



SUMMER SCHOOL
“ECOHYDROLOGY OF FORESTED WATERSHEDS”

BOOK OF ABSTRACTS

SLOVENIA

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SCHEDULE OF THE SUMMER SCHOOL

Venue

Gozdarski inštitut Slovenije / Slovenian Forestry Institute (SFI)

Večna pot 2, SI - 1000 Ljubljana, Slovenia

Monday, 6.10.2025

9:00 – 9:15 Introduction to the SFI

9:15 – 10:00 **Urša Vilhar** “Review of ecohydrological research in forested watersheds in Slovenia”

10:00 – 11:30 Visit to the labs at SFI

11:30 – 13:00 Visit to the urban forest research plot near SFI

14:30 – 15:15 **Jessenia Polack Huaman**: “From Soil to Stream: Dissolved Organic Carbon Fluxes in Ecuadorian High Andes”

15:15 – 16:00 **Christopher Pohle**: “Current and future measures for climate change adapted water management along forest roads - a survey study among German experts”

Tuesday, 7.10.2025

09:00 – 10:00 **Zuosinan Chen**: “Water movement along the soil-plant-atmosphere continuum”

10:00 – 10:45 **Xudan Zhu**: “The mechanism of aquatic browning in boreal catchments”

11:15 – 12:00 **Erika Kozamernik**: “The potential use of remote sensing for mapping and monitoring selected small-scale forest habitat types”

12:00 – 12:45 **Tinkara Mazej**: “Ecohydrology of Karst Systems: Insights from Planina and Postojna Caves”

14:00 – 14:45 **Urša Vilhar**: “Ecohydrological-Based Forest Management in Torrent Areas”

14:45 – 16:00 Discussion on publication options

Wednesday, 8.10.2025

9:00 – 12:00 Field trip to Cerknjško jezero (LifeWatch and eLTER site) and visit to the museum »Jezerski hram«

14:00 – 17:00 Visit to the karst valley Rakov Škocjan, created by the sinking and collapse of a cave ceiling and is included on the UNESCO World Heritage List

Thursday, 9.10.2025

09:00 – 10:30 Field trip to ForKarst research plots in the forest (LifeWatch and eLTER site)

11:00 – 12:30 Field trip to ForKart research plots in the Planinska jama cave (LifeWatch and eLTER site)

14:30 – 15:30 Return to the institute

Friday, 10.10.2025

9:00 – 10:00 Discussion on publication options – hybrid

10:00 – 11:00 Discussion on future collaboration: potential calls for project calls, partnership projects, secondments, etc.

11:00 – 15:30 Work on common paper

15:30 – 16:00 Wrap-up and closing of the summer school

1. INTRODUCTION

Authored by: Dr. Xudan Zhu and Dr. Urša Vilhar

Affiliation: *University of Eastern Finland and Slovenian Forestry Institute*

The Slovenian Forestry Institute (SFI) hosted a summer school on “*Ecohydrology of Forested Watersheds*” from 5 to 10 October 2025, led by Dr. Urša Vilhar. The event brought together early-career and senior researchers to explore a wide range of topics in **the ecohydrology of boreal, tropical, and karst landscapes**. The program combined research presentations, laboratory and field tours, and structured discussions, providing an integrated overview of ecohydrogeological processes across different scales, climates, and land-use contexts.

The scientific sessions addressed key themes such as **water movement along the soil–plant–atmosphere continuum, dissolved organic carbon fluxes, aquatic browning in boreal catchments, remote sensing applications in forest habitats, and climate change–adapted water management**. Emphasis was placed on forested watersheds, torrent areas, forest infrastructure, and karst systems, linking fundamental ecohydrogeological processes with applied forest management. The program highlighted the economic, ecological, and social functions of forest ecosystems under climate change, as well as the increasing use of Open Data and airborne remote sensing, including drone-based systems. Contributions covered a broad geographical scope, with case studies from the Boreal region, Central Europe, and the Ecuadorian High Andes.

In addition to indoor lectures, the summer school placed strong emphasis on **hands-on learning and field-based insights**. Participants visited research laboratories and experimental urban forest plots at SFI, followed by field excursions to **Cerknica Lake**, a prominent LifeWatch and eLTER site, and the karst landscapes of Rakov Škocjan, both listed as UNESCO World Heritage sites. Participants also visited the **ForKarst** project surface research plots in the forest and underground research plots in **Planina Cave**, both of which are part of the integrated multi-scale ecohydrogeological monitoring of the karst critical zone (KCZ) in the **Unica River catchment**. These excursions provided direct experience of long-term multi-level ecohydrogeological research infrastructures and an exemplary karst critical zone observatory of global importance.

The summer school concluded with a dedicated discussion on future **funding and publication opportunities, scientific exchange, collaboration, and the development of joint funding applications**. This session also featured presentations on the Fem2Forest project and WOFO by Dr. Katarina Flajšman (SFI), and the Handbook for Learning and Play in the Forest by Urša, highlighting practical applications and educational perspectives for promoting science to children, teachers, and families. Overall, the summer school offered a multidisciplinary platform for advancing understanding of ecohydrogeological interactions at the interface between the atmosphere, geosphere, hydrosphere, and biosphere. Furthermore, their relevance to sustainable forest and water management under climate change and changing environmental conditions was emphasized.

2. CONTRIBUTIONS` ABSTRACTS

2.1. Review of ecohydrological research in forested watersheds in Slovenia

Authored by: Dr. Urša Vilhar

Affiliation: Slovenian Forestry Institute

A comprehensive overview of ecohydrological research in forested watersheds in Slovenia was presented, focusing on three main research areas:

1. *The hydrological ecosystem services provided by urban and forested landscapes, particularly in Ljubljana, which was entitled to the Green Capital of Europe in 2016.*

Key topics included canopy interception, soil water infiltration, and water holding capacity, with mixed urban forests demonstrating the highest hydrological service provision (**Figure 1**). Indicators were measured using ecological and economic frameworks to inform decision-making. The study revealed that urban forests significantly contribute to water regulation, with mixed forests outperforming floodplain hardwood and riparian pine forests, while urban grasslands showed the least benefit.

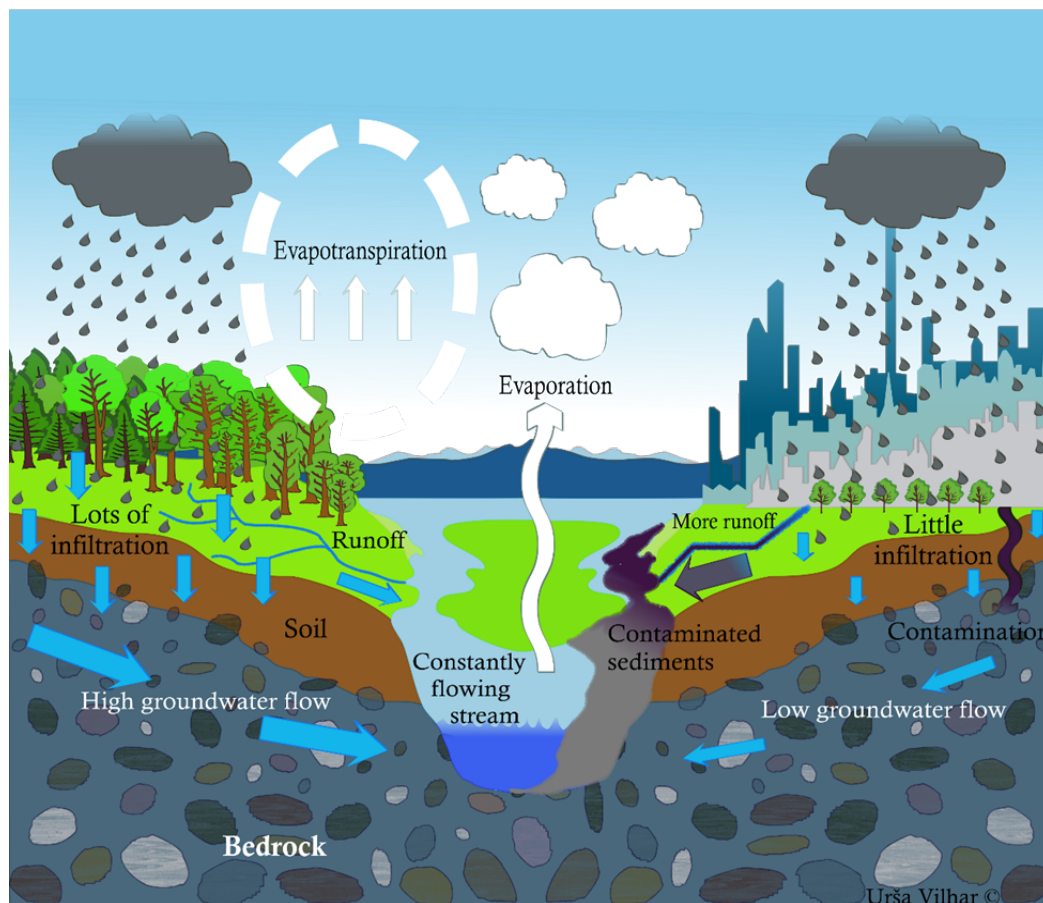


Figure 1: The importance of urban forests for water quality and quantity (Vilhar, 2017)

2. *Intensive forest monitoring under the UN/ECE CLRTAP ICP Forests program was highlighted, involving over 850 plots across Europe (Figure 2).*

Parameters such as precipitation, throughfall, stemflow, and soil chemistry were analyzed to assess forest health and water cycle. The research also explored rainfall interception's role in soil erosion at urban forest research plots. Drop size distribution (DSD) and rainfall erosivity were examined, revealing vegetation's critical role in mitigating soil erosion with precipitation interception.

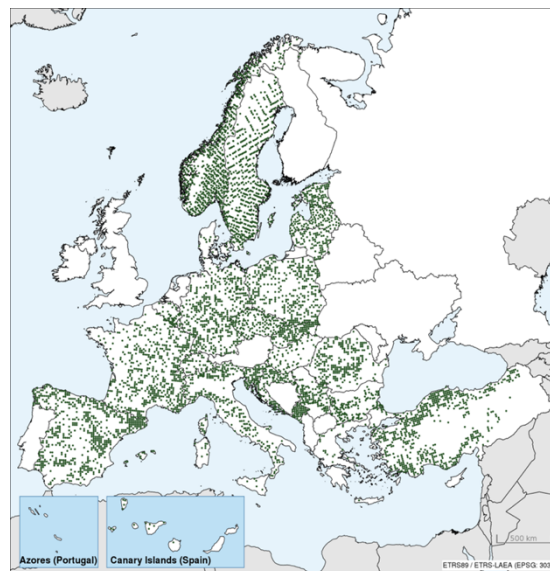


Figure 2: The pan-European forest monitoring and research network ICP Forests working under the UNECE Air Convention (<https://www.icp-forests.net/>)

3. A major focus was the karst critical zone (KCZ) in the Unica River catchment, where integrated multi-scale ecohydrogeological monitoring is conducted.

