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Research, Assessment, and Development of Documents on Biodiversity, the Impact of Climate Change on Biodiversity, Habitat Restoration, and Long-Term Habitat Management

Field Research on Biodiversity

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EXECUTIVE SUMMARY

This project "Research, assessment, and development of documents on biodiversity, the impact of climate change on biodiversity, habitat restoration, and long-term habitat management" offers an interdisciplinary approach by integrating spatial planning, legal frameworks, and ecological expertise alongside qualitative, scientific analysis. By combining knowledge from various fields, the aim is to create a comprehensive understanding of biodiversity challenges. The project emphasizes the importance of collaboration among environmental science, policy, and spatial design, creating a foundation for adaptive management strategies informed by both ecological data and spatial dynamics. This ensures that future actions are grounded in a well-informed, comprehensive perspective.
The project aims to identify and map key biodiversity areas at risk, focusing on Prizren, Suharekë, and the Sharr Mountains. Through field assessments, GIS data, spatial maps, spatial ecology analyses, and existing management plan reviews, critical habitats will be identified. These will be compared with historical and current climate patterns to predict future ecological changes and assess the impact of climate variability on biodiversity. Additionally, the project will evaluate the need for habitat restoration, documenting both the ecological and social benefits of restoration efforts.

This report focuses on aquatic insects as key biodiversity actors whose ecological roles and sensitivities make them valuable indicators of freshwater ecosystem health. Their study offers a concrete entry point into broader biodiversity dynamics. These findings complement spatial and climate analyses in other phases and lay the groundwork for resilience-based habitat restoration strategies.

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BACKGROUND

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Kosovo's freshwater and terrestrial ecosystems are under increasing pressure from climate change, land-use transformation, and fragmented or insufficient conservation frameworks. These pressures are particularly acute in ecologically sensitive zones such as cold-water springs, headwater creeks, riparian corridors, and upland forest buffers, where biodiversity plays a critical role in maintaining ecological stability. Despite their importance, these habitats remain understudied, and their biodiversity is poorly documented and monitored.

Freshwater macroinvertebrates—especially aquatic insects—are among the most sensitive indicators of ecological integrity. Their presence, abundance, and diversity reflect the condition of both aquatic and surrounding terrestrial environments, making them invaluable for detecting early signs of ecological stress. In Kosovo, data on these taxa remain sparse, and existing conservation planning does not fully account for rare or endemic species with narrow ecological tolerances.

This project was initiated to address these knowledge gaps by identifying, documenting, and supporting the protection and restoration of critical biodiversity hotspots. It integrates ecological survey data with spatial analysis, climate risk assessment, and policy review in order to inform adaptive conservation strategies. By connecting field-based evidence to broader spatial and policy contexts, it aims to highlight both the ecological value of these systems and the urgent need for targeted, habitat-specific conservation measures.

INTRODUCTION

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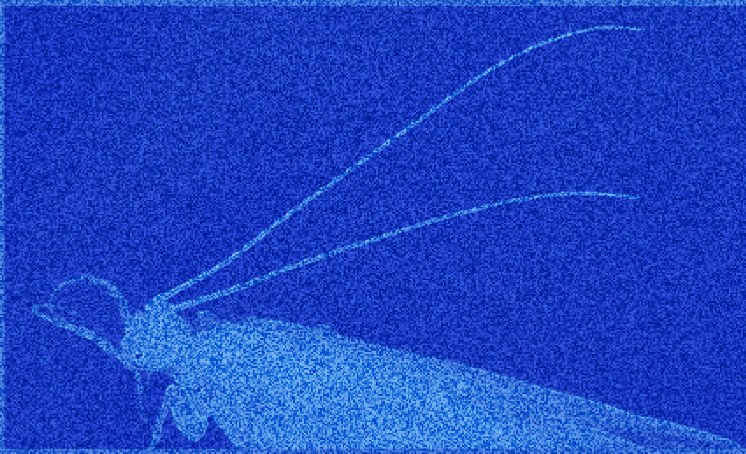
This report presents the results of field surveys and laboratory identifications of aquatic insect communities across multiple freshwater habitats in Kosovo. Surveys targeted sites representing different habitat types—rivers, streams, small creeks, cold springs—and included both high-altitude and lowland systems. Each site was selected to capture variation in riparian structure, thermal regime, and human disturbance.

Species were identified to the lowest reliable taxonomic level and assessed in relation to habitat characteristics and ecological function. The findings reveal the presence of rare, endemic, and thermally restricted species such as *Drusus sharrensis*, *Notidobia vaillanti*, *Rhyacophila sarplana*, *Rhyacophila obtusa*, and *Chaetopteryx stankovici*, many of which are confined to low-temperature spring areas with narrow ecological tolerances. These taxa exhibit low dispersal ability, small population sizes, and high habitat specificity, making them particularly susceptible to environmental change.

By linking biodiversity patterns to habitat condition, the study identifies key threats including climate change, riparian habitat degradation, deforestation, water extraction, and pollution. The results show that conservation strategies must extend beyond aquatic channels to encompass adjacent riparian and terrestrial habitats, which play essential roles in providing shelter, maintaining microclimatic stability, and enabling dispersal.

The documentation of new national records, such as *Limnephilus extricatus*, further emphasizes that Kosovo's freshwater biodiversity remains incompletely understood and that continued survey and monitoring efforts are essential. Ultimately, this study provides both a scientific foundation for conservation action and a call to protect and restore critical freshwater habitats—inside and outside formally designated protected areas.

OBJECTIVES OF FIELDWORK



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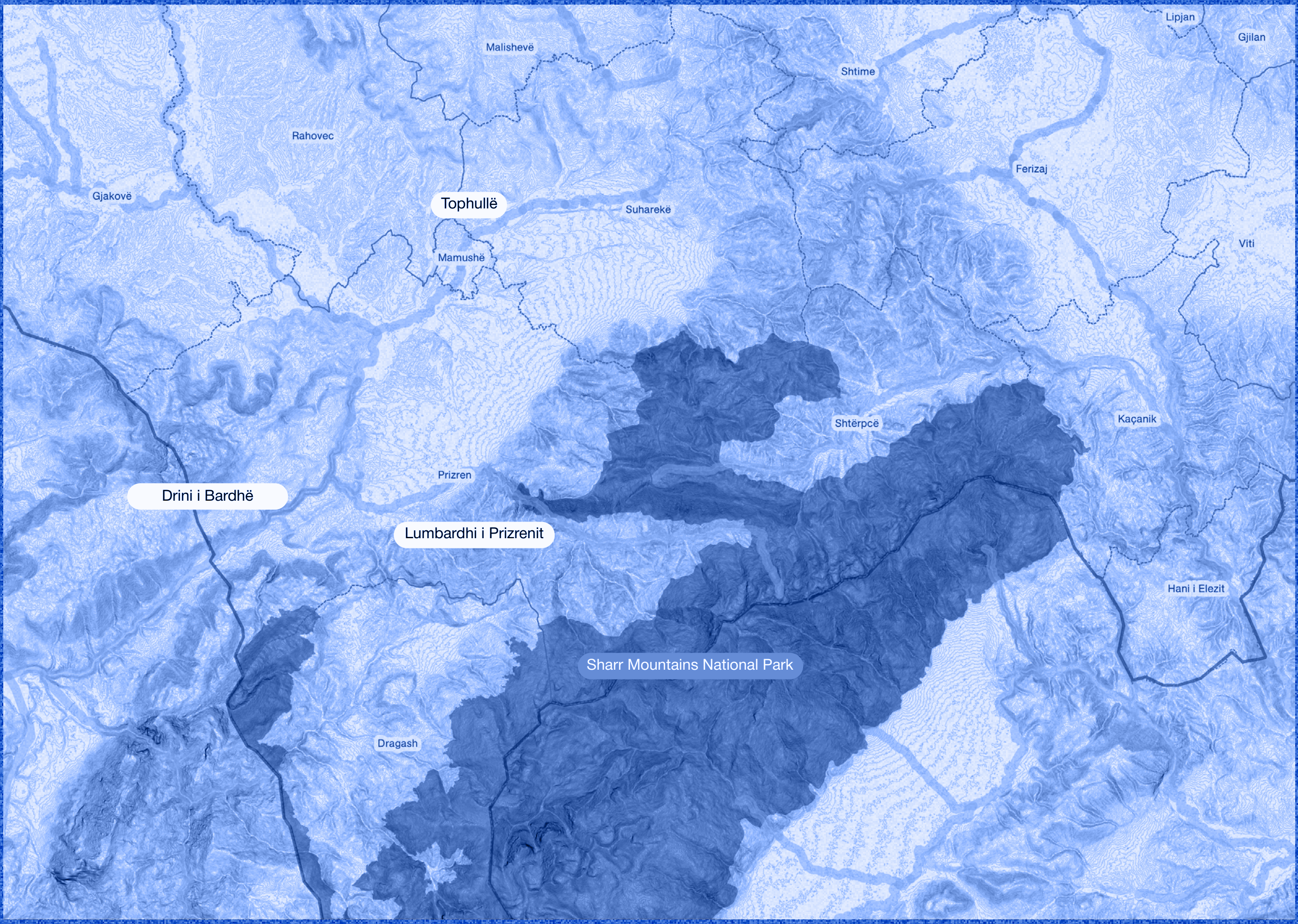
THE FIELDWORK BUILDS A SPATIALLY EXPLICIT BASELINE FOR KOSOVO'S FRESHWATER BIODIVERSITY BY COMBINING NEW, STANDARDIZED SURVEYS WITH HISTORICAL SOURCES ACROSS PRIORITY SITES IN PRIZREN, SUHAREKË, AND THE SHARR MOUNTAINS. IT CENTERS ON AQUATIC INSECTS (EPT TAXA) BECAUSE THEIR LIFE CYCLES BRIDGE WATER AND LAND, MAKING THEM SENSITIVE, EARLY-WARNING INDICATORS OF POLLUTION, HYDROLOGICAL CHANGE, TEMPERATURE SHIFTS, AND HABITAT FRAGMENTATION WHILE ALSO UNDERPINNING NUTRIENT CYCLING AND FOOD WEBS. BY RECORDING SPECIES IDENTITY, ABUNDANCE, AND HABITAT CONDITIONS, THE STUDY DETECTS SUBTLE SHIFTS IN COMMUNITY STRUCTURE BEFORE VISIBLE ECOSYSTEM DECLINE. CRITICALLY, IT COMPARES PROTECTED AND NON-PROTECTED AREAS TO TEST HOW WELL FORMAL PROTECTION WORKS, REVEAL ECOLOGICAL BLIND SPOTS, AND PINPOINT HIGH-RETURN RESTORATION OPPORTUNITIES. TOGETHER, THESE OBJECTIVES SUPPORT ADAPTIVE MANAGEMENT—PRIORITIZING RIPARIAN PROTECTION, CONNECTIVITY, AND TARGETED RESTORATION TO STRENGTHEN LONG-TERM ECOSYSTEM RESILIENCE.



