Study of below-canopy microclimate in managed forests

PhD THESES

BENCE KOVÁCS

Supervisor: PÉTER ÓDOR DSC.

scientific advisor

Eötvös Loránd University, Faculty of Science
Doctoral School of Biology

Head of the Doctoral School: ANNA ERDEI DSC.

Ecology, Conservation Biology and Systematics Doctoral Program

Head of the Program: JÁNOS PODANI DSC

MTA Centre of Ecology, Department of Ecology and Botany

ELTE TTK, Department of Plant Systematics, Ecology and Theoretical Biology

Vácrátót, Budapest, 2018

Introduction

Forests can be characterized by stable, buffered microclimate with lower daytime temperature, higher air humidity, lower light intensity and wind velocity or smaller daily microclimatic fluctuations compared to an adjoining non-forested, open habitat (Geiger *et al.* 1995; Chen *et al.* 1999). Factors regulating the microclimate under closed forest canopy can be classified hierarchically (Aussenac 2000). Beside higher-level components, such as mesoclimate, topography and habitat type that affect microclimate fundamentally, numerous other factors can modify the below-canopy climate: vegetation, forest structure, landscape elements or forest site conditions (von Arx *et al.* 2013; Frey *et al.* 2016).

A significant amount of forest-dwelling taxa are adapted to this constant environment; their long-term survival and diversity just as several biogeochemical processes and the ecosystem functionality are closely dependent on these abiotic conditions (De Frenne *et al.* 2013; Scheffers *et al.* 2014).

It is known that canopy layer plays a key role in creating a special forest microclimate; the buffering capacity of a forest is the highest in the peak of the growing season when the stand is fully leafed (Chen *et al.* 1999). There is a growing number of evidences that in structurally heterogeneous and natural forest stands, this effect could be stronger than in managed stands or in plantations (Frey *et al.* 2016; Lin *et al.* 2017; Norris *et al.* 2012). However, studies typically do not include a high number of background variables other than canopy closure or other simple metrics. Therefore, the effects of different stand structural attributes, landscape elements on the microclimate in the trunk space and the relationships between these attributes and the forest site conditions are still unexplored.

Studying below-canopy microclimate is increasingly important due to its relevance for climate change: the main goal of investigating forest microclimate is the improvement of species distribution models or climate modelling, especially for heterogeneous terrains (Bramer *et al.* 2018). Numerous studies compare contrasting environments created by natural disturbances or forest management practices with closed stands or deal with microclimatic edge effects (Chen *et al.* 1999; Heithecker & Halpern 2006). However, fewer studies investigate the relationships between the below-canopy microclimate and the stand characteristics or landscape variables even though it could support conservational or forest management planning to maintain biodiversity of forest-dependent species and ecosystem functionality (De Frenne *et al.* 2013; Frey *et al.* 2016).

Forest management practices cause changes within a short time-period in canopy closure and stand structure which alters the forest site and indirectly – through the abiotic conditions – affect several ecosystem functions and forest communities. The extent of the changes is highly dependent on the spatial pattern and the intensity of the applied methods. The most drastic changes are caused by the elimination of trees from a large area – typically by clear-cutting or final cutting –, but less intensive practices – e.g., gap-cutting or partial cutting – can also modify the buffered abiotic conditions (Gray *et al.* 2002; Heithecker & Halpern 2006). Although continuous cover forestry is spreading since the beginning of the 2000's (Lett & Schiberna 2012), we have still limited information about the effects of the different management types and practices. Beside observational studies, field experiments are substantial to compare the effects of several treatment types belonging to different management systems by applying the necessary replications of treatment levels and standardized circumstances Most of the forest ecological experiments dealing with the interactions between harvesting and forest site conditions concentrate on one selected forestry system with numerous treatment levels (e.g., Heithecker & Halpern 2006; Weng *et al.* 2007). However, it would be favorable to apply more silvicultural strategies within one experimental design to compare their effects on forest site conditions (like e.g. Knapp *et al.* 2014).

