eco.mont – Volume 10, Number 1, January 2018
ISSN 2073-106X print version – ISSN 2073-1558 online version: http://epub.oeaw.ac.at/eco.mont
https://dx.doi.org/10.1553/eco.mont-10-1s61

A growth simulation model as a support tool for conservation management strategy in a mountain protected area

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Keywords: acidophilous spruce forests, assessment of management plans, conservation targets, Natura 2000, SIBYLA

Abstract

The effectiveness of protected areas to conserve biodiversity depends on conservation management strategies and their application, usually to specific protected areas. This paper presents the results of an assessment of the conservation management strategy for a protected mountain area dominated by Norway spruce forests. The study was based on the prediction of future forest ecosystem development using a SYBILA growth simulation model. This model predicts the changes of forest stand over 25 and 50 years in the context of the conservation management strategy that is part of the broader management plan. The article presents a case study of acidophilous spruce forests below the alpine tree line in the Hruby Jesenik Mountains (Czech Republic), where the forest ecosystems are protected under the Natura 2000 European network and the Czech national system of protected areas. Conserving the character of forest habitats, especially those that are historically affected by humans, is the main target of conservation management strategies. Synthesizing the growth simulation results allows an assessment of the conservation management strategy in achieving management targets. The paper highlights the importance of growth simulation models as support tools for the assessment and creation of adaptive conservation management strategies in mountain protected areas.

Profile

Protected area

National Nature Reserve Praded

Mountain range

Hruby Jesenik Mountains

Country

Czech Republic

Introduction

In the last decade, growth simulation models have increasingly been used as a support tool for the development of forest management plans (Sedmak et al. 2013), but applying these models in the conservation of biodiversity is very rare (Parviainen & Frank 2003; Simon et al. 2015), despite their potential for predicting the development of forest ecosystems (Kangas et al. 2008; Peng 2000; Muys et al. 2010). We applied a growth simulation model as a decision support tool for conservation management within the Litovelske Pomoravi protected area, which consists of lowland floodplain forests (Simon, Machar 2014), and we believe that growth simulation can also be an important support tool for conservation management in mountain protected areas dominated by forests of Norway spruce (*Picea abies* L. Karst).

Forests with a natural dominance of Norway spruce below the alpine tree line (ATLE; see Holtmeier 2009) are the predominant type of vegetation in montane vegetation zones of temperate Europe (Svoboda et al. 2010). The conservation management strategy (CMS) for these mountain forest ecosystems is widely discussed in the contexts of adaptive spruce forest management under climate change impacts (Lindner et al. 2014; Yousefpour et al. 2013), of bark beetles as a driver for forest dynamics (Zeppenfeld et al. 2015), and of ecosystem services of montane forests (Carnol et al. 2014).

In the Hruby Jesenik Mountains (HJM; north-eastern Czech Republic; see Figure 1), the forest vegetation zone below the ATLE is classified as *spruce forest vegetation zone* within the Czech forest typology (Viewegh et al. 2003; Tuček et al. 2014) and comprises predominantly acidophilous spruce forests (Husová et al. 2002; Jirásek 1996). In the Natura 2000 European network (Natura 2000), acidophilous spruce forests are classified as habitat type 9410 (Miko 2012); within the Czech National Catalogue of Habitats (Chytrý et al. 2010), they have the code L9.1.

The CMS for acidophilous spruce forests in Natura 2000 sites must take into account the main conservation target defined by Natura 2000, i. e. maintenance of the habitat type (Roth 2003). In the HJM, the CMS for acidophilous spruce forests complies with the IUCN management category I, i. e. strict nature reserves (Dudley 2008), regardless of management history or the origin of forest stands (alochtonous or autochtonous). In order to assess this CMS, we applied a growth simulation model to predict forest ecosystem development in 25 and 50 years' time. The results of the growth simulation, based on a defined forest management strategy, allow the assessment of the sustainability of the forest management strategy (whether it allows the habitat character to be maintained or not).

