Silva Gabreta	vol. 24	p. 161–170	Vimperk, 2018

Changes in forest structure in the Bavarian Forest National Park – an evaluation after 10 years of the BIOKLIM-Project

Torben Hilmers[1,*], Claus Bässler[2], Nicolas Friess[3], Marco Heurich[2], Jörg Müller[2,4] & Linda Seifert[2]

[1]Technical University of Munich, Hans-Carl-Von-Carlowitz-Platz 2, D-85354 Freising, Germany
[2]Bavarian Forest National Park, Freyunger Str. 2, D-94481 Grafenau, Germany
[3]Faculty of Biology, Philipps-Universität Marburg, Karl-von-Frisch Str. 8, D-35032 Marburg, Germany
[4]University of Würzburg, Glashüttenstr. 5, D-96181 Rauhenebrach, Germany
[*] torben.hilmers@tum.de

Abstract
Biodiversity is diminishing globally at an unprecedented rate in times of intensive land use and ongoing climate change. Since biodiversity is related to important ecosystem functions and services it is nowadays the goal by law to maintain and improve biodiversity. In this perspective, the BIOKLIM-Project carried out two large forest structure and biodiversity surveys within the Bavarian Forest National Park in 2006 and 2016 to provide a broad range of data to assess the effects of a changing forest structure and climate on species and communities across different taxonomic groups. In this paper, we present the changes in forest structure between the two surveys. Results showed that study plots which were formerly affected from disruptive events such as storms and bark beetle infestations made progress in succession and thus occupy higher classes of forest succession. Furthermore, the results showed that disruptive events again caused disturbances, especially at the high elevations of the Bavarian Forest National Park. Hence, disturbances mainly affected spruce. Anyway, since the forest systems, with the exception of disturbances that might occur, are inert systems, the forest structure changed only slightly on the study plots between the two years of investigation.

Key words: Bavarian Forest National Park, Bohemian Forest, climate change, forest structure, forest succession, biodiversity

Introduction

Human activity affects biodiversity in terms of habitat transformation and degradation, habitat fragmentation, climate change, harvesting and pollution (Tittensor et al. 2014). Thus, global assessments show that the extinction risk of the species increases on average, while the population size decreases (Pimm et al. 2014). Over the last 20 years, remarkable progress has been made to understand how biodiversity loss affects the environment, the functioning of ecosystems and thus society (Cardinale et al. 2012). For instance, species extinction has serious impact on important key processes for the productivity and sustainability of the Earth's ecosystems (Isbell et al. 2011).

Since 1970, when the Bavarian Forest National Park was founded, the vast forests along the park have been allowed to develop without any human interference (Heurich et al. 2011).

This ensures the expression of natural environmental forces and the undisturbed dynamics of the area's natural communities. The major disturbances in mature spruce stands by bark beetles (mainly *Ips typographus*, >5000 ha; see Lehnert et al. 2013) in the 1990s could not be related to any species reaction due to a lack of data (but see Beudert et al. 2015). Apart from such structural changes due to a benign neglect strategy, the analysis of long-term climate data showed that the Bavarian Forest National Park experienced significant higher temperatures especially during the growing season (Bässler et al. 2008). Both, changes in forest structure and climate change can have a major impact on biodiversity (Hilmers et al. 2018, Schall et al. 2017).

Understanding the inherent changes in species diversity as forests develop provides an important baseline for assessing the effects of external drivers such as climate change (Thom et al. 2017). In the absence of such a dynamic baseline, observed changes in biodiversity that are simply the effect of forest dynamics could be easily misattributed to effects of climate change.

Within the framework of the BIOKLIM-Project of the Bavarian Forest National Park, long-term experimental plots have been established for regular monitoring of the state of forest structure and biodiversity. The first survey of forest structure and biodiversity took place in 2006 (Bässler et al. 2008). Repeat recordings in 2016 were carried out on the designated BIOKLIM plots (Bässler et al. 2015). In the course of the repeated survey the changes in forest structure between the two recording years 2006 and 2016 were analyzed comparatively.

During the last hundred years, spruce and fir show a general increasing level of radial growth which is interrupted by a growth decline mainly during the 1960s and 1970s. Due to the species-specific differences in growth, different growth relations occurred between spruce and fir in that period. In the time of high rates of sulphur dioxide emissions, spruce outranges fir while, particularly during the last 30 years, the growth relation inverts (Uhl et al. 2013). Results of studies of mixed mountain forests in Europe show that the growth of spruce is declining in the last decades while the growth of fir is increasing. The volume increment of fir even exceeded on average that of spruce in the last 20 years. Growth of beech has so far remained largely unaffected of climate change in mountain mixed forests (Hilmers et al., unpubl. results). Based on these results, it can be expected that spruce will be pushed back into its realized niche (before human intervention in the National Park and emission load) by the re-strengthening of fir.