Map of the study area, focusing on Sharri Mountains National Park and the surrounding landscape, including key river systems such as the Drini i Bardhë, Lumbardhi i Prizrenit, and Toplluha, in proximity to the settlements of Prizren and Suharekë.

3.1 Document primary and secondary data on biodiversity in selected zones

The fieldwork was designed to generate a robust dataset by collecting both direct (primary) and contextual (secondary) information on biodiversity in ecologically significant freshwater zones. These sites were strategically chosen based on preliminary spatial analysis and include locations in the municipalities of Prizren, Suharekë, and sections of the Sharr Mountains. The primary data comprise species records obtained through systematic field surveys, focusing on precise identification, abundance counts, and habitat condition assessments. Secondary data draw from historical biodiversity surveys, institutional archives, environmental monitoring reports, and peer-reviewed literature. Together, these sources provide not only a current taxonomic snapshot but also a temporal perspective on biodiversity trends. By documenting habitat characteristics, historical presence, and potential vulnerability of species, this component of the study builds a more comprehensive and spatially explicit understanding of local biodiversity dynamics—forming the ecological baseline needed for future monitoring, restoration planning, and conservation prioritization.

3.2 Focus on aquatic insects as indicators of freshwater ecosystem conditions

Aquatic insects were selected as the focal taxonomic group for this research due to their dual value as core biodiversity components and highly responsive ecological indicators. Their life cycles span both aquatic and terrestrial environments, making them especially sensitive to environmental pressures such as pollution, sedimentation, temperature fluctuations, hydrological changes, and habitat fragmentation. This sensitivity, coupled with their ecological importance in nutrient cycling, organic matter decomposition, and food web support, makes them an ideal group for assessing the health and resilience of freshwater systems.

By conducting site-specific surveys to record species presence, diversity, and abundance, the fieldwork not only captures a high-resolution picture of community composition but also reveals early warning signs of ecosystem stress. The integration of taxonomic identification with habitat analysis allows for the detection of subtle but significant shifts in ecological conditions that may precede more visible ecosystem decline. This approach ensures that biodiversity assessment is directly tied to actionable insights, providing a sound basis for targeted monitoring, adaptive management, and the design of habitat restoration measures.

3.4 Compare protected and non-protected zones to understand restoration potential

A key objective of the study is to compare biodiversity patterns and habitat conditions between protected zones (such as the Sharr Mountains National Park) and ecologically important but unprotected areas. This comparative framework enables the identification of both conservation successes and ecological gaps. By analyzing differences in species richness, community structure, habitat integrity, and the prevalence of sensitive or rare taxa, the study highlights the benefits of formal protection while also pinpointing areas outside these boundaries that hold significant restoration potential.

Such analysis is essential for guiding strategic conservation investments, as it reveals degraded or at-risk zones where targeted ecological restoration could yield high biodiversity returns. It also allows for the evaluation of existing protection measures and their effectiveness in mitigating threats from land use change, pollution, and climate stressors. Ultimately, this comparative approach supports a landscape-scale conservation strategy—one that bridges protected and non-protected zones to maintain ecological connectivity, genetic exchange, and the long-term resilience of freshwater ecosystems.

METHODOLOGY

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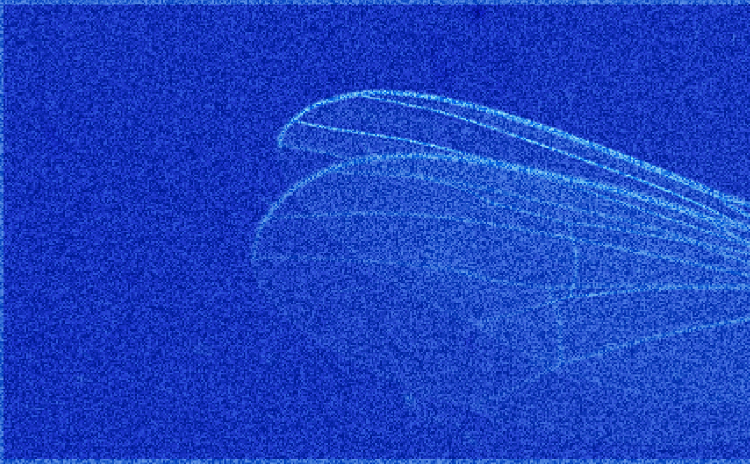

THE APPROACH USED FOR COLLECTING AND ANALYZING DATA ON FRESHWATER BIODIVERSITY IN KOSOVO COMBINES NEW FIELD OBSERVATIONS WITH HISTORICAL DATA, FOCUSING ON THE RIVERS AND MOUNTAIN AREAS OF PRIZREN, SUHAREKA, AND THE SHARR MOUNTAINS. METHODS INCLUDE SAMPLING AQUATIC INSECTS (THE EPT GROUPS – EPHEMEROPTERA, PLECOPTERA, TRICHOPTERA) AS KEY INDICATORS OF ECOLOGICAL QUALITY, THE USE OF SPATIAL TECHNOLOGIES FOR MAPPING AND DOCUMENTATION, AND THE STANDARDIZATION OF PROCEDURES TO ENSURE COMPARABILITY AND RELIABILITY OF RESULTS.

4.1 Site Selection

Sites were selected based on the potential presence of aquatic insects, which requires specific habitat conditions. These include the presence of freshwater bodies, streams or tributaries, consistently wet zones, riparian vegetation, and, ideally, higher surrounding vegetation that contributes to a stable microclimate. These ecological features are essential for hosting diverse aquatic insect communities, particularly taxa sensitive to environmental changes.
Locations:
Three study areas were selected: 1. First one represents a riverine habitat with adjacent streamlet tributaries located inside a forested area within the Sharr Mountains protected area; 2. Second study area represents an open riverine habitat area with adjacent streamlet tributaries with surrounding pasture habitats; and 3. Third study area represents a riverine habitat outside any formal protection status in the vicinity of Prizren. This distinction enables a comparative analysis of biodiversity conditions in protected versus non-protected freshwater ecosystems as well as conditions of freshwater biodiversity in forested vs. nonforested areas inside a protected zone. The selection also follows best practices in habitat restoration, which recommend studying ecologically similar habitats in close proximity—especially those with relatively intact or endemic conditions—as reference points for understanding restoration potential and setting realistic ecological baselines.
In total 25 sub-stations were surveyed.

