iForest
Biogeosciences and Forestry

Research Article
doi: 10.3832/ifor3953-015
vol. 15, pp. 187-196

The effects of forest management on biodiversity in the Czech Republic: an overview of biologists' opinions

Petr Kjučukov, Jeňýk Hofmeister, Radek Bače, Lucie Vítková, Miroslav Svoboda

Europe has been dominated by cultural landscape and rather intensively managed forests. It is thus no surprise that the ongoing global biodiversity crisis as well as the consequences of climate change have been apparent. In recent years, forestry in Central Europe has been going through a crisis caused by extensive disturbances primarily in commercial monocultures; this phenomenon is particularly striking in the Czech Republic. Given the significance of the situation, it is essential to review and optimise the current forest management practices in relation to biodiversity protection. Therefore, a survey among Czech biologists was conducted in an effort to provide specific feedback to foresters and other stakeholders based on scientific and empirical knowledge of the survey respondents. The survey assessed the forest habitat (in terms of light conditions and the structure of the forest environment), forest management tools and conceptual approaches regarding specific species and groups of organisms. The respondents negatively perceived the current forestry practices, especially in terms of creating homogeneity across the forest environment and eliminating important habitats. Structurally diverse old-growth forests as well as the open forests with the presence of old and habitat trees were emphasised by the survey respondents as essential environments. Large-scale non-intervention within protected areas is necessary to support the presence of old-growth forests. On the other hand, there is an urgent need to restore open forests which requires (but not exclusively) the active efforts of man. These two basic appeals are essential in order to diversify the landscape through a combination of segregative and integrative forest management tools that aim to support biodiversity.

Keywords: Biodiversity Conservation, Forest Management Approaches, Key Habitats, Questionnaire Survey

Introduction

The biodiversity of temperate forests in Central Europe has been influenced by human activities since the onset of forest formation in the postglacial era (Norton 1996). Numerous forest species had thus become extinct a long time ago and this is not only the case of big mammals such as wolves, bears or aurochs (Grove 2002). The trend of biodiversity decline has been accelerating during the last two centuries when the human activities resulted in distinctive and consistent exploitation and transformation of Central European landscapes (Eckelt et al. 2018) which has been taken into account by the latest strategic documents of the European Union, *e.g.*, EU Biodiversity Strategy for 2030 (European Commission 2020). The enforcement of appropriate management measures or changes in forest management in particular areas has faced difficulties in proving relationships between a specific forest management type and the presence or absence of particular species (Bengtsson et al. 2000, Lindenmayer & Laurance 2012). Moreover, conflicting beliefs such as forest management being negative for biodiversity *versus* forest management being considered as sustainable (also in terms of ecological functions) managing for biodiversity and thus negatively affecting forest productivity have been apparent.

Important factors such as spatial and temporal continuity of forest sites have been recognised by experts and their empirical observations (Hofmeister et al. 2019). However, research on professional opinions and views on the use of particular forest management practices (and the influence of management on biodiversity) has been lacking with several exceptions (Vítková et al. 2014, Mairota et al. 2016, Filyushkina et al. 2018). Furthermore, Central European forestry has been facing a multi-layered (operational, economic, ecologic) crisis caused by widespread natural disturbances (primarily bark beetle outbreaks) in commercial forests (Seidl et al. 2017). This unprecedented situation requires important administrative decisions taking into consideration the global climate change and biodiversity crisis. Endangered biodiversity itself is a serious reason for the revision of forest management approaches despite the lack of knowledge and uncertainties (Roberge & Angelstam 2004).

The aim of this study was to gain information regarding biologists' opinions on the effects of forest management on forest biodiversity by means of a survey. We used this information to outline the main challenges we have been facing in the field of forest biodiversity protection in the Czech Republic. The study focuses on whether and how current forestry management threatens biodiversity; what habitats, ecosystem features and structural elements deserve the most attention; and

Department of Forest Ecology, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Praha 6 - Suchdol (Czech Republic)

@ Petr Kjučukov (kjucukov@fld.czu.cz)

Received: Aug 21, 2021 - Accepted: Mar 01, 2022

Citation: Kjučukov P, Hofmeister J, Bače R, Vítková L, Svoboda M (2022). The effects of forest management on biodiversity in the Czech Republic: an overview of biologists' opinions. iForest 15: 187-196. - doi: 10.3832/ifor3953-015 [online 2022-05-19]

Communicated by: Emanuele Lingua

what management forms and tools are currently most relevant to support biodiversity in the Czech Republic. Additionally, we aimed to suggest changes in the approach to forest management that would lead towards a substantial mitigation of biodiversity decline and help raise crucial questions supporting further research and discussion on this topic.

Materials and methods

Administration system and sampling

The survey was conducted in the Czech Republic where forests cover about 33 % of the land (*i.e.*, 2.6 million ha). Almost three quarters of the forests are of commercial use with the remaining part having non-productive functions. Almost 54% of the forests are state-owned, 19% is owned by private persons, 17% by municipalities, 5% by church, 3% by private companies and 2% are of cooperative or other ownership. Almost 16% of the area of the Czech Republic is occupied by protected areas; 24% of the forests are located in protected landscape areas and less than 4% of forests are within the National Parks. Natural forests are reported to account for 1.1% of the forest area (Czech Ministry of Agriculture 2021). Approximately 60% of the current forest stands are mainly coniferous, 11% are formed mainly by deciduous species with the remaining 29% being mixed-species (Czech Ministry of Agriculture 2021). Although coniferous monocultures dominate the Czech forestry estate, the representation of deciduous stands has been slowly increasing over time, approximately by 6% between the years 2000 and 2020 (Czech Ministry of Agriculture 2021). Even-aged silvicultural systems especially the clearcutting and less so also the shelterwood system dominate the Czech forestry. In addition, a high level of salvage loggings whose volume exceeded the annual increment has taken place in the recent years.

In the survey we involved experts and professionals in biodiversity of forest ecosystems affiliated to scientific and specialised institutions focusing on ecology, biology and biodiversity protection. The expertise of the respondent in a specific field was required in order to complete the survey regarding the given biota. The survey was carried out between October 2016 and June 2017. A link to an online survey was created using the website https://www.survio.com and emailed to the following institutions in the Czech Republic: all university departments of natural sciences and forestry; the Czech Academy of Sciences; research institutes, professional and scientific societies; natural history museums; administration offices of all (4) Czech National Parks; and all (24) Czech protected landscape areas. The list of approached institutions is presented in the supplementary Tab. S1 (Supplementary material). The total of 64 institutions were approached and asked to forward the survey onto their members of staff. The survey website was visited 610 times (the total number of people who received the survey invitation is however unknown). A document including the definitions of the key forestry terms accompanied the survey.

We asked each respondent to complete the survey questions bearing in mind individual species or a group of organisms. The respondents were asked to complete the survey again in the case they wish to include another species or a group of species.

Although nearly a quarter of the surveys (23%) were completed for a particular genus or species, the majority was functionally or taxonomically defined group of organisms; the list of evaluated species and groups is presented in Tab. S2 (Supplementary material). The received responses were consequently sorted according to the taxonomical groups as follows: invertebrates (35), vertebrates (21), higher plants (26), fungi (7) and lichens (5). This subsequent classification eliminates any ambiguity in the cases where the respondents answered to functional groups without a nomenclature specification. One response was filled in for nature in general and could not be included in the defined taxonomic group; nevertheless, it was included in the overall summary.

Questionnaire description

The full detail of the survey is shown in the Appendix 1 (Supplementary material). First of all, the respondents were asked to evaluate whether they believe the forest management in the Czech Republic threatens, supports or remains neutral towards the species group or the taxon of their choice (question 2.3). Afterwards, they assessed the most significant, and in scientific literature widely discussed, attributes of forest management (question 2.4): the presence of non-native tree species composition, most commonly used forest management systems (*i.e.*, clear-cutting system, shelterwood system), the removal of biological legacies (*e.g.*, deadwood) and old-growth forests, the use of chemical treatments (*e.g.*, pesticides, herbicides, pheromones, fertilisation, etc.) and the heavy-duty machinery, the removal of naturally regenerated pioneer tree species, the homogeneity across forest ecosystem, high density within closed stands or abandonment of historical management approaches (*e.g.*, coppicing or forest grazing). These attributes were assessed on the range: positive, neutral, ambivalent, negative.