The aim of this study was to analyze changes in forest structure between the two surveys (2006 and 2016) in order to investigate whether possible changes in biodiversity can be attributed to changes in forest structure or to climate change. In this contribution we summarized the changes in forest structure on the BIOKLIM-Project plots between the two surveys in 2006 and 2016.

Material and methods

Study area

We used data from two surveys of forest structure in the Bavarian Forest National Park in south-eastern Germany in 2006 and 2016 (Bässler et al. 2008, Bässler et al. 2015). The study area covers ~5,000 km² and comprises a wide range of stages of forest succession that resulted from considerable variation in disturbance history and stand age (Fig. 1). The area is characterized by a homogenous geology (Bohemian Massif, granitic and gneissic bedrock) and predominantly acidic soils. Cultivation and management in this area became important only around 1850 and small areas of old-growth forests still exist (Röder et al. 2010).

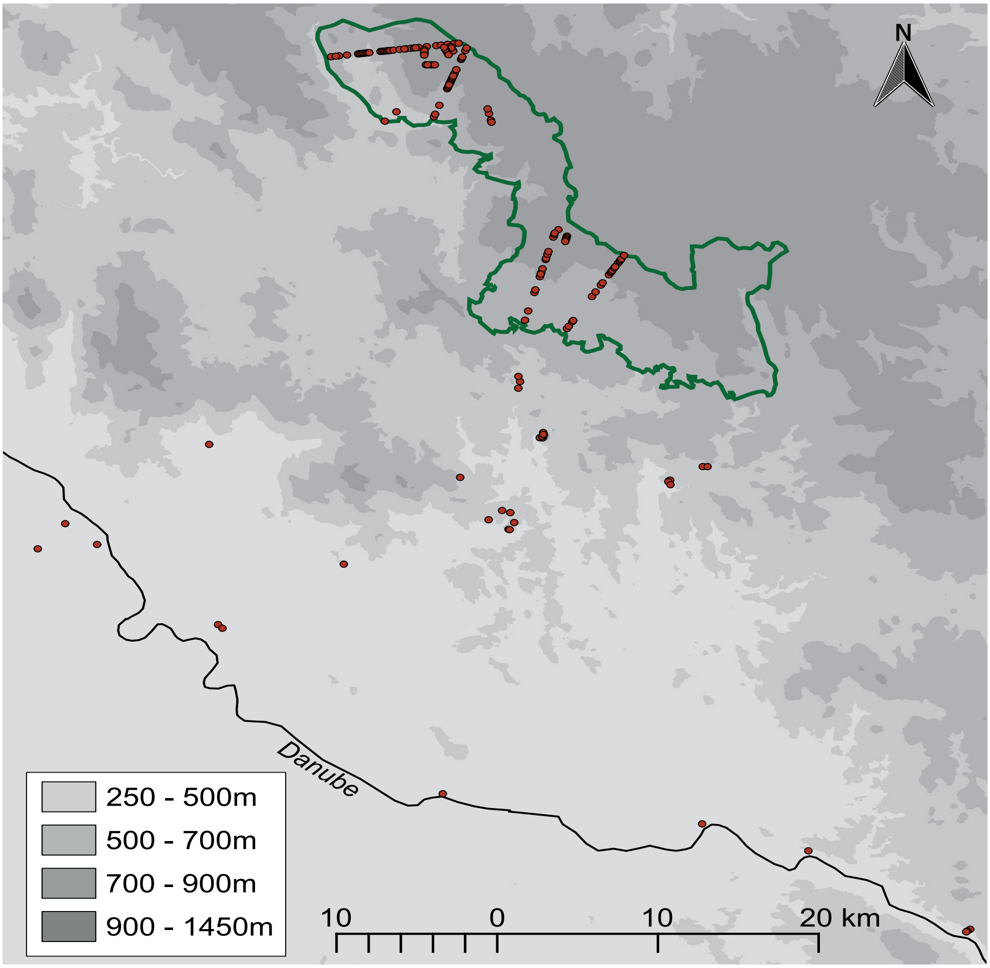

Fig. 1. An overview map of the 133 sampling plots (red points) across the elevational gradient. Main sampling transects are located within the Bavarian Forest National Park (green line). Additional lowland plots (<650m) outside the NP extended the elevation gradient down to the Danube River represent the gradient from 287–1420 m a.s.l. Some sampling points are not visible (overlayed) due to scaling.