This included surface and underground measurements of water fluxes, including precipitation, soil moisture, cave water chemistry, and spring flow dynamics. Results showed that forest disturbances accelerate infiltration, threatening water quality and quantity (**Figure 3**). The findings underscore the importance of sustainable forest management and climate adaptation strategies, especially in karst regions. Slovenian Forestry School, based on close-to-nature forest management, with continuous cover, predominantly natural regeneration and native species, serves as a global example of multifunctional forest stewardship.

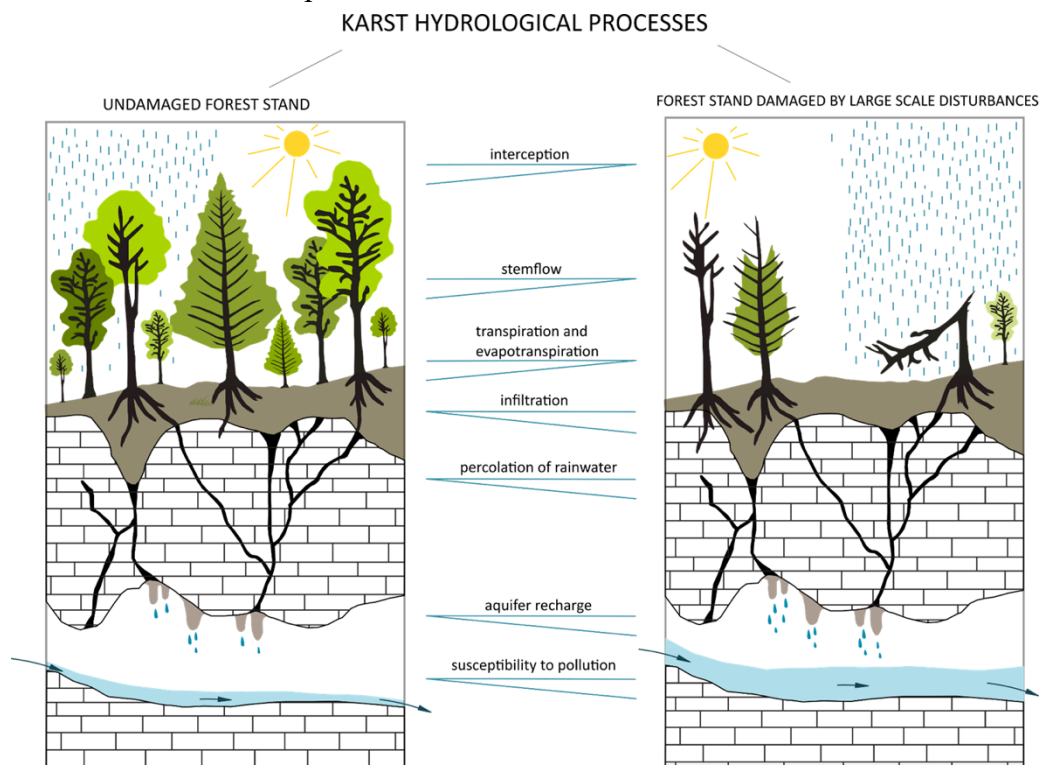


Figure 3: The effect of forest disturbances on ecohydrology in karst aquifers (Vilhar et al, 2022)

2.2. From Soil to Stream: Dissolved Organic Carbon Fluxes in Ecuadorian High Andes

Authored by: Jessenia Polack

Affiliation: *University of Eastern Finland, School of Forest Sciences*

Dissolved Organic Carbon (DOC) plays a crucial role in carbon cycling and can be found in both terrestrial and aquatic ecosystems. It contributes to ecosystem balance by serving as both a source and a product of microbial activity. Freshwater systems naturally contain DOC, but problems arise when its concentrations increase persistently, disrupting ecological balance. Elevated DOC levels can lead to the formation of disinfection by-products, which increase the cost of drinking water treatment, and DOC can also bind with mercury (Hg) and other harmful substances.

Within this context, it is essential to identify the sources and characteristics of DOC in terrestrial ecosystems, particularly the contributions of different land covers. This study aims to analyze DOC dynamics across three land covers within the páramo ecosystem in the Quinuas watershed, in Cuenca, Ecuador, an area of critical importance as a water resource for downstream communities and as a regional hydropower source (**Figure 4**). Field data was collected over one year, from March 2024 to February 2025, during which extreme climatic events such as prolonged droughts and intense rainfall occurred.

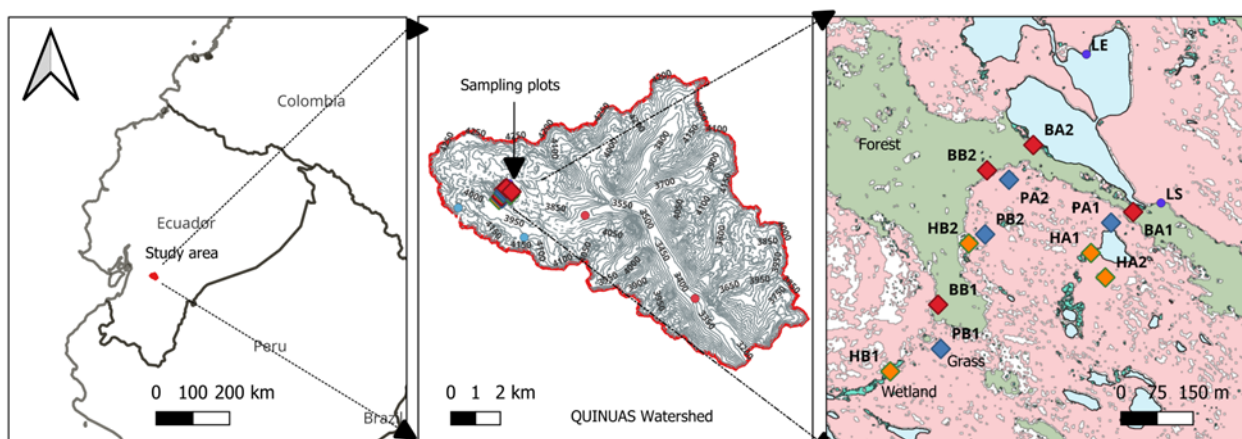


Figure 4: The location of study site and experiment setup in the Quinuas watershed

Our results indicate that DOC concentrations varied with climatic conditions, showing higher values during precipitation events and lower ones during droughts. Among the land covers studied, DOC concentrations in forested areas were significantly higher than those in wetlands and tussock grasslands. Optical signatures showed seasonal patterns, with clear differences between dry and rainy periods. Optical footprint patterns were observed for forest and river systems during dry periods, and for forest, lake, and grassland systems during rainy periods.

These findings contribute to a better understanding of DOC sources and dynamics in high-altitude ecosystems and suggest that in-situ optical instruments can effectively identify DOC sources, reducing the need for extensive field sampling and lowering associated costs.

2.3. Climate Change–Adapted Water Management along Forest Roads: A Survey of German Experts

Authored by: Christopher Pohle

Affiliation: *University of Göttingen, Faculty of Forest Sciences and Forest Ecology, Department of Forest Work Science and Engineering*

Progressing climate change makes it imperative to adapt forest road systems. Decentralizing drainage with the aim to reduce accumulation is expected to enhance the distribution of water in forest ecosystems and to mitigate risks of road damage.

To identify and evaluate potential measures for adapting water management along forest roads, we conducted a survey study among eleven German experts (**Figure 5**). The questionnaire covered 42 questions in five categories: (1) Decommissioning, (2) Segments prone to damage by water due to gradient, (3) Ditch relief, (4) Crossing structures, and (5) Timber extraction. Respondents were recruited from the “committee for forest access” and have comprehensive experience (mean of 19 years) with practical measures for drainage and water management. Their accumulated area of operation (2.2 Mio. ha) is representative for 19.1% of the forested land in Germany.

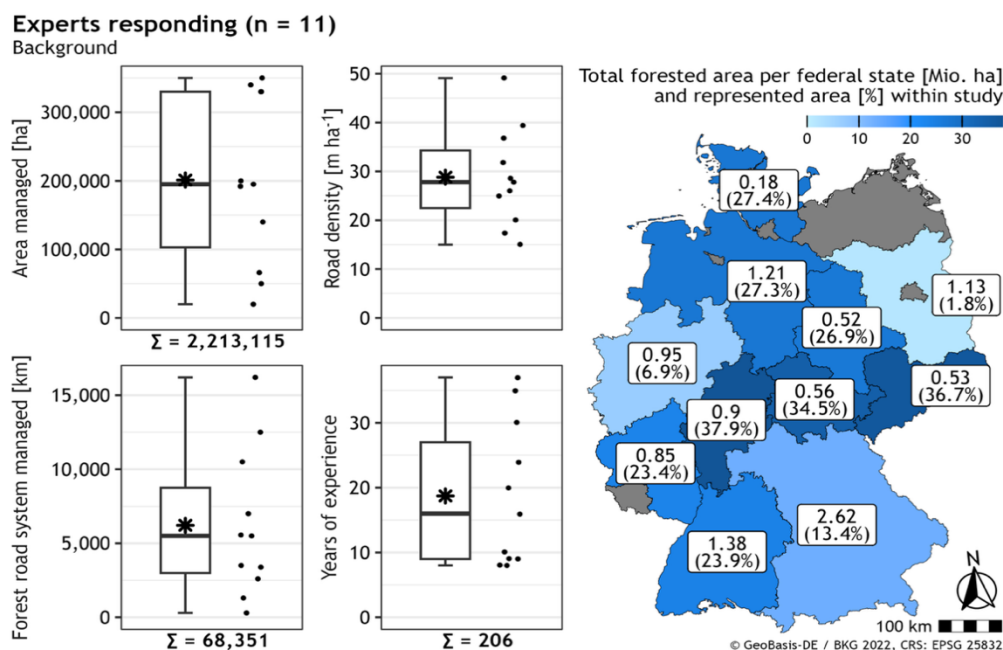


Figure 5: Metadata of the presented survey

Our survey showed that most experts are considering climate change in their practices. For example, a reduced spacing of ditch relief culverts is pursued by nine of them. Further measures are included like integration of off-take-ditches, adapting stream crossings, intensifying maintenance, or disconnecting ditches and streams. By contrast, outsloped cross-sectional profiles or decommissioning are not preferred.