The main objective of this article is to present the application of the growth simulation model for the evaluation of a forest management strategy, using the example of a mountain ecosystem of acidophilous

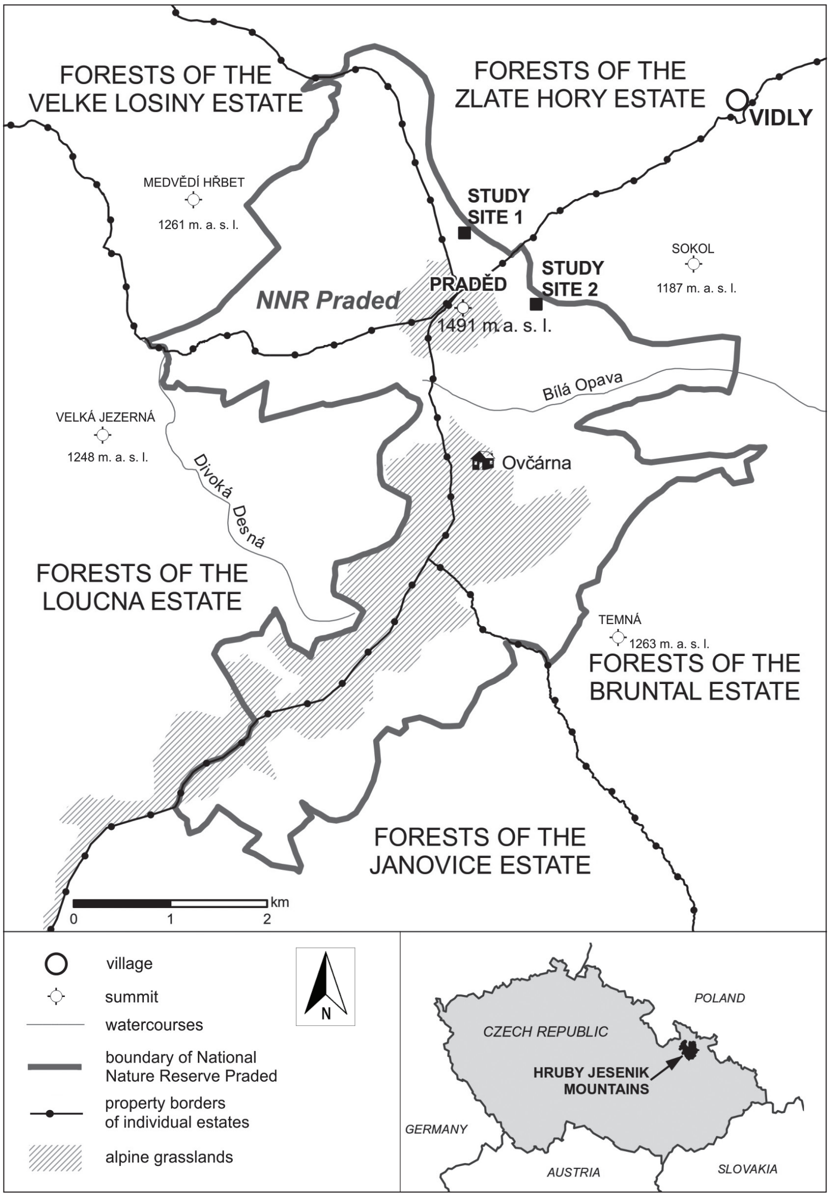

Figure 1 – National Nature Reserve Praded, with location of study sites 1 and 2, and location of the study area within the Czech Republic.

spruce forest below the ATLE in the central part of the HJM. We believe that the method could be especially valuable as a support tool for CMSs in protected areas. The paper aims to:

- predict future trends of the forest stands using a growth simulation model;
- evaluate the current forest management strategy and, based on the results of growth simulation, to decide whether it ensures maintaining the defined character of the forest habitat and thus complies (or not) with the Natura 2000 conservation targets.

Material and methods

Study area and study sites

The study area – National Nature Reserve Praded (NNR P) – is located in the HJM (Figure 1). The local bedrock geology consists of acidic crystalline rocks (gneisses, mica schists and flysches). The surface forms were modelled by mountain glaciers during the glacial period (Demek & Mackovčin 2006). The soils are shallow and very stony, mostly Cambic Podzols, with a high content of skeletal material. Around the highest peak in the study area (Praded – 1 491 m a.s.l.), the forests transition into alpine grassland habitats (Jenik 1961). The NNR P has a total area of 2031.4 ha. These grassland habitats are a protected site, the Site of Community Importance Praded (Czech national code CZ0714077), which covers the same area as the NNR P. Acidophilous spruce forests in the study area consist of a mosaic of two distinct types of vegetation: (i) alochtonous even-aged forests, originating from past clear-cut forests, and (ii) autochtonous uneven-aged forests dominated by autochtonous Norway spruce. We defined two study sites in order to predict forest development using a growth simulation model; one site represents a natural (autochtonous) forest type, the other an artificial (alochtonous) forest type.