Aims

Consequently, it is important to explore what the most important drivers of the buffered, cool and humid below-canopy microclimate are, not only for basic research but also for conservational purposes. In case of our observational study ("ŐRS-ERDŐ Project"), the main goals were to study

(1.1.) the variance of microclimate among the forest stands in the different measurement series;

(1.2.) the strength of the correlation of air temperature, relative humidity and the amount of light;

(1.3.) if it is possible to use only a few derived, generalized microclimate variables during building models instead of the numerous, separately measured ones;

(1.4.) what the most important species compositional, stand structural, forest site and landscape variables that determine the forest microclimate in closed mature forests are.

Since 2014, we continuously investigate the effects of different treatments available in Central Europe on below-canopy microclimate within the framework of a field-experiment ("Pilis Experiment"). The following specific questions were asked:

(2.1.) How do the applied treatments depart the microclimate variables from the control level and how much is the difference between the treatment levels during the first growing season?

(2.2.) What is the seasonal pattern of the means and ranges of the microclimate variables in the different treatments during the first year?

(2.3.) How do the diurnal patterns of the treatment levels in the peak of the first growing season (in summer) and in the transition period (in spring and autumn) differ from each other?

(2.4.) To what extent do the effects of the treatment levels change during the first three years after the forestry interventions (2015-2017)? Is there any significant year effect?

(2.5.) How much different are the treatment levels in the studied years (2014-2017) based on the microclimate variables? Which variables best distinguish among the treatment levels?

Materials and methods

Within the framework of the ŐRS-ERDŐ Project, numerous environmental variables were measured in 35 forest stands in a landscape where the forest cover is significant, the diversity of arboreal species is high and in spite of the similar forest site conditions, stands with differing species composition and various mixing ratio are present within small-scale. Between 2009 and 2011, air temperature and relative humidity were measured eight times in these stands and relative diffuse light was also gauged.

The variance between the stands in the different measurement periods was tested using Bartlett-test and Tukey-based all-pairwise multiple comparisons. The relationships of the different microclimate variables were explored by correlation analyses. The strong correlation of the air temperature and humidity data made possible to generalize the numerous separately collected means and ranges: standardized principal component analysis (PCA) was performed to derive new microclimate variables. The relationships between the microclimate and the potential background variables were analyzed by linear regression models.

Beside studying the most important drivers of the microclimate in closed forests, we established a field experiment in 2014 in the Hosszú Hill (Pilis Mts.) where the effects of the most common management practices applicable in Central Europe (rotation forestry system: clear-cutting, retention tree group, preparation cutting and continuous cover forestry: gap-cutting) on the microclimate and the departures from the uncut control were monitored. The study site was conducted in an 80 years old, homogenous sessile oak–hornbeam forest where five treatment types were applied in six replicates following a complete block design. Microclimate variables (light, air temperature, relative humidity, vapor pressure deficit, soil temperature, soil moisture content) were systematically measured before (2014) and after the forestry interventions in the center of the treatments. Data were collected using temporally synchronous loggers in every month for at least 48 hours.

Datasets were arranged into a database and the monthly datasets were split to daily subsets. Based on the 24-hr data, the relative values, i.e. departures from control data for each record were derived. Descriptive statistics (mean, interquartile range, etc.) of the relative data were used for the analyses. The effects of treatment and season (questions 2.1. and 2.2.) just as the treatment types with year effect (question 2.4.) were analyzed using linear mixed effects models. The same modeling framework was used: the treatment, time, and their interaction were used as fixed factors, while block was specified as a random factor. The differences between the treatment levels were evaluated using the Tukey procedure for all of the pairwise comparisons; the significance of the differences between the control

and the other treatment levels was tested using linear mixed effects models, without intercept. The separation of the applied treatments based on the microclimate variables were tested by linear discriminant analyses (LDA) for the individual years, separately. The power of the contrasts were analyzed by permutational multivariate analysis of variance (PERMANOVA) using Canberra distances. The contributions of the microclimate variables to the separation of the groups were tested by multivariate analysis of variance (MANOVA) with Wilks test.

Theses

1. Drivers of microclimate of closed, mature forests in the Őrseg region

1.1. Temporal variability of the microclimate

- We demonstrated that between stand variance of the temperature and humidity variables were higher in spring, while generally the most balanced values were recorded in summer and autumn that relates to the state of fully leaved canopy in the growing season.
- It was observed that the spatial variance of minimum values was higher than the means or the maxima that suggests that the diurnal variation and variance of temperature range chiefly depends on the variance of minimum values.

