Description of the Pilis Experiments (April 2022)

The Centre for Ecological Research and the Pilisi Parkerdő Forestry Ltd. have been operated a project since 2014 that consists of two field experiments which investigate the effects of different silvicultural treatments on forest site conditions, regeneration, and biodiversity. Both studies are located in the Hosszú-hill (Pilis Mountains, northern part of Central Hungary), established in an oak–hornbeam forest stand (***1.***) The Pilis Forestry Systems Experiment compares the elements of the regionally dominant shelterwood forestry system (clearcutting, retention tree group, and preparation cutting) to the most widely-used treatment type of the recently introduced continuous cover forestry system (gap-cutting); while (***2.***) the Pilis Gap Experiment focuses on the continuous cover forestry solely, and investigates the effects of different management options regarding the main characteristics of artificial gaps (small cut areas created by the logging of a group of trees). The experiments were designed in tight cooperation between the Centre for Ecological Research and Pilisi Parkerdő Forestry Ltd.

In all treatments, we study the microclimate conditions (light, air humidity and temperature, soil temperature and moisture), the soil physical and chemical characteristics (texture, pH, nutrient contents), and the litter conditions (litter weight and chemical characteristics). We investigate the changes of the understory vegetation and tree regeneration. In the case of the most important tree species, the individual growth of saplings is also monitored. Among the animals, arthropod communities (ground beetles, spiders, flies, collembolans, and litter-dwelling beetles), and an important decomposing organism group (enchytraeid worms) are regularly studied. In order to explore the treatment–biodiversity relationships to a more complete view, since 2020, we completed the project with e-DNA surveys on soil microbiome (especially fungi assemblages).

We would like to present strong scientific evidence for the establishment of ecologically sustainable forest management. Our knowledge obtained about the effects of forestry treatments on forest regeneration can also contribute to the management planning which ensures the natural regeneration of trees and mitigates the effects of climate change. More information about the project is available on our website:

https://www.piliskiserlet.okologia.mta.hu/en/node/1.

Hereinafter we describe the two experiments separately.

Pilis Forestry Systems Experiment

The Pilis Forestry Systems Experiment is located in a 40-ha sized, 80-year-old oak–hornbeam forest (Fig. 1). We investigate the effects of four forestry treatments, compared to uncut control parts of the stand: clearcutting, retention tree group, uniform preparation cutting (elements of the shelterwood forestry system), and gap-cutting (continuous cover forestry system). There are six replicates from each treatment in a complete block design, thus altogether 30 plots are sampled. In 2014, in the uncut stand, we recorded the before-treatment state. Interventions were carried out in the winter of 2014-2015, since then samplings have been performed every year with an unaltered methodology (Fig. 2).