Study site 1 (Figure 1) is located at 50° 09’ 42” N, 17° 23’ 22” E, with its centre at 1 226 m a.s.l., on a steep north-western slope with a gradient of 29 %. The site has an area of 1.0 ha (Figure 2) and is covered by an autochtonous spruce forest with admixed mountain ash trees. This forest stand has not been subject to any clear-cut harvests in the past. However, we cannot rule out past selective cutting. The forest cover has the character of a natural Norway spruce forest: the forest is mostly three-storeyed (Table 1), with patches of trees in different age stages (maturity, re-growth, decay). Throughout the forest, there are individual, fallen, rotting logs of old Norway spruce, providing conditions for regeneration of the trees. The total standing volume (TSV) of spruce is 394.5 m^3 per ha; for the admixed Rowan trees (*Sorbus aucuparia* L.), the TSV is just 0.2 m^3 per ha, with natural regeneration occurring in elevated forest openings.

Study site 2 (Figure 1) is located at 50’ 07’ 12” N, 17° 24’ 14” E, with its centre at 1 254 m a.s.l., on a western slope with a gradient of 32 %, and an area of 0.5 ha (Figure 3). The site is covered by an even-aged alochtonous spruce forest with a TSV of 444.89 m^3 per ha. The tree species include European beech (*Fagus sylvatica* L.) with 3.55 m^3 per ha TSV, and Sycamore maple (*Acer pseudoplatanus* L.) with 0.81 m^3 per ha TSV. Natural regeneration does not occur; fallen trees on the ground are rarely found (Table 1).

Table 1 – Basic dendrometric characteristics of forest stands in study sites 1 and 2.

Forest layer	Tree species	Average age [years]	Proportion of species in forest layer [%]	Average diameter at breast height [cm]	Average height [m]
Study site 1					
3	Norway spruce	22	100	10.13	6
5	Norway spruce	49	100	20.58	14
19	Norway spruce	195	85	55.67	27
19	Rowan	195	15	42.24	27
Study site 2					
17	Norway spruce	170	98	44.16	6
17	European beech	170	1	35.76	14
17	Sycamore maple	170	1	34.64	27

Growth simulation model

To predict the future forest development in both study sites (see Figure 1), we used the SIBYLA growth simulation model (Fabrika & Dursky 2006), modified as SIBYLA-Cz for the specific conditions of the Czech Republic by Simon (2007), and further developed by Macku (2014) for conditions in the spruce forest vegetation zone. The main climatic parameters of the study area for the period 1960–2014 were the average annual temperature, of 2.5°C (min. −0.5°C, max. 6.1°C), and the average annual precipitation, of 1 879.3 mm (min. 929.8 mm, max. 1 371.8 mm). The centre of each study site was recorded using GPS to allow, potentially, for the research to be repeated. The boundaries of the study sites were determined using the FieldMap software (IFER-Monitoring and Mapping Solutions Ltd.). All trees with a diameter at breast height (DBH) of more than 5 cm were located and marked in a rectangular coordinate system. The following dendrometric parameters were measured: DBH ($d_{1.3}$), total tree height (m), height from which green growth is found, and the trees’ social positions. Using a growth simulation model, we employed dendrometric measurements collected from study sites 1 and 2 in 2014 in order to visualize and simulate forest development at the sites for two forecast horizons (25 and 50 years) under a non-intervention management strategy prescribed by the current management plan for the NNR P. The time spans for these forecast horizons are those commonly recommended for growth simulation (Pretzsch et al. 2002): a period of less than 25 years would be very short for changes in forest ecosystems below the ATLE to be visible; periods of more than 50 years can include too many uncertainties. The growth simulations were based on a mortality model comprising two components: probability of tree necrosis (Dursky 1997), and competition threshold (Pretzsch 2005a). Our evaluation of the development of the forest stand also took into account the diversity of the tree species present, their representation, and horizontal and vertical structure, using the following structural indexes: the Clark-Evans aggregation index (Clark & Evans 1954), the Pielou segregation index (Pielou 1977), and the standardized Arten-profile index (Pretzsch 2005b) as a relative rate of diversity. These indexes were calculated as the next step after the growth simulation. (For the equations for these indexes, please refer to the literature cited.)