4.2 Scientific Field Methods

4.2.1 Use of standardized sampling techniques

Adult stages of caddisflies (Trichoptera) were beaten from the vegetation with entomological nets and also collected with ultraviolet light traps. Nocturnal light trapping followed Malicky (2004). Specimens were stored directly in 90% ethanol. The collected material is deposited at the Department of Biology, Faculty of Mathematics and Natural Sciences, University of Prishtina "Hasan Prishtina", Prishtinë, Kosovo. Morphological characteristics of male terminalia of the new species were examined in specimens cleared in KOH. Systematic nomenclature follows Morse (2025).
Ultraviolet light traps were deployed at varying distances from both sides of the stream or river, starting at 0 m and extending up to approximately 200 m, to assess the density of aquatic insect assemblages in relation to proximity to the water body. The traps operated from dusk until the following morning.
In addition to this we also sampled larval stages of aquatic insects and other macroinvertebrate groups, especially in the exercise for comparing protected areas vs. nonprotected areas. Sampling of macroinvertebrates was done with a standard D-net.

4.2.2 Temporal dimension

Sampling was carried out during the summer, the period when the majority of aquatic insect taxa emerge and are most detectable. This timing aligns with the optimal biological window for identifying diversity and ecological indicators, particularly for insect orders such as Trichoptera. Although limited to a single season, this timing offers high reliability for assessing the ecological status of freshwater habitats. Ultraviolet light traps methods for capturing biodiversity of aquatic insects operated during the period 15 June to 15 July 2025, with each sub-station surveyed three times during this period.

4.3 Scientific Protocols

The targeted taxa are:
Aquatic insects, with a primary focus on the order Trichoptera (caddisflies). This group is particularly important due to its relevance in biodiversity studies, microscale endemism, and its role as a freshwater bioindicator. Additional focus was placed on Plecoptera (stoneflies) and Ephemeroptera (mayflies), as well as other macroinvertebrate groups known for their sensitivity to environmental change, such as certain Diptera (e.g., Chironomidae) and Odonata. These supplementary taxa enhance the ecological breadth of the dataset and provide a broader picture of aquatic ecosystem health.
The reason for that is: Trichoptera includes both widely distributed and locally endemic species, making it highly suitable for assessing biodiversity patterns and climate change effects on freshwater biota. Adults of many species show limited dispersal, allowing the use of their presence as a proxy for site-specific ecological conditions. Together with Plecoptera and Ephemeroptera, these taxa (collectively referred to as EPT taxa) are internationally recognized for their value in ecological monitoring due to their high sensitivity to water pollution, hydromorphological changes, and habitat degradation. Their inclusion enables comparisons with both regional and broader European bioassessment frameworks.
Taxonomic identification:
Specimens were identified in the laboratory using standard taxonomic keys and reference materials. For Trichoptera, the primary identification source was Malicky (2004), supplemented by recent peer-reviewed publications specific to Balkan Trichoptera fauna. For Plecoptera, keys from Zwick (2004) and regionally relevant literature were used. Ephemeroptera were identified using Bauernfeind & Soldán (2012) and subsequent updates in Balkan checklists. Identification was performed to the species level where possible, especially for key indicator taxa, and at the genus or family level when specimens were damaged or lacked distinctive features.
Integration with existing datasets and local knowledge: Taxonomic results were cross-validated using regional biodiversity databases and previously published monitoring studies in Kosovo and surrounding areas. Collaboration with national and regional entomologists and institutions allowed for expert verification of rare or new records. Data collected will contribute to long-term datasets for future modeling of impacts related to climate change, pollution, and land use change, and will support conservation prioritization in freshwater habitats across the Balkans and adjacent biogeographical regions.

SPECIES OF INTEREST AND THEIR IMPORTANCE

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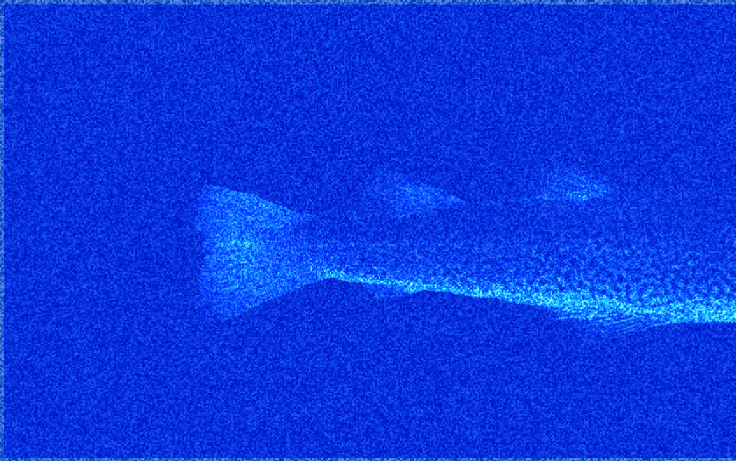

THE SELECTION OF STUDY AREAS WAS MADE IN THREE REGIONS WITH DIFFERENT ECOLOGICAL CONDITIONS, ENABLING COMPARISONS BETWEEN PROTECTED AND NON-PROTECTED HABITATS, AS WELL AS BETWEEN FORESTED AND NON-FORESTED ZONES. THE METHODS USED INCLUDED STANDARDIZED TECHNIQUES FOR COLLECTING AQUATIC INSECTS, SUCH AS UV LIGHT TRAPS AND ENTOMOLOGICAL NETS, COMBINED WITH LARVAL AND MACROINVERTEBRATE SAMPLING USING A D-NET. SAMPLES WERE IDENTIFIED AT THE TAXONOMIC LEVEL USING REGIONAL KEYS AND SCIENTIFIC LITERATURE, WHILE THE DATA WERE CROSS-CHECKED WITH EXISTING DATABASES FOR VERIFICATION. THE FOCUS WAS ON INDICATOR TAXA SENSITIVE TO POLLUTION AND CLIMATE CHANGE (EPT), ALLOWING THE ASSESSMENT OF ECOLOGICAL STATUS AND THE ESTABLISHMENT OF BASELINES FOR LONG-TERM MONITORING AND FRESHWATER HABITAT CONSERVATION.

This study focuses on aquatic insects, with particular attention to species within the Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) orders—collectively known as the EPT group. These taxa are widely recognized as central biodiversity components in freshwater ecosystems due to their diverse ecological roles and their exceptional sensitivity to environmental change. They function both as key contributors to ecosystem processes and as highly reliable bioindicators, providing early warnings of ecological stress long before it becomes evident through more visible changes in the environment.

The EPT taxa are involved in critical ecosystem services such as the breakdown of organic material, recycling of nutrients, and the transfer of energy through aquatic food webs. They also contribute to sediment processing, leaf litter decomposition, and the maintenance of water quality by grazing on periphyton and other organic matter. Their presence, abundance, and diversity are closely tied to habitat quality, water chemistry, and temperature regimes, making them highly responsive to disturbances such as:

- Pollution — including nutrient enrichment, chemical contamination, and organic loading.

- Thermal alterations — caused by climate change, loss of riparian shading, or altered flow regimes.

- Hydrological disruption — from dam construction, water extraction, or channel modification.

- Habitat degradation — including sedimentation, deforestation of riparian zones, and bank erosion.

Because many EPT species have narrow ecological tolerances, short life cycles, and limited dispersal capabilities, they are among the first organisms to decline in degraded environments. Conversely, their presence in healthy numbers is a strong indicator of ecosystem integrity. For these reasons, they are widely used in biomonitoring programs worldwide to assess water quality, detect pollution events, and evaluate the effectiveness of restoration measures.
In the context of Kosovo's freshwater ecosystems, the EPT taxa hold additional importance due to the region's unique biogeography. Cold, spring-fed streams and headwater creeks—particularly those in karst and mountainous regions—harbor rare and endemic species, some of which have highly restricted distributions and are not recorded elsewhere in Europe. Documenting and protecting these species not only preserves local biodiversity but also contributes to the conservation of broader regional and continental freshwater heritage.
By centering the study on these highly sensitive and ecologically significant insect groups, this research provides a scientifically robust foundation for monitoring environmental change, identifying conservation priorities, and guiding restoration planning in freshwater habitats that are increasingly under pressure from anthropogenic and climatic stressors.