In the second part of the survey, the respondents were asked to rank various types of habitats and structural features (question 2.5) according to their light conditions, stand age, structural complexity, but also according to the degree of human influence (*i.e.*, its type and extent). The habitats were sorted according to the following categories during the data processing and visualisation of the results: age, canopy, deadwood dimensions, deadwood environment, deadwood position, forest origin, forest patch, mixture degree, old tree environment, structure. The list of assessed habitats and features is shown in the Appendix 1 (Supplementary material). The habitat types were assessed on the following scale: key, usable, unexplored relation, unusable.

The respondents further evaluated the main management tools practised in both forestry and nature conservation (*e.g.*, regeneration methods, various forest stand types, various natural reserve types, retention methods, historical management types, etc.) on the following scale: key, suitable, ambivalent, unexplored relation, unsuitable, harmful. A short description of the assessed management tools is given in the Appendix 2 (Supplementary material). The respondents were also asked about their preferred protection concepts: minimal intervention *vs.* active management, segregation *vs.* integration (segregation is defined here as the protection of biodiversity in natural reserves whereas integration represents the application of biodiversity protection tools as a part of forest management).

The scale of answers used in the first two survey parts (*e.g.*, key, suitable, ambivalent, unexplored relation, unsuitable, harmful) was chosen according to the Likert scale. The respondents used the scale to assess the relationship between the assessed management tools or habitats and the long-term survival and protection of the given biota.

The respondents were asked to express whether the assessed groups or taxa can be considered as an umbrella species (or group of species) for another biota in the third part of the survey. This question was open-ended to allow the respondents to specify the relation. The respondents were also requested to provide additional comments or feedback at the end of the survey.

Data processing

The respondents' answers to particular questions were sorted according to their frequency and proportion. The taxonomic groups (due to the variation in respondents' specialisation) were unevenly represented in the total set of received answers. Therefore, the aggregated proportion of the responses for the whole set was calculated as the mean of the percentages achieved for a given response within individual taxonomic groups. All taxonomic groups were evaluated with the same weight.

Box plots were used to visualise the questions results related to forest management aspects (question 2.4) and forest management tools (question 2.6). The questions yielding a categorical range of answers, *i.e.*, from positive to negative (question 2.4) and from key to harmful (question 2.6) were transformed into marks with the range 1-4 and 1-5, respectively. The response "unexplored relation" in question 2.6 was excluded from the analysis because of the uncertain character of the potential mark. The weighted average of the assigned marks for each taxonomic group was calculated individually for the evaluated factors. The sets of all mean marks were classified according to their affiliation to individual factors and according to the individual taxonomic groups.

The importance of individual qualitative characteristics of forest sites and management tools in relation to biodiversity was discussed in a continuous prose. The study focused on apparent trends based on numerical majority or rarity of the given responses.

Preliminary survey results were presented as a pilot study in Kjučukov & Svoboda (2017).

Results

Characteristics of the respondents

The survey was completed by 83 respondents (specifically by 46 scientists, 12 natural history museum experts, 10 members of nature conservation administration and 15 nature conservation practitioners); 78 of them completed the survey once, three respondents completed it for two separate groups, one respondent completed it for three separate groups and one for eight separate species. Some respondents provided incomplete answers and their responses were therefore excluded from the analysis. Altogether, 95 completed surveys were analysed. The estimated survey response rate was 16% (the response rate was estimated from the number of visits to the survey website since the total number of people who received the survey invitation *via* their institution was unknown).

Ninety-four per cent of the respondents (*i.e.*, 78 respondents) had a university degree and 80% (*i.e.*, 66 respondents) of the respondents were men. We consider the group of respondents to be a representative sample of the Czech professionals and experts on endangered biota.

The influences of forest management

The biodiversity of evaluated species was reported to be endangered (in general) by the application of forest management practices in 84% of the completed surveys. However, one survey respondent (expert on birds) stated that forest management generally supports biodiversity. The respondents mentioned a neutral relationship between biodiversity and the application of forest management in 15% of the responses. The degree to which forest management endangered particular taxonomic groups varied with the highest being reported for lichens and invertebrates and the lowest for fungi (Fig. 1).

Overall, homogeneity across forest sites due to the use of forest management was most frequently stated as having a negative impact on individual species groups by the survey respondents. This trend was apparent in the overall summary (*i.e.*, 88%) but also in the case of individual species groups; *i.e.*, higher plants (81%), invertebrates (91%), vertebrates (95%) and lichens (100%). The elimination of old-growth forests and veteran trees was reported only as a negative factor influencing the species group of fungi (100%). The lack of light in managed stands (*i.e.*, the absence of open forest) resulting from the use of forest management was another factor stated as negatively influencing the species in question (66%). This concerned vertebrates (76%), invertebrates (77%), higher plants (77%) and lichens (100%). However, the lack of light was not evaluated as negative in the case of the group of fungi by any respondents.

The respondents considered the presence of non-native tree species composition as negative in three quarters of the responses. As for the practice of particular forest management system, clear-cutting in even-aged forest stands was most frequently ranked as having a negative influence on biodiversity of stated species in 79% responses but was reported as ambivalent in 15%. The use of chemical treatments and heavy-duty machinery was evaluated by the survey respondents as having a negative influence on the species groups (81%), which was similar as in the case of post-disturbance salvage logging and deadwood removal (82%); these factors were not assessed positively by any respondents.

The utilisation of shelterwood system was graded as the most positive factor since only 27% of the responses mentioned it as having a negative influence. In addition, the shelterwood system was pronounced as having the most positive and ambivalent influence in 20% and 19% of responses, respectively. Nonetheless, 80% of the responses showed shelterwood system as having a negative impact on the group of lichens. The exclusion of natural regeneration formed by pioneer species was considered as neutral in 42% of cases. The abandonment of historical forest management types was evaluated negatively (46%), especially concerning invertebrates (77%), although it was seen as rather neutral (29%) or ambivalent (43%) for fungi and completely neutral (100%) for lichens. The respondents' answers are shown in full in Fig. S1 (Supplemetary material).

Data processing using boxplots visualised (in an alternative way) the negative evaluation of most commonly used forest management aspects (Fig. 2) with the homogeneity across the forest ecosystem being the most pronounced aspect. The factor "the elimination of historical management methods" and "the removal of naturally regenerated pioneer tree species" were both evaluated as ambivalent. The shelterwood system was the most widely accepted compared to the average mark. In terms of individual taxonomic groups (due to the specialisation of respondents) the evaluation was somewhat milder for higher plants and fungi in comparison to the average mark. On the contrary, the lichens were evalu-

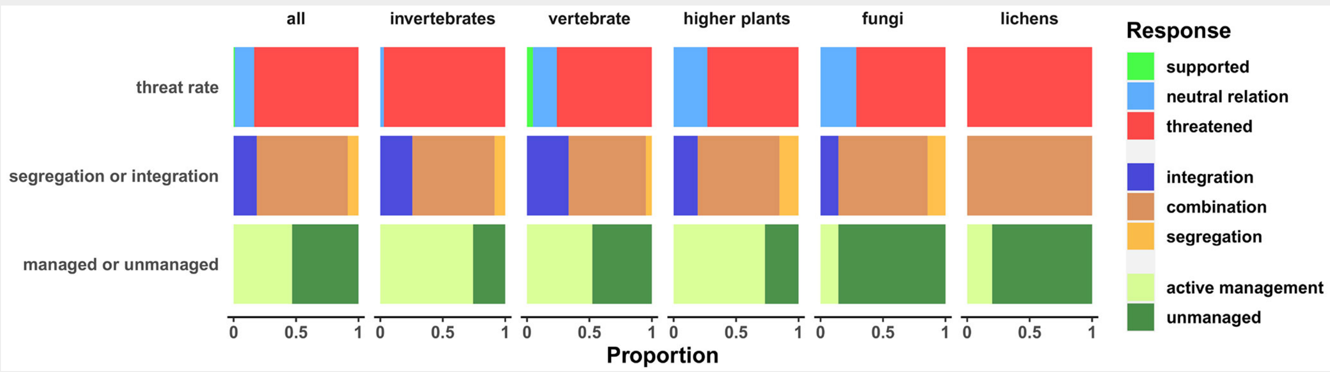

Fig. 1 - The conglomerated visualisation of three evaluated general questions: (i) the rate of threat to biodiversity generated by forest management (scale: supported, neutral relation, threatened); (ii) the choice among conceptual biodiversity protection approaches (integrative tools, segregative tools, their combination); and (iii) the choice between managed and unmanaged forests maintaining biodiversity protection. The total numbers of responses vary among taxonomic groups. The group "all" shows the mean values of the proportions for the answers obtained within individual taxonomic groups.