The final synthesis of the results from the growth simulation allows an evaluation of whether the spontaneous succession development of the forest ecosystem resulting from the current conservation management plan ensures that the existing character of the mountain Norway spruce forest habitat, as defined by Natura 2000, is being maintained, or whether it would be appropriate to apply a special management plan in order to achieve the defined habitat character at the forecast time horizons.

Results

Predicting the future development of the forest ecosystem in the study area

Visualization of the growth-simulation results for the autochtonous forest stand in study site 1 shows that the non-intervention conservation strategy induces an increase of spatial differentiation of the ecosystem in both forecasts (25 and 50 years) (Figure 2): over 50 years, the canopy layer (forest layer 19; see Table 1) gradually transitions from an optimum stage to decay and thins out (Figure 2), providing space for a new generation of trees (i. e. for forest layers 3 and 5; see Table 1). The overall visual appearance of the habitat, however, remains practically unchanged; the

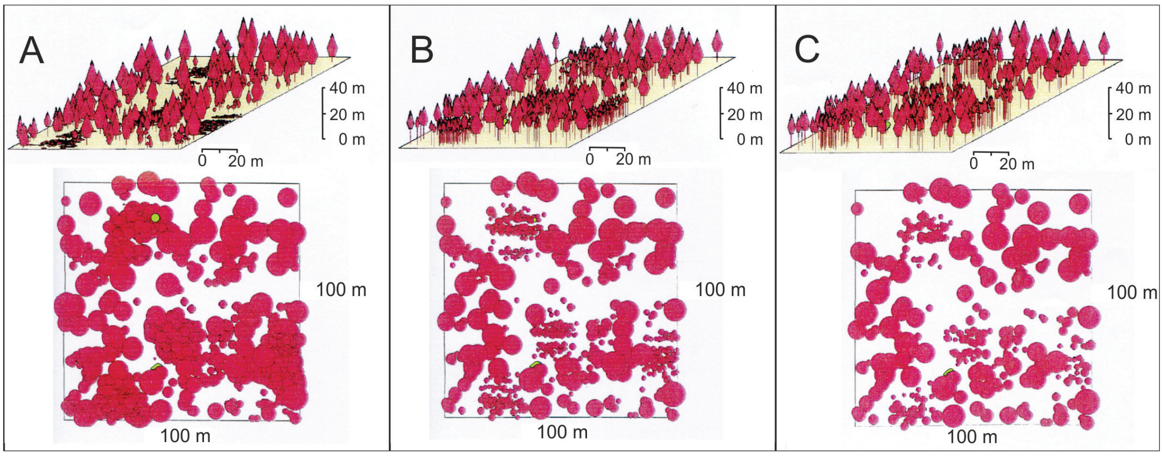

Figure 2 – Growth simulation model SIBYLA-Cz for study area NNR P, study site 1, under a non-intervention management strategy, for autochthonous mountain acidophilous spruce forests below the alpine tree line: A) status quo; B) visualization of the predicted forest stand development for the 25-year forecast, and C) for the 50-year forecast. Red = Picea abies*, blue =* Sorbus aucuparia