5.1 Why aquatic insects matter

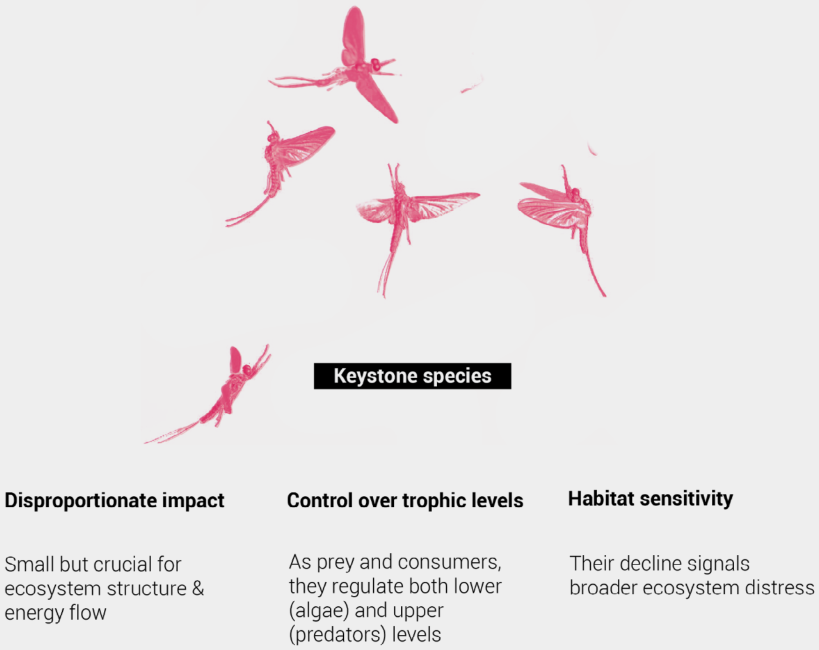

Figure 1. Aquatic insects as keystone species

Aquatic insects are essential components of freshwater ecosystems and play diverse ecological, functional, and scientific roles. In this study, they are treated not only as taxonomic subjects of interest, but as key biodiversity actors — organisms whose presence, behavior, and ecological roles provide deep insights into the health and resilience of aquatic systems. Their relevance unfolds across several interconnected dimensions:

Indicators of ecosystem health

Aquatic insects are among the most reliable bioindicators in freshwater assessments. Their sensitivity to changes in water quality, oxygen levels, pollution, temperature, and habitat structure enables them to reflect ecological integrity with precision. Monitoring their population dynamics allows early detection of environmental stress, even before visible signs emerge in the landscape. Their cumulative responses integrate both short- and long-term pressures, making them ideal for tracking trends across seasons or restoration phases.

Connectors between aquatic and terrestrial environments

Aquatic insects are uniquely positioned across ecological boundaries. Most species undergo metamorphosis from aquatic larvae to terrestrial adults, creating a life cycle that bridges river systems and surrounding landscapes. This dual existence allows them to transfer energy, nutrients, and ecological signals across systems, linking riparian zones, streambeds, and adjacent forests or agricultural areas. Their population health reflects not only aquatic conditions but also broader land-use patterns.

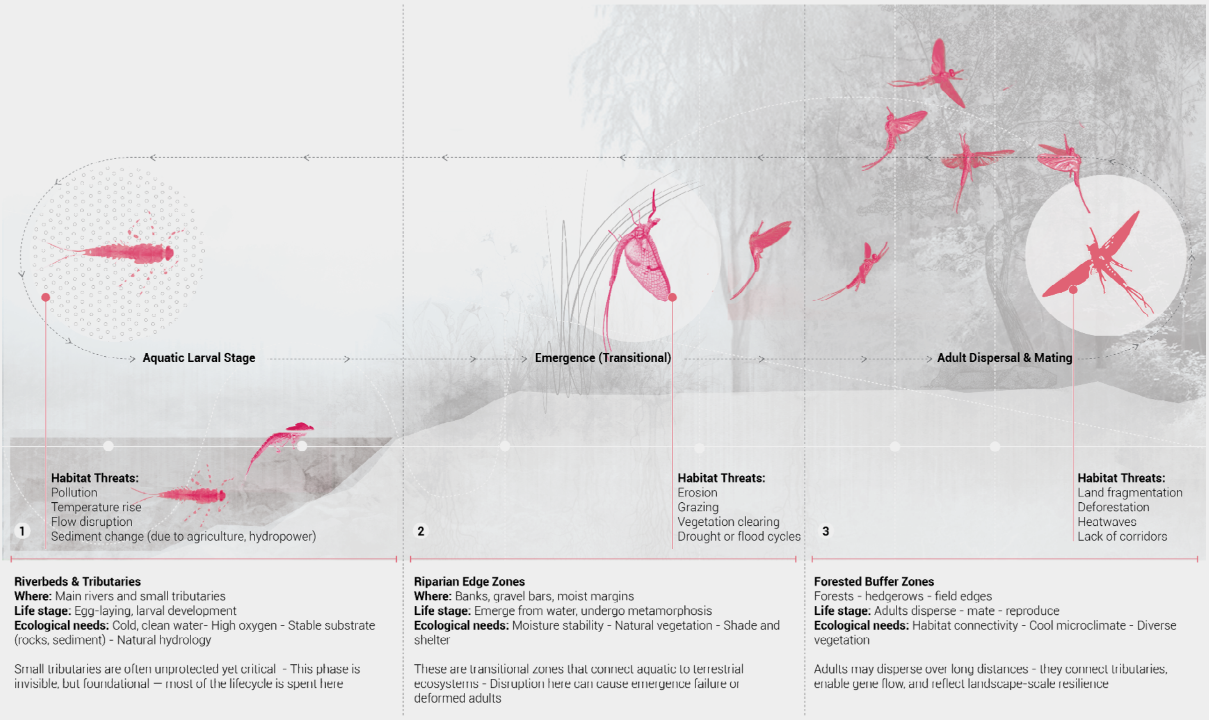

Figure 2. The Metabolic Landscape : Aquatic Insect Life and Habitat Are Connected Across Space and Time

Supporters of food webs

From their role as detritivores in the larval stage to their function as prey in the adult stage, aquatic insects sustain the dietary needs of a wide range of organisms — including amphibians, birds, bats, and fish. Their functional diversity contributes to trophic stability and supports a resilient food web both in and around freshwater bodies.