The proportion of spruce at all elevations increased during the last century owing to forest management (Röder et al. 2010). The total annual precipitation is between 900 and 1800 mm and increases with elevation (Fig. 2), which ranges from 300 to 1450 m a.s.l. Annual mean air temperature varies between 3.4°C at high elevations and 9.7°C at low elevations (Fig. 2). The study plots are dominated by mixed mountain forests of European beech (*Fagus sylvatica;* ~50%), Norway spruce (*Picea abies* (L.) Karst.; ~30%) and silver fir (*Abies alba* Mill.; ~10%), however admixed with oak (*Quercus* sp.; ~7%) at the lowest elevations. Above 1200 m a.s.l., Norway spruce (~ 85 %) becomes dominant with a lower proportion of beech (~12 %).

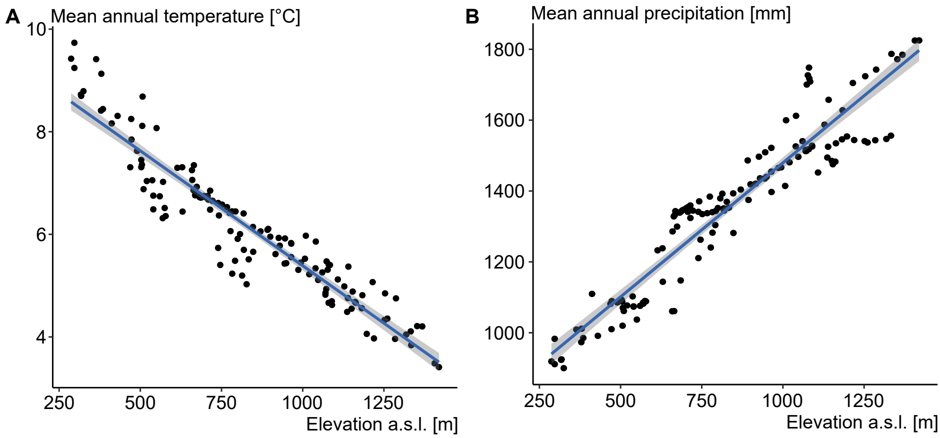

Fig. 2. Climate of the study region based on interpolated data from 1980 to 2006. A – mean annual temperature (°C) in relation to elevation (m a.s.l.) of all 133 study plots; the blue regression line is based on a linear model; the grey area depicts the 95% confidence interval ($R^2 = 0.89$, $p < 0.001$). B – mean annual precipitation (mm) in relation to elevation (m a.s.l.) of all 133 study plots; the blue regression line is based on a linear model, with the grey area depicting the 95% confidence interval ($R^2 = 0.89$, $p < 0.001$).

Data

Forest structure was characterized on two different scales (1 ha and 500 m²). On the 1-ha scale forest structure was characterized visually on 133 plots in the field (Fig. 1). The 133 study plots were selected by optimizing the design from Bässler et al. (2009). Optimization was done by categorization of all plots in respect to their available taxonomical information. Out of the most informative sampling plots we selected those best covering the structural gradient (canopy cover) across the elevation gradient (for final selection, see Fig. 1). For representation of the elevation gradient, we created a set of 100 plots out of the original 331 plots, including 62 highly informative plots and all 38 lowland plots (<650m). As special additions, we added the 33 old-growth forest and meadow plots due to their great importance for the area.

Canopy cover of the upper- (>2/3 of dominant height), middle- (1/3–2/3 of dominant height) and under layer (<10m) was determined by the sample area shaded by horizontal projection of tree layer separated for the occurring tree species (leaves, branches, trunks) in percent. Gaps were measured by the sample area covered by horizontal projection in percent. Height of the under layer was addressed visually in meter. Furthermore, we visually described the immediate surroundings around the plot center. It was addressed whether the center of the plot is in a gap, at the edge of a gap or in a closed forest. Standing and downed woody debris were recorded in the field on a 1000 m² circular plot (see Bässler et al. (2008) for a detailed description).

Forest structure recordings in the BIOKLIM project were extended by more detailed recordings when they were taken in 2016. During the last recording, every tree >7cm DBH was recorded in the field on plots with a circular area of 500 m². Since this detailed information are not available for the 2006 survey, required data were obtained from airborne light detection and ranging (LiDAR). Full-waveform LiDAR data were collected across our plots using a Riegl LMS-Q560 under leaf-on conditions (nominal sensor altitude: 400 m, average point density: 25 points m^{-2}) in the year 2006. Single trees in an area of 500 m² around the center of each plot were detected using 3D segmentation (Yao et al. 2012). On both surveys (2006 and 2016) the vegetation in the herbaceous layer (up to 1 m height), shrub layer (up to 5 m height), tree layer 1 (>5 to 15 m height) and tree layer 2 (>15 m) were estimated on 200 m² circular plots in the field. As there is a lack of LiDAR data for the plots outside the Bavarian Forest National Park these analyses contain only 99 plots within the National Park which both surveys have in common. Standing and downed woody debris were again recorded in the field on a 1000 m² circular plot.