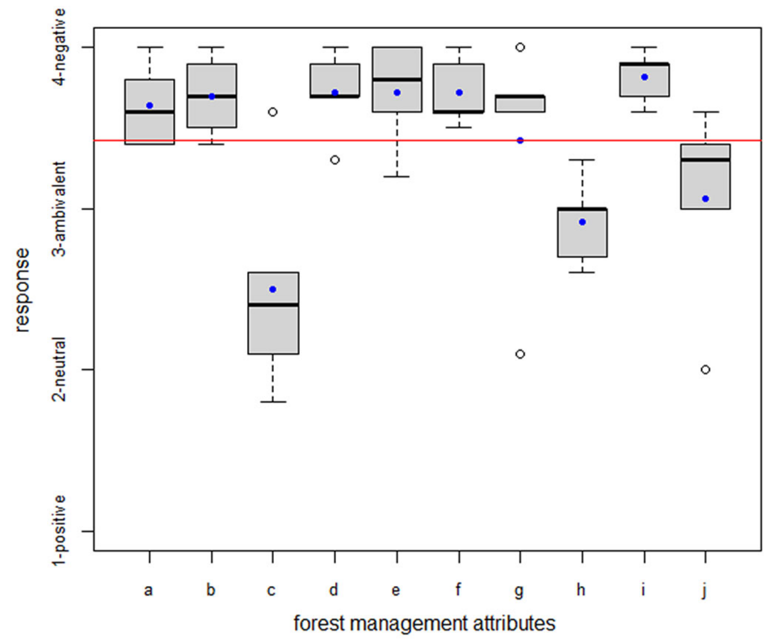

Fig. 2 - Boxplots showing the markings of forest management factors by the survey respondents. The marks (*y*-axis) are based on the following scale: 1 - positive, 2 - neutral, 3 - ambivalent and 4 - negative. The boxplots were created from the weighted averages of marks assigned to taxonomic groups and grouped according to their affiliation to individual factors. Factors (*x*-axis) are coded as follows: (a) non-native tree species composition; (b) clear-cutting in even-aged stands; (c) shelterwood system; (d) the removal of biological legacies following natural disturbance (salvage logging, deadwood removal, etc.); (e) the removal of old-growth forests and veteran trees; (f) chemical treatments and the use of heavy machinery; (g) the lack of light in closed forests; (h) the removal of naturally regenerated pioneer tree species; (i) homogeneity across forest ecosystem; (j) the elimination of historical management methods (coppicing, forest grazing etc.). The blue points represent the mean values and the red line shows the overall mean mark.

ated as the most negative (see Fig. S2 in Supplementary material).

Key habitats

Old-growth forest was stated as the key habitat in almost three quarters of the responses (*i.e.*, 74 %). This was followed by the primary forests or spontaneously developed forests (72%), structurally rich forests (65%), open forest (63%) and large deadwood (also 63%). We highlight the importance of open forest since it is the only habitat which was not evaluated by any respondent as unusable for a particular species group. Frequencies of responses sorted according to specific criteria (age, canopy complexity, forest origin, species mixture, forest structure, forest size, deadwood presence and its properties) show particular contrasts between extreme positions of defined scales. In other words (with respect to the average proportions of responses evaluating the habitats as key), the respondents preferred old-growth forests (74%) to young forests (6%), open forests (63%) to closed forests (5%), mixed-species stands (45%) to monocultures (2%), structurally rich forests (65%) to forests of simple structure (1%), large deadwood parts (63%) to small ones (17%) and sun-exposed old trees (48%) to shaded ones (39%) with the exception of fungi. Regarding the forest stand type, the forest of

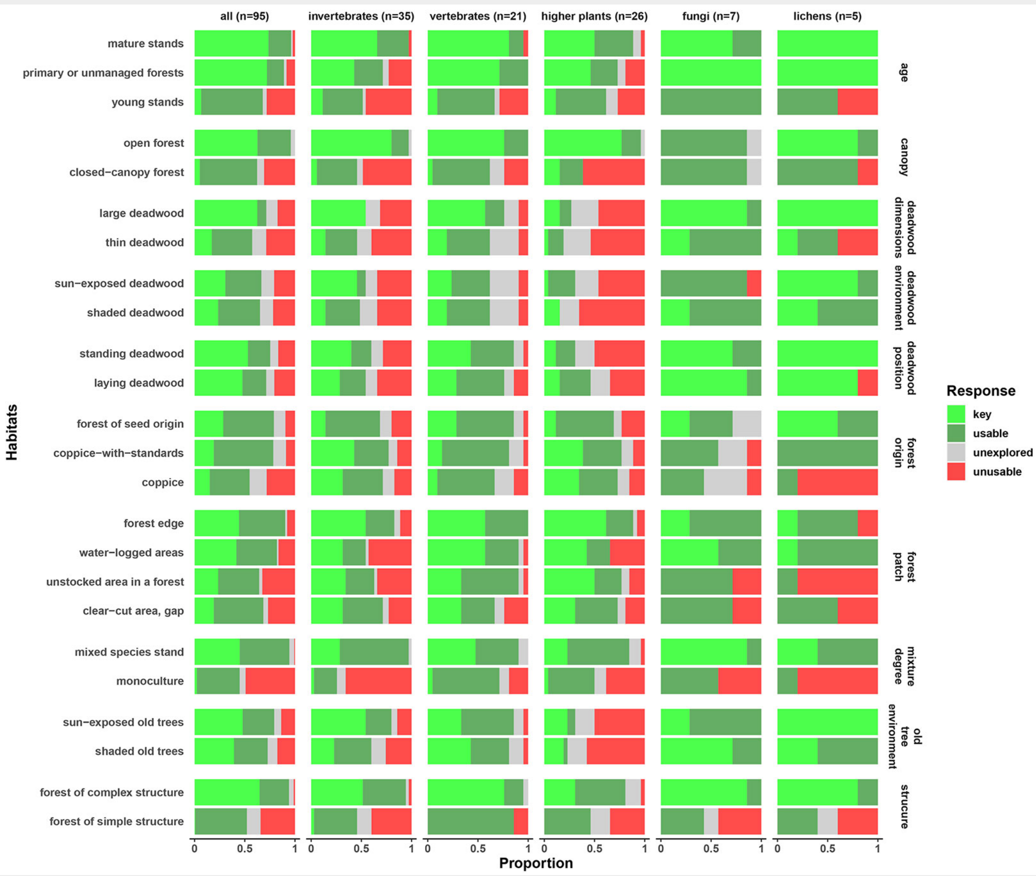

Fig. 3 - Evaluation of different habitat types in terms of their importance for particular biota (scale: key, usable, insufficiently known relation, unusable). The complete set of all responses as well as the responses for individual taxonomic groups are presented. The total numbers of responses vary among taxonomic groups. The group "all" shows the mean values of the proportions for the answers obtained within individual taxonomic groups.

