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A.2.01 Assessing the influence of forest management on microclimate

– Methodology Report –

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1 Introduction

In Central Europe, the weather extremes of the past years, in combination with insect outbreaks and other calamities, have already contributed to large-scale tree dieback (Schuldt et al., 2020; Seidl et al., 2017). Heat and drought stress, forest fires, storms and late frost events, as well as associated pests and diseases, often occur in complex interaction with each other and cause impacts with unpredictable outcomes (Allen et al., 2010; Carnicer et al., 2011). Extreme temperatures, for example, can cause physiological damage and have an impact on the vitality, growth and mortality of trees (Buras et al., 2018). This can trigger a decline in productivity, carbon sequestration and woody biomass (Smith et al., 2020; Vieira et al., 2020). Warmer temperatures can directly impair organisms, but also drive a nonlinear rise in water vapour deficit and contribute to the desiccation of plants (Hatfield & Prueger, 2015). Higher temperatures can increase the production of seeds by trees but compromise their establishment and survival due to increased water stress (Ibáñez et al., 2017). Although species have different mechanisms to cope with drought (Volaire, 2018), tree vitality and productivity already declined in response to recent drought events (Rohner et al., 2021; Senf et al., 2020). Microclimatic regulation is an important ecosystem service facilitated especially by trees, woodlands or forests, which is increasingly appreciated and taken into account in urban development and planning (Fung & Jim, 2019). In the context of urban adaptations to climate change, microclimate regulation for the mitigation of heat island effects by green infrastructure has been investigated much more intensively (Kong et al., 2014; Lindén et al., 2016; Shashua-Bar et al., 2009; Wang et al., 2018) than in open landscapes and within forest ecosystems. Despite the fact that forest management influences a variety of forest ecosystem structures and processes relevant to meso- and microclimatic regulation, so far, there is a knowledge gap of how forest management could contribute to a reduction of temperature extremes, mean temperatures and temperature fluctuations within forest stands and could thus improve climate change adaption at the stand or even at the landscape level. (Extracted from Blumroeder et al. 2021)

Forest management or timber harvesting in particular can have an impact on the forests' microclimate and reduce the cooling capacity of forests, which is particularly important during extreme summers (Blumroeder et al. 2021).

Within this work package (WP 2.01), an empirical microclimatic study will be conducted to measure the temperature and relative humidity across four UNESCO World Heritage Beech Forests (WHS) in Germany (Grumsin, Serrahn, Hainich, Kellerwald). In addition, remote sensing analyses (land surface temperature, NDVI, NDWI in relation to land cover and forest type) will be conducted on all five German WHS (Grumsin, Serrahn, Hainich, Kellerwald, Jasmund) with a focus on meso-climatic patterns.

The microclimatic study focuses on the temperature regime across different sites within the WHS by distributing microclimatic data-loggers in parts of old growth forests within the core zone, (formerly or recently) managed stands and adjacent open areas (such as grassland or pastures) as well as the transition zones at the forest edges. The measurements will be made at least for one summer season, starting from May 2022 until October/November 2022. The applied methodology allows for the quantification of regulating forest ecosystem services related to landscape cooling and microclimatic buffering, representing a pivotal aspect of ecosystem-based climate change adaptation.

The remote sensing analyses will produce and process data on land surface temperature, the vitality of vegetation (represented by NDVI) and water stress (NDWI) using available satellite data (such as MODIS or Landsat). The data will be analysed in relation to the actual land cover within the core and buffer zones of the WHS as well as neighbouring land cover types such as agricultural lands.

2 Geographic scope of the study

The study will be conducted in German WHS (Fig. 1). However, the microclimatic study using data-loggers will cover only four of the five sites (Grumsin, Serrahn, Hainich and Kellerwald). The remote sensing analysis will encompass all five sites (Grumsin, Serrahn, Hainich, Kellerwald and Jasmund) and their surroundings.