Stages of forest succession

In our study, the 99 plots which both surveys have in common were classified to successional stages by combining the decision trees of Zenner et al. (2016) and Tabaku (2000). The decision trees incorporate information on canopy projection area, maximum diameter at breast height (DBH), proportion of dead wood, normalized quartile of the DBH, and the cover and height of the regeneration layer. The combination of these two protocols was necessary as Zenner et al. (2016) only considered trees with DBH >7 cm, and Tabaku (2000) explicitly also included regeneration and establishment stages. The combined decision tree was used to identify nine successional stages on 99 plots in the Bavarian Forest National Park, i.e., gap, regeneration, establishment, early-optimum, mid-optimum, late-optimum, planter (mixture of trees of different ages, sizes and heights), terminal and decay stages.

Results and discussion

The results show that the canopy cover of the upper layer has increased at medium elevations, compared to the first survey in 2006 (Fig. 3B) and there are less percentages of gaps on the study plots (Fig. 3F). During the last 10 years, the plots which had been exposed due to storms and bark beetle infestations in the first survey have grown over again. At higher elevations, the canopy cover of the upper layer decreased due to renewed disturbances by storms and bark beetle infestations, especially in the Northern part of the Bavarian Forest National Park (Fig. 3B). At the same time, the volume of deadwood at higher elevations (Fig. 3A) and the percentages of gaps (Fig. 3F) have increased. The middle and under layer remained unchanged (Fig. 3C-E). The evaluations of the position of the plot center within the 1 ha plot and the percentage of gaps on the plots also reflected the renewed disturbances of storms and bark beetles in the Bavarian Forest National Park. Above all, a change in the position of the plot center within the 1 ha plot in the direction of the open area could be observed. In particular, the plots which had been already disturbed at the first survey in 2006 (at the edge of the gap) were again affected by disturbances. The gaps have widened to such an extent that the centers of the plots were on the open area at the last survey in 2016 (Fig. 3G).

Considering tree species-specific changes in the canopy covers, revealed that the above-mentioned disturbances in the higher elevations affected spruce particularly (Fig. 4). Compared to the first survey, some areas were affected by disturbances and the spruce was removed completely on some plots. Looking at the middle layer, it is striking that beech is the dominant tree species there. In the under layer, there is a balanced ratio between beech and spruce, except for the high elevations. There are only few study plots with beech at elevations above 1200 m a.s.l. However, it should be emphasized that despite the disturbances in the upper layers, a new generation of spruce trees is already present on some plots (Fig. 4F). Due to the benign neglect strategy of the Bavarian Forest National Park coarse woody debris will remain in the forest. Given the importance of deadwood for forest regeneration and recovery from disturbance, this will favor the future natural regeneration in the disturbed stands especially spruce regeneration (Svoboda et al. 2010).