1.2. Correlations among microclimate variables

- We revealed a strong negative relationship between air temperature and relative humidity.
- Due to the consistent and strong negative correlation, it was possible to generalize the numerous variables of air temperature and relative humidity. The performed unconstrained ordination represented a “warm–less humid” microclimatic gradient (PC1) and a variability gradient towards the stable below-canopy climate (PC2).
- In our study, the expected relationships between light and the other two microclimate variables (temperature and humidity) were not observed, correlation coefficients were low.

1.3. Effects of forest stand, site and landscape variables on below-canopy microclimate

- Our results corroborated that tree species composition, stand structure, site conditions and landscape variables are fundamental in creating the microclimate of mature closed forests.
- However, our findings suggested that the vertical complexity and structural heterogeneity (e.g. presence of subcanopy and shrub layer) were of similar or even greater importance in determining forest microclimate than tree species composition of the overstory: the main drivers of the cool and humid microclimate were the subcanopy and the density of the shrub layer. In contrary, the mature deciduous stands and the relative volume of oak species create warmer and drier environment.

- We demonstrated that the presence and amount of the litter may be highlighted as essential factors for the buffer capacity of closed forests due to the decreasing amount of incoming radiation, the retarding of the irradiation and having a high water retention capacity that makes litter layer a protracted source of water vapor. Additional important variables creating moderate and stable forest microclimate were the proportion of forest in the landscape and tree size diversity. A higher structural heterogeneity results in more packed canopies, vertically complex leaf distributions and uneven stem densities with lower turbulent mixing of air or more shade.
- Based on our analyses, basal area and tree size diversity were identified as significant variables, decreasing the amount of diffuse light. Moreover, we found that the relative proportion of oak species created more illuminated trunk space in the studied stands.
- According to our models, mean DBH, total basal area and the relative proportion of beech decreased the horizontal heterogeneity of the understory light climate. It might be stated that a more homogeneous light environment can be created by forest stands with high total volume of living trees and high relative amount of shade tolerant species.

2. The effects of different forestry treatments on microclimate based on the Pilis Experiment

2.1. The effects of the forestry treatments on microclimate in the first growing season

- According to our results, the microclimate variables showed strong short-term deviations among the different treatment types in the first growing season which were generally different from the uncut control. Two different, but highly interrelated processes can be highlighted in the context of microclimate alteration by forest management, radiation balance and evapotranspiration. The forest canopy plays an important role in both of the mechanisms.
- Light variables had the strongest response to the treatments. The increase in the amount of total and diffuse light just as the daily range of the irradiation were the highest in the clear-cuts with intermediate effects in the gap-cuts. We detected lower but significant departures in the case of light levels in the partial cuttings and in the retention tree groups.
- The means and variances of the air and soil temperature were the highest in the clear-cuts as well as the vapor pressure deficit. A limited but positive moderating effect was observed in the retention tree group. Although the mean air and soil temperature and vapor pressure deficit were similar to that in the clear-cuts, it could buffer the extremes. The air characteristics and soil temperature remained the most similar to the uncut control in gap-cuts and partial cuttings.
- A notable increase in soil moisture was observed in the gap-cuttings and, to a smaller extent, in the clear-cuts.

2.2. Studying the seasonal differences of the treatments in the first growing season

- Microclimatic differences showed unequivocal seasonality: the contrasts between the treatments were the largest during the summer (with fully leaved canopies) which demonstrates the buffering effect of the foliage.

2.3. The effects of the treatments on diurnal cycles

- The treatment effect resulted smaller differences in the individual microclimate variables during the transition period (spring and autumn), their diurnal patterns were similar.
- Contrarily, we recorded larger disjunctions in the diurnal cycles of the microclimate in summer: the daily maxima and the 24-hr patterns differed more in the peak of the growing season. For example, we demonstrated that retention tree groups provided the most extreme environment in the forenoon due to the high lateral irradiance, though these patterns concerning abiotic variables were moderated with time.