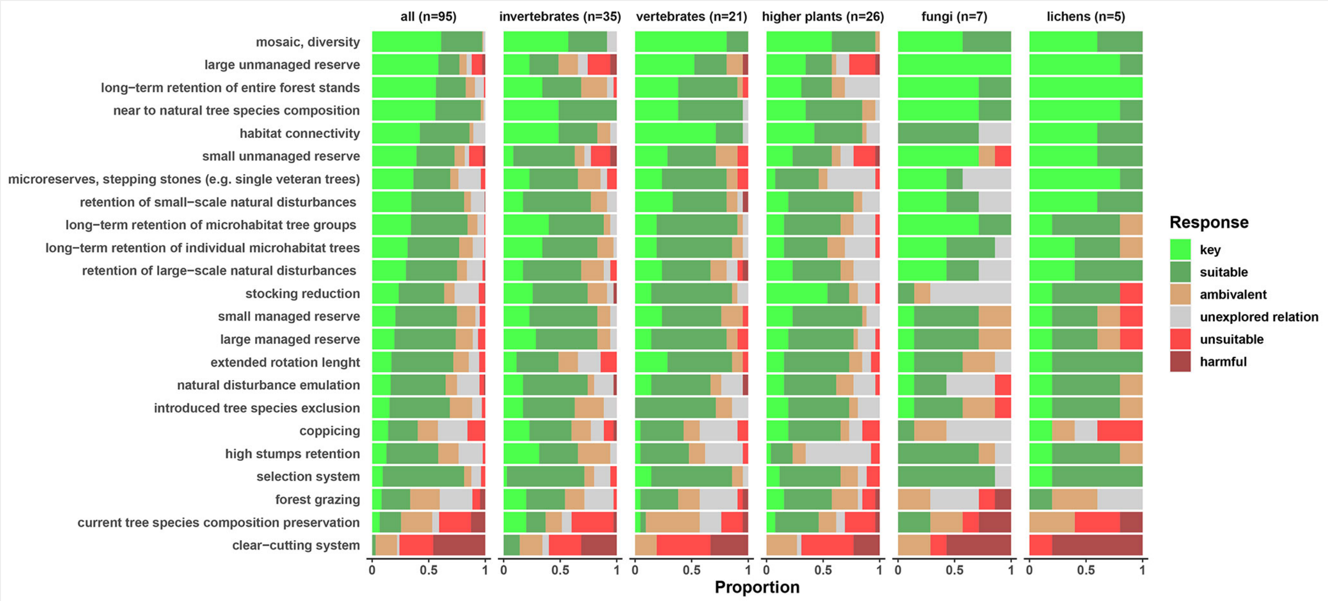

Fig. 4 - The evaluation of different types of management measures in terms of their influence on biota (scale: key, suitable, ambivalent, insufficiently known relation, unsuitable, harmful). The complete set of all responses as well as the responses for individual taxonomic groups are presented. The total numbers of responses vary among taxonomic groups. The group "all" shows the mean values of the proportions for the answers obtained within individual taxonomic groups.

seed origin was preferred in 29% of the responses as the key habitat to the coppice with standards (19%) and to the coppice (15%). The importance of forests of seed origin was stressed by the respondents in 60% of lichens and 29% of fungi. In addition, the forest edge was also found to be an important biotope; *i.e.*, key in 44 % and usable in 46% of the responses. The clear-cut areas and gaps were ranked as the key habitats for biodiversity in 19% of all responses. The respondents' answers are shown in full in Fig. 3.

Key management tools

Diverse forest stand structure and diversity in general were considered as the key factors in 56% of the responses. These were followed by the large unmanaged reserves (54%), the long-term retention of entire forest stands (52%) and the presence of near-natural tree species composition (51%). In the case of higher plants, the respondents observed an importance in reduction of stand density (evaluated as key in 54%). The clear-cutting system and the maintenance of the current tree species composition were seen as negative in 70% and 38%, respectively. In the case of biodiversity protection, clear-cutting system was not evaluated as key by any respondent and was marked as suitable only in five cases. Uneven-aged forest management and the use of selection systems were most frequently (66%) marked as suitable and as key in 9% of the responses. Although the influence of historical forest management types (*e.g.*, forest grazing and coppicing) was perceived as positive in 8% and 13%, respectively and as ambivalent in 24% and 16%, respectively, they were seen as unsuitable in 6% and 14 % of the responses, respectively. In addition, it is important to note that forest grazing and coppicing was considered as insufficiently known in 26% and 24 % of the responses, respectively. The respondents' answers are shown in full in Fig. 4.

The clear-cutting system and the current tree species composition were shown to have been negatively evaluated (see Fig. S3 in Supplementary material). Coppicing and forest grazing were perceived as having a neutral effect. On the contrary, close to nature tree species composition, large non-intervention reserves, retaining micro-reserves and small-scale disturbances within the forests, long-term retention of entire forest stands, the efforts to achieve spatial diversity and connectivity of habitats were evaluated above the mean. The evaluation of individual taxonomic groups was balanced with a slightly higher urgency for changes in the management of lichens (see Fig. S4 in Supplementary material).

General forest management approaches for biodiversity conservation

Most of the responses (73%) showed the combination of segregation and integration approach to be the most important in terms of forest biodiversity protection. The importance of integration and segregation separately reached 19% and 9% of the responses, respectively. Minimal intervention (53%) was favoured (on average) over active forest management approaches (47%) considering the conceptual forest management approaches. The minimal intervention was strongly preferred for lichens and fungi in 80% and 86% of the responses, respectively (Fig. 1).

The umbrella species

Three quarters of the responses found the assessed species or species groups to be umbrella species. The proportion varied among individual groups: higher plants (65%), fungi (71%), invertebrates (77%), lichens (80%) and vertebrates (81%).

Discussion

The influences of forest management

The survey results pointed out towards numerous detrimental effects of current management practices on forest biodiversity. Such survey has not been published for the Central European area, however, its focus is closest to the study conducted for northern European boreal forests by Filyushkina et al. (2018). The respondents consider forest management practices to be one of the major causes of rare species endangering. This finding contradicts the self-presentation of European forestry as a sustainable and efficient management system based on a long tradition (Bengtsson et al. 2000, Freer-Smith et al. 2019). Although the relationship between forest management and biodiversity decline has been widely acknowledged by the scientific community (Grove 2002, Paillet et al. 2010), this perception has not been appropriately reflected in practice. This was consistent with the respondents' perspective in our study. If we highlight the most harmful aspect of the current forest management, the respondents agreed on the homogeneity of the forest habitats. Although the effort for sustainable forest management have been growing in the past few decades throughout Europe, even-aged, single-storey monocultures dominated by commercial and exotic conifers that are clear-felled at the end of the rotation have still been an important component of commercial forestry (Emmer et al. 1998, Paillet et al. 2010). Moreover, the management of such commercial forests is based on the use of intensive technologies, chemical treatments and heavy mechanisation that are considered as another negatively impacting factor (Worrell & Hampson 1997). The survey study focusing on boreal forests also found the negative impact of intensive forest management on biodiversity (Filyushkina et al. 2018). On the other hand, it is necessary to see the decline of forest biodiversity in the context of global biodiversity crisis resulting from socio-economic pressures towards not only forests but towards the entire landscapes and environment (Essl et al. 2015).

Forest management is mostly represented by logging that has a negative influence on biodiversity, which has been well-documented, but often difficult to prove in a short-term perspective, especially in the case of less extensive management types such as the selection and shelterwood systems (Lindenmayer & Laurance 2012). Our respondents stated less extensive harvesting forms as not threatening to biodiversity to such an extent as the clear-cutting. Shelterwood system was also considered to be more negative than positive (on average) but the prevalence of negative evaluations over the positive ones was rather low. The positive evaluations of shelterwood system may follow theoretically-based expectation of supporting light condition variability rather than real conditions in these forest stands. It reveals possible weaknesses of the expert evaluation based on empirical experience without data representing the real forest stands. Consequently, underestimating the negative effects of forest management on biodiversity often relies on expert opinions instead of on data collected from a representative network of managed forest stands (Brockerhoff et al. 2008, Freer-Smith et al. 2019). It is also important to note that even continual application of low impact (*e.g.*, selection) felling can substantially change the vegetation structure and have negative effects on a range of forest organisms (Lindenmayer & Laurance 2012). With the exception of intensive plantation we do not have sufficiently robust data based on regularly managed forests covering different environmental gradients that would support the expert observations. In addition, there is a sufficient amount of evidence showing the negative effects of post-disturbance salvage logging on biodiversity with biological legacy destruction (especially deadwood removal – Grove 2002, Thorn et al. 2018). Therefore, the impact of forest management practices on biodiversity shall not be underestimated, both in intensive and low impact forms.