Still, we discussed numerous points where follow-up research can proceed. Especially the development of GIS tools should have the potential to facilitate the practical implementation of the proposed measures. Even though this study is not considered to be complete, several measures have been collected and evaluated by experts. Therefore, other practitioners should already be empowered by the results to adapt their road systems.

2.4. Water movement along the soil-plant-atmosphere continuum

Authored by: Dr. Zuosinan Chen

Affiliation: University of Oulu, Water, Energy and Environmental Engineering Research Unit

Ecohydrology is a discipline studying the relationship between plants and water. In the sense of forest ecohydrology, it investigates the interactions between forests and water (**Figure 6**). One of the focuses is the process of plant water uptake, i.e., transpiration.

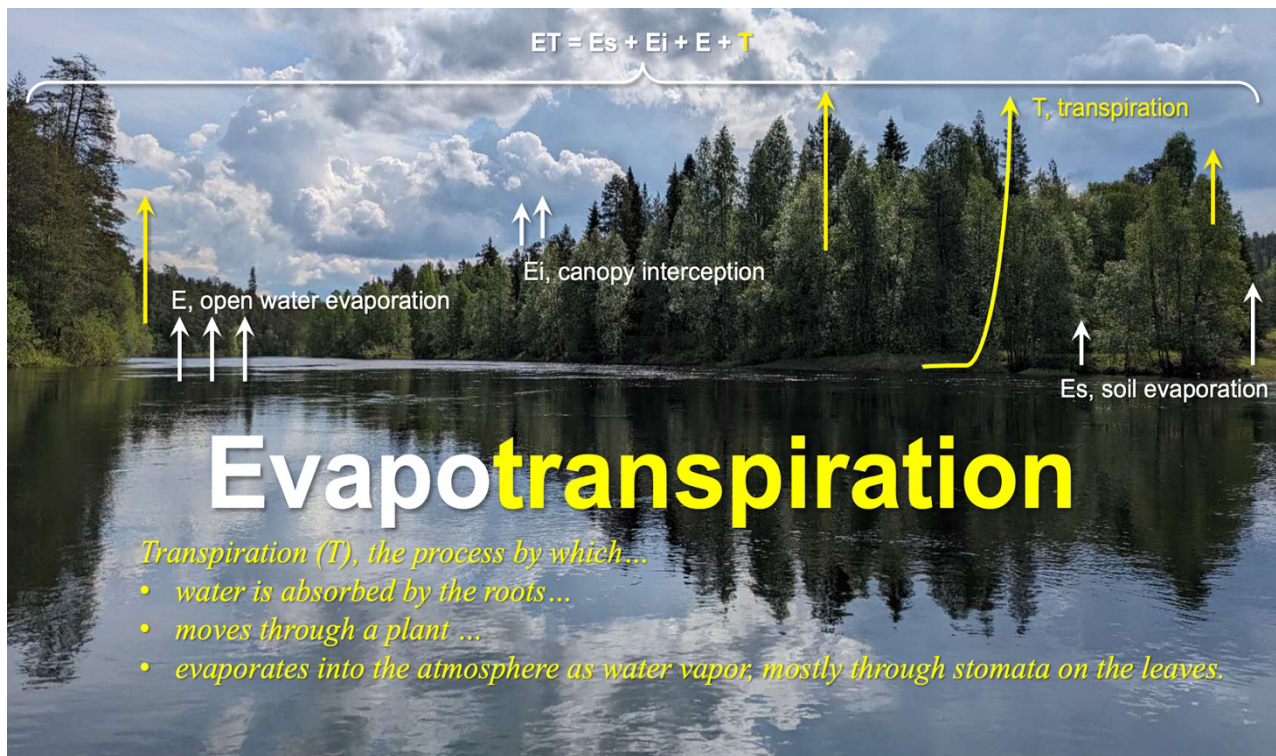


Figure 6: The schematic diagram of Evapotranspiration

In the first part of the presentation, the key elements and processes of water movement along the soil-plant-atmosphere continuum (SPAC) were explained, such as soil water types, water in rhizosphere, root system, root distribution, root anatomy, apoplast and symplast pathways, vascular system, xylem cell types, leaf anatomy, water movement along soil-cortex-stele-xylem-vein-stoma (**Figure 7**).

Different tree species have different types, distribution, and density of roots and xylem cells, as well as different stomata structure, density, and length, etc., which regulate the water uptake (i.e., sap flow) patterns biologically. Meanwhile, each climate zone has its specific weather patterns and soil conditions. These environmental conditions control the diurnal, daily, intra-annual, and inter-annual sap flow. For example, precipitation, soil moisture, solar radiation, air temperature, air relative humidity, wind speed, etc. Among these, two key governing factors are relative extractable water (REW) and vapor pressure deficit (VPD).

In the second part of the presentation, detailed information about our research in understanding the impact of changing snow-rain seasonality on boreal forest ecohydrology was presented (project BFF-Water and BoTWU). With apparent changes in snow-rain seasonality, boreal regions are warming more strongly and faster than the global average. This leads to changes in the total amount and the timing of precipitation (**Figure 8**) and could also change the hydrological processes in boreal forests. However, how boreal forest (eco)hydrology responds to the changing seasonal precipitation is not well understood. The methods and equipment for measuring forest water fluxes are well developed.

For example, the widely used sap flow technique allows us to estimate the tree water uptake of individual trees and upscale it to the forest level via the sapwood area. The stable water isotope technique is currently the best tool available to track water movement. However, the widely used ‘traditional’ sampling method is discrete, destructive, and time-consuming, which is not ideal for investigating the highly dynamic forest (eco)hydrological processes. Therefore, for the first time in northern environments, we combine the innovative in-situ continuous measurements and event-based sampling of stable water isotopes and water fluxes along the entire water movement pathway in a typical boreal forest (Scots pine, *Pinus sylvestris*) in the Oulanka Research Station i.e., snow (snowfall-snowpack-snowmelt), rain (rainfall-throughfall and stem flow), soil (vertical and horizontal profiles), roots, and trunks. Meanwhile, the 6-year snowpack manipulation allows the long-term effect of reduced and additional snow on root and tree water uptake to be tested.

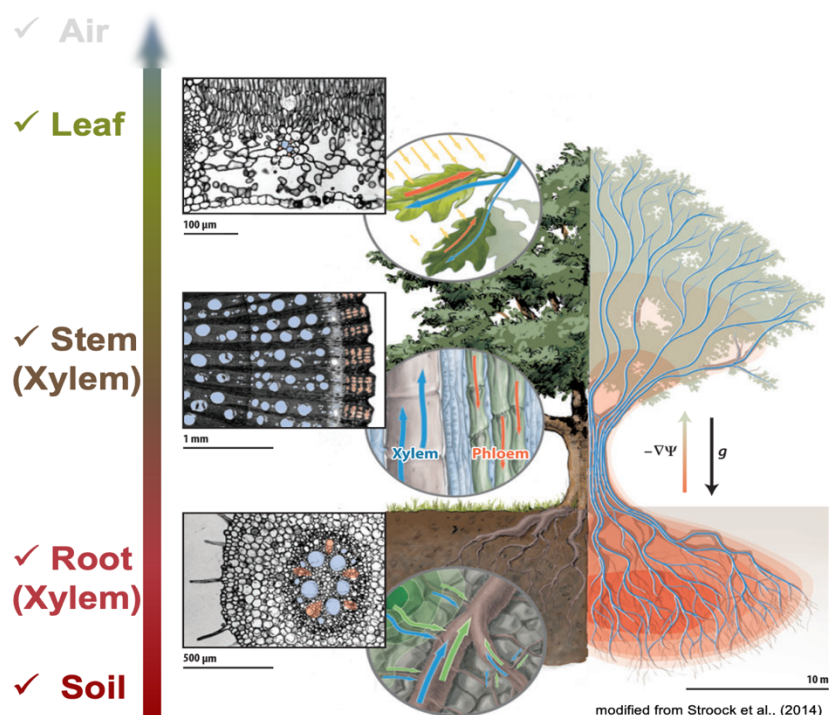


Figure 7: Conceptual anatomy and water movement along the soil-plant-atmosphere continuum

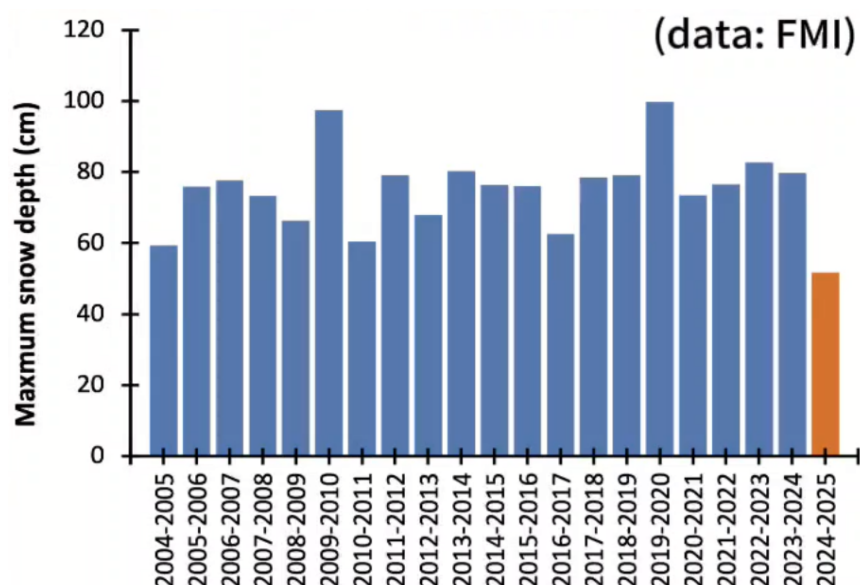


Figure 8: Maximum snowpack depth in Oulanka Research Station (data source: FMI)

2.5. The mechanism of aquatic browning in boreal catchments

Authored by: Dr. Xudan Zhu

Affiliation: *University of Eastern Finland, Faculty of Science and Forestry, Department of Environmental and Biological Science*

This presentation introduced the change of lateral carbon flux from land to water in boreal ecosystems with case studies. Increases in dissolved organic carbon (DOC) concentrations, or browning, have occurred in many freshwater ecosystems across Europe and North America in recent decades, giving the water a brownish color (**Figure 9**). Several mechanisms have been proposed to explain aquatic browning, but consensus regarding the relative importance of recovery from acid deposition, climate change, and land management remains elusive. Meanwhile, elevated CO₂, longer growing seasons and permafrost thaw induced by climate change have increased terrestrial productivity, which may alter the export of DOC from terrestrial to aquatic ecosystems. Although the link between terrestrial greening and aquatic browning has recently gained more attention, it is not yet well established. Moreover, heterogeneities of browning across space and time have been observed, but the reasons behind these differences are still unclear.