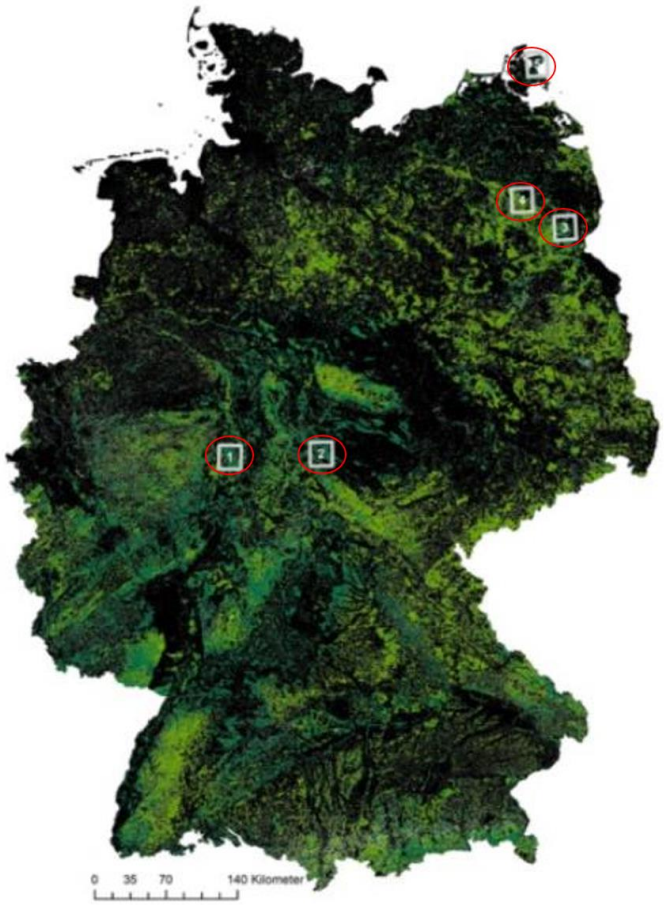


Figure 1: Test sites for micro- and meso-climate measurements in Germany (WP2.01)

In two of the selected sites, National Park Hainich and National Park Kellerwald, further investigations on carbon storage and biodiversity will be conducted by the Northwest German Forest Research Institute (NW-FVA) (compare Table 1).

Table 1: Test sites of the LIFE Prognoses project

Test site		**Executive organization / Ecosystem services**			
Country, Name	*Biogeographic region*	*Micro-climate*	*Carbon storage*	*Biodiversity*	*Recreation & Tourism*
BE, Sonian Forest Foundation (SOFO)	Atlantic		INBO [1)]	INBO	SOFO
AT, National Park Kalkalpen (NPKA)	Alpine		NPKA	NPKA	NPKA
SI, Krokar	Alpine		UL [2)]	UL	
SI, Snežnik-Zdrocle	Alpine		UL	UL	
BG, National Park Central Balkan (NPCB)	Alpine		NPCB	NPCB	
UA, Chornohora in Carpathian Biosphere Reserve (CBR)	Alpine		CBR	CBR	CBR
DE, NP Hainich	Continental	UNIE [3)] *remote sensing* *on-site data collection*	NW-FVA [4)]	NW_FVA	
DE, NP Kellerwald	Continental	UNIE *remote sensing* *on-site data collection*	NW-FVA	NW_FVA	
DE, Grumsin	Continental	UNIE *remote sensing* *on-site data collection*			
DE, Jasmund NP	Continental	UNIE *remote sensing*			
DE, Müritz NP (Serrahn)	Continental	UNIE *remote sensing* *on-site data collection*			
IT, Abruzzo, Lazio and Molise National Park (NPAB)	Mediterranean		UNITUS [5)]	UNITUS	NPAB

1) BE, INBO Research Institute Nature and Forest (INBO); [2)]SI, University of Ljubljana, Biotechnical Faculty (UL); [3)] DE, Eberswalde University for Sustainable Development (UNIE); [4)] DE, Northwest German Forest Research Institute (NW-FVA); [5)] IT, University of Tuscia (UNITUS);

3 Mesoclimatic analyses using satellite data

Available satellite data will be used to analyse the difference of land surface temperature in relation to the actual land cover or land-use (CORINE land cover). The following data-sets will be processed (Landsat 7, Landsat 8, 30 m spatial resolution) after downloading them via Google Earth Engine:

- Land surface temperature,
- NDVI,
- NDWI.

The analysis will focus on the distribution of high temperature across the landscape especially during extremely warm years. It will also allow for a time-series analysis, for example looking at the development of the vitality of the vegetation over time.

4 Microclimatic study using data-loggers

The on-site microclimate study will be conducted by the use of 250 data-loggers measuring temperature (Onset HOBO-Pendant, Fig. 2) and 125 data-loggers to record relative humidity and temperature (HOBO Pro v2, Fig. 3). Stakes made of Robinia wood with a length of 2.00 m will be installed at the respective measuring locations (Fig. 4). The temperature loggers are mounted on the stake at a height of approx. 1.3 m, the loggers for measuring the relative humidity at a height of approx. 0.1 m. The loggers will face north and are protected against direct sunlight by a white measurement shelters (Fig. 4). A warning label with contact details is attached to the stake (Fig. 5). At each measuring point, the canopy coverage will be estimated using a spherical crown densiometer at least once during the growing season (Fig. 6).