2.4. Changes in microclimate in the three post-treatment years

- We hypothesized that the strength of the effects of the applied forestry treatments – i.e. the departures from the control levels – become lower as a function of time since treatment. However, we could demonstrate only limited regeneration in microclimate variables within the studied three years.
- According to the natural regeneration of the herb layer and the decreasing cover of bare soil, the mean and interquartile range of soil temperature decreased in time, whereas the sequences of the treatment levels remained similar.
- In the case of the other studied microclimate variables, the largest disjunctions were not measured in the expected first growing season but in the second year. We found that the year effect was generally less significant than the treatment effect which was consistent throughout the three post-treatment years.

2.5. Multivariate analysis of the treatments in the first three years

- The contrast between the treatment types was highly significant after the interventions; the highest separations were found in the second growing season (2016). This strong separation in this period can be mainly addressed to the severe disjunction of the control and clear-cutting groups while the other three groups overlapped more. In 2015 and 2017 all *a priori* groups showed unequivocal and strong separation.
- In the first year, the contrasts of the applied treatments were primarily based on the maxima and the range of soil temperature, and from the second year after the interventions, air temperature showed higher discriminating power.

Conclusions for practitioners

- Considering the other results of the ŐRS-ERDŐ Project, it can be stated that forest microclimate represents essential background variables for several forest-dwelling organism groups (forest herbs, terricolous and epiphytic bryophytes, epiphytic lichens, saprotrophic and dendrotrophic fungi, forest-dwelling spiders).
- Based on our model results, the mixed, multi-layered stands, the heterogeneous age structure or the support of the subcanopy and the well-developed shrub layer could facilitate the subsistence and the conservation of taxa adapted to closed forests. Most of these recommendations are already part of the aims of the continuous cover forestry, therefore, these identified structural elements can be protected or even restored quite cost-efficiently and rapidly by management practices.
- The stable forest microclimate as a consequence of heterogeneous forest structure could mitigate the negative effects of global climate change, thus it can maintain the habitat and suitable environment for the forest specialists in the long term. As a consequence, these more close-to-natural forests could be potential refugia.
- It is important to underline that any forestry management practice modifies the canopy closure and the below-canopy structural elements which alter the buffering capacity of forests.
- The applied management practices of the Pilis Experiment caused strong short-term deviations in the forest site conditions, especially in microclimate and the community structure of several forest-dwelling organism groups, although, these experimental treatments were smaller than in case of a real forestry treatment.
- For the achievement of conservational aims and to guarantee a higher ecosystem functionality, it is recommendable to apply small-scale or spatially dispersed forestry treatments to preserve the original characteristics of the forest environment as much as possible. Gap-cutting and similarly to our preparation cutting, irregular shelterwood or precommercial thinning may be suitable for these purposes.
- Homogeneous managed forest stands are exposed more to the negative impacts of climate change, thus it is important to apply forestry management practices which can maintain the structural complexity of the forests not just in stand- but also in landscape scale to preserve their buffering capacity.
- If the use of the large, even-aged forestry practices is unavoidable, the application of different retention tree group schemes seems to be particularly important to provide the ‘lifeboat’ environment for the forest-dwelling organism groups during the regeneration to survive the extremely altered environmental conditions.

Publications

Publications in refereed journals

Articles related to the dissertation

Kovács, B., Tinya, F., Németh, Cs., Guba, E., Sass, V., Bidló, A., Ódor, P.: The short-term effects of experimental forestry treatments on site conditions in an oak–hornbeam forest. FORESTS 9(7): 406. (2018)

Kovács, B., Tinya, F., Ódor, P.: Stand structural drivers of microclimate in mature temperate mixed forests. AGRICULTURAL AND FOREST METEOROLOGY 234-235: pp. 11–21. (2017)

Other articles

Erdős L., Kröel-Dulay Gy., Bátori Z., **Kovács B.**, Németh Cs., Kiss P. J., Tölgyesi Cs.: Habitat heterogeneity as a key to high conservation value in forest-grassland mosaics. BIOLOGICAL CONSERVATION 226: pp. 72–80. (2018)

Lhotsky B., Csecserits A., **Kovács B.**, Botta-Dukát Z.: New plant trait records of the Hungarian flora. ACTA BOTANICA HUNGARICA 58:(3-4) pp. 397–400. (2016)

Lhotsky B., **Kovács B.**, Ónodi G., Csecserits A., Rédei T., Lengyel A., Kertész M., Botta-Dukát Z.: Changes in assembly rules along a stress gradient from open dry grasslands to wetlands. JOURNAL OF ECOLOGY 104:(2) pp. 507–517. (2016)