Figure 9: Brown-colored water in boreal rivers with spatial and temporal color variations.

Study I developed methods to predict real-time high-frequency DOC concentrations in catchments using in-situ UV-Vis spectrophotometers, which can be applied especially in remote areas to save time and money. Study II used the methods developed by Study I to predict high-resolution time series DOC concentrations and analyzed the relationship between terrestrial productivity and short-term DOC variations across boreal catchments. Study III extended the analysis to longer time periods and wider range catchments by integrated mechanisms (recovery from acid deposition, climate change, and site characteristics), quantified the contributions of multiple drivers on long-term DOC trends and provided an explanation for the spatiotemporal heterogeneity of browning.

Collectively, these studies revealed that increased terrestrial productivity induced by climate change can alter terrestrial DOC exports to aquatic ecosystems through the priming effect. Whereas no single mechanism can fully explain long-term DOC trends; instead, recovery from sulfate deposition, terrestrial productivity, discharge, and temperature jointly shaped DOC trends. Site characteristics (catchment size and land cover type) can affect the response rate of DOC to these drivers leading to the spatial heterogeneity of browning across sub-catchments. Moreover, browning has weakened in the last decade as sulfate deposition has fully recovered, and other current drivers are insufficient to sustain the long-term DOC trends.

2.6. The potential use of remote sensing for mapping and monitoring selected small-scale forest habitat types

Authored by: Erika Kozamernik

Affiliation: Slovenian Forestry Institute

Habitat types are classifications of environments based on a combination of physical characteristics and the specific plant (and animal) communities that inhabit them, providing the resources organisms need to survive and reproduce. The European classification includes forest habitat types under the main group “Forest and other wooded land habitat type”, identifying forests by their dominant tree species, climate, soil conditions, and location.

Mapping and regular monitoring of forest habitats are crucial for biodiversity conservation. Traditional field methods are intensive and unsustainable in terms of time and cost for monitoring the spatial and temporal dynamics of forest habitats. Remote sensing offers an alternative approach to mapping forest habitat types. This study focuses on the potential of remote sensing techniques for mapping and monitoring the following small-scale priority forest habitats: I) 9180*: *Tilio-Acerion* forests of slopes, screes, and ravines; II) 91E0*: Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno Padion*, *Alnion incanae*, *Salicion albae*); and III) 91D0*: Bog woodland.

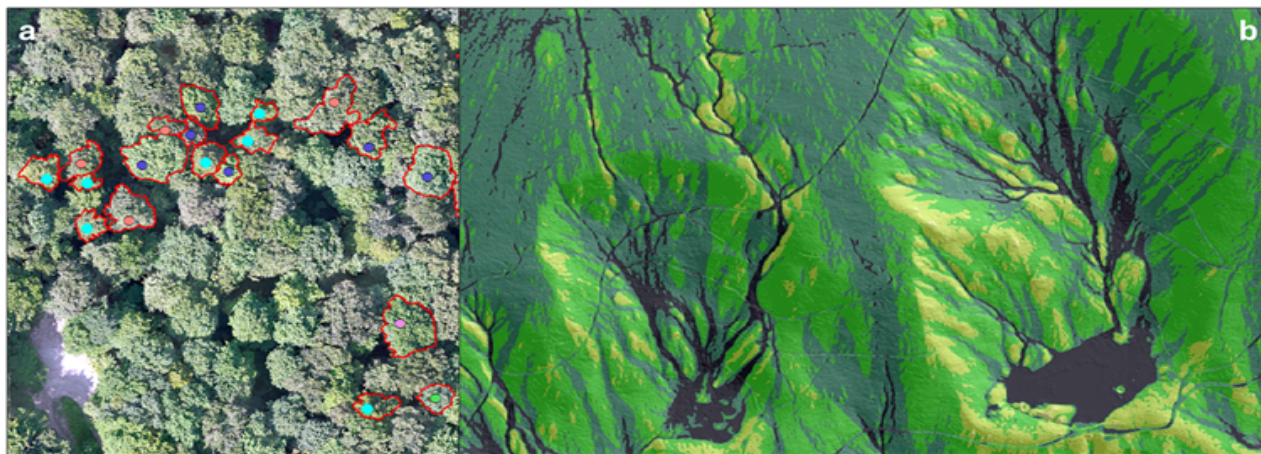


Figure 10: The presence of a) the dominant tree species and b) the model of potential distribution of the forest habitat type.

A key aspect of monitoring forest habitat types is determining their spatial distribution. For this purpose, we used a drone to acquire multispectral images (in June and October) and conducted laser scanning of the surface (June) in the pilot areas. These datasets serve as input for the classification of tree species, which is one of the key distinguishing factors between individual forest habitat types. In addition to the presence of dominant tree species, growing conditions are also crucial, which we modeled using national ALS data and available soil, lithological, and climatic data. Where conditions for a particular forest habitat type are favorable, we predict its potential spatial distribution. Where the dominant tree species overlap with the area of potential distribution, we identify the area of actual distribution of the forest habitat type.

In addition to remote sensing data, we also collected terrestrial data. For each dominant tree species in a particular forest habitat type, we measured the exact locations of 30 trees (**Figure 10**). These data are necessary for validating the classification of tree species based on remote sensing data. Remote sensing therefore provides an alternative to traditional mapping of forest habitat types, but field validation of the results remains necessary.

2.7. Ecohydrology of Karst Systems: Insights from Planina and Postojna Caves

Authored by: Tinkara Mazej

Affiliation: Karst Research Institute ZRC SAZU

Karst aquifers represent highly complex hydrological systems characterized by extreme heterogeneity and a dual flow regime combining slow percolation through the rock matrix and rapid flow through enlarged conduits. Understanding the functioning of the karst critical zone (KCZ)—the interface between the lithosphere, atmosphere, biosphere, and hydrosphere—is essential for interpreting groundwater dynamics and recharge processes in karst. This study focuses on the ecohydrology of the Postojna–Planina cave system in southwestern Slovenia, which represents a typical Dinaric karst landscape with extensive forest cover and diverse recharge conditions. A monitoring network was established including 10 surface stations (recording precipitation, air temperature, relative humidity, soil temperature, soil water content) and 12 stations in caves (recording drip water discharge, electrical conductivity and temperature). These high-resolution datasets enable detailed analysis of hydrological responses to rainfall events and seasonal patterns. Distinct seasonal patterns were observed. Soil water content remains relatively stable throughout the year, except for a notable decline during the summer months due to increased evapotranspiration. Drip discharge follows this pattern with the lowest values in summer and highest in winter and early spring.

Preliminary results show differences between the two caves (**Figure 11**). In Planina Cave, drips respond rapidly to rainfall, indicating a direct hydrological connection between the surface and the subsurface. Discharge peaks occur within hours after precipitation, and strong correlations are observed between rainfall totals and maximum drip discharge. In contrast, drips in Postojna Cave exhibit delayed and smoother responses, reflecting the influence of storage processes within the epikarst and unsaturated zone. Here, discharge dynamics are more closely related to soil water content than to precipitation.

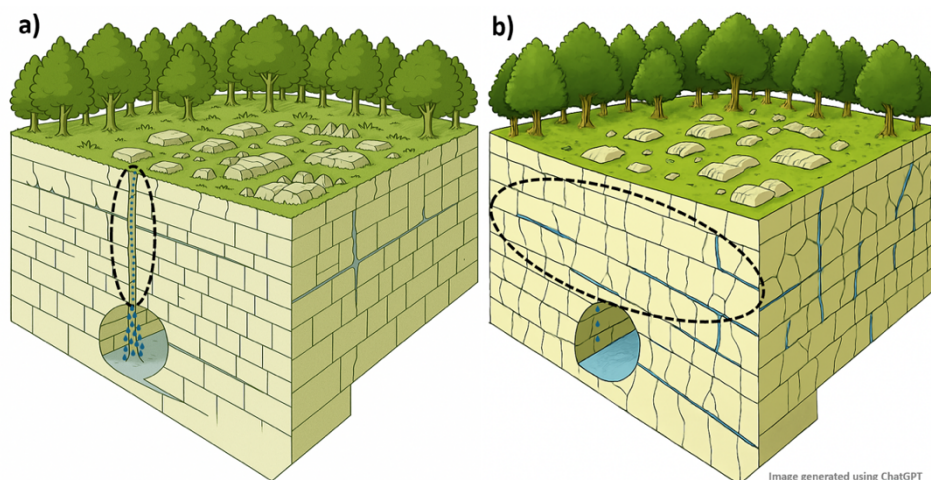


Figure 11: Conceptual model of infiltration and recharge processes in a) Planina Cave and b) Postojna Cave

Generalized additive models (GAM) further confirm these distinct recharge mechanisms. While precipitation is the dominant driver of drip discharge in Planina Cave, soil water content is a better predictor for drip discharge in Postojna Cave. These findings highlight the contrasting hydrological behaviour of karst systems and demonstrate the importance of surface conditions and antecedent hydrological conditions in regulating infiltration and recharge processes in karst landscapes.

2.8. Ecohydrological-Based Forest Management in Torrent Areas

Authored by: Dr. Urša Vilhar

Affiliation: *Slovenian Forestry Institute*

In August 2023, Slovenia experienced extreme flash floods triggered by unprecedented rainfall—over 200 mm in just a few hours—following an already saturated July. These extreme rainfall events severely affected multiple watersheds, causing extensive damage to infrastructure and forest roads. The presentation highlights the ecohydrological role of forests in mitigating such disasters, emphasizing the protective function of forested areas against landslides and torrential erosion.

A total of 380 landslides in forests were recorded during the flash-flood events in summer 2023 by the Slovenia Forest Service, extending over 228 ha of forest areas. A study by Kobel et al. (2024) revealed that landslide density was significantly lower in forested areas compared to agricultural land. Forest landslides occurred on steeper slopes but had shorter reach, and the presence of skid trails did not increase landslide occurrence. These findings underscore the importance of active and continuous forest management in maintaining forest stability and maximizing its protective function.

The Slovenian Forestry School promotes close-to-natural, multifunctional forest management, adapting silvicultural and forest management measures to site-specific conditions and supporting natural regeneration. However, a key challenge remains: the lack of detailed erosion-prone maps in torrent catchments. The proposed methodology for identifying forested areas prone to erosion in the catchments of torrents integrates hazard maps, forest cover, and river catchments using GIS tools to identify vulnerable areas and adapt forest management strategies.