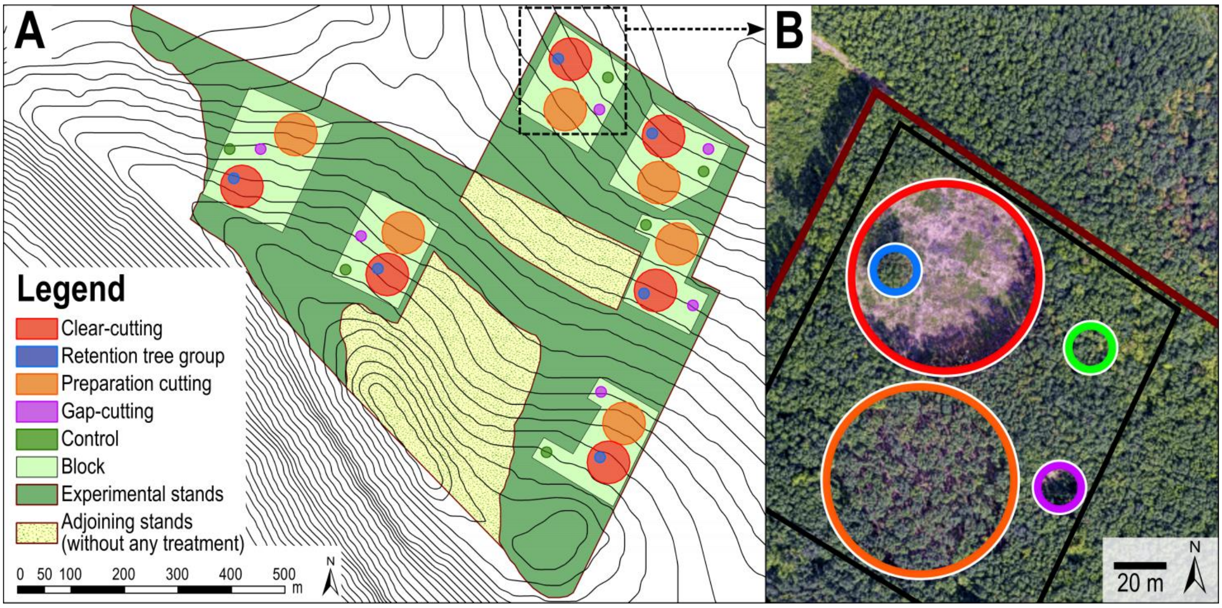

Figure 1. A) The map of the study area (Hosszú Hill, near Pilisszántó and Pilisszentkereszt settlements) and B) aerial photo of a block with the different treatments (Drone photo by Dr. Viktor Tóth).

Data collection is carried out around a 6 m × 6 m fenced area in the centre of each plot (Fig. 2). Microclimate is measured in the centre of the fenced area. The development of the understory vegetation and the natural regeneration are monitored using pairs of fenced and unfenced quadrates (2 m × 2 m), thus we can study the effect of ungulate browsing separately. The individual growth of both natural and planted tree saplings are monitored.

In four out of the six blocks, we also explore the spatial pattern of the understory, regeneration, light, and soil moisture within the plots by a finer-grained, more detailed survey. Here we sample 0.5 m × 0.5 m quadrates arranged in a systematic grid, in all second years (to date in 2016, 2018, and 2020). From 2014 to 2018, the development of two planted bryophyte species (a specialist deadwood-inhabiting and a generalist bark-inhabiting species) was also investigated in the different treatments. Ground beetles and spiders were collected using pitfall traps; moreover, we studied the movement pattern of ground beetle individuals within the treatments by radiotelemetry. Dipterans are collected with Malaise traps, collembolans and litter-dwelling beetles are sampled by litter collection, and enchytraeid worms by soil sampling. Soil microbiome is investigated by e-DNA sampling. Besides the changes in biodiversity, several forest ecosystem functions are also studied, such as the decomposition processes and the control of herbivore insects by birds. Decomposition was measured on litter and wood samples placed out into the different treatments, while bird predation on herbivore insects was investigated by using artificial caterpillars.