Although the pioneer species significantly contribute to forest biodiversity (Swanson et al. 2010), the exclusion of naturally regenerated pioneer species (the preparatory phase in forest development) was stated as having a negative and neutral influence in 43% and 42% of the responses, respectively. The reason for such an attitude is likely to be the fact that many rare or threatened species are relicts of primeval forests related to climax communities where the pioneer species regeneration is supposed to take place following logging. Another reason could be a rather frequently occurring spontaneous reforestation of non-forest areas within the landscape. However, the initial forest succession in open habitats has different implications for biodiversity as opposed to the secondary succession in forest stands with a continuous forest cover (Hofmeister et al. 2019). Sparse occurrence of the early successional stages that has lasted for decades in Europe (including nature protected areas focused on the over-mature forest remnants) may have also caused the underestimation of their importance in the scientific perception as a consequence of "shifting baseline syndrome" (Soga & Gaston 2018). This phenomenon describes and explains the limits of human experience that cannot exceed the length of human life. Consequently, a part of the species bound to early succession stages of forest vegetation can be seen as the species of forest edges (Imbeau et al. 2003). The biotope of forest edges was evaluated as important by the survey respondents for instance for the group of vertebrates.

The key habitats

The survey results show the importance of two habitats, *i.e.*, the old-growth forest (including the primary and unmanaged forests) and the open canopy forest. The importance of old-growth forests is also evidenced by a similar survey study conducted for boreal forests (Filyushkina et al. 2018). The respondents preferred the open forests to those of closed canopy ones and the old-growth forests to the young ones from a biological point of view. The open forests were stressed mainly in relation to higher plants and invertebrates whereas the old-growth forests (unmanaged reserves) in relation to fungi and lichens. Since there is a lack of information about these habitats, we believe the respondents emphasised them due to their species richness, which is, however, endangered and has an uncertain future. The decline of open forests as well as that of old-growth forests has been well presented in literature (*e.g.*, open forests: Miklín & Čížek 2014, Šebek et al. 2015, and old-growth forests: Hofmeister et al. 2015, Seibold et al. 2015), which is similar for the loss of species bound to these precious disappearing environments (Bengtsson et al. 2000, Seibold et al. 2015). In relation to open forests, it has to be mentioned that the survey confirmed the importance of water-influenced sites, permanent forest-free areas as well as the importance of certain forms of glades and cleared areas.

As far as the old-growth forests are concerned, it is known that the areas of several or tens of hectares in Central Europe, which are common sizes of current forest reserves, are insufficient for an adequate functioning of their dynamics (Abrego et al. 2015). A lot of fungi, lichens or insect species use very specific substrates with a relatively short lifespan (Halme et al. 2013, Eckelt et al. 2018). The restoration of population after its decline is a problematic and a long-lasting process due to larger distances amongst individual sites. The lack of suitable environment can be seen as an issue in protected areas that do not exceed tens of hectares during the critical period that causes extinction of local populations bound to native tree species (Dvořák et al. 2017).

The negative impact of simply-structured commercial monocultures on biodiversity is apparent. Commercial monocultures (primarily in a sense of plantations) replacing more complex forests have to be distinguished from natural species-poor and other specific native ecosystems which was also noted by the survey respondents. In other words, native broadleaved stands (*e.g.*, dominated by *Fagus sylvatica* L.) should not be replaced by Norway spruce (*Picea abies* (L.) H. Karst) and Scots pine (*Pinus sylvestris* L.) monocultures. This finding is again in line with the results of a survey study based in northern European forests (Filyushkina et al. 2018).

The presence of key structures such as deadwood is essential for the forest biodiversity (Filyushkina et al. 2018, Vítková et al. 2018) and this was consistent with our respondents' answers; *i.e.*, they considered the large deadwood more important than the small deadwood, the sun-exposed deadwood than the shaded and the standing over the lying. These results support the assumption that although any deadwood is needed in the forest ecosystem, the large fragments are essential (Grove 2002). It is important to note that forest management approaches such as salvage logging or elimination of deadwood that are commonly used forest management practices were not evaluated as positive by any of the survey respondents.

The forest of seed origin was given priority over other stand types (*i.e.*, coppice with standards and coppice). Nevertheless, the loss of historical management methods (*e.g.*, coppicing) was considered as having a negative effect on biodiversity according to the survey respondents. Therefore, the restoration of historical forest management types in suitable locations within the landscape can be considered as an important tool for slowing down the biodiversity loss (Douda et al. 2016), which is confirmed by a survey study dealing with coppicing in Natura 2000 sites (Mairota et al. 2016). However, the presence of specific features such as microhabitat trees or high stumps when opening the forest canopy has to be preserved. After all, the sun-exposed old trees were preferred by the survey respondents over the shaded mostly due to their importance for invertebrates.

The key management tools

The results indicated that it is important for biodiversity protection to achieve a rich mosaic of connected habitats within the landscape and to support the native tree species composition in the managed forests. The landscape mosaic, according to the survey respondents should contain elements of large unmanaged reserves where whole stands or their parts are retained in a long-term and where the application of active management also aims at restoration and preservation of the open forests, *e.g.*, by reducing the stand density especially in lowlands (Šebek et al. 2015).

Other management tools (forest grazing, coppicing, removing introduced tree species, high stumps creation, etc.) were evaluated as suitable. These tools were stated as being ambivalent, insufficiently researched, unsuitable or harmful. Such answers can be explained by the respondents' emphases on the need of mosaic and diversity all the way up to the landscape scale. That is why the active management tools should be combined. The application of a single management tool could lead to a large-scale forest homogenisation with an insufficient presence of necessary habitats. This also includes the selection system (Nagel et al. 2017) which was marked by the respondents as key only in eight responses although this forest management tool is considered the core of close-to-nature silviculture (Remeš 2018). At the same time, the use of selection system in uneven-aged stands was considered as suitable by the majority of the survey respondents; its advantages in comparison to the clear-cutting system in even-aged stands are apparent (Atlegrim & Sjöberg 2004). However, the survey results also show that the clear-cutting system also has its use in forest management. Logging the entire stand and removing the biomass is substantially different from the effects of natural disturbance and such differences should not be confused (Lindenmayer & Laurance 2012). On the other hand, small-scale clear-cut areas and gaps, especially with retention of biologically valuable structures can host precious biota (Šebek et al. 2015, Gustafsson et al. 2020). The clear-cut areas, moreover, sometimes serve as refugia for endangered biota of agricultural landscape (Ram et al. 2020).

The benefits and novelty of this study can be further recognised in the context of recent natural disturbances of commercial forests in Europe caused primarily by climatic effects, the spread of bark beetles and the effects of previous forest management (De Groot et al. 2019). An unprecedented number of managed forests in Central Europe has been subjected to large-scale natural disturbances caused mainly by bark beetle outbreaks, droughts and windstorms (Senf et al. 2020). Moreover, an increased occurrence and severity of these disturbances particularly in conifer forests has been predicted in relation to climatic changes (Seidl et al. 2017). Since snags and windthrown trees are usually cleared as a part of salvage logging and large clear-cut areas are formed, it is necessary to retain (on a landscape level) those snags that do not threaten health and safety since extensive salvage logging not only supports further disturbances but also causes additional damage to biodiversity (Thorn et al. 2020).

Natural disturbances are widely recognised as a key factor for forest biodiversity (Mikoláš et al. 2017). The biological legacies that remain in the ecosystem following the natural disturbance are very important not only for species survival but also for the consequent recovery of the ecosystem after the disturbance (Gustafsson et al. 2020). This biological legacy is formed mainly by the opening and exposing the habitat to light, by the presence of surviving trees, standing dead trees, snags and uprooted trees, lying deadwood as well as by the preserved natural regeneration and the presence of various successional stages. The intersection of the late and early succession stages is often considered a biodiversity hotspot (Hilmers et al. 2018) and occurs after the disturbance. Mimicking the effects of natural disturbances is based in ecological forestry (Palik et al. 2020) where the concept of forest management seeks to protect and support biodiversity in addition to production.