Figure 2: Hobo Pendant data-logger to measure temperature.



Figure 3: Hobo Pro v2 to measure relative humidity and temperature.



Figure 4: Data-loggers in the protective shields mounted on a wooden pole.



Figure 5: Information label to be attached to the wooden pole in order to prevent disturbance by humans



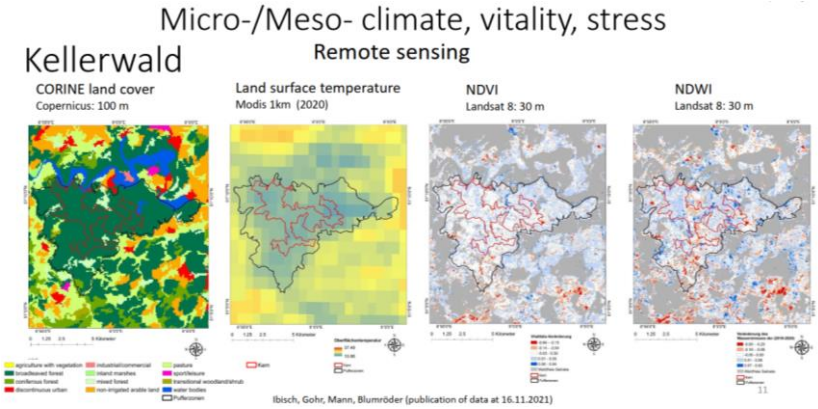
Figure 6: Spherical crown densiometer to measure canopy coverage.

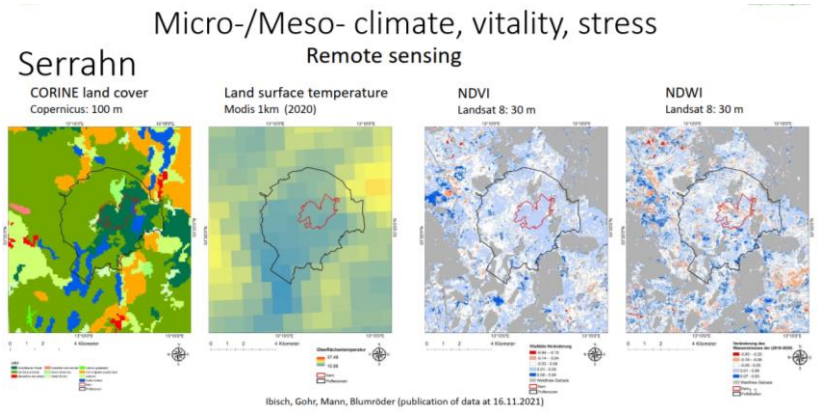
The measurement period is set for one year, starting in May 2022 and ending around in May 2023. While a focus in the analysis of the cooling performance is on the warmest days, the investigation shall also include the temperature course in the cold season. Relevant here is, for example, the number of frost days, late frost events, etc.

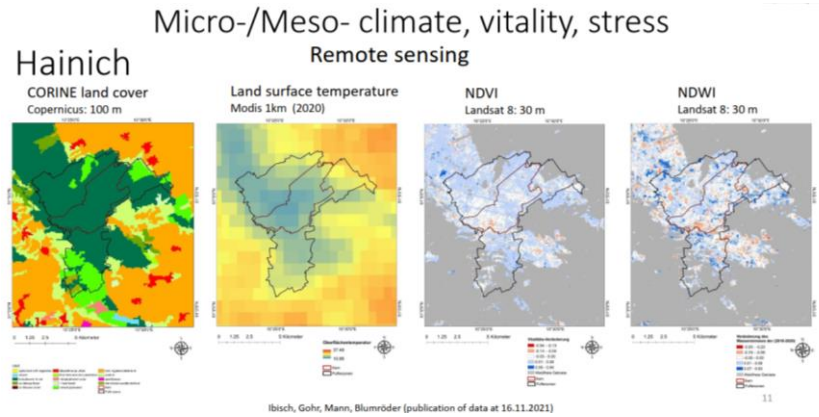
The data-loggers will be programmed to record the data simultaneously and at defined intervals of ten minutes and therefore allow for a high temporal resolution. However, the data is only stored locally on the devices. To collect up the data, project staff will have to manually read out the data-loggers on site, which is planned for about every four to six weeks.

