Update*, *5*, 49–99.

Peterken, G. F. (1996). *Natural woodland: ecology and conservation in northern temperate regions*. Cambridge: Cambridge University Press.

Pickett, S. T., & Cadenasso, M. L. (2005). Vegetation dynamics. In E. Van den Maarel (Ed.), *Vegetation ecology* (pp. 172–198). Malden: Blackwell Science Ltd.

Pommerening, A., & Murphy, S. (2004). A review of the history, definitions and methods of continuous cover forestry with special attention to afforestation and restocking. *Forestry*, *77*, 27–44. http://dx.doi.org/10.1093/forestry/77.1.27

Prach, K., Řehounková, K., Lencová, K., Jírová, A., Konvalinková, P., Mudrák, O., . . . & Petřík, P. (2014). Vegetation succession in restoration of disturbed sites in Central Europe: the direction of succession and species richness across 19 seres. *Applied Vegetation Science*, *17*, 193–200. http://dx.doi.org/10.1111/avsc.12064

Pressey, R. L., Cabeza, M., Watts, M. E., Cowling, R. M., & Wilson, K. A. (2007). Conservation planning in a changing world. *Trends in Ecology & Evolution*, *22*, 583–592. http://dx.doi.org/10.1016/j.tree.2007.10.001

Pretzsch, H. (2009). *Forest dynamics, growth, and yield*. Berlin, Heidelberg: Springer-Verlag.

Pukkala, T., & von Gadow, K. (2011). *Continuous cover forestry*. Dordrecht, Heidelberg, London, New York: Springer Science & Business Media.

Raymond, P., Bédard, S., Roy, V., Larouche, C., & Tremblay, S. (2009). The irregular shelterwood system: review, classification, and potential application to forests affected by partial disturbances. *Journal of Forestry*, *107*, 405–413.

Remmert, H. (2013). *Ökologie: Ein Lehrbuch*. Berlin, Heidelberg, New York, Budapest: Springer-Verlag.

Roberts, M. R., & Gilliam, F. S. (1995). Patterns and mechanisms of plant diversity in forested ecosystems: implications for forest management. *Ecological Applications*, *5*, 969–977. http://dx.doi.org/10.2307/2269348

Schlaepfer, R., Gorgerat, V., & Bütler, R. (2004). *A comparative analysis between sustainable forest management (SFM) and the ecosystem approach (EA). Report prepared for the Swiss Agency for Environment, Forests and Landscape*. Lausanne: Swiss Forest Agency, Laboratory of Ecosystem Management, Swiss Federal Institute of Technology, Lausanne.

Schmithüsen, F. (2007). Multifunctional forestry practices as a land use strategy to meet increasing private and public demands in modern societies. *Journal of Forest Science*, *53*, 290–298.

Schmithüsen, F. (2013). Three hundred years of applied sustainability in forestry. *Unasylva*, *240*, 3–11. http://www.fao.org/3/a-i3364e/i3364e01.pdf

Schütz, Saniga, M., Diaci, J., & Vrška, T. (2016). Comparing close-to-nature silviculture with processes in pristine forests: lessons from Central Europe. *Annals of Forest Science*, *73*, 911–921. http://dx.doi.org/10.1007/s13595-016-0579-9

Schütz, J. P. (1999). Close-to-nature silviculture: is this concept compatible with species diversity? *Forestry*, *72*, 359–366. http://dx.doi.org/10.1093/forestry/72.4.359

Schütz, J. P. (2001). Opportunities and strategies of transforming regular forests to irregular forests. *Forest Ecology and Management*, *151*, 87–94. http://dx.doi.org/10.1016/S0378-1127(00)00699-X

Schütz, J. P. (2002). Silvicultural tools to develop irregular and diverse forest structures. *Forestry*, *75*, 329–337. http://dx.doi.org/10.1093/forestry/75.4.329

Sitzia, T., Semenzato, P., & Trentanovi, G. (2010). Natural reforestation is changing spatial patterns of rural mountain and hill landscapes: a global overview. *Forest Ecology and Management*, *259*, 1354–1362. http://dx.doi.org/10.1016/j.foreco.2010.01.048