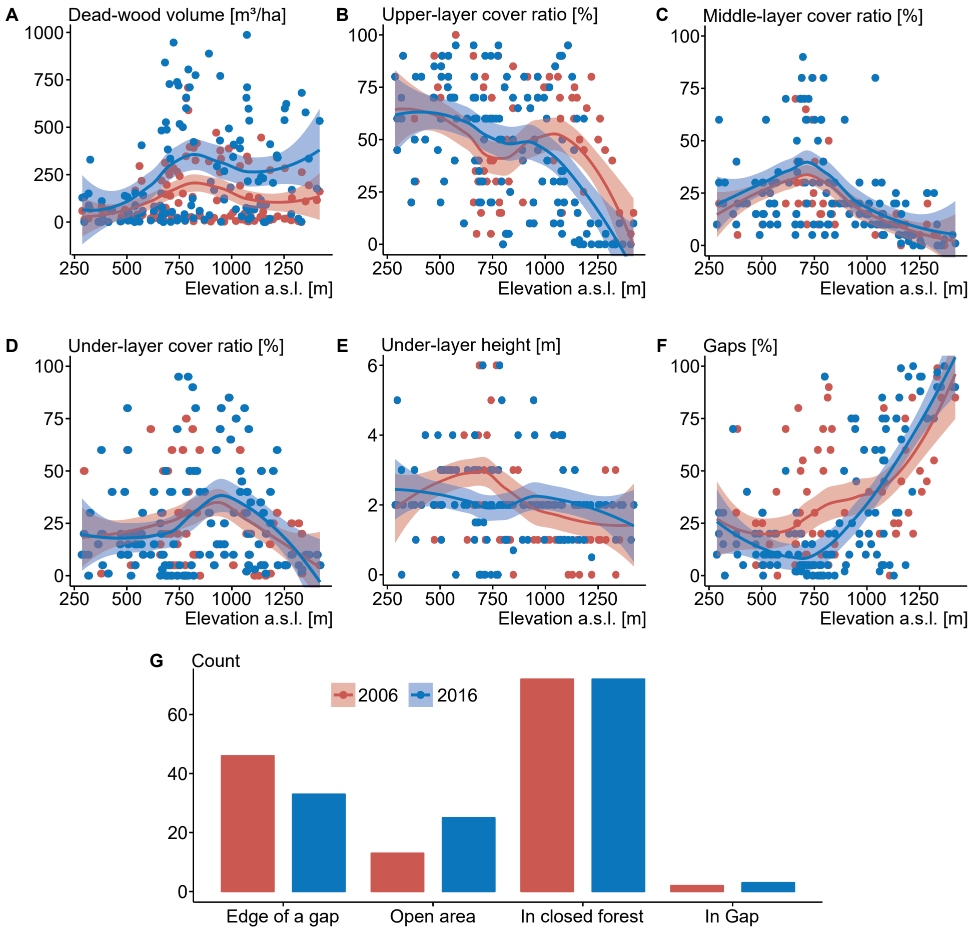

Fig. 3. Comparative representation of forest structure parameters of the BIOKLIM-Project surveys from 2006 (red) and 2016 (blue). Data are based on 133 plots which both surveys have in common: A – volume of dead-wood on the study plots; B – canopy cover of the upper layer in percent; C – canopy cover of the middle layer in percent; D – canopy cover of the under layer in percent; E – height of the under layer; F – the percentage of gaps on the study plots; G – position of the plot center within the 1 ha rectangle around the plot. Lines were generated by fitting a loess curve.

The situation of fir along the elevational gradient remains largely unchanged. Although the biological possibility exists to colonize higher elevations, no changes are visible after 10 years. This is consistent with the findings of Máliš et al. (2016). In their study about tree range shifts in the Western Carpathians they also did not find any elevation shifts for fir and beech in the last decades. Other authors, e.g. Janík et al. (2014), have also shown that fir has a disadvantage in rejuvenation compared to beech. This is primarily due to the increased shade tolerance of beech in advanced regeneration.

If forest structure parameters are combined into forest successional stages, the results are similar to those already described (Fig. 5). It becomes clear that many of the formerly disturbed plots from 2006 have made progress in succession and occupy higher stages of suc-

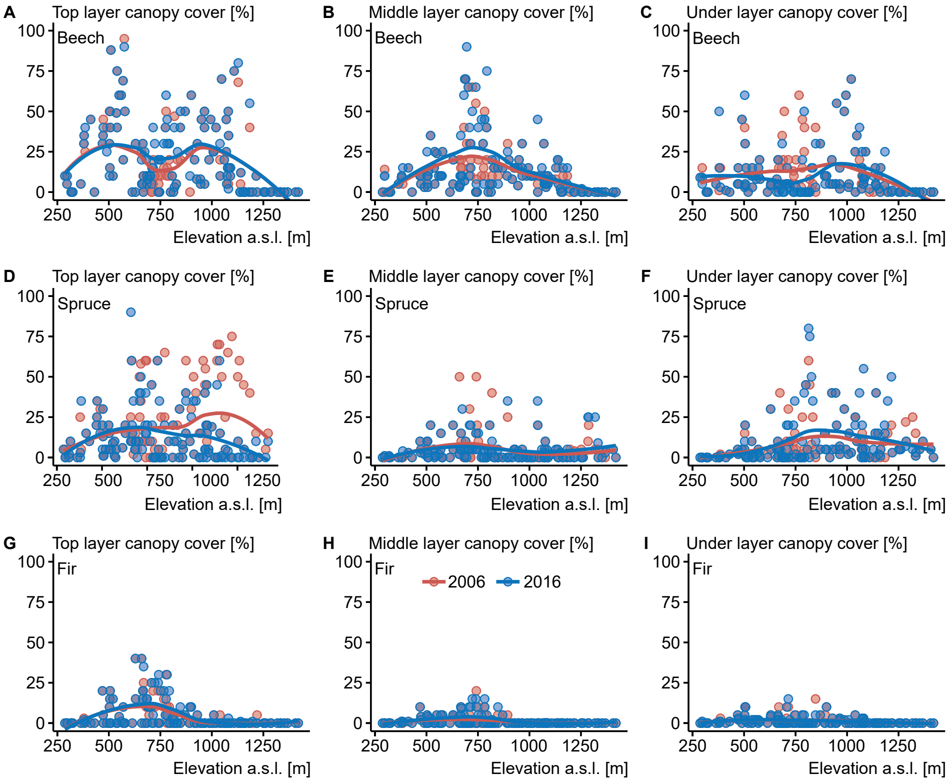

Fig. 4. Comparative representation of the canopy cover of beech (A, B, C), spruce (D, E, F) and fir (G, H, I) of the BIOKLIM-Project surveys from 2006 (red) and 2016 (blue). Data are based on 133 plots which both surveys have in common: A, D, G – canopy cover of the upper layer in percent; B, E, H – canopy cover of the middle layer in percent; C, F, I – canopy cover of the under layer in percent. Lines were generated by fitting a loess curve.

cession. In comparison between the two recording years there are 7% less study plots situated in the gap stage and 13% more study plots situated in the regeneration or establishment stage (Fig. 5).