5 Distribution of data-loggers

The remote sensing data could be used to support the selection of sampling sites within the WHS. First maps were produced and areas of interest identified. *CORINE* (Coordination of Information on the Environment) *land cover* maps were used to indicate land use and different biotope types of the test sites (Copernicus, resolution of 100m). Furthermore, maps displaying the *land surface temperature* were produced (Modis, resolution 1 km, 2020). The *normalized difference vegetation index (NDVI)* (Landsat 8, resolution 30m) maps indicate the conditions of vegetated areas. Finally, *normalized difference water index (NDWI) (Landsat 8, resolution 30m)* allows for insights into the water stress level in the analyzed areas (Fig. 7).







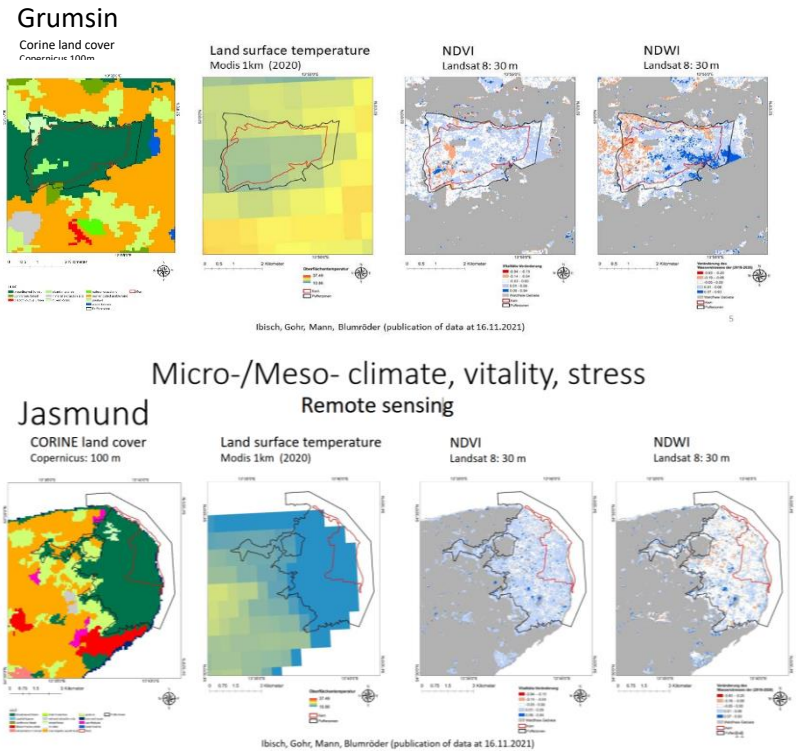


Figure 7: First remote sensing maps for the five WHS prepared in the frame of Ibisch et al. 2021[1].

These initial maps were used for a first discussion with the LIFE Prognoses project group as well as the steering committee of German Beech forest World Heritage Sites. An outcome of the discussions was that there will be no on-site measurements in Jasmund National Park. This decision bases on the realization that the geographic location of Jasmund National Park, being surrounded by the Baltic sea, would have a major impact on the microclimatic data; the cooling effect of the sea would assumedly mask the cooling effect of the forest. Data measurement in this surrounding would hence not provide the required data to finally assess the ecosystem services of old-growth beech forests.

Field visits to the four on-site measurement sites (National Park Hainich, National Park Kellerwald, Grumsin and Müritz National Park (Serrahn)) helped to proceed with the designing and planning of the field measurements. The visits allowed for screening specific locations that had been identified as potential test sites as result of the remote sensing analysis. In close cooperation with the managers and scientific staff of the WHS sites, the suitability of different locations within the areas was discussed. As result, a specific proposal of the research designs could be elaborated for all four test sites that were to be approved by the responsible WHS managers. The following research designs are still preliminary drafts and might be object to change. The distribution of additional 125 data-loggers to measure relative humidity (additional financing by the co-financier BMU) is still to be designed.

[1]https://www.greenpeace.de/publikationen/ibisch_et_al_2021_der_wald_in_deutschland_auf_dem_weg_in_die_heisszeit_final.pdf

5.1 Grumsin

In Grumsin WHS, 64 loggers are placed in different treatment areas (Fig.8). Limitations here inhibit measurements further than 50m from the path through the core zone. Furthermore, access to a favored managed forest area was denied by the private owner.