Field observations in the Zala torrent catchment, focusing on silent witnesses field mapping, revealed signs of erosion and debris accumulation, reinforcing the need for targeted silvicultural measures. Ecohydrological forest management guidelines were presented to reduce the risk of woody debris and enhance forest erosion resilience. Slovenia has a long tradition in the construction of hazard mitigation structures, like the “Carniolian wall” (**Figure 12**, Saražin, 2024), utilizing locally occurring tree species, gravel and rocks. It is therefore not surprising that the extensive knowledge of the use of timber for this purpose was awarded as the Slovenian intangible cultural heritage status in 2013, emphasizing the interplay of traditional knowledge, technology and folk culture (2013). Forests play a crucial role in reducing the cascading effects of landslides and torrential floods. Strengthening their protective function through informed, site-adapted management is essential for climate resilience and disaster risk reduction in torrent-prone forest regions.



Figure 12: Wooden chest or Carniolian wall – a biotechnical measure for increasing erosion resistance (Saražin, 2024); https://youtu.be/btj_nt4FHUw

3. EXCURSIONS

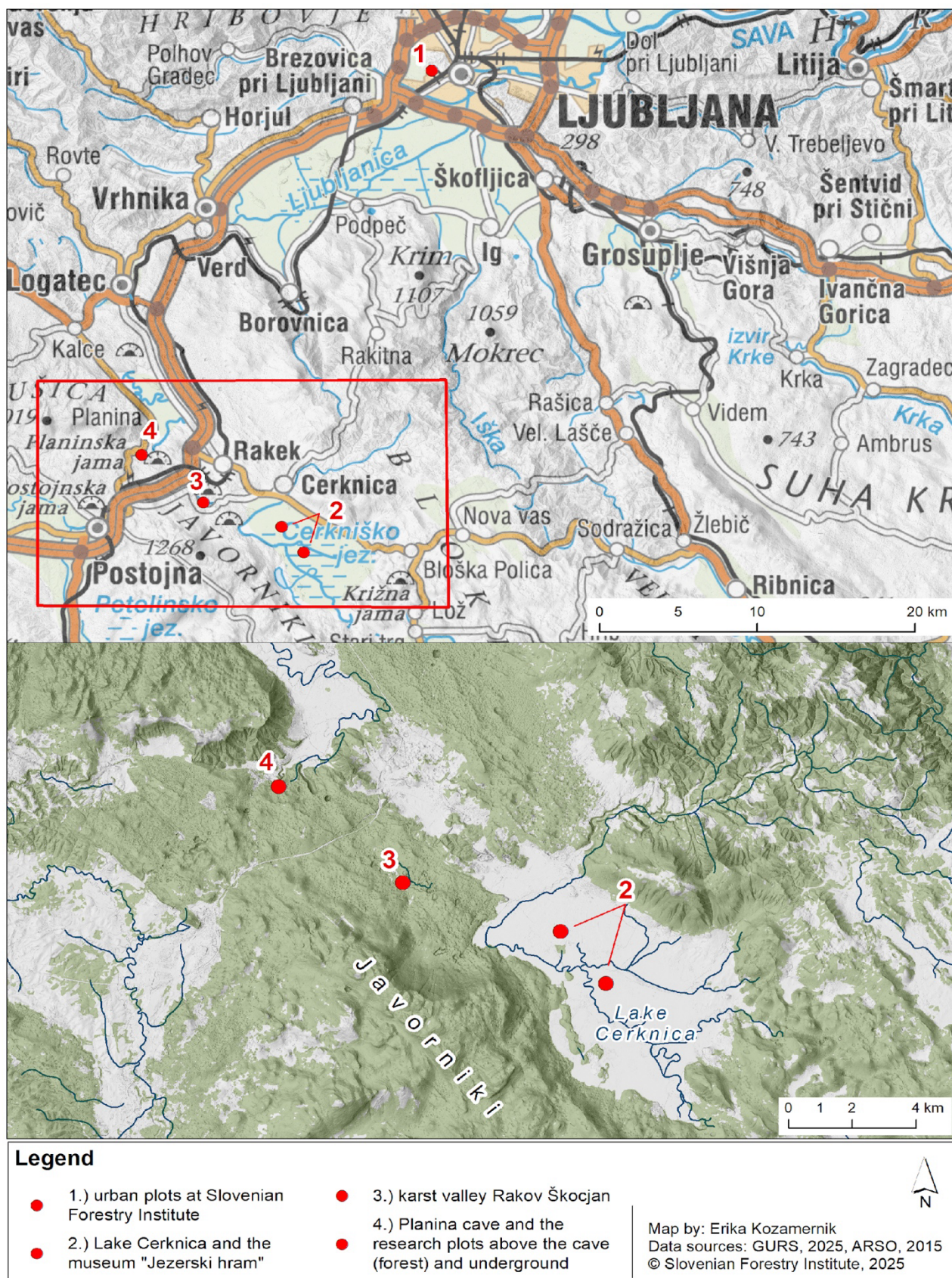


Figure 13: Map of excursion sites during summer school

3.1. Visit to the labs and urban research plots of Gozdarski Inštitut Slovenije

3.1.1 Visit to the labs in SFI

Authored by: Dr. Xudan Zhu

Affiliation: *University of Eastern Finland, Faculty of Science and Forestry, Department of Environmental and Biological Science*

On Monday, 06.10.2025, we started the day by an introduction to the Slovenian Forestry Institute (SFI) from Dr. Urša Vilhar. She provided an overview of the SFI’s mission, organizational structure, and its key areas of research. Following this, she introduced the participants to all the laboratories within the Department of Forest Ecology, including the Laboratory for Forest Ecology, the Laboratory for Electronic Devices, and the Laboratory for Wildlife and Game Management.



Figure 14: Laboratory for Forest Ecology at Slovenian Forestry Institute, tour guided by Daniel Žlindra

During the visit to the Laboratory for Forest Ecology, the group was warmly welcomed and guided by Engineer Daniel Žlindra, the Head of the Laboratory (**Figure 14**). The visit began with an overview presentation, introducing the main research goals of the laboratory—focusing forest health, tree physiology, and soil–plant interactions. Participants were then guided through several specialized equipment rooms: water lab, soil lab and sample preparation room. Key instruments included analyzers for soil physicochemical properties, a metal analyzer for solid samples, and liquid sample analyzers for Ion, carbon and nitrogen (**Figure 15**). Throughout the tour, Daniel provided detailed explanations of the scientific principles behind each instrument, emphasizing their application in long-term ecological research. The group also observed active experiments, sample analyses in progress, and laboratory documentation illustrating data collection and interpretation.

Thereafter, the participants had a short visit to the Laboratory for Electronic Devices, led by Dr. Janez Pavčič, to observe how the staff assembled various devices and equipment to support ongoing research activities. The visit also included an introduction to a 3D printer, where participants were shown how the technology is utilized to design and fabricate customized components essential for experimental and developmental work (**Figure 16**).



Figure 15: Soil physical property analyzers for soil particle size (a), soil water retention-PF curve (b); Soil chemical property analyzers: Calcimeter (c), UV-Visible Spectrometer (d), and Conductivity module (e); Solid sample analyzer for carbon, nitrogen, and sulfur (f); Liquid sample analyzers for Ions: Na, K, Mn, Ca, Mg, NH_4^+ , NO_3^- (g & h), as well as carbon and nitrogen analyzers (i).

The tour ended at the Laboratory for Wildlife and Game Management, led by Dr. Katarina Flajšman. During this visit, the participants engaged in an open discussion session with Katarina and her research team, focusing on current projects, research methodologies, and collaborative opportunities in the field of wildlife and game management (**Figure 16**). Overall, the lab tour offered a comprehensive insight into the laboratory’s work, highlighting how advanced analytical tools, new technologies, and dedicated scientific expertise contribute to understanding and preserving forest ecosystems.



Figure 16: Tour in Laboratory for Electronic Devices guided by Dr. Janez Pavči (Top) and tour in Laboratory for Wildlife and Game Management guided by Dr. Katarina Flajšman (Bottom) at Slovenian Forestry Institute

3.1.2 Visit to urban research plots

Authored by: Tingting Zhu

Affiliation: *University of Eastern Finland, Faculty of Science and Forestry, Department of Environmental and Biological Science*

After lunch, we visited the urban research plot near SFI, which is characterized by a mixed forest. During the visit, Urša and Saša explained the operating principles and measurement mechanism of the system, and we had the opportunity to observe it in operation.

Before moving to the main site, Urša showed some other measurements near the institution building. We observed an automated soil respiration monitoring system powered by solar energy (**Figure 17**). The device enables continuous, daily data collection at a relatively low cost compared to traditional manual chamber-based measurements. This system is particularly valuable during winter when field data collection is often challenged due to harsh conditions. Additionally, the meteorological station in front of the institute is designed to measure total precipitation and associated meteorological variables. However, as noted by Saša, the tall trees around the station may introduce measurement biases, particularly affecting wind-related parameters (**Figure 17**).



Figure 17: Automated soil respiration monitoring system (left) and meteorological site at urban forest research plot near the Slovenian Forestry Institute (right)

The urban forest research plot is established to study hydrological processes in a mixed forest, with a focus on precipitation dynamics and water sample collection (**Figure 18**). The forest canopy is dense and dominated by sessile oak (*Quercus petraea*), sweet chestnut (*Castanea sativa*), and Norway spruce (*Picea abies*). The precipitation monitoring system, installed in an open area, allows for the measurement of total precipitation, including both rainfall and snowfall, and enables the collection of samples for subsequent chemical analysis. Throughfall is captured using a network of gutter collectors (3 m length, 4 cm diameter) equipped with three parallel slits (87 cm × 0.9 cm each) and mounted 0.60 m above the forest floor, with water directed into polyethylene tanks for storage and analysis. Additionally, a soil water collection system was designed to sample pore water at multiple depths directly in the field.

In summary, the urban forest research plot provided a comprehensive example of experimental design for studying hydrological processes, integrating precipitation, throughfall, stemfall and soil solution monitoring systems. This field-based approach offers practical insights for research that is otherwise limited to laboratory measurements, enabling monitoring of both aboveground and belowground hydrological dynamics. The visit illustrated professional methodologies for continuous data collection, bridging theoretical knowledge with practical application, and left a strong impression by demonstrating how experimental design can directly inform and support ongoing research objectives.



Figure 18: Devices for collecting precipitation (left), throughfall (middle) and soil water (right)

3.2. Field trip to the museum »Jezerski hram« and the Cerknica Lake

Authored by: Jessenia Polack

Affiliation: *University of Eastern Finland, School of Forest Sciences*

On Wednesday, 8.10.2025, we visited the museum “Jezerski hram”, located in the village of Dolenje Jezero. There, we were introduced to a living model of the Cerknica Lake, one of the largest karst polje phenomena in Europe. The model, created by Vekoslav Kebe, is a detailed representation of the lake’s intermittent nature shapes the surrounding landscape throughout the seasons (**Figure 19**).