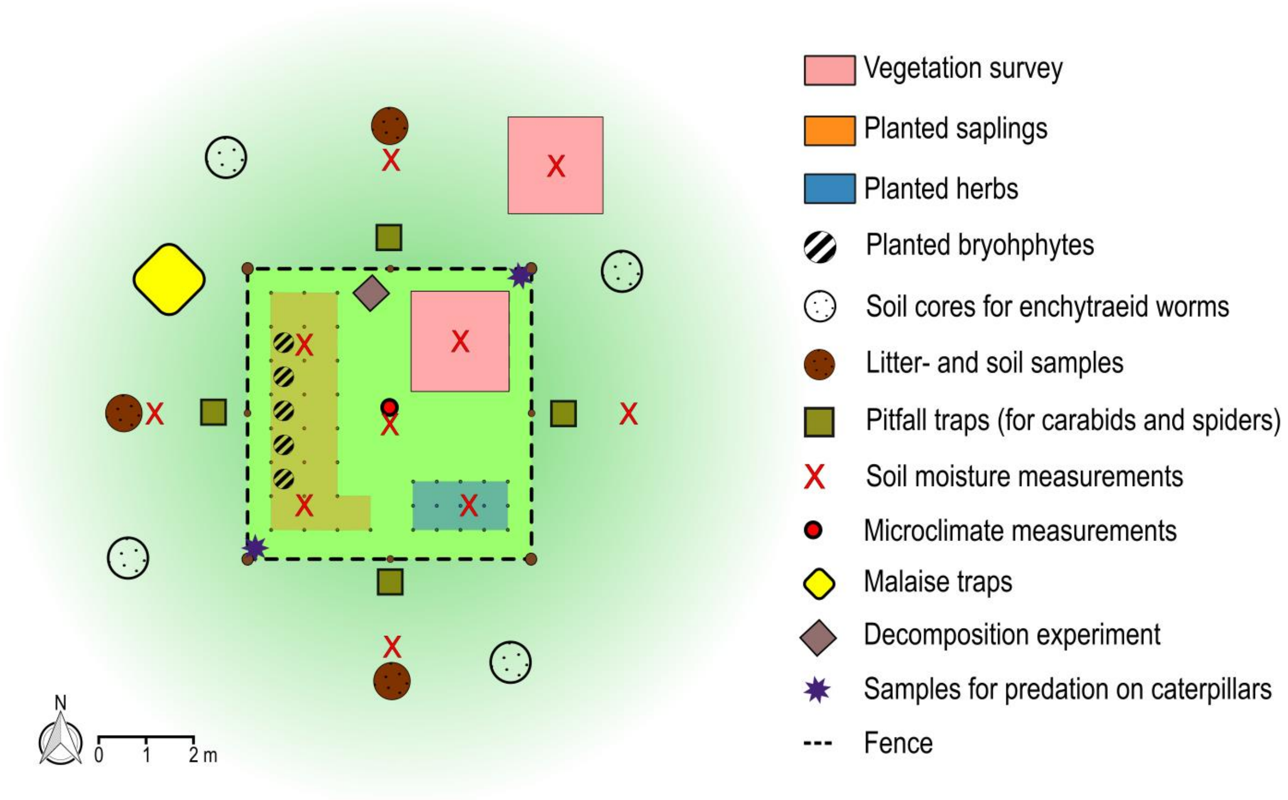

Figure 2. The location of the sampling points within a plot.

Our most important results can be summarized as follows:

Microclimate, forest site conditions:

- Microclimatic conditions changed immediately after the interventions and remained relatively consistent during the first three years. The recovery of the original closed-forest microclimate can be expected only after a longer time – even in the less drastic treatments.
- Temperature maxima and variance were the main determinants of the microclimatic differences between the treatments. In certain treatments, in summer days, these temperature variables can be quite high.
- The most drastic changes were observed in the clearcuts. This treatment is characterized by extreme high amount of light, high air and soil temperature, increased soil moisture, and low air humidity. The daily range of the microclimate is also the highest here, thus the animals and plants living in clearcuts must adapt to very extreme conditions.
- In the gaps, the most important change was the increment of the soil moisture. Light also increased, compared to the closed forest, however, air and soil temperature and air humidity remained balanced, similarly to the conditions of the closed stand.
- Retention tree groups are able to compensate the extremities of the microclimate, compared to the clearcuts (e.g., by the more moderated daily maxima), but the mean values of most variables were similar to those in the cutting areas. However, the amount of light is lower here than in the clearcuts, and the soil moisture remained similarly low as in the closed forest.
- Microclimatic conditions of the preparation cuts are similar to those of the closed stand. Light, air, and soil temperature showed a slight increase, but the air humidity and soil moisture did not change.
- Differences in the microclimate of the treatments are the most pronounced in the summer period.
- Soil conditions did not show notable changes in the first years after the interventions; we suppose that their alteration needs longer time. The amount of litter decreased in the clearcuts, and its pH became more neutral, due to the vegetation changes (tree removals and dominance of herbs).

Understory vegetation:

- Vegetation of the clearcuts and gaps altered significantly even in the first years: both species richness and abundance (cover and height) of the understory increased. Some new species also established in the retention tree groups but the biomass changes were more moderate and slower in this treatment type.
- In the clearcuts, due to the appearance of many non-forest (meadow and weed) species, the species composition of the understory changed remarkably.
- Contrary to this, in the gaps, despite the biomass of the understory increased, the dominance of forest species was maintained.
- The cover of the annual herb species increased in the first two years in the clearcuts and gaps, but for the fourth year, it has withdrawn.
- Retention tree groups are able to preserve the forest characteristics of the understory for some years but later, their vegetation also begins to change.

Bryophytes:

- The response of bryophytes to the treatments depends considerably on the life strategy of the species.
- The generalist species survived in every treatment but in the clearcuts, its cover decreased.
- The specialist deadwood-inhabiting species died off in the clearcuts and retention tree groups, while in the preparation cuts and gaps – after an early relapse – it survived. We can conclude that shelterwood system cannot ensure the survival of specialist, humidity-demanding bryophyte species, while the continuous cover forestry may be able to preserve these species.

Regeneration:

- Survival of the woody saplings was better in every treated site than in the closed stand.
- Based on the results of the first four years, regeneration is the most successful in the clearcuts and gaps.
- In the retention tree groups, many seedlings establish and survive; however, microclimatic conditions of this treatment (dry topsoil, low air humidity, and little extra light) are not suitable for their growth.

- The response of the different tree species to the treatments depends on the dispersal mechanism of the species.
- The establishment of new oak individuals in the gaps, and especially in the clearcuts after the fellings, is strongly limited because acorns cannot reach the inner parts of these treatments. However, tree recruits, which have been present there originally, showed the most intensive growth. Oak seedlings cannot survive for a long time in closed stands; in the preparation cuttings and retention tree groups, they survive but do not grow.
- Tree species of mesic forests (hornbeam, beech) respond to the increased light with an intensive growth in every treated site, compared to closed stand. They showed the fastest growth in the gaps and cut areas.
- Ash and animal-dispersed wild fruit species germinated the best in the retention tree groups; however, the growth of ash was the best in gaps while the that of wild fruits was the most intensive in the clearcuts.