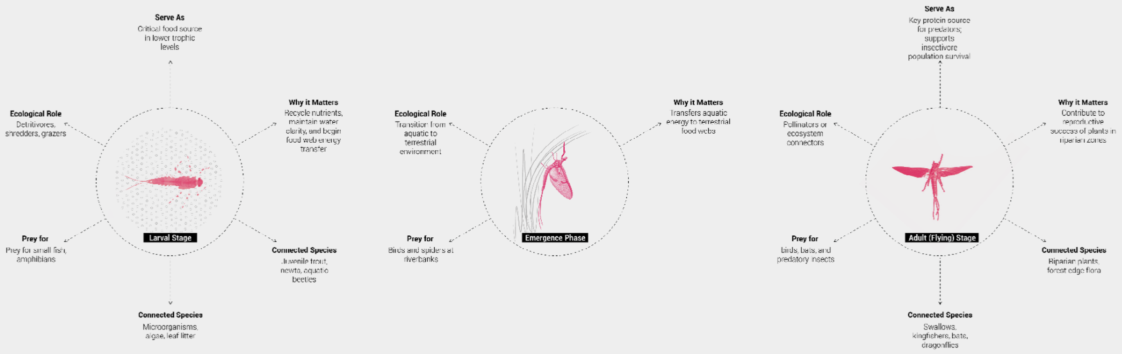

Figure 3. Aquatic Insects Cross phase importance

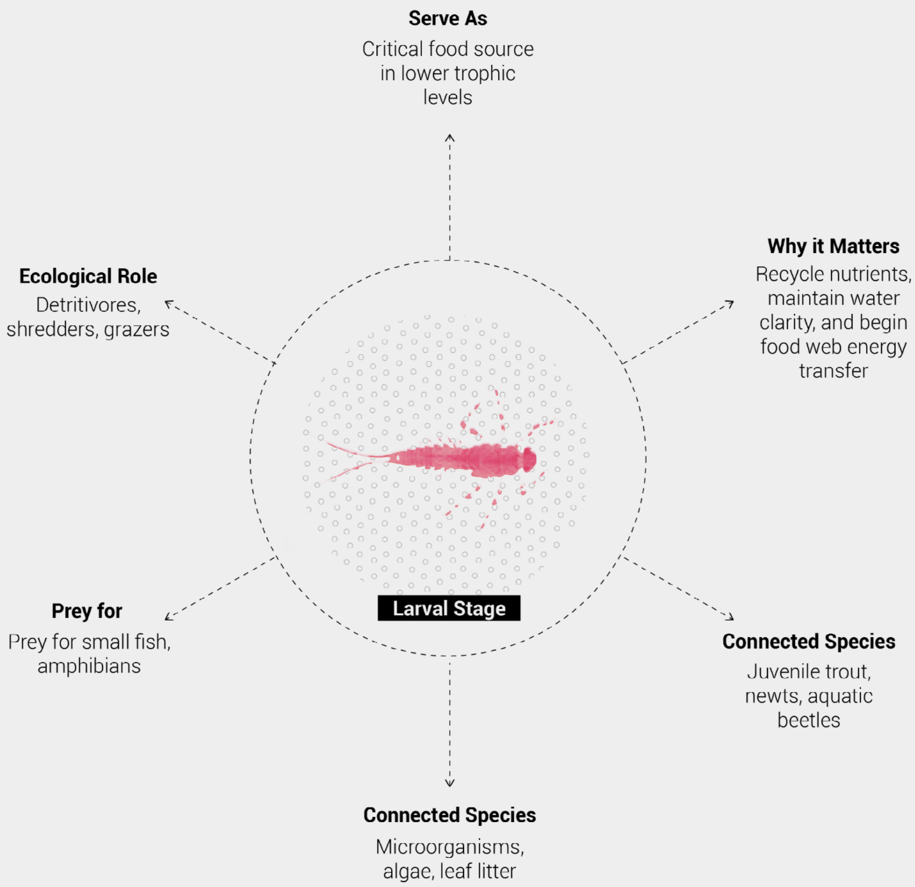

Figure 4. Importance of Aquatic Insects during the Larval Stage

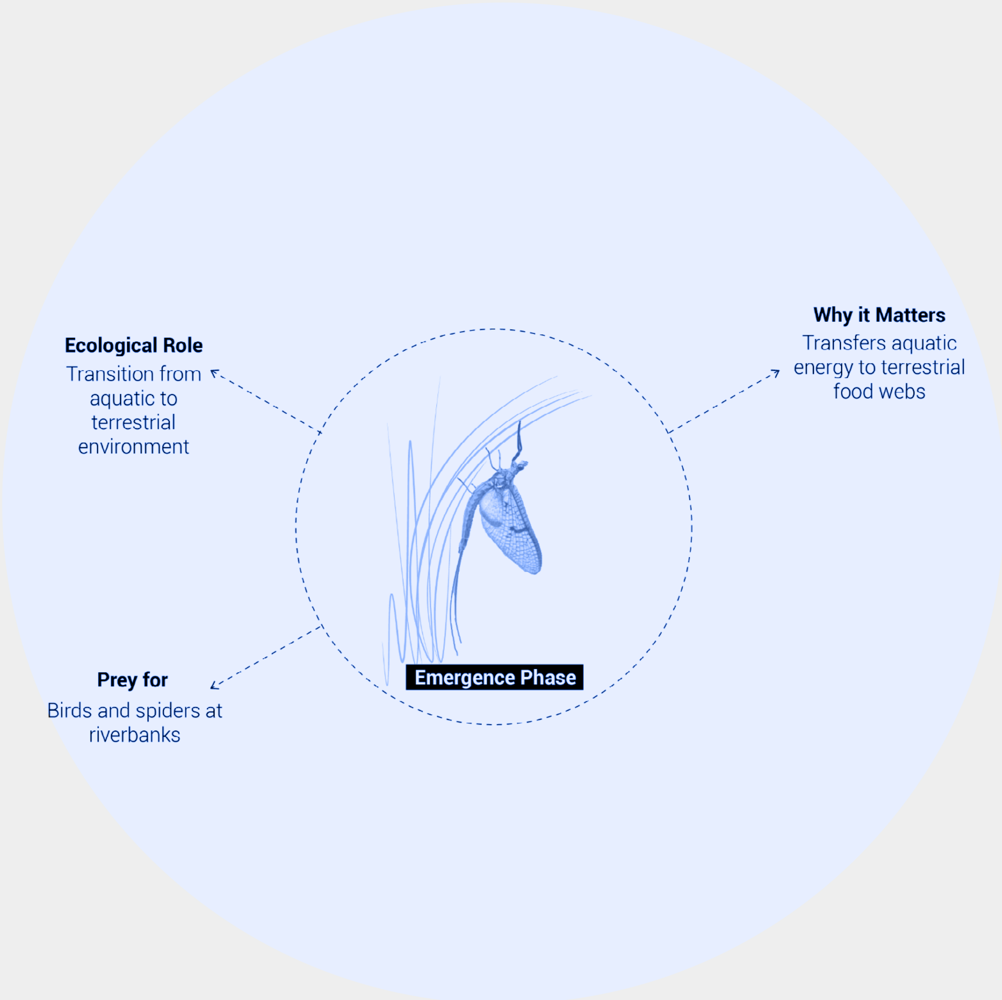

Figure 5. Importance of Aquatic Insects during the Emergence Stage

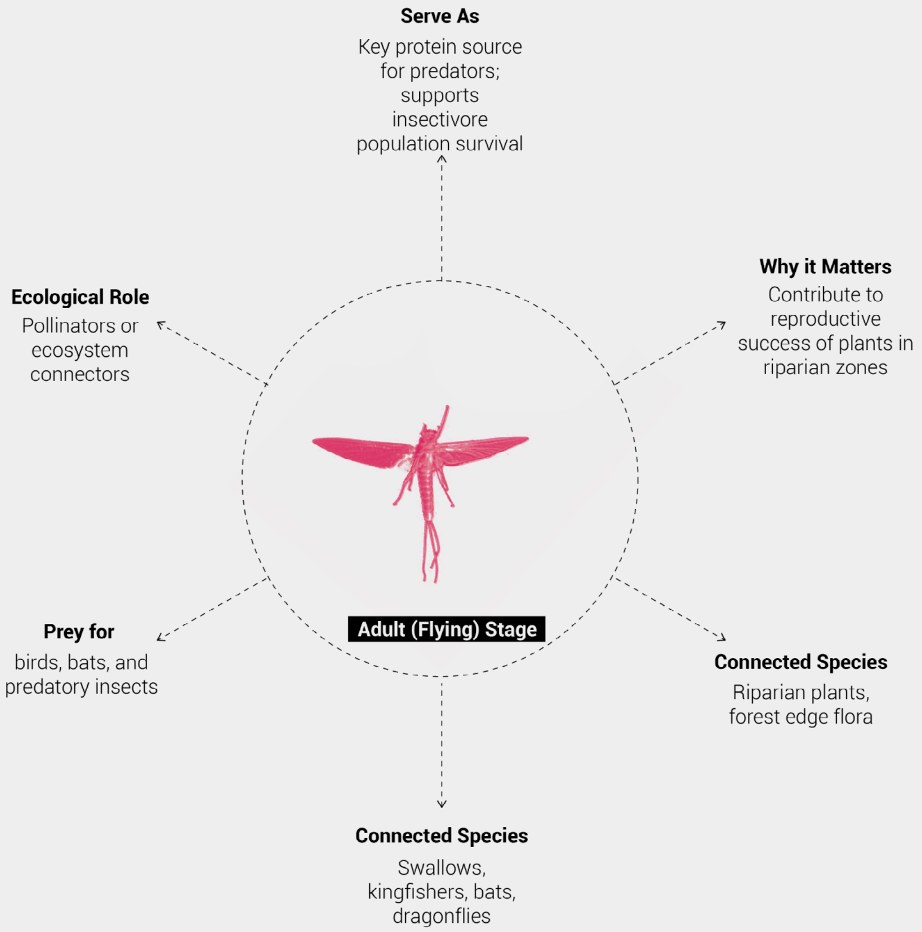

Figure 6. Importance of Aquatic Insects during the Adult Stage

Specialists with narrow habitat requirements

Many aquatic insect species have highly specific environmental needs: clean, oxygenated, fast-flowing waters; particular substrate types; or shaded, undisturbed banks. As such, they are often the first organisms to disappear in response to degradation, pollution, or hydrological change. Their presence or absence can thus help identify subtle or emerging vulnerabilities in freshwater habitats — even those that may appear intact on the surface.