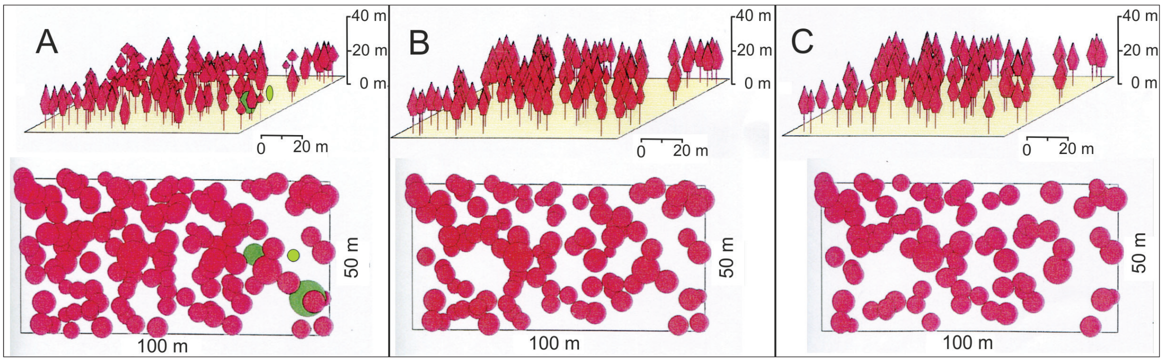

Figure 3 – Growth simulation model SIBYLA-Cz for study area NNR P, study site 2, under a non-intervention management strategy, for alochtonous mountain acidophilous spruce forests below the alpine tree line: A) status quo; B) visualization of the predicted forest stand development for the 25-year forecast, and C) for the 50-year forecast. Red = Picea abies*, blue =* Acer pseudoplatanus*, green =* Fagus sylvatica

forest stand maintains a character of spatially differentiated, natural mountain forest. The growth simulation for tree diameter diversity (Figure 5) under a non-intervention strategy shows a slight increase in average tree diameter and a decrease in number of trees in the canopy layer. This finding is significant in terms both of the nature conservation target (maintaining the habitat character) and of forest management goals (static stability, i. e. resistance of spruce stands to abiotic factors). Highly structured forests will be considerably resistant to abiotic and biotic factors threatening their static stability in the 50-year forecast. The indicators of changes in forest structure (Figures 6–8) show a general trend towards sustaining remarkable forest stand stability (without any significant tendency towards dynamic changes).

Growth simulation for study site 2 shows a similar trend under the non-intervention strategy (Figure 3). Visualizations indicate a trend towards forest self-thinning, with a gradual slight decline in the total number of trees (Figure 4) and loss of the oldest tree specimens (Figure 5). Over 50 years, the forest maintains its character of artificially planted monoculture in the stage of optimum production, with low values for structural indexes (Figures 6–8), indicating low spatial differentiation of the forest.

Assessment of the conservation management strategy in the study area

The main target of the CMS in the NNR P study area (in compliance with the relevant targets of Natura 2000) is to maintain the character of the habitat type. From this perspective, it is important that the growth simulation model in study site 1 does not assume any significant changes in the character of this habitat type under the non-intervention regime. The growth simulation for the 50-year horizon shows that the current forest structure, resulting from the forest's historical management, will not gradually change. Further, no major trends in the forest development are expected that would significantly affect biodiversity conservation. Based on the synthesis of the results from the growth simulation model, we conclude that in the next 50 years, the non-intervention CMS, which is based on the succession of the ecosystem, will not contravene the Natura 2000 requirement to protect this forest stand. The CMS for study site 1 does not, therefore, require any adjustments with regards to the conservation target.