Browsing effect:

- There was a significant difference in the rate of browsed saplings between the fenced and unfenced areas. It was detectable even in the first year after the interventions, which shows an intensive browsing pressure in the region.
- All investigated woody species have grown better in the fenced areas.
- Browsing was more intensive on shrubs than on tree saplings, thus the preservation of shrubs in the stands can moderate the browsing pressure on the tree species.

Ground beetles:

- Treatments did not have any effect on the species richness and abundance of ground beetles, but they altered the species composition of this group. In the initial stage (2015-2016), the assemblages of clearcuts and retention tree groups differed from the other treatments, while in the later phase (2017-2018), the compositional difference was only present between the control and the other treatments.
- The functional groups responded to the treatments differently. Besides the control, forest species remained in the gaps and preparation cuts, while in the clearcuts and retention tree groups, the proportion of generalist and open-field species increased. This difference did not change during the survey period indicating that the populations of

forest specialists (which are mainly flightless predators) need more than four years to regenerate.

- Additional studies showed that the behaviour and movement pattern of ground beetles also differ between the control and treated plots. Ground beetles use disturbed stands (i.e., harvested plots with tree removals) only temporarily, primarily as feeding site.
- Besides, our results show that there is a stronger predation pressure on ground beetles in the treated areas than in the controls. This effect does not have any seasonal pattern.

Spiders:

- In the case of spiders, species composition changed considerably after the interventions. Some species favoured the increased light, vegetation cover, and temperature in the treated sites, while the altered environmental conditions were adverse for others. There was another distinct group of spiders whose species composition was determined by the various amount of litter in the different treatments.
- In the first two years, spider communities of the treated sites begin to differ from those of the closed stand; however, in the third year, this process stopped and returned.

Dipterans:

- Among dipterans, crane fly assemblages (superfamily *Tipulidae*) were analysed based on a sampling carried out in the third post-harvest year. Other groups of the order *Diptera* are currently under identification and analysis.
- We found the highest species number and abundance of crane flies in the gaps due to the favourable site conditions (moist topsoil with increased but buffered soil temperatures) and well-developed, species-rich herbaceous layer.
- The lowest species number was observed in the retention tree groups.
- Species pools of the treatment types substantially differed, the highest separation was found between the species composition of gaps and retention tree groups.

Collembolans and litter-dwelling beetles:

- After a pilot study, we collected data in one complete season. Currently, the collected samples are under identification.

Enchytraeid worms:

- Species richness and abundance of enchytraeid worms decreased drastically in the clearcuts and retention tree groups. As they are soil-dwelling organisms with low dispersal ability, they are not able to tolerate the altered microclimatic conditions of the cut areas. In their case, even the retention tree groups could not serve as a refuge.
- However, in the gaps and preparation cuts, their abundance and species composition were similar to those in the closed forest. Therefore, we can conclude that continuous cover forestry may be more favourable for this important decomposer organism group than shelterwood forestry system.

Soil microbiome:

- We identified the DNA sequences of 4480 fungi genotypes altogether.
- Forestry treatments had a significant effect both on the diversity and composition of fungi assemblages. The various functional groups responded to the treatments differently. For example, in the clearcut areas and gaps, the diversity of ectomycorrhizal fungi decreased, while that of wood-decaying fungi increased.
- There were substantial differences within the functional groups regarding the habitat preferences of the different genera. For example, among ectomycorrhizal fungi, *Amanita* species had the highest species richness in the control, while *Laccaria* species were the most species-rich in the strongly disturbed treatments.
- The species composition of all functional groups strongly differed among treatments; the clearcut and the gap were the most divergent from the other treatment types.
- Considering the measured environmental variables, the cover and species richness of the understory and soil water content were the strongest drivers of the compositional changes in fungi assemblages.

Summary

Our results show that cut areas created under the scheme of rotation forestry system result in strongly unfavourable abiotic conditions for the forest biodiversity. The composition of forest-dwelling communities changes due to the large daily temperature range, the lower air humidity, and the substantially increased light. The proportion and abundance of non-forest species increase, while forest species are forced back.

Contrary to this, in the gaps created by continuous cover forestry, despite the increased light, the microclimate remained buffered which is a characteristic feature of the forest habitats. The increased water content in the topsoil layer is favourable for plants and soil-dwelling organisms. The composition of the different forest organism groups becomes altered but essentially, it keeps its original forest character.