Such notion was supported by our study where the survey respondents positively evaluated the abandonment of salvage logging after both small- and large-scale natural disturbances. The post-disturbance presence of biological legacies in forest stands provides an opportunity (at least temporary) for the creation of an open forest and for natural regeneration; however, vast clear-cuts were created instead in numerous places.

General forest management approaches for biodiversity conservation

This study's results confirmed the necessity to combine segregative and integrative tools in order to protect species in the hotspots of their presence as well as within the landscape matrix (Kraus & Krumm 2013). Integrative and ecological forest management practices striving for complexity and structural diversity of the forests (Palik et al. 2020) shall be used outside strict natural reserves and commercial plantations (Lindenmayer & Laurance 2012).

These efforts may be concerning due to the loss of viable production. The need for research into the effects of various forest management approaches (including conservation practices) on ecology and the economy stems from an expert survey conducted in Hungary (Mihók et al. 2015). Our study does not focus on the economic aspects; nevertheless, combining management adjustments supporting biodiversity with timber production function is feasible (Hanson et al. 2012). In addition, forest management approaches focusing on biodiversity are of high potential in terms of other ecosystem functions such as carbon sequestration and adaptation to climate change that are highly topical and of growing economic importance (D'Amato & Palik 2021).

Minimal intervention with nature protection in mind is commonly considered to be a basic (or the best) form of forest ecosystem management (Paillet et al. 2010, Thorn et al. 2018). The survey confirmed this for example in the case of *Trogossitidae* demanding large reserves in connection with natural disturbances. It is beyond doubt that some forests shall be left to spontaneous development as they form an indispensable environment for a range of endangered species such as fungi and lichens. However, this approach should not be the only one since other retention forms (*e.g.*, group retention of old broadleaved trees) can substantially support biodiversity of endangered species.

The fact that most respondents whose expertise is on invertebrates and higher plants preferred an active management can be explained by an urgent need of open forests recovery. The efforts to replace or restore the presence of large herbivores, wildfires or historical management types requires an active management approach, especially in lowlands. Forest management should consider the millennia-lasting human activities.

It has to be mentioned that some respondents found the general choice between minimal intervention and active management very difficult. For example, one respondent assessing saproxylic beetles of higher altitudes confirmed the minimal intervention preference but pointed out that forest grazing supports biodiversity in the Alps. The preferences for non-intervention and active management were, on average, very balanced. The question where and in which situation shall be the biodiversity supported by either minimal intervention or active management is considered as essential for further research and for the discussions regarding the effects of forest management practices on biodiversity.

The umbrella species

A substantial part of specific biota or even whole habitats can be effectively protected by focusing on umbrella species. Studies related to these species are often applied (Roberge & Angelstam 2004). The fact that the majority of surveyed species and species groups were assessed as so-called umbrella improved the survey scope. The survey findings are therefore more justified in terms of serving as a basis for decision-making. Respondents may have been somewhat biased in answering this question because of their specialisation. Nevertheless, a quarter of the respondents did not mark the species or group of species of their interest as umbrella species. On the contrary, respondent's specialisation allows for a better assessment of the given factor.

Advantages and disadvantages of the method adopted

The adverse impact of commercial forestry on biodiversity is rather difficult to be unambiguously researched mainly due to the delayed results in science. However, many of these influences can be suitably identified on the basis of personal experience of experts and professionals. The research focused on empirical knowledge of biologists supported both by their research findings and their overall view. Although such data are inherently subjective, they allow revealing potentially significant factors influencing biodiversity that have not been sufficiently focused on so far.

Survey-based studies appear to be a suitable tool to fill the gaps between research and practice (Mihók et al. 2015). Surveys among biodiversity experts and experts on forest and conservation management as well as on the importance of specific habitats and forest environment characteristics are lacking in Central Europe. The current study most resembles the study by Filyushkina et al. (2018) that evaluated the influence of different types of forest management on the biodiversity of boreal forests in northern Europe using the Delphi method. Evaluating expert opinions revealed similar results to ours since intensive forms of forest management were reported to threaten biodiversity, while species and structural diversity of forests, the presence of old-growth stands and deadwood habitats were important for biodiversity protection.

Study shortcomings

Since the study is based on the knowledge on endangered species and groups of organisms, the respondents are primarily biologists or experts in biodiversity but not necessarily foresters. This may be limiting since the respondents may not be fully familiar with details of forest management practices and terminology. However, we tried to overcome such constraints by including the explanation of basic forestry terms in the survey. We believe that experts on forest biota are well able to assess the effects of the environment and management on the given biota even without detailed knowledge of forest management practices and terminology.

Another shortcoming of the study may be the subjective interpretation of some assessed categories such as "primary or unmanaged forest" or "mature stands". Potential differences, similarities, overlaps and contexts of the assessed categories could affect the respondents' understanding and answers. However, every effort was made to use self-explanatory terms that have long been established in the scientific and professional literature when creating the survey.

The restraints arising from a limited number of responses have to be taken into an account when assessing the results especially in relation to particular groups of organisms. On the other hand, all the responses related to the groups with the lowest frequencies (fungi and lichens) comprised of a wide range of these groups. Uneven response frequencies and respondents' freedom in filling in made the statistical comparison between individual groups impossible. Such study approach can, to a certain extent, help stakeholders deal with biodiversity crisis in Central European forests and make decisions that can translate into practice.

Conclusion and recommendation

The conventional forest management practices used in many countries create conditions that lead to the risk of local extinction of a range of species. Therefore, it is necessary to revise current forestry approaches since the recent improvements have not been sufficient. This finding should be a starting point for dealing with forest biodiversity crisis. Complex forest structure and habitat connectivity were considered by the survey respondents as a key factor to support biodiversity in contrast to uniform commercial forest (mostly monocultures) of simple stand structure. Changes in tree species composition and logging forms are important. The structural diversity of European commercial forests is rather low, *e.g.*, the lack of microhabitat trees and large segments of deadwood. Moreover, whole environment types are endangered – the survey respondents emphasised the importance of old-growth and open forests. Achieving a rich mosaic of sites on a landscape scale requires a range of management tools where active management aiming at biodiversity protection along with the designation of unmanaged areas with a minimal human intervention is applied. In the case of an active management, it is necessary to apply both historical management types (*e.g.*, coppice with standards) but also specific forestry approaches, *e.g.*, ecological silviculture (Palik et al. 2020), which was confirmed by the survey results. The open forest restoration calls for an active forest management, especially in the lowlands. The presence of specific structural features (*e.g.*, sun-exposed microhabitat and veteran trees) in the open forests is essential. On the other hand, minimal intervention still remains the key conservation approach. The crucial survey finding is to balance the need of the active management with the minimal intervention, *i.e.*, the urgency for large unmanaged reserves. Both the approaches are important in the context of a landscape. In a similar way, it is necessary to combine segregation and integration tools in order to protect the endangered species. The combination accommodates the much-needed diversity of forest environment, landscape mosaic, spatial interconnection and temporal continuity of individual habitats.

All the above-mentioned findings are applicable to the current Central European forestry crisis. The uniform commercial forests in Central Europe have been increasingly affected by severe natural disturbances which offer an opportunity for developing structurally more complex forests. Therefore, partial retention of certain biological legacies (*e.g.*, snags) following natural disturbances (including landscape scale forest management) is considered fundamental similarly as the spatial distribution of such elements. However, this represents a challenge for further research. In addition, large natural reserves are especially important in the perspective of minimal intervention approach. The combination of spatial and temporal arrangement of the above-mentioned management approaches is a crucial point for further research and decisions concerning landscape management that protects and enhances biodiversity.

Acknowledgements

This research has been supported by funding from the Czech University of Life Sciences Prague (EVA 4.0 project: CZ.02.1.01/0.0/0.0/16_019/0000803).