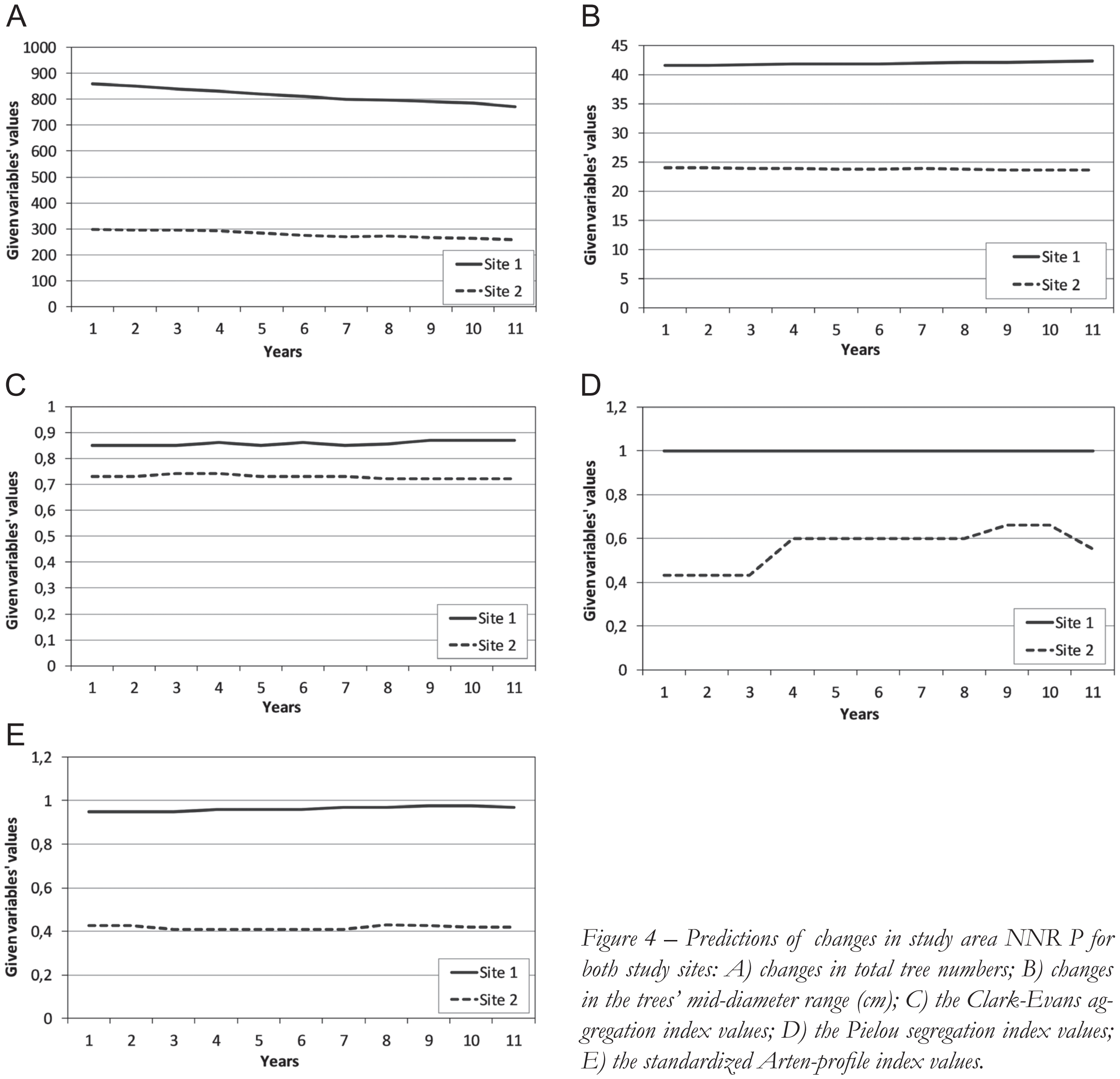

Figure 4 – Predictions of changes in study area NNR P for both study sites: A) changes in total tree numbers; B) changes in the trees' mid-diameter range (cm); C) the Clark-Evans aggregation index values; D) the Pielou segregation index values; E) the standardized Arten-profile index values.

The growth simulation model for study site 2 shows that the development of alochtonous forest leads to a decrease in forest density, which can greatly endanger its static stability. The conservation target for this site (i. e. restoring the natural habitat) cannot be achieved by the 50-year horizon without applying an adaptive CMS aiming at the gradual active creation of highly-structured montane Norway spruce forest and initiation of its natural regeneration. The current (i. e. non-intervention) CMS is therefore not suitable for study site 2 in terms of the Natura 2000 target.

Discussion and conclusion

Norway spruce is a major economic tree species in Central European forests (FAO 2010; Hanewinkel et al. 2013). Its survival is currently threatened by drought resulting from ongoing climate changes (Neuner et al. 2015). Both the natural Norway spruce forests and the artificially established pure Norway spruce forests in the mountains suffer from various types of natural or man-made disturbances (Hresko et al. 2015; Svoboda et al. 2012), such as windthrow, ice breakage, and bark-beetle outbreaks (Hanewinkel et al. 2008). Although bark beetles have an important role in the dynamics of montane Norway spruce forests, there are no sufficiently large areas of montane Norway spruce-dominated forests in the HJM which could enable us to consider spontaneous forest ecosystem development, with bark beetles as a natural driver of this dynamic. Thus, the forest and conservation authorities do not support the idea of the free activity of bark beetles in the Protected Landscape Area HJM, and bark beetles are actively discouraged in the context of integrated forest protection (Machar et al. 2014). The growth simulation model in this article does not, therefore, consider bark beetles as a driver of forest dynamics in the study sites discussed here.