For tree regeneration, environmental conditions created by gap-cutting and clear-cutting are similarly suitable. However, to ensure the adequate development of oaks, it is necessary to control fast-growing shade-tolerant species in both treatment types. Ungulate browsing has a strong effect in both treatments, and it is more pronounced on the admixing tree and shrub species than on the main tree species (in our case, oaks).

In the preparation cutting, both the original forest characteristics of microclimate and taxa might be preserved. The slight decrease in canopy closure does not change the forest conditions.

Retention tree groups can compensate the unfavourable effects of clearcuts for certain organism groups (e.g., for understory vegetation), but for the soil-dwelling taxa, the dry and warm soil provides limited survival success and unfavourable conditions. Regarding the temperature, retention tree groups can buffer the daily variation but do not have an ameliorating effect on the mean values. In order to preserve forest biodiversity under rotation forestry system, we suggest retaining larger tree groups than 300 m^2, especially at dry forest sites.

In summary, we can conclude that treatments of continuous cover forestry better ensure the protection functions of forests than rotation forestry system.

Publications

Scientific publications and our conference presentation with detailed results are available in the continuously updated Document repository of the project: https://www.piliskiserlet.okologia.mta.hu/en/node/5.

Our most important publications published so far are as follows:

Elek, Z.; Růžičková, J.; Ódor, P. Functional plasticity of carabids presume better the changes in community composition than taxon-based descriptors. *Ecological Applications* 2022, 32 (1). https://doi.org/10.1002/eap.2460.

Elek, Z.; Růžičková, J.; Ódor, P. Colorful beetles of a temperate forest: *Carabus scheidleri*. *Bulletin Ecological Society of America* 2022, 103 (1). https://doi.org/10.1002/bes2.1942.

Samu, F.; Elek, Z.; Kovács, B.; Fülöp, D.; Botos, E.; Schmera, D.; Aszalós, R.; Bidló, A.; Németh, Cs.; Sass, V.; Tinya, F.; Ódor, P. Resilience of spider communities affected by a range of silvicultural treatments in a temperate deciduous forest stand. *Scientific Reports* 2021, 11 (1), 20520. https://doi.org/10.1038/s41598-021-99884-8.

Růžičková, J.; Elek, Z. Unequivocal differences in predation pressure on large carabid beetles between forestry treatments. *Diversity* 2021, 13 (10), 484. https://doi.org/10.3390/d13100484.

Růžičková, J.; Elek, Z. Recording fine-scale movement of ground beetles by two methods: Potentials and methodological pitfalls. *Ecology and Evolution* 2021, 11 (13), 8562–8572. https://doi.org/10.1002/ece3.7670.

Růžičková, J.; Bérces, S.; Ackov, Sz.; Elek, Z. Individual movement of carabids as a link for activity density patterns in various forestry treatments. *Acta Zoologica Academiae Scientiarum Hungaricae* 2021, 67 (1), 77–86. https://doi.org/10.17109/AZH.67.1.77.2021.

Elek, Z.; Růžičková, J.; Ódor, P. Individual decisions drive the changes in movement patterns of ground beetles between forestry management types. *Biologia* 2021, 76 (11), 3287–3296. https://doi.org/10.1007/s11756-021-00805-x.

Tinya, F.; Kovács, B.; Aszalós, R.; Tóth, B.; Csépányi, P.; Németh, Cs.; Ódor, P. Initial regeneration success of tree species after different forestry treatments in an oak-hornbeam forest. *Forest Ecology and Management* 2020, 459, 117810. https://doi.org/10.1016/j.foreco.2019.117810.

Kovács, B.; Tinya, F.; Németh, Cs.; Ódor, P. Unfolding the effects of different forestry treatments on microclimate in oak forests: Results of a 4-yr experiment. *Ecological Applications* 2020, 30 (2). https://doi.org/10.1002/eap.2043.

Tinya, F.; Kovács, B.; Prättälä, A.; Farkas, P.; Aszalós, R.; Ódor, P. Initial understory response to experimental silvicultural treatments in a temperate oak-dominated forest. *European Journal of Forest Research* 2019, 138 (1), 65–77. https://doi.org/10.1007/s10342-018-1154-8.

Boros, G.; Kovács, B.; Ódor, P. Green tree retention enhances negative short-term effects of clear-cutting on enchytraeid assemblages in a temperate forest. *Applied Soil Ecology* 2019, 136, 106–115. https://doi.org/10.1016/j.apsoil.2018.12.018.

Kovács, B.; Tinya, F.; Guba, E.; Németh, Cs.; Sass, V.; Bidló, A.; Ódor, P. The short-term effects of experimental forestry treatments on site conditions in an oak–hornbeam forest. *Forests* 2018, 9 (7), 406. https://doi.org/10.3390/f9070406.