Sitzia, T., Trentanovi, G., Dainese, M., Gobbo, G., Lingua, E., & Sommacal, M. (2012). Stand structure and plant species diversity in managed and abandoned silver fir mature woodlands. *Forest Ecology and Management*, *270*, 232–238. http://dx.doi.org/10.1016/j.foreco.2012.01.032

Sitzia, T., Campagnaro, T., Gatti, E., Sommacal, M., & Kotze, D. J. (2015). Wildlife conservation through forestry abandonment: responses of beetle communities to habitat change in the Eastern Alps. *European Journal of Forest Research*, *134*, 511–524. http://dx.doi.org/10.1007/s10342-015-0868-0

Torras, O., & Saura, S. (2008). Effects of silvicultural treatments on forest biodiversity indicators in the Mediterranean. *Forest Ecology and Management*, *255*, 3322–3330. http://dx.doi.org/10.1016/j.foreco.2008.02.013

UN – United Nations (1992a). Convention on Biological Diversity. https://www.cbd.int/. [Accessed 12 January 2017].

UN – United Nations (1992b). Non-legally binding authoritative statement of principles for a global consensus on the management, conservation and sustainable development of all types of forests. http://www.un.org/documents/ga/conf151/aconf15126-3annex3.htm/. [Accessed 12 January 2017].

UrL RS (2007). Resolucija o nacionalnem gozdnem programu (ReNGP). Ljubljana: Uradni list RS, št. 111/2007 z dne 5. 12. 2007.

Van der Maarel, E. (2005). Vegetation ecology – an overview. In E. Van der Maarel (Ed.), *Vegetation ecology* (pp. 1–51). Malden: Blackwell Science Ltd.

Van Dyck, H. (2012). Changing organisms in rapidly changing anthropogenic landscapes: the significance of the 'Umwelt'-concept and functional habitat for animal conservation. *Evolutionary Applications*, *5*, 144–153. http://hdl.handle.net/2078.1/146613

Von Carlowitz, H.-C. (1713). *Sylvicultura Oeconomica Oder Haußwirthliche Nachricht und Naturmäßige Anweisung zur Wilden Baum-Zucht Nebst Gründlicher Darstellung Wie zu förderst durch Göttliches Benedeyen. dem allenthalben und insgemein einreissenden Grossen Holtz Mangel, Vermittelst Säe-Pflantz-und Versetzung vielerhand Bäume zu prospicirenrathen. Alles zu nothdürfftiger Versorgung des HAsuß-Bau-Brau berg und Schmelz Wesens.. Worbey zugleich eine gründliche Nachricht von denm in Churfl. Sächß. Landen Gefundenen Turff dessen Natürlich Beschaffenheit/grossen Nutzen/Gebrauch und nützlichen Verkohlung*. Leipzig: Bey Leipzig, Johann Friedrich Brauns sel. Erben.

von Gadow, K. (2005). *Forsteinrichtung: Analyse und Entwurf der Waldentwicklung*. Göttingen: Universitätsverlag Göttingen.

White, P. S., & Walker, J. L. (1997). Approximating nature's variation: selecting and using reference information in restoration ecology. *Restoration Ecology*, *5*, 338–349. http://dx.doi.org/10.1046/j.1526-100X.1997.00547

Williams, B. K. (2011). Adaptive management of natural resources—framework and issues. *Journal of Environmental Management*, *92*, 1346–1353. http://dx.doi.org/10.1016/j.jenvman.2010.10.041

Winter, S., Fischer, H. S., & Fischer, A. (2010). Relative quantitative reference approach for naturalness assessments of forests. *Forest Ecology and Management*, *259*, 1624–1632. http://dx.doi.org/10.1016/j.foreco.2010.01.040

Winter, S. (2012). Forest naturalness assessment as a component of biodiversity monitoring and conservation management. *Forestry*, *85*, 293–304. http://dx.doi.org/10.1093/forestry/cps004

Winter, S., Vrška, T., & Begehold, H. (2013). Forest Naturalness as a key to forest biodiversity preservation. In D. Kraus, & F. Krumm (Eds.), *Integrative approaches as an opportunity for the conservation of forest biodiversity* (pp. 52–63). European Forest Institute.

ZGS (2014). Gozdnogospodarski načrt gozdnogospodarske enote Soteska 2014–2023. Novo Mesto: Zavod za gozdove Slovenije, OE Novo Mesto.