In the HJM, the Dwarf mountain pine was artificially planted in the 19th and 20th centuries, precisely to stabilize the ATLE, as the ATLE had been pushed to lower elevations by grazing (Treml et al. 2010). Currently, a climate-induced upward shift of the ATLE is inhibited by competition between Norway spruce and Dwarf mountain pine (*Pinus mugo* Turra) (Senfelder et al. 2014). But in neither of our study sites is there a predicted shift or change of forest vegetation zone under climate change for the 50-year forecast; and the 25-year results show just one change: the disappearance of *Fagus sylvatica* from both study sites (Figures 2 and 3).

These results suggest future climate change impacts – both a shift of the climate conditions affecting mountain vegetation in the Czech Republic themselves (Machar et al. 2017a), and future changes in distribution of *Forest sylvatica* in Central European mountains (Machar et al. 2017b).

There is no special focus on the natural regeneration of forest stands in the study area, because the growth simulator used was not able to take it into account. Special growth simulators which include natural regeneration, such as the single-tree growth simulator *BWINPro-S* (Schröder et al. 2007), were not available for this study. However, we believe that the growth model used was adequate in relation to the main aim and focus of the study. An advantage of applying growth simulation models to forest management is that these models enable broader and more detailed research of forest tree stand characteristics (e.g. changes over time of distributional characteristics). However, this issue, though important for forest ecology, is not particularly important, on a practical level, in the context of management strategies in protected areas.

The results of this research (Figures 2–4) relating to the predicted changes in forest structure agree with the predictions of impacts of future forest structure on forest animals' mountain habitats (e.g. Konvička et al. 2003; Reif et al. 2008). The structure and dynamics of managed and unmanaged Norway spruce forests have long been of interest to European foresters and the subject of many ecological studies (Kulhavý 2004). In recent years, forest growth models (Pretzsch et al. 2014) have increasingly been used in forestry, resulting in the definition of principles of sustainable forest management (Angelstam et al. 2004; Spathelf 2010). The growth model allows the prediction of the development of forest ecosystems, which is of interest in determining the conservation targets of particular forest management strategies (Jonsson & Villard 2009); its results also help in evaluating the current CMS and to suggest potential adjustments in order to comply with the mission of retaining the character of specific habitats and biodiversity, as defined by Natura 2000 (Idle & Bines 2005; Schultze et al. 2014).

In the case study presented in this article, it is important that the growth simulation model does not assume any significant changes in the character of the habitat type (study site 1) under the non-intervention regime for the next 50 years. The long-term spontaneous development of forest ecosystems in the study area will lead to the creation of valuable habitats for numerous endangered species (Götmark 2013). As non-interventionist forest management undoubtedly contributes to an increase of dead wood in the ecosystem, it will affect the biodiversity of organisms that depend on dying trees and various forms of decomposing wood (Trotsiuk et al. 2016). A gradual increase in dead wood biomass (notably fallen spruce trees on the ground) will probably lead to the natural regeneration of spruce, as spruce seedlings in mountain areas grow best on the decaying trunks of dead trees (Senfeldr & Maděra 2011). The current structure of the autochtonous spruce forest in study site 1, with a clear concentration of certain tree groups in rows, may be evidence that this is already happening, that seedlings have successfully taken root on fallen spruce trees.

Growth simulation helps to make the assessment of forest management strategies more objective, provided that standard dendrometric data for the forest ecosystem being studied are available. The method presented here could be applied more widely to assess forest management strategies in other forested protected areas, notably ones situated in the European temperate zone.

Acknowledgments

We would like to thank the anonymous reviewers for their comments and recommendations. We also thank the PLA Jeseniky Mountains Administration Office for providing data related to the National Nature Reserve Praded. This study was conducted with the financial support of the *Zapomenutá historie horských lesů Hrubého Jeseníku – klíč ke kulturní identitě Moravy a Slezska* (Forgotten History of Montane Forests in Hruby Jeseniky Mountains - a Key to Cultural Identity of Moravia and Silesia). The grant is supported by Ministry of Culture in the frame of NAKI Programme.

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