Elek, Z.; Kovács, B.; Aszalós, R.; Boros, G.; Samu, F.; Tinya, F.; Ódor, P. Taxon-specific responses to different forestry treatments in a temperate forest. *Scientific Reports* 2018, 8 (1), 16990. https://doi.org/10.1038/s41598-018-35159-z.

The Pilis Gap Experiment

The Pilis Gap Experiment, as the second part of the project, has been started in 2018. It is located in a 90-year-old oak–hornbeam forest, adjacent to the Pilis Forestry Systems Experiment. The Pilisi Parkerdő Forestry Ltd. manages numerous oak-dominated stands with continuous cover forestry. Their initial experiences raised the issue that what kind of gaps should be created to ensure the forest regeneration, the preservation of the forest microclimate, site conditions and biodiversity simultaneously. We investigate the effects of different gap sizes (small/large), gap shapes (circular/elongated) and creation methodologies (created in one step/created in two steps: small elongated gap enlarged some years later to large circular). All of these gap types are compared to closed forest controls (Fig. 3).

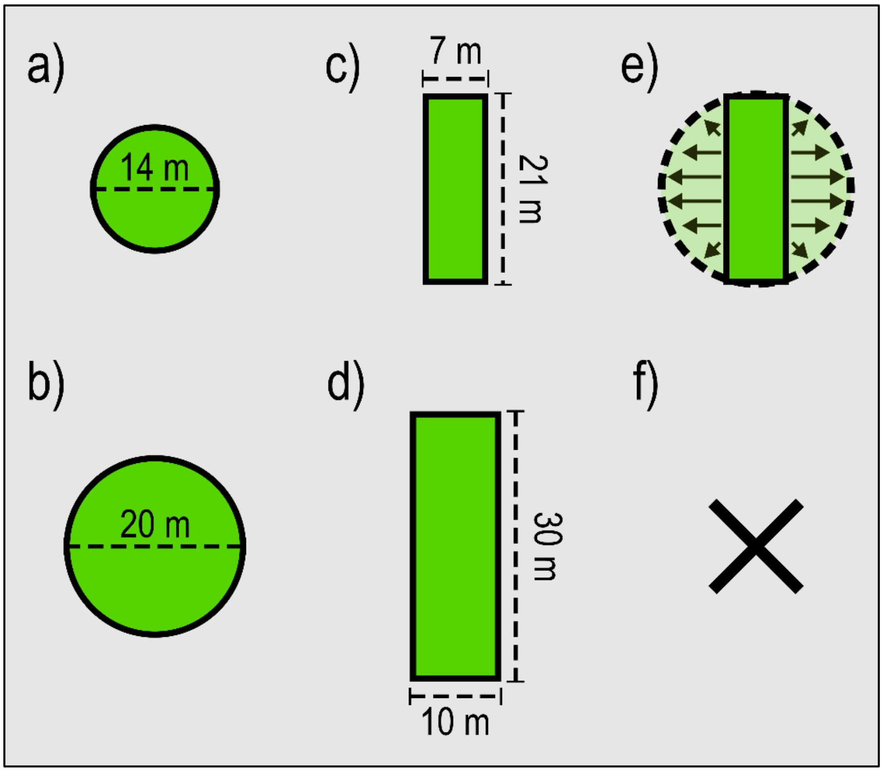

Figure 3. The investigated gap types in the Pilis Gap Experiment. a) Small circular, b) large circular, c) small elongated, d) large elongated gap, e) gap created in two steps (small elongated gap enlarged some years later to large circular), f) uncut control.

The treatments have been configured in six replicates in a complete block design, thus altogether 36 plots are sampled (Fig. 4). In 2018, the before-treatment conditions were estimated; the gaps have been created in February of 2019. The yearly after-treatment survey began in 2019. Similarly to the Pilis Forestry Systems Experiment, we are continuously monitoring the microclimate and soil conditions and the changes of different animal and plant groups. Ground-dwelling beetles and spiders are collected by pitfall traps, dipterans by Malaise-traps and enchytraeid worms by soil cores. Understory vegetation is sampled in permanent 2 m × 2 m quadrates (species, cover, and for the woody regeneration, also count per species in four size categories). Within the woody regeneration, we are specifically focusing on sessile oak; its natural regeneration, survival and growth are investigated in a distinct quadrate in each gap. We plan to study the soil microbiome with environmental DNA sampling in 2022. In the case of the Pilis Gap experiment, the whole forest stand has been fenced, thus the study is carried out with the complete exclosure of large-bodied game species.