Standovár T., Szmorad F., **Kovács B.**, Kelemen K., Plattner M., Roth T., Pataki Zs.: A novel forest state assessment methodology to support conservation and forest management planning. COMMUNITY ECOLOGY 17:(2) pp. 167–177. (2016)

Kelemen K., Mag Zs., Aszalós R., Benedek Zs., Czúcz B., Gálhidy L., **Kovács B.**, Standovár T., Tímár G. (2013): Hazai erdők jövője a klímaváltozás tükrében. TERMÉSZET VILÁGA 144:(1) pp. 7–10.

Kovács B., Kelemen K., Ruff J., Standovár T. (2013): Üzemi léptékben alkalmazott átalakító üzemmód lékes felújításának tapasztalatai a Királyréti Erdészet területén. ERDÉSZETTUDOMÁNYI KÖZLEMÉNYEK 3:(1) pp. 55–70.

Book chapters

Ódor P., **Kovács B.**: Előszó. In: Ódor P. (Szerk.): *A biodiverzitást meghatározó környezeti változók vizsgálata az őrségi erdőkben*. p. 67. Tihany: MTA Ökológiai Kutatóközpont, 2015. p. 7. (ISBN:978-963-89460-7-2)

Ódor P., Bidló A., Király I., **Kovács B.**, Kövendi-Jakó A., Kutszegi G., Lakatos F., Mag Zs., Márialigeti S., Samu F., Siller I.: Anyag és módszer: Az adatgyűjtés módszerei. In: Ódor P. (Szerk.): *A biodiverzitást meghatározó környezeti változók vizsgálata az őrségi erdőkben*. 67 p. Tihany: MTA Ökológiai Kutatóközpont, 2015. pp. 15–20. (ISBN:978-963-89460-7-2)

Kovács B., Ódor P.: Eredmények és megvitatás: A faállomány és a mikroklíma összefüggései. In: Ódor P. (Szerk.): *A biodiverzitást meghatározó környezeti változók vizsgálata az őrségi erdőkben*. 67 p. Tihany: MTA Ökológiai Kutatóközpont, 2015. pp. 23–26. (ISBN:978-963-89460-7-2)

International conferences (oral presentations)

Kovács B., Tinya F., Németh Cs., Ódor P.: Erdészeti beavatkozások mikroklímára gyakorolt hatásainak kísérletes vizsgálata a Pilisben. *11. Magyar Ökológus Kongresszus*. Nyíregyháza, 2018.08.28-2018.08.30.

Kovács B., Tinya F., Aszalós R., Boros G., Elek Z., Samu F., Bidló A., Csépányi P., Ódor P.: The effects of forestry treatments on microclimate, regeneration and biodiversity: first results of an experimental study. *2nd International Conference on Forests, Nationalpark Bayerischer Wald.* Neuschönau, Németország, 2017.04.26-2017.04.29.

Kovács B.: The effect of management on forest microclimate: observational and experimental approaches. *Student Conference on Conservation Science – SCCS Hungary*. Tihany, 2016.08.30-2016.09.02.

Kovács B., Ódor P.: A faállomány és a mikroklíma összefüggései őrségi erdőkben. *X. Magyar Ökológus Kongresszus*. Veszprém, 2015.08.12-2015.08.14.

International conferences (poster presentations)

Kovács B., Tinya F., Németh Cs., Sass V., Bidló A., Ódor P.: Erdészeti fahasználatok termőhelyre gyakorolt hatásának kísérletes vizsgálata. *XI. Magyar Természetvédelmi Biológiai Konferencia „Sikerek és tanulságok a természetvédelemben”*. Eger, 2017.11.02-2017.11.05.

Kovács B., Aszalós R., Bidló A., Boros G., Dombos M., Elek Z., Flórián N., Guba E., Samu F., Sass V., Somay L., Ódor P.: Erdészeti fahasználatok termőhelyre, felújulásra és biodiverzitásra gyakorolt hatásának kísérletes vizsgálata – egy új kísérlet bemutatása. *X. Magyar Ökológus Kongresszus*. Veszprém, 2015.08.12-2015.08.14.