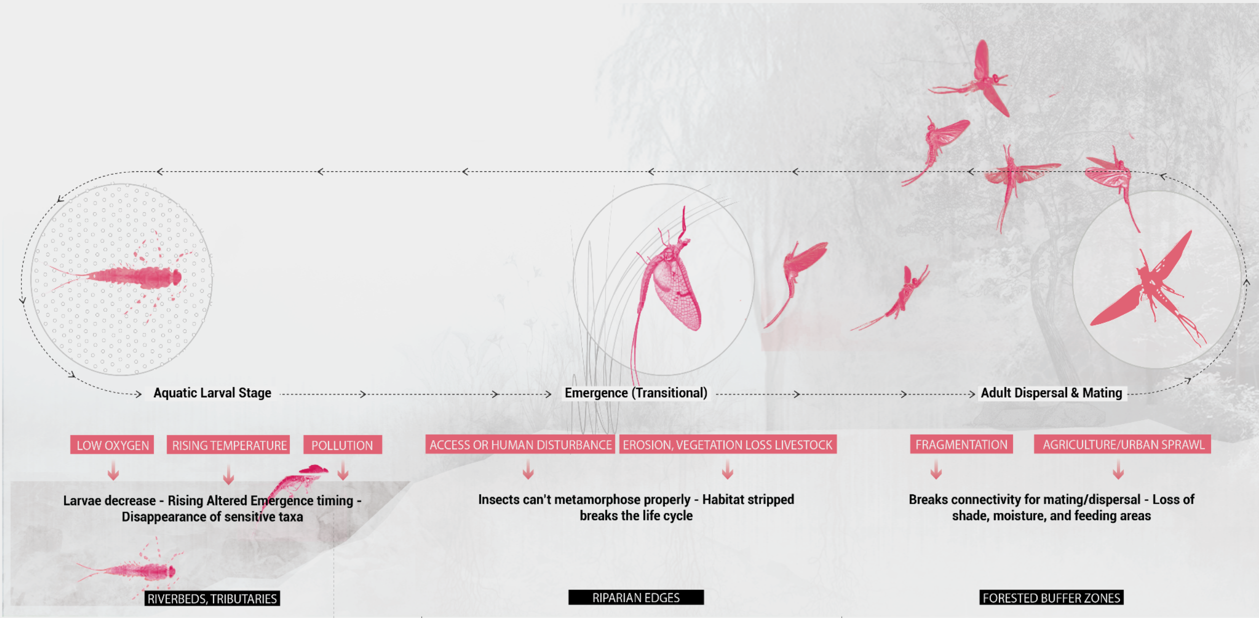

Figure 7. Risk Levels of Aquatic Insects: Aquatic insects react to environmental changes before we see visible damage

Catalysts of ecosystem processes and biodiversity resilience

Through behaviors such as sediment mixing (bioturbation), organic matter decomposition, and nutrient recycling, aquatic insects actively shape freshwater ecosystems. These ecosystem services increase water clarity, oxygenation, and overall system health, contributing to a multifunctional habitat that is more capable of withstanding stress and change. Their role is particularly valuable in dynamic or degraded environments where resilience is key.

Ecological function

Aquatic insects occupy foundational ecological roles. They process detritus, regulate algal populations, and facilitate the flow of energy across trophic levels. These ecological processes are vital not just for species survival, but for maintaining the physical and biological integrity of freshwater ecosystems over time.

Liminal position

By inhabiting both water and land, aquatic insects are embedded in edge ecologies — zones where multiple systems overlap and interact. Their life cycles are highly attuned to environmental conditions in both domains, and they are affected by changes in microclimate, hydrology, vegetation, and land use. Their liminal nature underscores the need for integrated, landscape-scale approaches to biodiversity monitoring and habitat restoration.

Data scarcity

Despite their ecological significance, aquatic insects remain understudied in Kosovo and much of the Western Balkans. This is partly due to the taxonomic complexity of the group, the lack of trained specialists, and the resource intensity of identification. As a result, aquatic insects are often excluded from baseline assessments and environmental planning, leading to gaps in ecological understanding and limited inclusion in biodiversity strategies.

Policy relevance

Globally, aquatic insects form the backbone of many standardized monitoring frameworks, such as the EU Water Framework Directive, which emphasizes biological quality elements like macroinvertebrate diversity. Including them in national assessments supports evidence-based environmental governance, aligns with European directives, and allows for comparative analysis across regions and timeframes.

Restoration guidance

Because aquatic insects are habitat-sensitive and occur in well-characterized ecological niches, they are highly valuable in assessing the potential for habitat restoration. Studying relatively intact sites (e.g. in protected areas) alongside degraded ones (e.g. in non-protected zones) enables the identification of reference conditions and informs practical, site-specific restoration strategies that consider both biological needs and landscape dynamics.

5.2 Sensitive Taxa and Emerging Biodiversity Vulnerabilities

Emerging Vulnerabilities

The fieldwork deliberately engages with a wide range of aquatic insect taxa—not only well-established bioindicators, but also those species that may currently lie outside formal conservation frameworks yet exhibit signs of ecological stress. This includes taxa with habitat specialization, reduced local abundance, or limited adaptability, which may not (yet) carry a protected status but reveal latent or emerging vulnerabilities. These organisms act as anticipatory signals—biological sentinels capable of exposing degradation trajectories before they manifest in broader ecosystem collapse or reach thresholds requiring legal recognition. Their observation enables a more precautionary and forward-looking ecological analysis.

Endemic and Regionally Vulnerable Species

The study accords heightened attention to endemic or regionally vulnerable species, where encountered. These taxa often possess narrow ecological niches and limited geographic distribution, rendering them disproportionately sensitive to climatic variability, hydrological changes, and habitat disturbance. Their presence not only reflects evolutionary distinctiveness and contributes to the resilience of localized ecosystems but also holds legal and policy relevance. Detection and documentation of such species can inform urgent conservation priorities, support additions to national red lists, and strengthen the biodiversity knowledge base in a context where systematic records remain scarce. This layered focus—on both emerging and recognized vulnerabilities—reinforces the role of aquatic insects as key agents in both ecological assessment and adaptive conservation action.

STUDY IN PROTECTED AND NON-PROTECTED AREA

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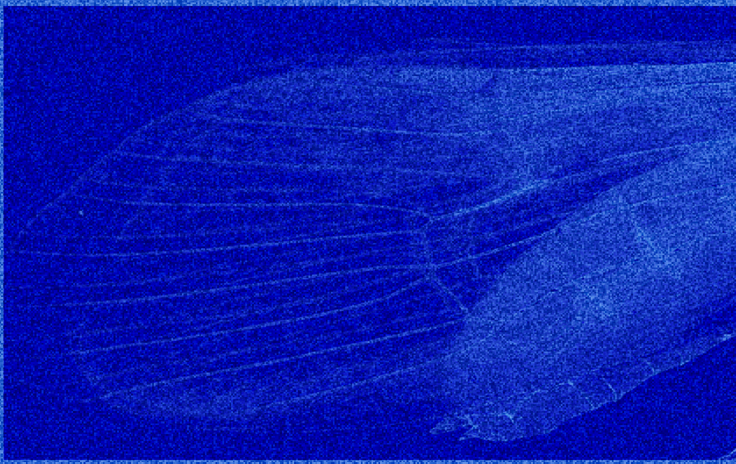

THE STUDY WAS CARRIED OUT IN BOTH PROTECTED AND NON-PROTECTED AREAS TO ASSESS BIODIVERSITY CONDITIONS UNDER DIFFERENT ECOLOGICAL PRESSURES AND LAND-USE REGIMES. PROTECTED AREAS, SUCH AS THE SHARR MOUNTAINS, REVEALED SHRINKING HABITATS FOR SPECIALIZED AQUATIC INSECTS DUE TO CLIMATE CHANGE, WITH SOME SPECIES BEGINNING TO SHIFT THEIR RANGES. THESE AREAS PROVIDE VALUABLE MODELS FOR RESTORATION STRATEGIES, AS THEY STILL MAINTAIN SUITABLE CONDITIONS FOR SENSITIVE TAXA. IN CONTRAST, NON-PROTECTED AREAS OFFERED INSIGHTS INTO ECOLOGICAL TRANSITIONS AND RESTORATION POTENTIAL, HIGHLIGHTING OPPORTUNITIES TO CREATE CONNECTIVITY AND NEW REFUGES FOR VULNERABLE SPECIES UNDER CLIMATE STRESS.

The field study was conducted in both protected and non-protected areas to understand biodiversity conditions under varying ecological pressures and land-use regimes. This dual approach is essential for mapping species vulnerability, anticipating shifts, and identifying restoration opportunities.

6.1. Protected Areas: Shrinking Habitats for Specialists, Shifting Ranges, and Restoration

Protected areas, such as the Sharr Mountains, are key zones where many specialist species of aquatic insects are still found. These organisms are highly adapted to specific ecological conditions — cold, clean, oxygen-rich freshwater bodies, often with stable riparian vegetation and little disturbance. However, climate change is rapidly altering these habitats, causing changes in water temperature, seasonality, and flow regimes, leading to the shrinking of suitable habitats for these specialists.

Beyond this, there is increasing evidence that some species are beginning to shift their ranges, moving in search of new viable habitats as conditions change. This raises the urgent need for long-term monitoring to understand these movements and anticipate biodiversity loss or transformation before it becomes irreversible.