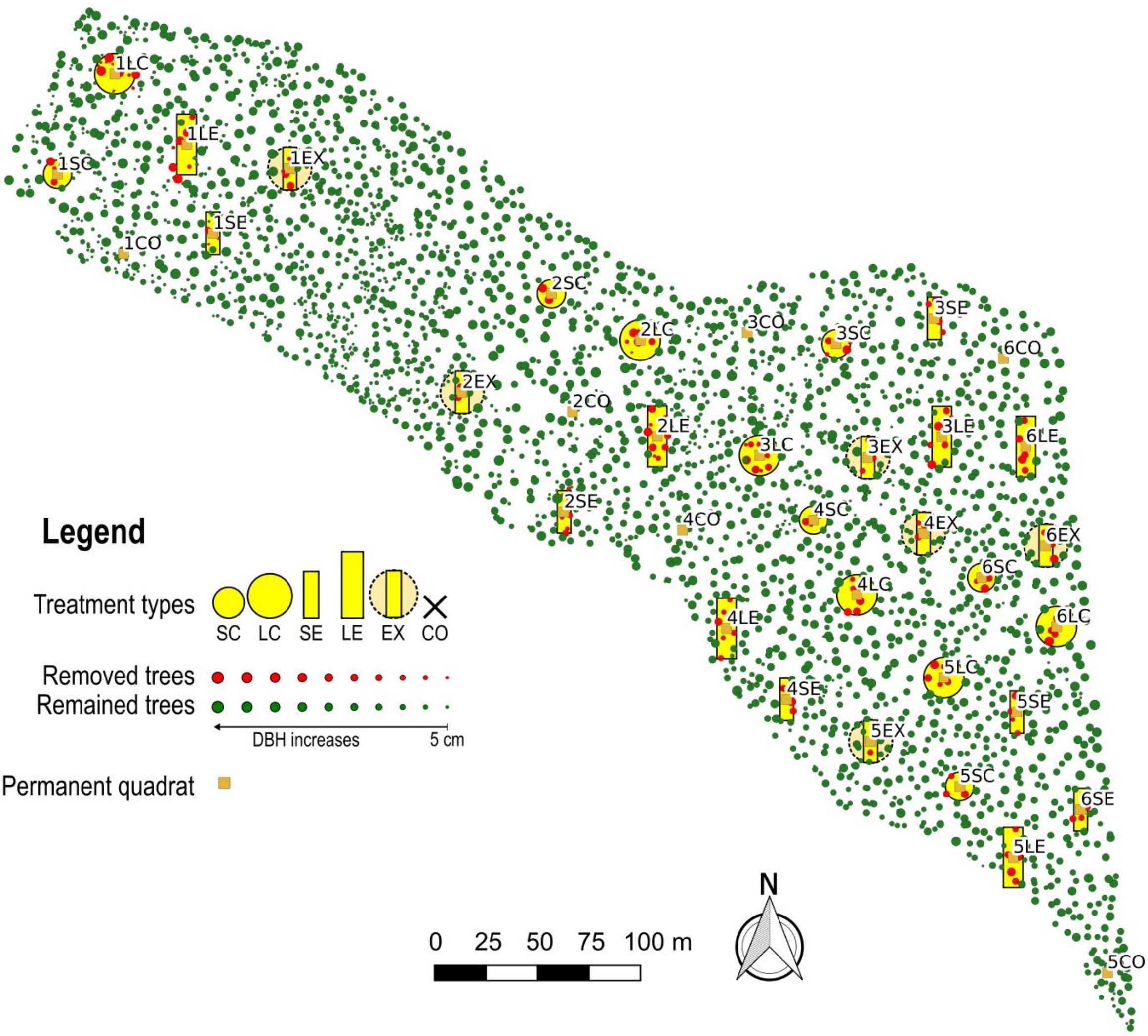

Figure 4. Map of the forest stand encompassing the Pilis Gap Experiment, with the artificial gaps. SC = small circular, LC = large circular, SE = small elongated, LE = large elongated, EX = extended gap, CO = control plot.

Before the gap fellings, the whole experimental forest stand (~9.7 ha) was mapped (Fig. 4) with the Field-Map system, and its database was merged with the three-dimensional forest model created by terrestrial laser scanning (TLS-LiDAR) (Fig. 5.a). Based on these detailed data, we can also follow up the changes of the stand structure (timber volume, individual development of trees on different gap positions), the closure of the gaps, and the development of regeneration patches.