References

Abrego N, Bässler C, Christensen M, Heilmann-Clausen J (2015). Implications of reserve size and forest connectivity for the conservation of wood-inhabiting fungi in Europe. Biological Conservation 191: 469-477. - doi: 10.1016/j.biocon.2015.07.005

Atlegrim O, Sjöberg K (2004). Selective felling as a potential tool for maintaining biodiversity in managed forests. Biodiversity and Conservation 13: 1123-1133. - doi: 10.1023/B:BIOC.0000018148.84640.fd

Bengtsson J, Nilsson SG, Franc A, Menozzi P (2000). Biodiversity, disturbances, ecosystem function and management of european forests. Forest Ecology and Management 132: 39-50. - doi: 10.1016/S0378-1127(00)00378-9

Brockerhoff EG, Jactel H, Parrotta JA, Quine CP, Sayer J (2008). Plantation forests and biodiversity: oxymoron or opportunity? Biodiversity and Conservation 17: 925-951. - doi: 10.1007/s10531-008-9380-x

Czech Ministry of Agriculture (2021). Report on forest management of the Czech Republic. Ministry of Agriculture of the Czech Republic, Prague, Czech Republic, pp. 128. [online] URL: http://www.eagri.cz

D'Amato AW, Palik BJ (2021). Building on the last "new" thing: exploring the compatibility of ecological and adaptation silviculture. Canadian Journal of Forest Research 51 (2): 172-180. - doi: 10.1139/cjfr-2020-0306

De Groot M, Diaci J, Ogris N (2019). Forest management history is an important factor in bark

beetle outbreaks: lessons for the future. Forest Ecology and Management 433: 467-474. - doi: 10.1016/j.foreco.2018.11.025
Douda J, Boublík K, Doudová J, Kyncl M (2016). Traditional forest management practices stop forest succession and bring back rare plant species. Journal of Applied Ecology 54 (3): 761-771. - doi: 10.1111/1365-2664.12801
Dvořák D, Vašutová M, Hofmeister J, Beran M, Hošek J, Běťák J, Burel J, Deckerová H (2017). Macrofungal diversity patterns in central European forests affirm the key importance of old-growth forests. Fungal Ecology 27: 145-154. - doi: 10.1016/j.funeco.2016.12.003
Eckelt A, Müller J, Bense U, Brustel H, Buler H, Chittaro Y, Čížek L, Frei A, Holzer E, Kadej M, Kahlen M, Köhler F, Möller G, Mühle H, Sanchez A, Schaffrath U, Schmidl J, Smolis A, Szallies A, Németh T, Wurst C, Thorn S, Christensen RHB, Seibold S (2018). Primeval forest relict beetles of Central Europe: a set of 168 umbrella species for the protection of primeval forest remnants. Journal of Insect Conservation 22: 15-28. - doi: 10.1007/s10841-017-0028-6
Emmer IM, Fanta J, Kobus AT, Kooijman A, Sevink J (1998). Reversing borealization as a means to restore biodiversity in Central-European mountain forests - An example from the Krkonoše Mountains, Czech Republic. Biodiversity and Conservation 7 (2): 229-247. - doi: 10.1023/A:1008840603549
Essl F, Dullinger S, Rabitsch W, Hulme PE, Pyšek P, Wilson JRU, Richardson DM (2015). Delayed biodiversity change: no time to waste. Trends in Ecology and Evolution 30: 375-378. - doi: 10.1016/j.tree.2015.05.002
European Commission (2020). EU Biodiversity strategy for 2030. Web site. [online] URL: http://ec.europa.eu/environment/strategy/biodiversity-strategy-2030_en
Filyushkina A, Strange N, Löf M, Ezebilo EE, Boman M (2018). Applying the Delphi method to assess impacts of forest management on biodiversity and habitat preservation. Forest Ecology and Management 409: 179-189. - doi: 10.1016/j.foreco.2017.10.022
Freer-Smith P, Muys B, Bozzano M, Drössler L, Farrelly N, Jactel H, Korhonen J, Minotta G, Nijnik M, Orazio C (2019). Plantation forests in Europe: challenges and opportunities. From Science to Policy 9, European Forest Institute, Joensuu, Finland, pp. 52. - doi: 10.36333/fs09
Grove SJ (2002). Saproxylic insect ecology and the sustainable management of forests. Annual Reviews of Ecology and Systematics 33: 1-23. - doi: 10.1146/annurev.ecolsys.33.010802.150507
Gustafsson L, Bauhaus J, Asbeck T, Augustynczik ALD, Basile M, Frey J, Gutzat F, Hanewinkel M, Helbach J, Jonker M, Knuff A, Messier Ch Penner J, Pyttel P, Reif A, Storch F, Winiger N, Winkel G, Yousefpour R, Storch I (2020). Retention as an integrated biodiversity conservation approach for continuous-cover forestry in Europe. Ambio 49: 85-97. - doi: 10.1007/s13280-019-01190-1
Halme P, Allen KA, Auninš A, Bradshaw RHW, Brümelis G, Čada V, Clear JL, Eriksson AM, Hannon G, Hyvärinen E, Ikauniece S, Iršenaite R, Jonsson BG, Junninen K, Kareksela S, Komonen A, Kotiaho JS, Kouki J, Kuuluvainen T, Mazziotta A, Mönkkönen M, Nyholm K, Oldén A, Shorohova E, Strange N, Toivanen T, Vanha-Majamaa I, Wallenius T, Ylisirniö AL, Zin E (2013). Challenges of ecological restoration: lessons from forests in northern Europe. Biological Conservation 167: 248-256. - doi: 10.1016/j.biocon.2013.08.029
Hanson JJ, Lorimer CG, Halpin CR, Palik BJ (2012). Ecological forestry in an uneven-aged, late-successional forest: simulated effects of contrasting treatments on structure and yield. Forest Ecology and Management 270: 94-107. - doi: 10.1016/j.foreco.2012.01.017
Hilmers T, Friess N, Bässler C, Heurich M, Brandl R, Pretzsch H, Seidl R, Müller J (2018). Biodiversity along temperate forest succession. Journal of Applied Ecology 55: 2756-2766. - doi: 10.1111/1365-2664.13238
Hofmeister J, Hošek J, Brabec M, Dvorák D, Beran M, Deckerová H, Burel J, Krí M, Borovička J, Belák J, Vašutová M, Malíček J, Palice Z, Syrovátková L, Steinová J, Černajová I, Holá E, Novozámská E, Čížek L, Iarema V, Baltaziuk K, Svoboda T (2015). Value of old forest attributes related to cryptogam species richness in temperate forests: a quantitative assessment. Ecological Indicators 57 (4): 497-504. - doi: 10.1016/j.ecolind.2015.05.015
Hofmeister J, Hošek J, Brabec M, Hermy M, Dvorák D, Fellner R, Malíček J, Palice Z, Tenčík A, Holá E, Novozámská E, Kuras T, Trnka F, Zedek M, Kašák J, Gabriš R, Sedláček O, Tajovsky K, Kadlec T (2019). Shared affinity of various forest-dwelling taxa point to the continuity of temperate forests. Ecological Indicators 101: 904-912. - doi: 10.1016/j.ecolind.2019.01.018
Imbeau L, Drapeau P, Mönkkönen M (2003). Are forest birds categorised as “edge species” strictly associated with edges? Ecography 26 (4): 514-520. - doi: 10.1034/j.1600-0587.2003.03509.x
Kjučukov P, Svoboda M (2017). Biodiversity protection and forest management in the Czech Republic. In: Abstract collection of the conference “Kostelec Inspiration (9)”. Kostelec nad Černými lesy (Czech Republic) 23-24 Nov 2017. Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Prague, pp. 29.
Kraus D, Krumm F (2013). Integrative approaches as an opportunity for the conservation of forest biodiversity. European Forest Institute, Joensuu, Finland, pp. 285.
Lindenmayer DB, Laurance WF (2012). A history of hubris - Cautionary lessons in ecologically sustainable forest management. Biological Conservation 151: 11-16. - doi: 10.1016/j.biocon.2011.10.032
Mairota P, Buckley P, Suchomel C, Heinsoo K, Verheyen K, Hédl R, Terzuolo PG, Sindaco R, Carpanelli A (2016). Integrating conservation objectives into forest management: coppice management and forest habitats in Natura 2000 sites. iForest 9: 560-568. - doi: 10.3832/ifor1867-009
Mihók B, Kovács E, Balázs B, Pataki G, Ambrus A, Bartha D, Czirák Z, Csányi S, Csépányi P, Csöszi M, Dudás G, Egri C, Erös T, Göri S, Halmos G, Kopek A, Margóczi K, Miklay G, Milon L, Podmaniczky L (2015). Bridging the research-practice gap: conservation research priorities in a Central and Eastern European country. Journal of Nature Conservation 28: 133-148. - doi: 10.1016/j.jnc.2015.09.010
Miklín J, Čížek L (2014). Erasing a European biodiversity hot-spot: open woodlands, veteran trees and mature forests succumb to forestry intensification, succession, and logging in a UNESCO Biosphere Reserve. Journal for Nature Conservation 22 (1): 35-41. - doi: 10.1016/j.jnc.2013.08.002
Mikoláš M, Svitok M, Bollmann K, Reif J, Bače R, Janda P, Trotsiuk V, Cada V, Vítková L, Teodosiu M, Coppes J, Schurman JS, Morrissey RC, Mrhalová H, Svoboda M (2017). Mixed-severity natural disturbances promote the occurrence of an endangered umbrella species in primary forests. Forest Ecology and Management 405: 210-218. - doi: 10.1016/j.foreco.2017.09.006
Nagel TA, Firm D, Pisek R, Mihelic T, Hladnik D, De Groot M, Rozenbergar D (2017). Evaluating the influence of integrative forest management on old-growth habitat structures in a temperate forest region. Biological Conservation 216: 101-107. - doi: 10.1016/j.biocon.2017.10.008
Norton TW (1996). Conservation of biological diversity in temperate and boreal forest ecosystems. Forest Ecology and Management 85: 1-7. - doi: 10.1016/S0378-1127(96)03745-0
Paillet Y, Berges L, Hjalten J, Odor P, Avon C, Bernhardt-Roemermann M, Bijlsma Rienk-Jan De Bruyn L, Fuhr M, Grandin U, Kanka R, Lundin L, Luque S, Magura T, Matesanz S, Mészáros I, Sebastia MT, Schmidt W, Standovár T, Tóthmérész B, Uotila A, Valladares F, Vellak K, Virtanen R (2010). Biodiversity differences between managed and unmanaged forests: meta-analysis of species richness in Europe. Conservation Biology 24 (1): 101-112. - doi: 10.1111/j.1523-1739.2009.01399.x
Palik BJ, D’Amato AW, Franklin JF, Johnson KN (2020). Ecological silviculture: foundations and applications. Waveland Press, Long Grove, IL, USA, pp. 343. [online] URL: http://books.google.com/books?id=4UfhDwAAQBAJ
Ram D, Lindstrom A, Pettersson LB, Lars B, Caplat P (2020). Forest clear-cuts as habitat for farmland birds and butterflies. Forest Ecology and Management 473 (1-3): 119-133. - doi: 10.1016/j.foreco.2020.118239
Remeš J (2018). Development and present state of close-to-nature silviculture. Journal of Landscape Ecology 11 (3): 17-32. - doi: 10.2478/jlecol-2018-0010
Roberge JM, Angelstam P (2004). Usefulness of the umbrella species concept as a conservation tool. Conservation Biology 18 (1): 76-85. - doi: 10.1111/j.1523-1739.2004.00450.x
Šebek P, Bače R, Bartoš M, Beneš J, Chlumská Z, Doležal J, Dvorský M, Kovář J, Machač O, Mikátová B, Perlík M, Plátek M, Poláková S, Škorpík M, Stejskal R, Svoboda M, Trnka F, Vlašín M, Zapletal M, Čížek L (2015). Does a minimal intervention approach threaten the biodiversity of protected areas? A multi-taxa short-term response to intervention in temperate oak-dominated forests. Forest Ecology and Management 358: 80-89. - doi: 10.1016/j.foreco.2015.09.008
Seibold S, Brandl R, Buse J, Hothorn T, Schmidl J, Thorn S, Müller J (2015). Association of extinction risk of saproxylic beetles with ecological degradation of forests in Europe. Conservation Biology 29 (2): 382-390. - doi: 10.1111/cobi.12427
Seidl R, Thom D, Kautz M, Martin-Benito D, Pel-