Finally, protected areas serve as ecological blueprints. Their relatively intact habitats provide reference conditions that can inform restoration strategies in degraded zones. By observing which conditions support specialist taxa, we gain insight into what kinds of habitats should be restored elsewhere, particularly nearby where similar ecological potentials exist.

6.2 Non-Protected Areas: Observing Transitions and Restoration Potential

Non-protected sites—like those in the vicinity of Prizren—offer a complementary perspective. These areas may still host fragmented or degraded habitats with potential to support aquatic insects, especially as species begin to migrate from stressed protected zones. By studying these sites, we gain a better understanding of the current ecological state, the feasibility of connectivity, and the potential for habitat restoration.

The goal is to not only document what still exists in non-protected landscapes, but also to evaluate their future role in supporting biodiversity as shifting ecologies unfold. This includes identifying suitable conditions that could be restored or enhanced to provide refuge and continuity for vulnerable species under climate stress.

CHALLENGES AND GAPS

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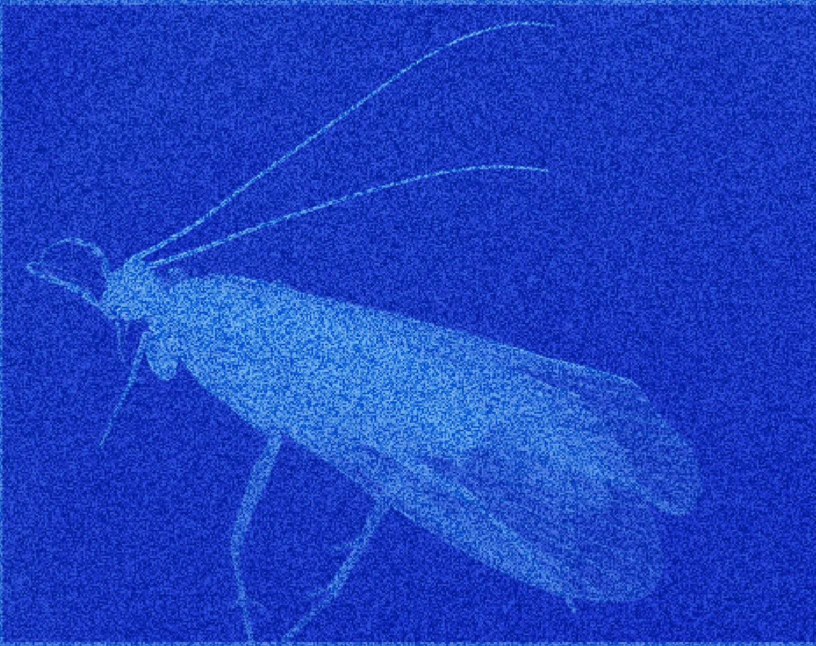


THE MAIN CHALLENGES AND GAPS IN STUDYING AQUATIC INSECTS IN KOSOVO STEM FROM THE LACK OF BASELINE DATA AND CONTINUOUS MONITORING, SEASONAL DIFFICULTIES IN SAMPLING, SHORTAGE OF TRAINED SPECIALISTS, AND ABSENCE OF DETAILED SPATIAL BIODIVERSITY INFORMATION. AQUATIC INSECTS REMAIN ONE OF THE LEAST STUDIED GROUPS IN THE REGION, WITH EXISTING RECORDS FRAGMENTED AND GEOGRAPHICALLY LIMITED, HINDERING NATIONAL BIODIVERSITY ASSESSMENTS AND CONSERVATION POLICIES. THIS STUDY ADDRESSES THESE SHORTCOMINGS BY GENERATING NEW, SPATIALLY DISTRIBUTED DATA, PROVIDING A FOUNDATION FOR REGIONAL COMPARISONS, TREND ANALYSIS, AND THE DEVELOPMENT OF FUTURE CONSERVATION AND RESTORATION STRATEGIES.

1. Challenges and Gaps

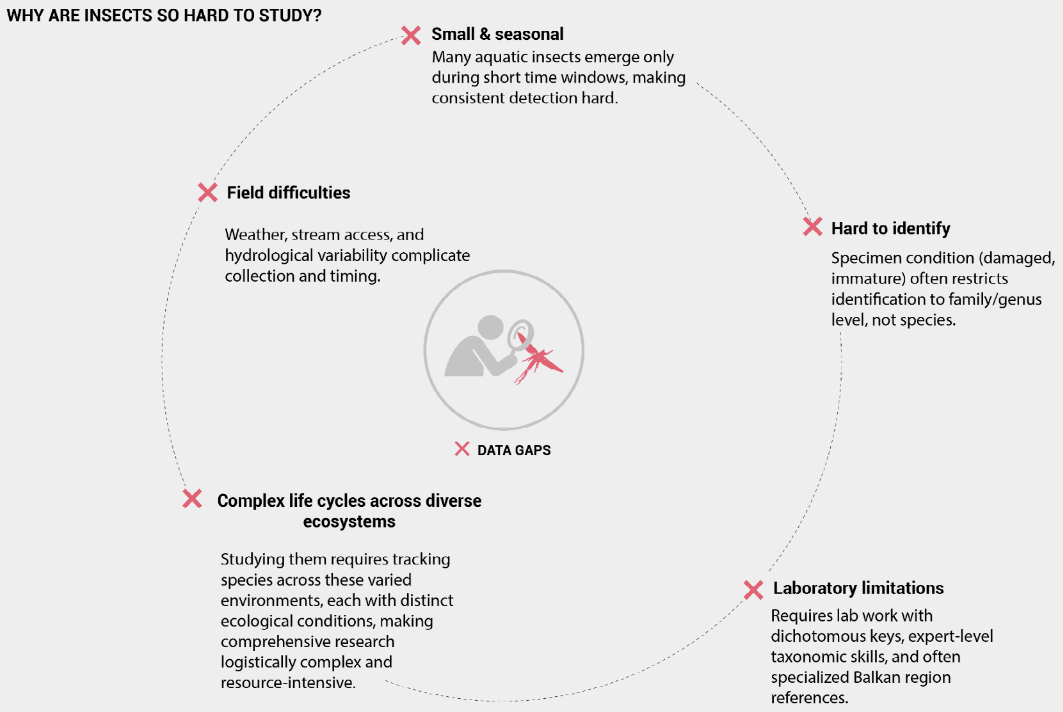


Figure 8. Why Is It Difficult to Study Insects? Scientific & Technical Barriers

- **Limited prior data on aquatic insects in Kosovo**

There is a significant lack of baseline data on aquatic insect biodiversity in Kosovo. Although this study benefits from the expertise of one of the few entomologists in the Balkans specializing in this field, aquatic insects remain among the least studied biological groups in the region. Most existing records are either fragmented, or geographically narrow, offering limited insight into current ecological conditions, species diversity, or spatial distribution patterns. The absence of consistent monitoring, taxonomic research, and ecological assessments has left major knowledge gaps, particularly concerning the role of aquatic insects in freshwater ecosystem health. This scarcity of data not only hinders national biodiversity assessments but also limits the development of evidence-based conservation policies and restoration strategies. By generating new, site-specific, and spatially distributed data, this study aims to lay the groundwork for future ecological monitoring and decision-making in Kosovo and the wider region.

- **Seasonal variation and sampling difficulties**

The detectability of aquatic insects is highly seasonal, with many taxa emerging only during specific periods—such as late summer—making it difficult to obtain a comprehensive understanding through single-season sampling. Weather variability, stream flow changes, and logistical constraints further complicate sampling efforts.

- **Shortage of trained specialists in freshwater entomology**

There is a limited number of local experts with training in aquatic insect taxonomy and ecological assessment, which restricts the depth and continuity of long-term biodiversity monitoring and conservation planning.

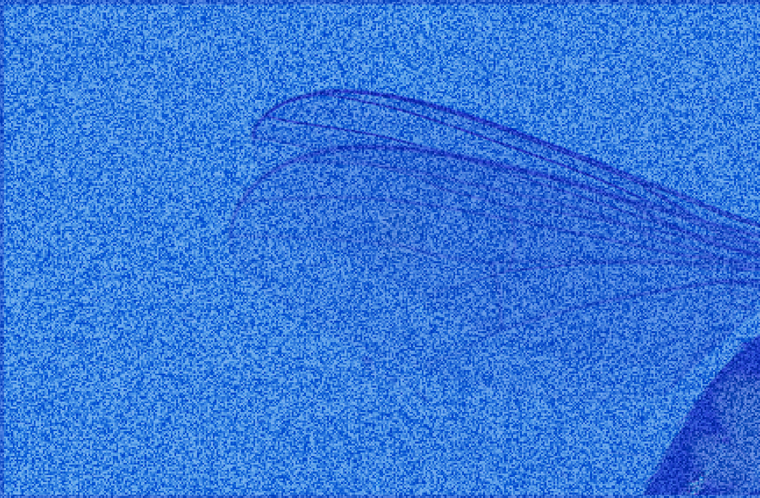
- **Absence of spatially explicit biodiversity data**

This study addresses a major gap by collecting not only data on the presence of aquatic insects, but also on their spatial distribution across different sites. The longitudinal and elevational spread of species occurrences has not been systematically mapped before in Kosovo. As a result, there has been no basis for regional comparison or trend analysis. This project represents a first step toward establishing that spatial baseline and enabling future comparative studies.