Figure 8: Sampling design and the distribution of data-loggers in Grumsin



Figure 9: 44 plots in open area and buffer zone forest

- *Pink plots: 2 x 12 plots in the open area (5; 10; 15; 20; 25; 30; 40; 50; 75; 100; 150m);*
- *Green plots: 20 plots in the buffer zone forest (ca. 20-30 m distance)*



Figure 10: 20 plots in the core zone forest (ca. 20-30 m distance)

5.2 Serrahn

In Serrahn National Park there shall be a transect of 650 m, composed of 34 loggers, spanning from open land in the buffer zone into the core zone of the WHS (Fig. 11). The loggers shall be distributed more densely at the forest edge. A second transect of 5-6 loggers shall have the same starting points in the open land and it shall be located on existing sample plots. Furthermore, there shall be five data-loggers located in different pine stands within the surrounding buffer zone: pure pine stand, pine stand with few beech trees in the understory, and a pine stand with more dense beech understory. This shall provide insights into the natural development of the forest from planted and formerly managed pine monocultures towards beech forest across different development stages.

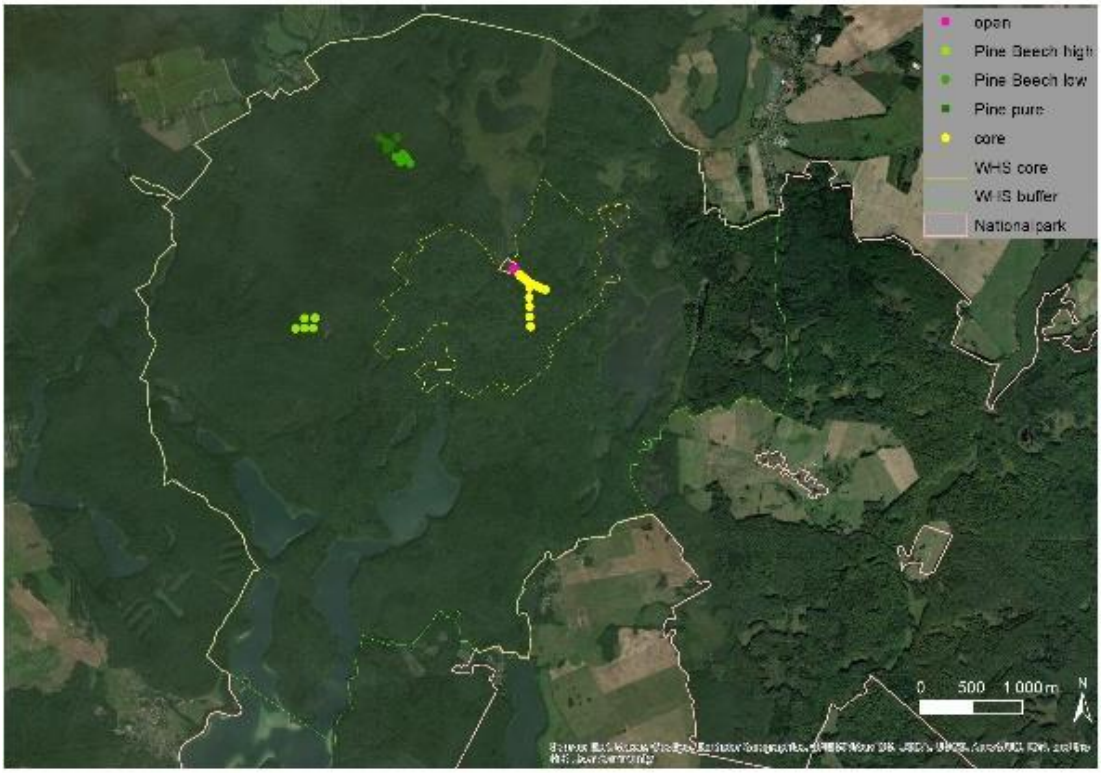


Figure 11: Sampling design and the distribution of data-loggers in Serrahn



Figure 12: Darker green plots (upper left): 5 plots in pure pine stand
Light green plots (lower right): 5 plots in pine stand with low beech and oak understory



Figure 13: 5 plots in pine stand with high beech and oak understory



Figure 14: Transect consisting of:

- *1 plot at the forest edge (0 m)*
- *Pink plots: 11 plots in the open area (5; 10; 15; 20; 25; 30; 40; …; 70; 90)*
- *Yellow plots: 17 plots in the core zone (5; 10; 15; 20; 25; 30; 40; 100; 150; …; 300)*
- *Yellow plots; 5 plots in the core zone (existing sampling points)*

5.3 Hainich

In Hainich National Park, there are 77 sampling plots. They are distributed in two parallel transects of 650 m, composed of 35 and 37 data-loggers respectively, and 5 plots on existing sampling points in the core zone (Fig. 15). The transects reach from non-forested grassland through the forested buffer zone into the core zone of the WHS. The loggers shall be installed more densely at the forest edge to gain insight into the edge effect. The additional five loggers are located randomly in the core of the WHS.