When full, the Cerknica Lake covers about 26 km², making it the largest lake in Slovenia. It is an important RAMSAR site that provides habitat for endangered species and serves as a key resting point for migratory birds. The lake fills quickly, often within two to three days after heavy rain, and dries up gradually within three to four weeks during dry periods. This natural cycle is driven by the inflow and outflow of water through the karst underground system.



Figure 19: Overview of Museum “Jezerski hram” (top) and the model of the Cerknica Lake, created by Vekoslav Kebe (bottom)

During our visit, we also explored the “Cerknica Polje Ethnological Park” and attended a multimedia presentation showing the lake through different seasons. The presentations helped us appreciate the lake’s ecological and cultural importance. At the park, we could see traditional tools once used by the local residents, such as wooden skates and boats, reflecting how communities have long adapted to the lake’s changing conditions (**Figure 20**).



Figure 20: Exhibition of handmade works in Cerknica Polje Ethnological Park

After visiting the museum, we crossed the Cerknica polje. Seeing the landscape firsthand allows us to imagine how it transforms during wetter or drier periods of the year, highlighting the dynamic nature of this unique karst environment (**Figure 21**).

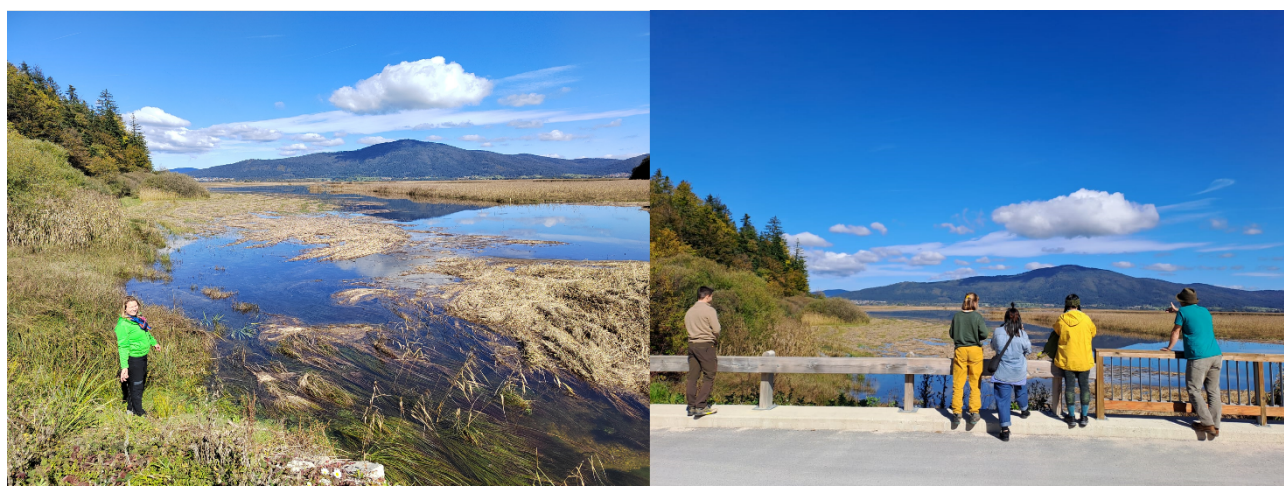


Figure 21: Views of Lake Cerknica

3.3. Visit to the karst valley Rakov Škocjan

Authored by: Christopher Pohle

Affiliation: *University of Göttingen, Faculty of Forest Sciences and Forest Ecology, Department of Forest Work Science and Engineering*

After lunch, we went on a hike through Rakov Škocjan, a karst valley located about 45 km southwest of Ljubljana. There, we were able to see the rugged landscape, formed by hydrogeological processes over millions of years, mainly through dissolution and carbonic acid weathering. Karst landscapes, found throughout Slovenia, illustrate these processes impressively (**Figure 22**). However, Rakov Škocjan stands out from other areas because the river Rak formed a large cave that eventually collapsed. This is why the valley was designated Slovenia's first nature reserve in 1949.



Figure 22: Impressions from the karst valley. View on Mali naravni most (little natural bridge) which forms the previous inlet of the cave (left). Typical forest around Rak River (top right). Bridge over Rak river (bottom right).

The Rak River is fed by waters from Cerknica Polje (refer to section 3.5) and the Javorniki Mountains (**Figure 22**). It then merges with the Pivka River to form the Unica River. The subterranean confluence of the two rivers in Planina Cave is one of the largest in Europe (refer to section 3.5). It also links the Rak River to the Ljubljana aquifer. Like the rest of the karst landscape, the Rak River is highly dependent on precipitation amounts. Due to this, water levels can vary so much that the riverbed almost dries up, while at other times, the river flows wide.

3.4. Field trip to ForKarst research plots in the forest

Authored by: Dr. Urša Vilhar

Affiliation: *Slovenian Forestry Institute*

On Thursday, 9.10.2025, we had a field trip to the ForKarst research plots in the forest and in the Planina Cave, which are both part of the integrated multi-scale ecohydrogeological monitoring of the karst critical zone (KCZ) in the Unica River catchment (**Figure 23**).

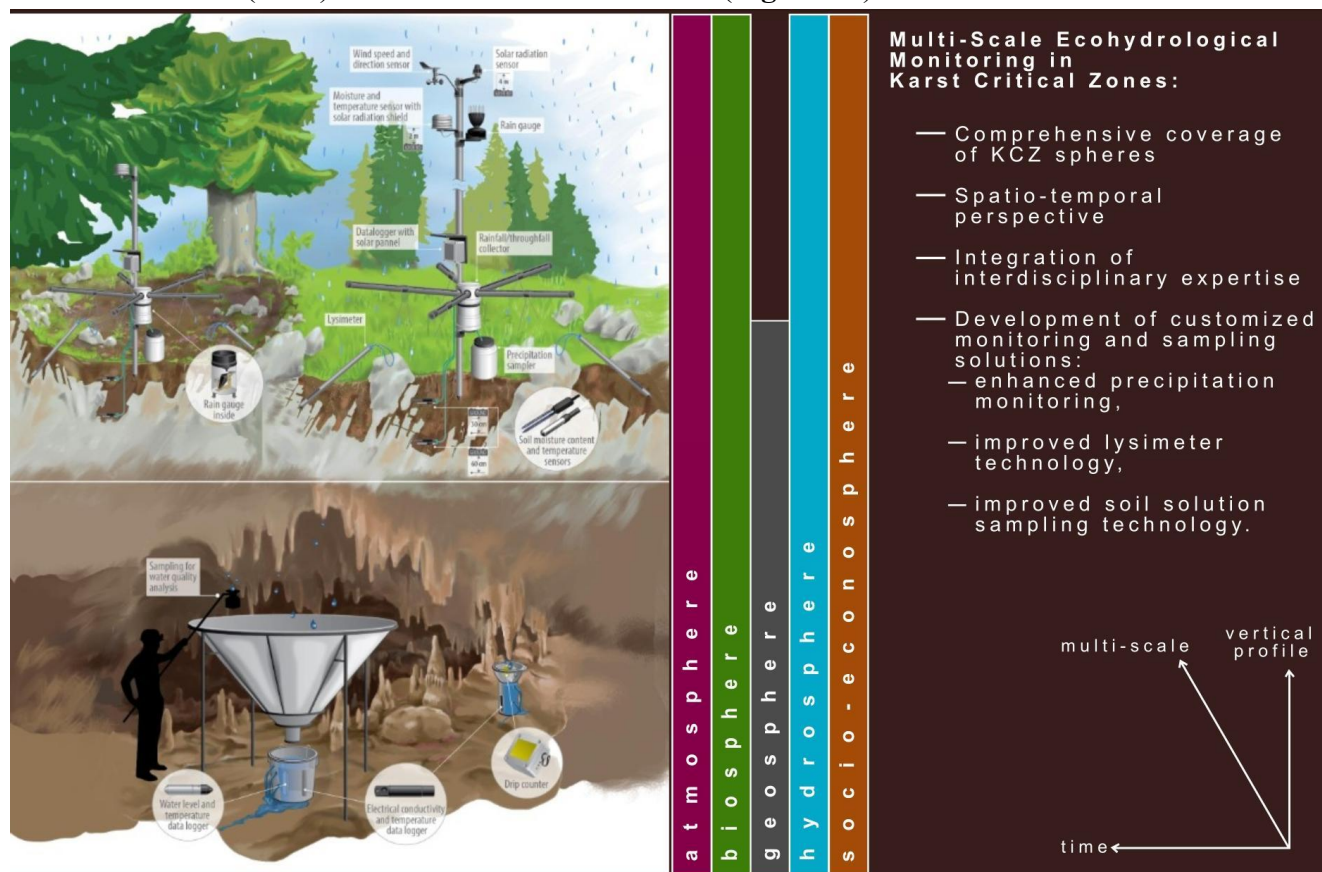


Figure 23: Integrated Multi-Scale Ecohydrogeological Monitoring in the Karst Critical Zone (KCZ) (Ravbar et al., in review) with schematic representation of the measuring devices at the surface research plots in the large canopy gap and in the forest (top) (Ravbar et al., in review). For the underground research plots, the sketch shows the measuring devices under the cave drips (bottom). Sketch not to scale.

The ForKarst project “[Infiltration processes in forested karst aquifers under changing environment](#)” was initiated in 2019 by Dr. Nataša Ravbar from the Karst Research Institute Scientific Research Centre of Slovenian Academy of Sciences in cooperation with Dr. Urša Vilhar from the Slovenian Forestry institute and their teams. From 1.7.2019 till 30.6.2023 the ForKarst project (No. J2-1749) was founded by the Slovenian Research and Innovation Agency and later became part of the [RI-SI LifeWatch](#) (Research Infrastructure for the international competitiveness of the Slovenian development of research infrastructure space) as part of the EU research infrastructure LifeWatch and eLTER network and serves as an incubator for testing new monitoring methods and research innovations.