Kovács B., Ódor P.: A faállomány és a mikroklíma összefüggései őrségi erdőkben. *IX. Magyar Természetvédelmi Biológiai Konferencia: "Tudományoktól a döntéshozatalig"*. Szeged, 2014.11.20-2014.11.23.

Kovács B., Ódor P.: The effect of forest stand on microclimate in mature temperate mixed forests. *Forest landscape mosaics: disturbance, restoration and management at times of global change*. Tartu, Észtország, 2014.08.11-2014.08.14.

References

von Arx, G., Graf Pannatier, E., Thimonier, A. & Rebetez, M. (2013) Microclimate in forests with varying leaf area index and soil moisture: potential implications for seedling establishment in a changing climate. *Journal of Ecology* 101, 1201–1213.

Aussenac, G. (2000) Interactions between forest stands and microclimate: Ecophysiological aspects and consequences for silviculture. *Annals of Forest Science* 57, 287–301.

Bernes, C., Jonsson, B.G., Junninen, K., Lõhmus, A., Macdonald, E., Müller, J. & Sandström, J. (2015) What is the impact of active management on biodiversity in boreal and temperate forests set aside for conservation or restoration? A systematic map. *Environmental Evidence* 4, 25.

Bramer, I., Anderson, B.J., Bennie, J. *et al.* (2018) Advances in monitoring and modelling cimate at ecologically relevant scales. In: *Advances in ecological research*. Elsevier, pp. 101–161.

Chen, J., Saunders, S.C., Crow, T.R., Naiman, R.J., Brosofske, K.D., Mroz, G.D., Brookshire, B.L. & Franklin, J.F. (1999) Microclimate in forest ecosystem and landscape ecology. *BioScience* 49, 288–297.

De Frenne, P., Rodriguez-Sanchez, F., Coomes, D.A. *et al.* (2013) Microclimate moderates plant responses to macroclimate warming. *Proceedings of the National Academy of Sciences* 110, 18561–18565.

Frey, S.J.K., Hadley, A.S., Johnson, S.L., Schulze, M., Jones, J.A. & Betts, M.G. (2016) Spatial models reveal the microclimatic buffering capacity of old-growth forests. *Science Advances* 2, e1501392–e1501392.

Geiger, R., Aron, R.H. & Todhunter, P. (1995) *The climate near the ground*. Vieweg+Teubner Verlag, Wiesbaden.

Gray, A.N., Spies, T.A. & Easter, M.J. (2002) Microclimatic and soil moisture responses to gap formation in coastal Douglas-fir forests. *Canadian Journal of Forest Research* 32, 332–343.

Heithecker, T.D. & Halpern, C.B. (2006) Variation in microclimate associated with dispersed-retention harvests in coniferous forests of western Washington. *Forest Ecology and Management* 226, 60–71.

Knapp, B.O., Olson, M.G., Larsen, D.R., Kabrick, J.M. & Jensen, R.G. (2014) Missouri Ozark Forest Ecosystem Project: A long-term, landscape-scale, collaborative forest management research project. *Journal of Forestry* 112, 513–524.

Lett, B. & Schiberna, E. (Szerk.) (2012) *Múlt és jövő III.: a folyamatos erdőborítás gazdálkodói szemmel*. Nyugat-magyarországi Egyetem Kiadó, Sopron.

Lin, H., Chen, Y., Song, Q. *et al.* (2017) Quantifying deforestation and forest degradation with thermal response. *Science of The Total Environment* 607–608, 1286–1292.

Norris, C., Hobson, P. & Ibisch, P.L. (2012) Microclimate and vegetation function as indicators of forest thermodynamic efficiency: Forest thermodynamic efficiency. *Journal of Applied Ecology* 49, 562–570.

Scheffers, B.R., Edwards, D.P., Diesmos, A., Williams, S.E. & Evans, T.A. (2014) Microhabitats reduce animal's exposure to climate extremes. *Global Change Biology* 20, 495–503.

Weng, S.-H., Kuo, S.-R., Guan, B.T., Chang, T.-Y., Hsu, H.-W. & Shen, C.-W. (2007) Microclimatic responses to different thinning intensities in a Japanese cedar plantation of northern Taiwan. *Forest Ecology and Management* 241, 91–100.