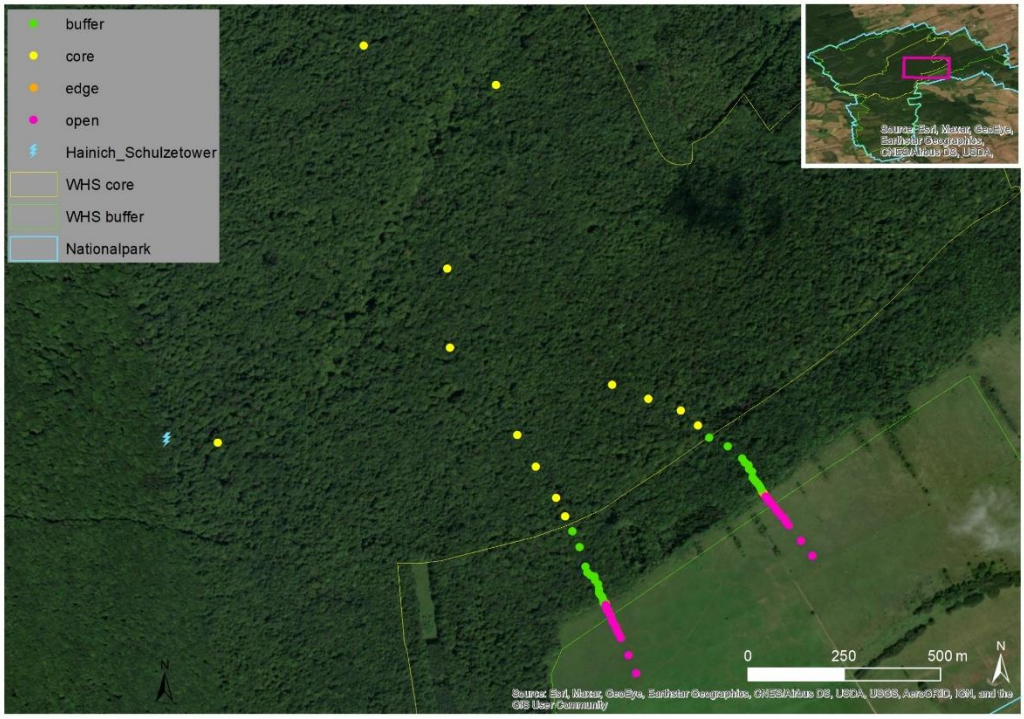


Figure 15: Sampling design and the distribution of data-loggers in Hainich

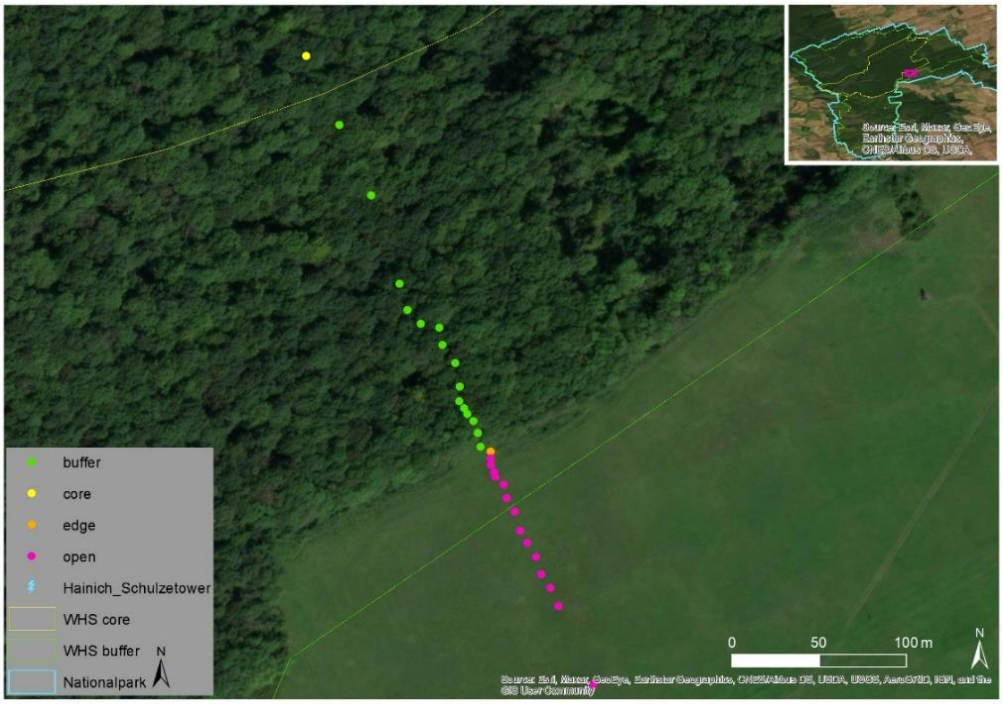


Figure 16: 1. Transect, composed of
- 1 plot at the forest edge (0 m)
- 15 plots in the open area (5; 10; 15; 20; 25; 30; 40; …; 100; 150; 200)
- 19 plots in the forest (5; 10; 15; 20; 25; 30; 40; …; 100; 150; …; 300; 400; 500m)

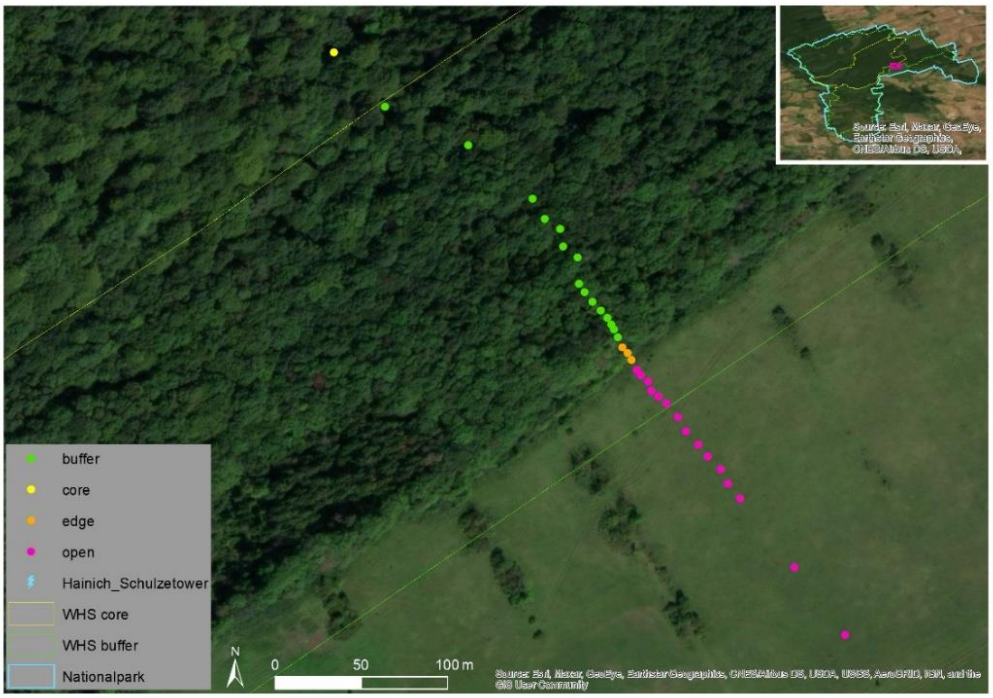


Figure 17: 2. Transect, composed of
- 3 plots at the forest edge (shrubby edge)
- 15 plots in the open area (5; 10; 15; 20; 25; 30; 40; …; 100; 150; 200m)
- 19 plots in the forest (5; 10; 15; 20; 25; 30; 40; …; 100; 150; …; 300; 400; 500m)

5.4 Kellerwald

In Kellerwald National Park, there are two measurement sites (Fig. 18). In the first site, there shall be measurements of different treatments: There shall be ten loggers each in 1) dense forest in the core zone of the WHS, 2) open, old beech forest, 3) non-forest grassland (Fig. 19). In the second site, there shall be one line of 10 loggers situated in the core zone of the WHS in dense forest. Furthermore, there shall be another line of 10 loggers placed in open forest which mainly consists of dead spruce. Additionally, there shall be 10 loggers installed in open land (Fig. 20).