The surface research plots are located on the slopes of the Javorniki Mountains at an altitude between 530 and 640 m (**Figure 24**). They extend over a karst landscape characterized by rounded hills and karst depressions, the so-called dolines. Stratigraphically, Jurassic and Cretaceous limestones predominate, which are highly karstified. Climatically, the study area is in the transition zone between the Mediterranean and Continental climate with an average annual air temperature of 9.3 °C and almost 1500 mm of precipitation. The limestone is generally covered by Rendzic Leptosol or Chromic

Cambisols, that occur in patches. There is no flowing surface water, as the rivers draining non-carbonate rocks, sink underground and reappear in two springs. The predominant forest type is the Dinaric silver fir–beech forest (*Omphalodo-Fagetum* s. lat. association). These mostly uneven-aged forests are dominated by European beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.), with an artificially increased proportion of Norway spruce (*Picea abies* Karst.) and admixtures of various broadleaves (e.g., *Acer pseudoplatanus* L., *Fraxinus excelsior*, *Ulmus glabra* Huds.). These forests were significantly damaged by various disturbance factors, starting with a large-scale ice storm in 2014, followed by bark beetle outbreaks, windthrow and subsequent salvage logging, and the canopy gaps are now being overgrown.

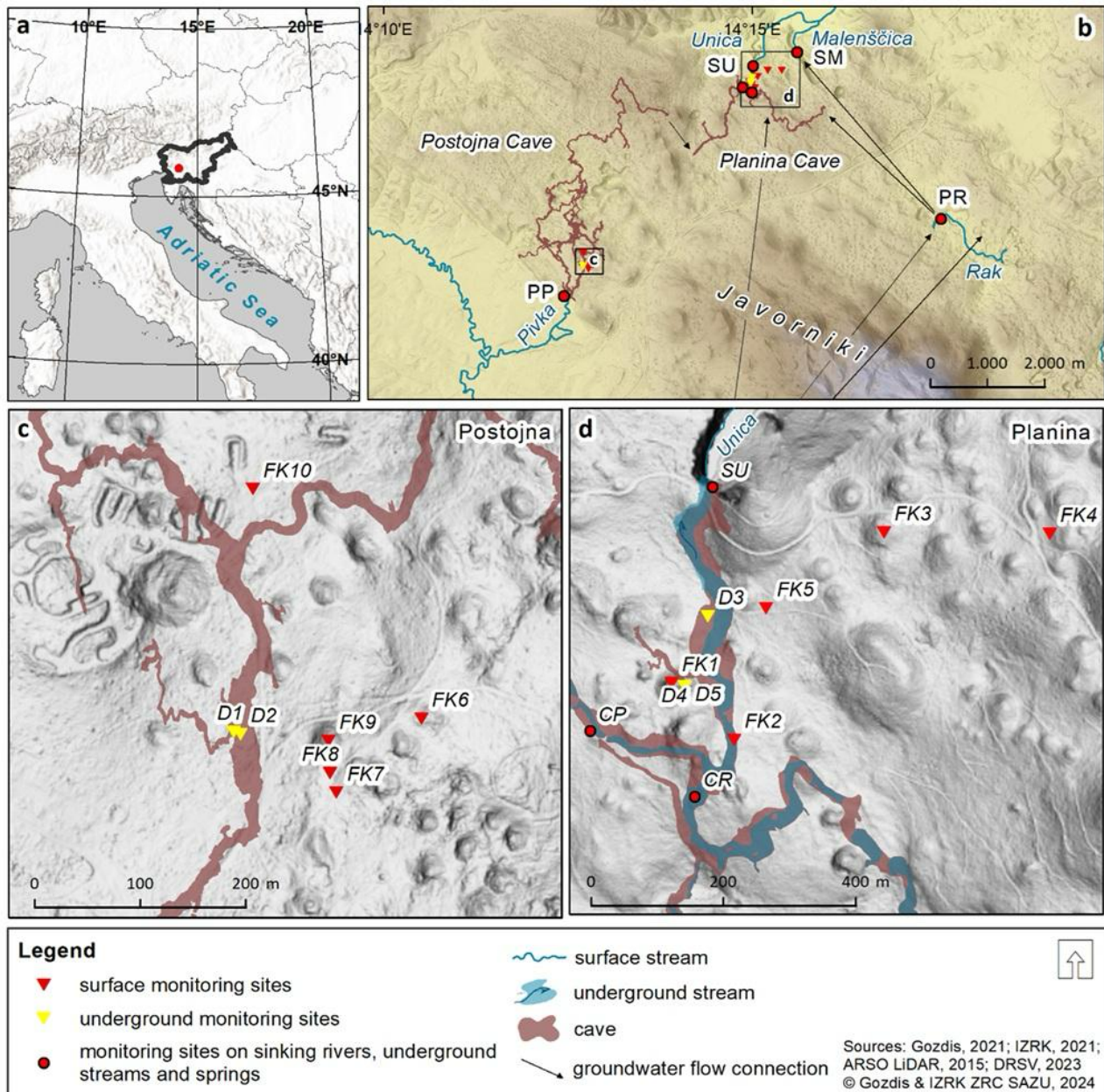


Figure 24: Location of the Postojna-Planina Karst in southwestern Slovenia (Ravbar et al, in review): (a), surface and underground research plots (b), with zoomed rectangles to research plots at Postojna (c) and Planina (d). Surface research plots are labelled FK1 – FK10, in the underground research plots are labelled D1 – D5 in case of cave drips and streams. Labelling of the sinking rivers, underground streams and springs connected to the cave system is the following: ponor of the Pivka River – PP, ponor of the Rak River – PR, Pivka – CP and Rak channels of the Planina Cave – CR, Unica Spring – SU and Malenščica Spring – SM.

In total 10 surface research plots (5 above the Planina Cave and 5 above the Postojna Cave) were strategically selected to represent different topographic karst features (dolines, interdoline areas), forest development stages (canopy gap, regeneration, mature forest stands), and soil conditions (**Figure 25**). The surface research plots are used for measurements of water fluxes, including precipitation in the open, throughfall under the forest canopies, air temperature and relative humidity, soil temperature, and soil water content. The micro-meteorological measuring systems in the open also include wind speed and direction and solar radiation. In addition to continuous monitoring in a 30-minutes time interval, these measuring systems also allow precipitation and throughfall sampling, since they are equipped with precipitation collectors.

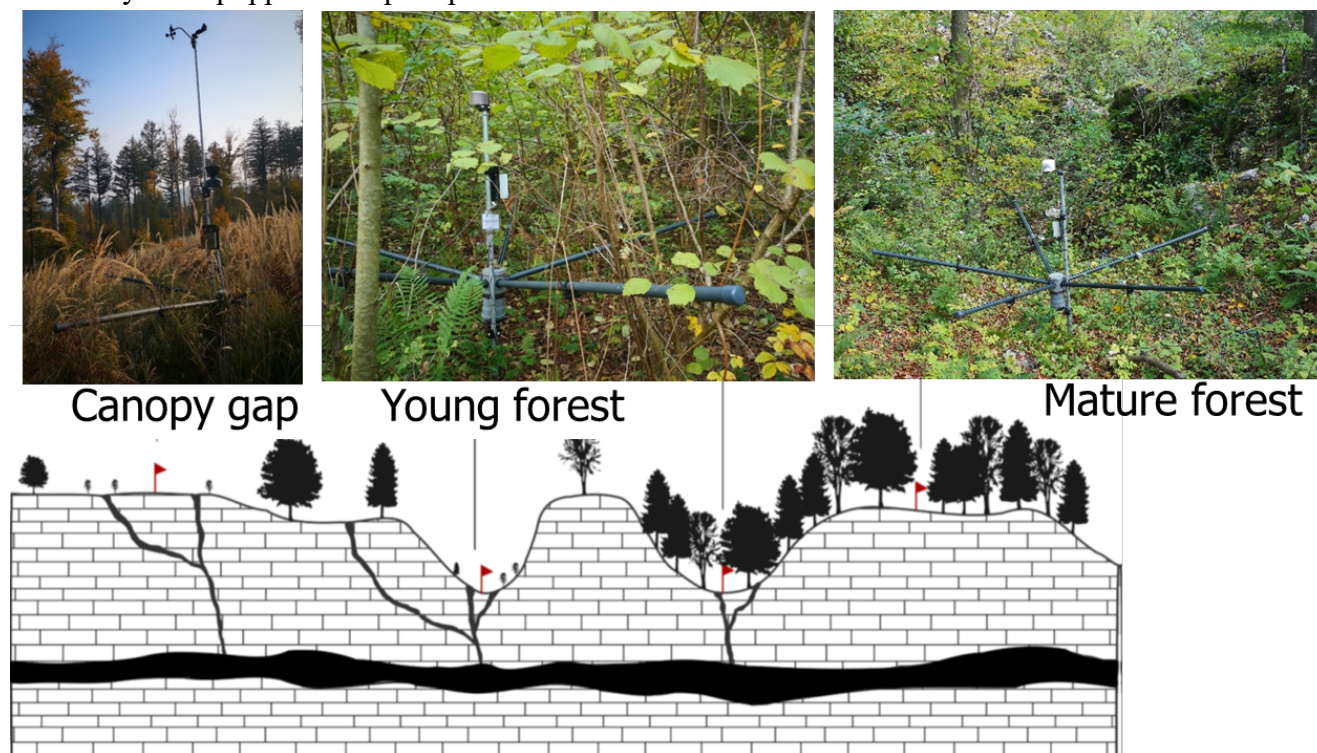


Figure 25: Surface research plots were strategically selected to represent different topographic karst features (dolines, interdoline areas), forest development stages (canopy gap, regeneration, mature forest stands), and soil conditions (Ravbar et al, in review).

On Thursday morning we visited surface research plots in the mature forest and the large canopy gap above the Planina cave (**Figure 26**). After a short presentation of the ForKarst research project by Nataša Ravbar, we walked to the surface research plot in the doline with the mature forest stand. The micro-meteorological measuring systems, specifically designed for this karst forested landscape, were presented by Dr. Urša Vilhar. Preliminary results of discharge, precipitation, and soil water content relationships were presented by Tinkara Mazej. We discussed monitoring and sampling approaches for water fluxes in karst soils and microscale adaptations to ensure representativeness in these heterogeneous environments.



Figure 26: Field tour to the surface research plots

3.5. Field trip to ForKarst research plots in the Planina cave

Authored by: Tinkara Mazej

Affiliation: Karst Research Institute ZRC SAZU

During Thursday’s field trip, we visited Planina Cave, which is located on the southern edge of the Planina Polje. Planina Cave is part of the Postojna–Planina Cave System, which includes more than 24 km of surveyed passages in Postojna Cave and 6.6 km in Planina Cave. It functions as a major underground river system (**Figure 27**).