The recurring disturbances at higher elevations mainly affect the optimal and terminal stages. There are fewer plots in the optimal and terminal stages (–17%) and more plots in the decay stage (+11%). On the one hand, plots have changed from the terminal stage to the decay stage, but some plots have also changed from the optimum stages to the decay stage (Fig. 5). These are primarily the plots at high elevations of the northern part of the Bavarian Forest National Park, which have been affected by disturbances. This makes it clear that forest succession does not always strictly follow the sequence shown, but can change into the gap, regeneration or decay stage at any time due to disturbances (Fig. 5).

Since forest systems, with the exception of disturbances that might occur, are inert systems, the forest structure in relation to the values described above changed only slightly on the study plots between the two years of investigation (2006 and 2016).

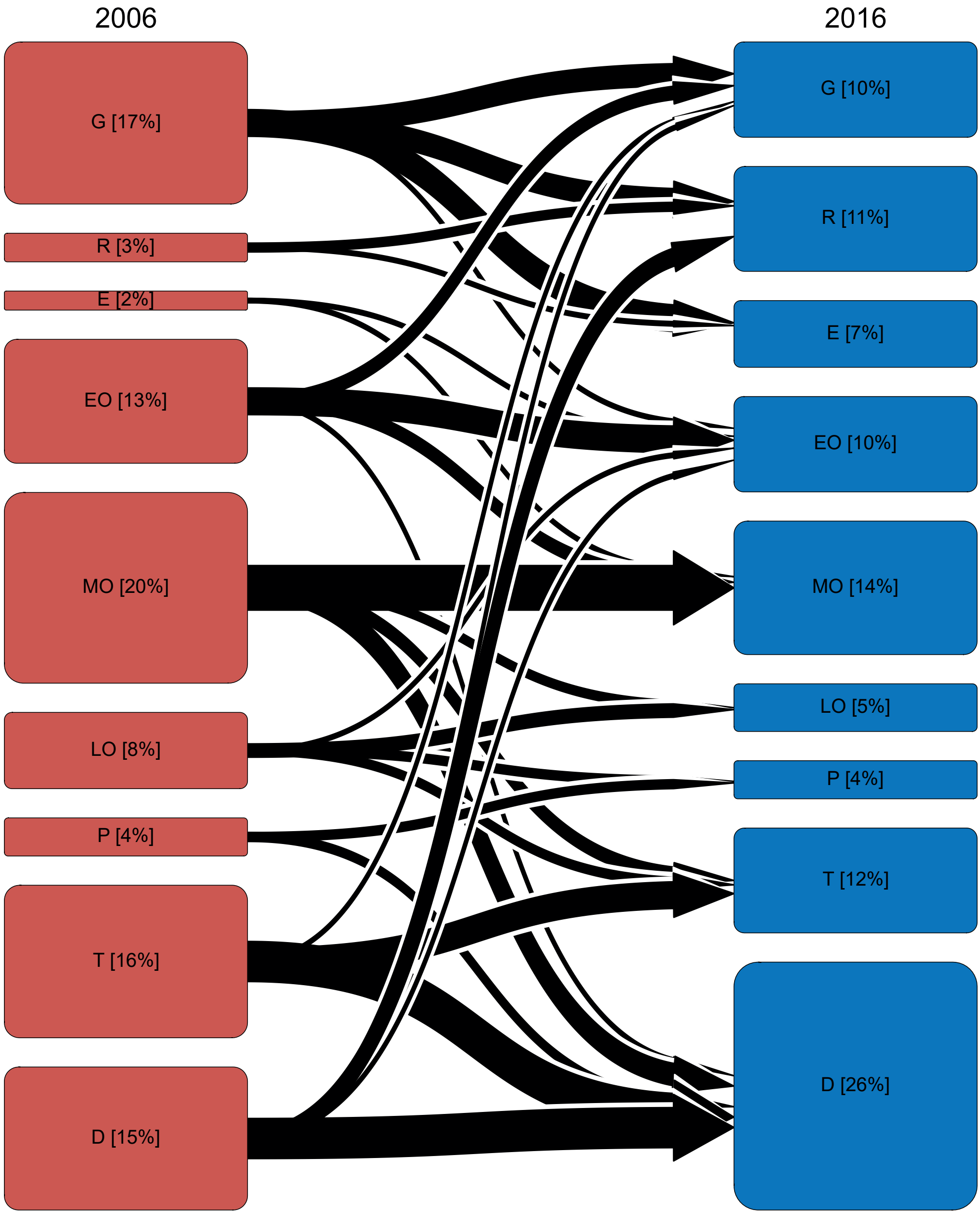

Fig. 5. Comparison of the percentages of plots in every forest successional stage in our study between the two surveys in 2006 (red) and 2016 (blue) and their transition between the two surveys. The successional stages considered here follow TABAKU (2000) and ZENNER et al. (2016). Data are based on 99 plots in the Bavarian Forest National Park. Stages of forest succession: G – gap; R – regeneration; E – establishment; EO – early optimum; MO – mid optimum; LO – late optimum; P – plenter; T – terminal; D – decay. Note that it was not possible to determine forest successional stages for the plots outside the national park in the year 2006 due to missing LiDAR data.

Conclusion

Forest systems, with the exception of occurring disturbances, are inert systems. Therefore, no major changes in the described variables were expected during the first BIOKLIM-Project repeat recording, since no major disturbances occurred either. However, at mid elevations, we found a recovery from disturbances and at higher elevations we found renewed minor disturbances due to bark beetle infestation. Especially spruce is affected by these new disturbances. Anyway, we found that plots formally disturbed in the 2006 survey have made progress and occupy higher stages of forest succession nowadays. As conclusions about the response of multiple taxa to climate change can only be drawn with the information about changes in forest structure (Schall et al. 2017, Hilmers et al. 2018) it is crucial to continue the monitoring of forest structure in future BIOKLIM surveys. Information on changes in forest structure provides the basis for characterizing responses of biodiversity caused by climate change. In the absence of such a dynamic baseline, observed changes in