toniemi M, Vacchiano G, Wild J, Ascoli D, Petr M, Honkaniemi J, Lexer MJ, Trotsiuk V, Mairota P, Svoboda M, Fabrika M, Nagel TA, Reyer C (2017). Forest disturbances under climate change. Nature Climate Change 7: 395-402. - doi: 10.1038/nclimate3303

Senf C, Buras A, Zang CS, Ramming A, Seidl R (2020). Excess forest mortality is consistently linked to drought across Europe. Nature Communications 11: 6200. - doi: 10.1038/s41467-020-19924-1

Soga M, Gaston KJ (2018). Shifting baseline syndrome: causes, consequences, and implications. Frontiers in Ecology and the Environment 16: 222-230. - doi: 10.1002/fee.1794

Swanson EM, Franklin JF, Beschta RL, Crisafulli C, DellaSala DA, Hutto RL, Lindenmayer DB, Swanson FJ (2010). The forgotten stage of forest succession: early-successional ecosystems on forest sites. Frontiers in Ecology and the Environment 9 (2): 117-125. - doi: 10.1890/090157

Thorn S, Bässler C, Brandl R, Burton PJ, Cahall R, Campbell JL, Castro J, Choi CY, Cobb T, Donato DC, Durska E, Fontaine JB, Gauthier S, Hebert C, Hothorn T, Hutto RL, Lee EJ, Leverkus AB, Lindenmayer DB, Obrist MK, Rost J, Seibold S, Seidl R, Thom D, Waldron K, Wermelinger B, Winter MB, Zmihorski M, Müller J (2018). Impacts of salvage logging on biodiversity: a meta-analysis. Journal of Applied Ecology 55: 279-289. - doi: 10.1111/1365-2664.12945

Thorn S, Chao A, Georgiev KB, Müller J, Bässler C, Campbell JL, Castro J, Chen Y-H, Choi Ch-Y, Cobb TP, Donato DC, Durska E, Macdonald E, Feldhaar H, Fontaine JB, Fornwalt PJ, Hernández RM, Hutto RL, Koivula M, Lee E-J, Lindenmayer D, MikusiA, Obrist MK, Perlík M, Rost J, Waldron K, Wermelinger B, Wei I, Zmihorski M, Leverkus AB (2020). Estimating retention benchmarks for salvage logging to protect biodiversity. Nature Communications 11: 4762. - doi: 10.1038/s41467-020-18612-4

Vítková L, Dhubháin AN, Upton V (2014). Forestry professionals' attitudes and beliefs in relation to, and understanding of continuous cover forestry. Scottish Forestry 68 (3): 17-25.

Vítková L, Bače R, Kjučukov P, Svoboda M (2018). Deadwood management in Central European forests: key considerations for practical implementation. Forest Ecology and Management 429: 394-405. - doi: 10.1016/j.foreco.2018.07.034

Worrell R, Hampson A (1997). The influence of some forest operations on the sustainable management of forest soils - a review. Forestry 70 (1): 61-85. - doi: 10.1093/forestry/70.1.61

Supplementary Material

Appendix 1 - An example of a survey released to the respondents.

Appendix 2 - A short description of the management tools.

Fig. S1 - Frequency of responses evaluating particular factors of forest management in terms of their influence on species.

Fig. S2 - Boxplots showing the markings of forest management factors by the survey respondents according to individual taxonomic groups.

Fig. S3 - Boxplots showing the markings of forest management factors by the survey respondents.

Fig. S4 - Boxplots showing the markings of forest management factors by the survey respondents according to individual taxonomic groups.

Tab. S1 - The list of contacted institutions where the survey was distributed.

Tab. S2 - The list of evaluated species and species groups.

Link: Kjucukov_3953@suppl001.pdf