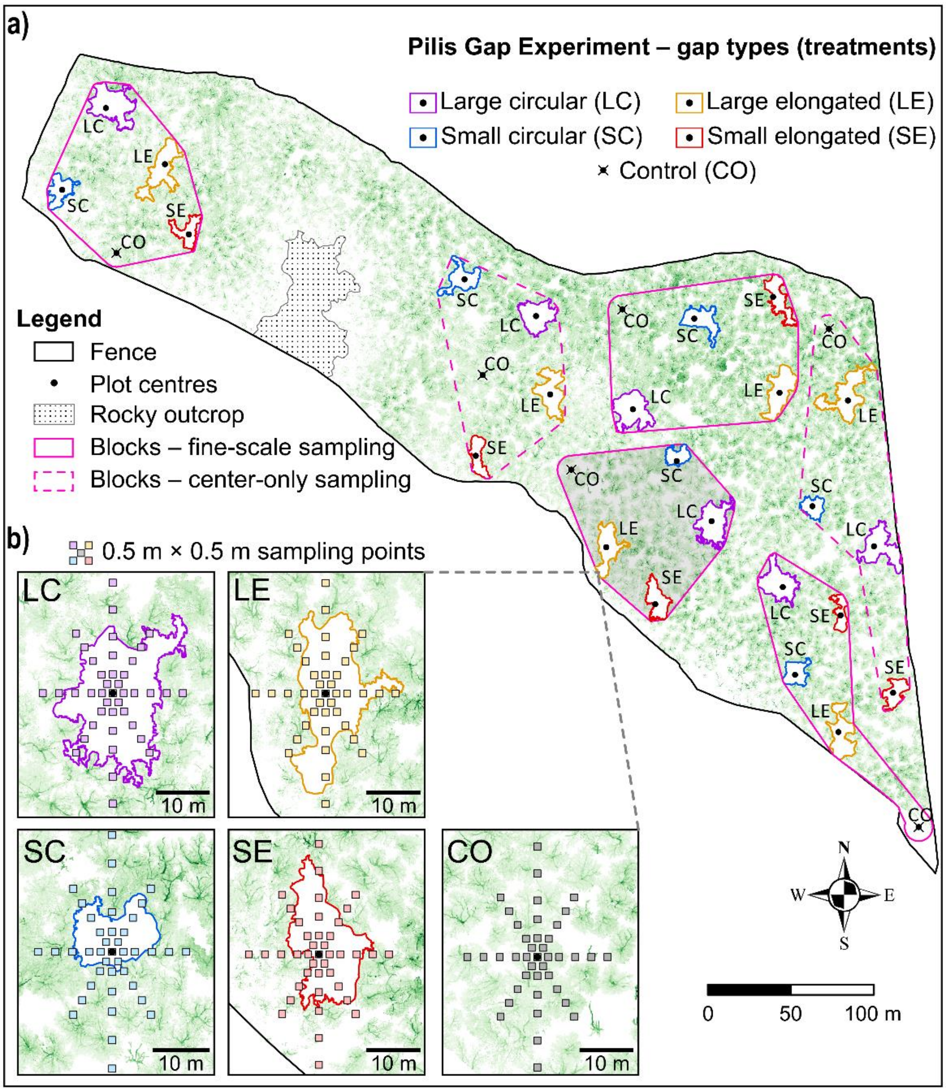

Figure 5. Two-dimension representation of the stand model created by terrestrial laser scanning with the gaps established in the Pilis Gap Experiment (a), and the systematic fine-scale sampling design used within the gaps (b). SC = small circular, LC = large circular, SE = small elongated, LE = large elongated, EX = extended gaps, CO = unmanaged control plot.

Besides the gap-level studies, we also explore the fine-scale spatial patterns within the gaps every second year (up to now, in 2019 and 2021). In the framework of this subproject, we sample the vascular plants (species and cover) and measure the light and soil moisture in 41 0.5 m × 0.5 m quadrates, using a systematic design (Fig. 5.b).

Publications

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Our most important publications published so far are as follows:

Kovács, B., Tinya, F., Bidló, A., Boros, G., Csépányi, P., Elek, Z., Horváth, Cs. V., Illés, G., Locatelli, J., Németh, Cs., Soltész, Z., Samu, F., Sass, V., Ódor, P. 2020. Introducing the "Pilis Gap Experiment": a new multi-taxa study focusing on the effects of continuous cover forestry. Poster. Governing and managing forests for multiple ecosystem services across the globe, Bonn, Germany. Book of Abstracts pp. 105-106. https://www.piliskiserlet.ecolres.hu/node/113

Locatelli, J. 2020. Effects of gap size and shape on the understory vegetation in an oak-hornbeam forest. MSc Thesis. Loránd Eötvös University, Budapest, 72 pp. https://www.piliskiserlet.ecolres.hu/node/115