biodiversity that are simply the effect of forest dynamics could be easily misattributed to effects of climate change. LiDAR provides an excellent tool to describe changes in forest structure to a sufficient scale for forest structure and biodiversity analyses in the future. In addition, a merger with data of long term experimental plots following the same approach in the Šumava National Park is in preparation and allows us to expand our analyses on the influence of climate change and forest structure on biodiversity.

Acknowledgements. This research was mainly supported by the Bavarian State Forestry and the Bavarian State Ministry of the Environment, Public Health, and Consumer Protection. The survey 2016 and publishing was granted by the Cross-border cooperation program Czech Republic − Bavaria Free State ETC goal 2014−2020, the Interreg V Project No. 26 "SILVA GABRETA Monitoring of Biodiversity and Water Regime". TH and NF received additional scholarships from the Rudolf and Helene Glaser Foundation organized in the "Stifterverband für die deutsche Wissenschaft".

References

Bässler C., Förster B., Moning C. & Müller J., 2008: The BIOKLIM-Project: biodiversity research between climate change and wilding in a temperate montane forest–the conceptual framework. *Waldökologie, Landschaftsforschung und Naturschutz*, 7: 21–33.

Bässler C., Seifert L. & Müller J., 2015: The BIOKLIM Project in the National Park Bavarian Forest: Lessons from a biodiversity survey. *Silva Gabreta*, 21: 81–93.

Beudert B., Bässler C., Thorn S., Noss R., Schröder B., Dieffenbach-Fries H., Foullois N. & Müller J., 2015: Bark beetles increase biodiversity while maintaining drinking water quality. *Conservation Letters*, 8: 272–281.

Cardinale B.J., Duffy J.E., Gonzalez A., Hooper D.U., Perrings C., Venail P., Narwani A., Mace G.M., Tilman D., Wardle D.A., Kinzig A.P., Daily G.C., Loreau M., Grace J.B., Larigauderie A., Srivastava D.S. & Naeem S., 2012: Biodiversity loss and its impact on humanity. *Nature*, 486: 59−67.

Heurich M., Baierl F., Günther S. & Sinner K.F., 2011: Management and conservation of large mammals in the Bavarian Forest National Park. *Silva Gabreta*, 17: 1–18.

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.

Isbell F., Calcagno V., Hector A., Connolly J., Harpole W.S., Reich P.B., Scherer-Lorenzen M., Schmid B., Tilman D., van Ruijven J., Weigelt A., Wilsey B.J., Zavaleta E.S. & Loreau M., 2011: High plant diversity is needed to maintain ecosystem services. *Nature*, 477: 199–202.

Janík D., Adam D., Hort L., Král K., Šamonil P., Unar P. & Vrška T., 2014: Tree spatial patterns of *Abies alba* and *Fagus sylvatica* in the Western Carpathians over 30 years. *European Journal of Forest Research*, 133: 1015–1028.