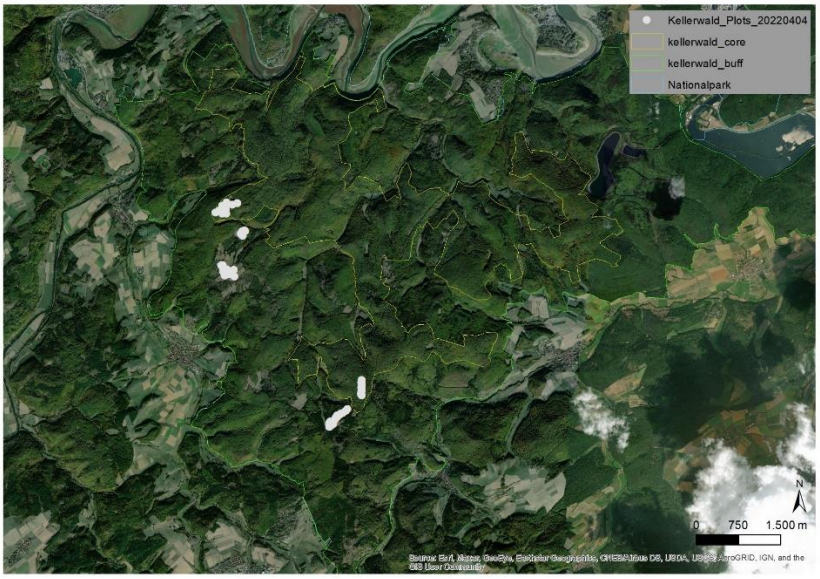


Figure 18: Sampling design and the distribution of data-loggers in Kellerwald

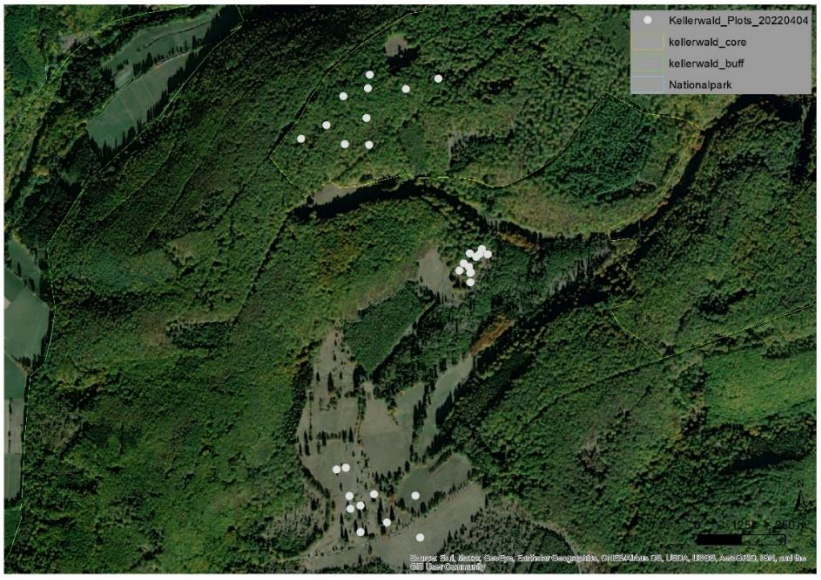


Figure 19: First sampling site

- *10 plots in the core zone – dense beech (partly on existing sampling points) (upper plots on the map)*
- *10 plots in an open beech forest (middle plots on the map)*
- *10 plots in the open area (lower plots on the map)*



Figure 20: Second sampling site

- *10 plots in the core zone – dense beech (upper plots on the map)*
- *10 plots in the open forest – dead spruce (middle plots on the map)*
- *10 plots in the open area (lower plots on the map)*

6 Distribution of temperature loggers

Site	Temp. loggers	Proposal for distribution
Grumsin	64	24 open area 20 buffer zone forest 20 core zone forest
Hainich	77	5 core zone 35 transect 1 (1 edge + 15 open + 19 forest) 37 transect 2 (3 edge + 15 open + 19 forest)
Kellerwald	60	10 core zone – dense beech 10 open beech 10 open area 10 core zone – dense beech 10 open forest – dead spruce 10 open area
Serrahn	49	29 transect (1 edge + 11 open area + 17 forest) 5 core zone 5 pine pure 5 pine with low beech understory 5 pine with high beech understory
TOTAL	250	

125 Data loggers that measure the relative humidity are installed at roughly every second plot.

7 Data processing and analyses

All data analyses will be conducted using the software R. The main goal is the quantification of temperature offset in the forest in relation to non-forested areas. After processing and aggregation of data, the data will be provided to E.C.O. for further use related to the quantification of monetary benefits derived from the microclimatic regulation. One combined scientific publication with in-depth statistical analyses will be produced.