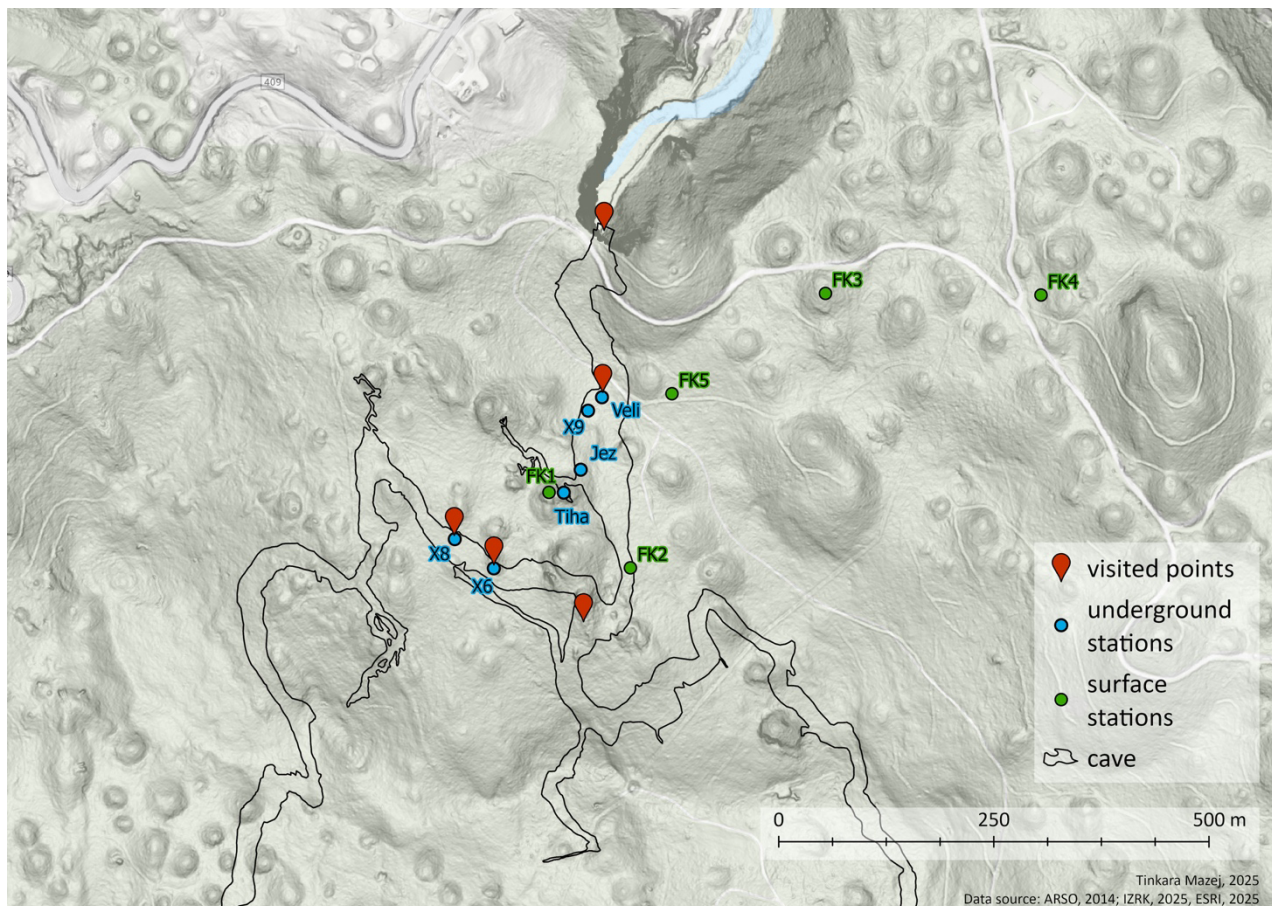


Figure 27: Planina Cave with underground stations and visited points.

The entrance to the cave lies in a pocket valley with very steep rock walls (**Figure 28**). At the entrance, we can observe the Unica spring, whose discharge varies from only a few m³/s to over 90 m³/s. Inside the cave, we observed the underground confluence of the Rak and Pivka rivers. The Pivka River flows through the left (Pivka) branch and receives water from the Postojna Cave. The Rak River flows through the right (Rak) branch and receives water from Rakov Škocjan. In Rakov Škocjan, the Rak River is fed by waters from the Cerknica Polje and the Javorniki Mountains. The Rak and Pivka rivers merge underground in the cave as the Unica River, which then flows out of the cave and into the Planina Polje.

As part of the ForKarst project, several underground measuring stations were established, and some more stations were added during last year. During our visit to Planina Cave, we examined a few of them (**Figure 29**). These underground stations measure discharge, electrical conductivity, and temperature of percolating water — water that infiltrates from the surface into the cave system.



Figure 28: *The entrance and interior landscape of Planina Cave*

The stations in Planina Cave consist of measuring containers with holes and two sensors that record absolute pressure, electrical conductivity, and temperature (**Figure 29**). Based on absolute pressure, the actual discharge can be determined using discharge curves, which are derived from manual discharge measurements. The stations are fully automated, recording data every 30 minutes, and the data are collected manually every few weeks. Data from the stations in Planina Cave show several characteristics of percolating water. The drips respond rapidly to rainfall, indicating a direct hydrological connection between the surface and the subsurface. Discharge peaks occur within hours after precipitation, but discharge also quickly returns to pre-event conditions. The average discharge of drip water is a few liters per minute, while during precipitation events it can exceed ten liters per minute, indicating a very rapid response.

Electrical conductivity provides insight into whether the water is “old” or “new.” “Old” water refers to water that has been previously stored in the karst aquifer and therefore has higher electrical conductivity. “New” water refers to recent precipitation that infiltrates directly into the drips, resulting in lower electrical conductivity. For the stations in Planina Cave, it is typical that under normal conditions, water with higher electrical conductivity predominates, indicating the presence of previously stored water. During precipitation events, as discharge increases, the electrical conductivity of drip water drops significantly, which indicates direct infiltration of precipitation from the surface into the cave.



Figure 29: *Underground stations in Planina Cave*

4. PLANNED FURTHER ACTIONS

4.1. 6th IUFRO International Conference

Authored by: Dr. Xudan Zhu

Affiliation: University of Eastern Finland, Faculty of Science and Forestry, Department of Environmental and Biological Science

6th IUFRO: Forests and Water in a Changing Environment

Dates: 20-23.10.2025

Location: Beijing Forestry University, Beijing, China

Participates:

- Xudan Zhu (*University of Eastern Finland, Finland*)
- Jessenia Polack (*University of Eastern Finland, Finland*)
- Zuosinan Chen (*University of Oulu, Finland*)

Activities:

From 20–23 October 2025, the 6th IUFRO International Conference on Forests and Water in a Changing Environment (FWCE) was successfully held at the Beijing Forestry University. The conference was organized by *the IUFRO Task Force Forest–Water–Livelihood–Governance Nexus and IUFRO Working Party 8.01.04 Hydrological Processes and Water Quality* and co-hosted by the *Beijing Forestry University and the Chinese Academy of Forestry*. The event attracted approximately 130 scientists, policymakers, and practitioners from 22 countries, providing an important international platform for knowledge exchange and collaboration.

During the conference, **Xudan** and **Zuosinan** delivered oral presentations to share their research with the international scientific community, while **Jessenia** presented her research outcomes through a poster presentation. Their contributions generated valuable discussions and feedback from peers. In addition to the academic sessions, an excursion to the Great Wall of China was organized, introducing participants to forest management practices at the Badaling Forest Farm while showcasing the region’s natural and cultural heritage (**Figure 30**). Throughout the conference, all participants actively engaged in networking activities, strengthening existing collaborations and establishing new connections with researchers, policymakers, and practitioners from around the world.



Figure 30: Participants of field trip in front of Great Wall of China

4.2. Summer school 2026

Authored by: Jessenia Polack

Affiliation: *University of Eastern Finland, School of Forest Sciences*

Summer School 2026: **Forest-Carbon-Water Nexus**
Dates: 10-21.08.2026
Location: University of Eastern Finland (UEF), Joensuu campus, Finland
Format: In person only
Course Coordinator: Jessenia Polack, University of Eastern Finland
Contact: ss2026_affer@uef.fi

Lecturers:

- Patricio Crespo (*Universidad de Cuenca, Ecuador*)
- Andrés Alvarado (*Universidad de Cuenca, Ecuador*)
- Christian Birkel (*Universidad de Costa Rica, Costa Rica*)
- Zoila Cruz (*Universidad Nacional Agraria La Molina, Peru*)
- Karin Begazo (*Universidad Nacional Agraria La Molina, Peru*)
- **Urša Vilhar (*Slovenian Forest Institute, Slovenia*)**
- Frank Berninger (*University of Eastern Finland, Finland*)
- Blas Mola (*University of Eastern Finland, Finland*)
- **Xudan Zhu (*University of Eastern Finland, Finland*)**
- Liang Chen (*University of Eastern Finland, Finland*)
- Lei Wang (*Zhejiang A&F University, China*)
- **Zuosinan Chen (*University of Oulu, Finland*)**

Assessment criteria: Active participation in lectures, practicals and field visits.

Grading: Pass/Fail

Learning outcomes: After completing this course the student:

- understands through lectures, seminars and field work how forest, water and carbon are connected
- learns and compares processes in tropical and boreal ecosystems
- Design and carry out field sampling and basic laboratory analyses
- Communicate scientific results effectively to an international audience

Contents/Overview: The course deals with dynamics in physical environments in boreal and tropical ecosystems, and potential effects of climate change in these “vulnerable” ecosystems. The course contents lectures, demonstrations and field work focus on behavior and adaptation of the environments. During this course, we will carry out field work in the vicinity of Joensuu campus, in Eastern Finland. This course will contain five modules:

Module 1: Ecohydrology (Monday 10.08 and Tuesday 11.08)
Module 2: Water quality and treatment (Wednesday 12.08)
Module 3: Carbon dynamics and flux measurements (Thursday 13.08)
Module 4: Socio-ecological and ecosystem services (Friday 14.08)
Module 5: Group work, field visit, laboratory measurements, lecture seminars and presentations (Monday 17.08 - Friday 21.08)

4.3. Future collaboration

Authored by: *Dr. Urša Vilhar and Dr. Xudan Zhu*

Affiliation: *Slovenian Forestry Institute and University of Eastern Finland*

- **Discussion on future collaboration:** potential calls for projects, partnership projects, secondments, etc.
- **Research exchange to SFI:** Tingting plans to visit SFI as a visiting researcher for 1–2 months to receive training in the Laboratory for Forest Ecology (Daniel Žlindra) and to collaborate on a joint paper with Urša and Daniel.
- **EU call: Water4All 2025** –Water security for all, at least 3 or 4 institutions
- **European Research Council (ERC) application by Xudan**
- **Synergy Grant - European Research Council (ERC)**