Lehnert L.W., Bässler C., Brandl R., Burton P.J. & Müller J., 2013: Conservation value of forests attacked by bark beetles: Highest number of indicator species is found in early successional stages. *Journal for Nature Conservation*, 21: 97–104.

Máliš F., Kopecký M., Petřík P., Vladovič J., Merganič J. & Vida T., 2016: Life stage, not climate change, explains observed tree range shifts. *Global Change Biology*, 22: 1904–1914.

Pimm S.L., Jenkins C.N., Abell R., Brooks T.M., Gittleman J.L., Joppa L.N., Raven P.H., Roberts C.M. & Sexton J.O., 2014: The biodiversity of species and their rates of extinction, distribution, and protection. *Science*, 344: 1246752.

Röder J., Bässler C., Brandl R., Dvořák L., Floren A., Goßner M.M., Gruppe A., Jarzabek-Müller A., Vojtěch O., Wagner C. & Müller J., 2010: Arthropod species richness in the Norway Spruce (*Picea abies* (L.) Karst.) canopy along an elevation gradient. *Forest Ecology and Management*, 259: 1513–1521.

Schall P., Gossner M.M., Heinrichs S., Fischer M., Boch S., Prati D., Jung K., Baumgartner V., Blaser S., Böhm S., Buscot F., Daniel R., Goldmann K., Kaiser K., Kahl T., Lange M., Müller J., Overmann J., Renner S.C., Schulze E.D., Sikorski J., Tschapka M., Türke M., Weisser W.W., Wemheuer B., Wubet T. & Ammer C., 2017: The impact of even-aged and uneven-aged forest management on regional biodiversity of multiple taxa in European beech forests. *Journal of Applied Ecology*, 55: 267–278.

Svoboda M., Fraver S., Janda P., Bače R. & Zenáhlíková J., 2010: Natural development and regeneration of a Central European montane spruce forest. *Forest Ecology and Management*, 260: 707–714.

Tabaku V., 2000: Struktur von Buchen-Urwäldern in Albanien im Vergleich mit deutschen Buchen-Naturwaldreservaten und Wirtschaftswäldern [Structure of beech primeval forests in Albania in comparison with German beech natural forest reserves and commercial forests]. Ph.D. thesis, Universität Göttingen, Cuvillier Verlag, Göttingen, 206 pp. (in German).

Thom D., Rammer W., Dirnböck T., Müller J., Kobler J., Katzensteiner K., Helm N. & Seidl R., 2017: The impacts of climate change and disturbance on spatio-temporal trajectories of biodiversity in a temperate forest landscape. *Journal of Applied Ecology*, 54: 28–38.

Tittensor D.P., Walpole M., Hill S.L.L., Boyce D.G., Britten G.L., Burgess N.D., Butchart S.H.M., Leadley P.W., Regan E.C., Alkemade R., Baumung R., Bellard C., Bouwman L., Bowles-Newark N.J., Chenery A.M., Cheung W.W.L., Christensen V., Cooper H.D., Crowther A.R., Dixon M.J.R., Galli A., Gaveau V., Gregory R.D., Gutierrez N.L., Hirsch T.L., Höft R., Januchowski-Hartley S.R., Karmann M., Krug C.B., Leverington F.J., Loh J., Lojenga R.K., Malsch K., Marques A., Morgan D.H.W., Mumby P.J., Newbold T., Noonan-Mooney K., Pagad S.N., Parks B.C., Pereira H.M., Robertson T., Rondinini C., Santini L., Scharlemann J.P.W., Schindler S., Sumaila U.R., Teh L.S.L., Kolck J. van, Visconti P. & Ye Y., 2014: A mid-term analysis of progress toward international biodiversity targets. *Science*, 346: 241–244.

Uhl E., Ammer C., Spellmann H., Schölch M. & Pretzsch H., 2013: Zuwachstrend und Stressresilienz von Tanne und Fichte im Vergleich [Growth trend and stress-resilience of fir and spruce in comparison]. *Allgemeine Forst und Jagdzeitung*, 11–12: 278–292 (in German).

Yao W., Krzystek P. & Heurich M., 2012: Tree species classification and estimation of stem volume and DBH based on single tree extraction by exploiting airborne full-waveform LiDAR data. *Remote Sensing of Environment*, 123: 368–380.

Zenner E.K., Peck J.E., Hobi M.L. & Commarmot B., 2016: Validation of a classification protocol: meeting the prospect requirement and ensuring distinctiveness when assigning forest development phases. *Applied Vegetation Science*, 19: 541–552.

Received: 28 June 2018
Accepted: 30 August 2018