Figure 9. Why Is It Difficult to Study Insects? Institutional & Social Barriers

SURVEY AND LABORATORY FINDINGS

8



THE RESULTS OF THE STUDY SHOW THAT AQUATIC INSECTS (PARTICULARLY EPT GROUPS) SERVE AS CLEAR INDICATORS OF THE ECOLOGICAL STATUS OF FRESHWATER HABITATS IN KOSOVO, REVEALING CONTRASTS BETWEEN PROTECTED AND NON-PROTECTED AREAS AS WELL AS BETWEEN FORESTED AND NON-FORESTED HABITATS. SENSITIVE SPECIES WERE MOSTLY RECORDED IN WELL-PRESERVED SITES, WHILE DEGRADED AREAS EXHIBITED FRAGMENTED COMMUNITIES AND LOWER DIVERSITY. THESE FINDINGS CONFIRM THE ROLE OF AQUATIC INSECTS AS BIOINDICATORS AND HIGHLIGHT THE NEED FOR LONG-TERM MONITORING AND RESTORATION MEASURES TO STRENGTHEN ECOSYSTEM RESILIENCE UNDER CLIMATIC AND ANTHROPOGENIC PRESSURES.

8.1 Species list and classification

To date, the field surveys have yielded a preliminary inventory of aquatic insect taxa across the three study areas, focusing on Trichoptera, Ephemeroptera, and Plecoptera, along with other macroinvertebrate groups. Species have been organized by order, family, and genus to the highest resolution achievable given specimen condition and diagnostic features. This classification not only provides a taxonomic snapshot of current biodiversity but also forms the basis for subsequent ecological analysis, including comparisons between protected and non-protected sites, assessments of habitat specificity, and the identification of sensitive or potentially vulnerable taxa.

8.2 Habitat descriptions

These insects are ecologically sensitive and spatially embedded. Their lifecycle depends on the functioning of distinct yet interconnected habitat types, from riverbeds and sediment layers to riparian zones and surrounding forested areas. By grounding biodiversity assessment in their life cycle and translating each developmental stage into a corresponding spatial habitat, we are able to better understand how landscape-level pressures such as pollution, land use change, and climate variability impact ecological functioning.

To do so, we identify three critical phases in the life cycle of selected aquatic insect species:

- Aquatic breeding and larval development phase
- Transitional emergence and riparian edge phase
- Terrestrial dispersal and reproduction phase

Each of these phases corresponds to a specific habitat that can be spatially mapped and assessed for vulnerability. This translation from life cycle to habitat forms the core of our spatial and ecological mapping methodology. By analyzing the conditions and pressures facing each of these habitat types, we gain a more precise and actionable understanding of how biodiversity is being reshaped.

A. Riverbeds and secondary tributaries (Aquatic breeding and larval development phase)
This habitat corresponds to the aquatic breeding and larval development phase. It includes the main river channels, smaller tributaries, and seasonal watercourses where aquatic insects lay eggs and complete their early developmental stages. These zones are highly sensitive to changes in water temperature, pollution, hydrological regime, oxygen levels, and substrate composition. Disruption in these conditions can lead to significant reductions in larval survival.

B. Riparian edge zones (Transitional emergence and riparian edge phase)
These areas reflect the transitional emergence phase, where insects move from water to land.

Comprising riverbanks, gravel bars, moist soil margins, and low riparian vegetation, these zones support metamorphosis and successful emergence into the terrestrial phase. Their integrity is often compromised by erosion, grazing, vegetation clearance, and changes in moisture and temperature regimes.

C. Forested buffer zones (Terrestrial dispersal and reproduction phase)
This final habitat corresponds to the terrestrial dispersal and reproduction phase. Adult insects rely on surrounding forested and shrubby areas for feeding, mating, and dispersal. These zones also serve as ecological corridors, supporting gene flow and population connectivity. They are threatened by land fragmentation, deforestation, rising temperatures, and loss of habitat complexity—all of which limit species mobility and resilience.
By starting from the ecological specificity of these life stages and translating them into spatial units of analysis, the study produces a framework for mapping biodiversity vulnerability in a way that is both biologically meaningful and spatially relevant. This methodology allows us to anticipate where vulnerabilities are emerging—often before they are captured in conventional conservation inventories such as red lists—and to develop more proactive, habitat-based strategies for biodiversity resilience.

8.3 Survey Findings and Species Identification

The following section compiles and interprets the outcomes of the field surveys and subsequent laboratory analyses undertaken across the designated study areas. Building on the preceding taxonomic overview and habitat descriptions, the focus here is on the detailed distribution and identification of aquatic insect taxa, interpreted within the ecological and spatial frameworks previously outlined. Species presence and relative abundance are presented at the highest possible taxonomic resolution achievable from the collected material—progressing from order to family, genus, and, where diagnostic characters permitted, species level.

The analysis is organized by study site, reflecting the diversity of aquatic and riparian habitats examined, including riverine channels, small tributaries, forested creeks, and riparian edge zones. Within each site narrative, the results are structured to include:

- Site location and sampling approach, including geographic coordinates, habitat type, and trapping or collection methods.
- Key taxa and notable records, highlighting species of conservation interest such as endemic, rare, or threatened taxa, as well as records that extend known distributions or indicate ecological change.
- Patterns of distribution and abundance, examined in relation to riparian distance gradients, altitudinal differences, or longitudinal river profiles, as relevant to the site's characteristics.
- Ecological and conservation implications, identifying potential vulnerabilities, habitat dependencies, and management priorities derived from the observed patterns.

Detailed tabulated data accompany each site description, providing quantitative context for the qualitative interpretations. These tables include counts and proportional representation of taxa, enabling cross-referencing between field-collected data and broader ecological trends. Where relevant, observations from multiple collection periods or seasonal replicates are included to illustrate temporal dynamics in species composition and abundance.
Together, these site-specific results contribute to a more granular understanding of biodiversity distribution within the study region, offering a basis for detecting habitat-specific assemblages, identifying areas of high conservation value, and informing targeted management strategies.

8.3.1 Study area 1: Riverine ecosystem inside a beech forested area inside Sharr Mountain National Park

Description of the site: Upper reach of the Lepenc River surrounded by forested area inside National Park. The site is concentrated around these coordinates 42.172216N, 20.988126E.
Sampling method: Ultraviolet light traps placed at different distances from the river.
This dataset (Table 1) highlights the distribution of adult Trichoptera species relative to the riverine environment and shows that the surrounding terrestrial habitats play a significant role in their ecology.

- Most species have the highest number of specimens found directly at the river edge (0 m), which aligns with their aquatic larval stages that develop in the river or stream.
- However, many species also have notable numbers of adult individuals found at increasing distances from the riverbank (up to 500 m). For example, Hydropsyche sp. females show a broad distribution, with adults present from 0 m all the way out to 500 m, including large numbers at 50 m (41 specimens) and 100 m (19 specimens). This indicates that adults of this species disperse quite far from the aquatic habitat, utilizing the surrounding terrestrial zones. Hydropsyche sp. are otherwise adaptable to different water quality and rarely contain any rare species from the endemism perspective.
- Other species such as Drusus discolor, Rhyacophila balcanica, and Plectrocnemia conserpsa also have a considerable number of adults found at 50 m and 100 m distances, suggesting these riparian zones are important for adult activities such as mating, feeding, or shelter.
- The critically endangered species Drusus sharrensis was found with only one specimen and strictly at the river edge (0 m), indicating either a very restricted distribution or low dispersal ability, emphasizing its vulnerability. The species' main habitat is however not the riverine ecosystem but small creeks in vicinity.
- Species with fewer specimens found farther from the river, such as Limnephilus lunatus and Wormaldia subterranea, might be more closely tied to the aquatic habitat or less capable of dispersal.
- The presence of adults at distances up to 500 m shows the importance of buffer zones and intact riparian vegetation for maintaining healthy populations of Trichoptera. These areas provide shelter, and microhabitats critical for the adult terrestrial phase.

Importance of surrounding habitats for Trichoptera:

- The riparian terrestrial zone surrounding rivers and streams is crucial for adult caddisflies. These habitats support behaviors like dispersal, reproduction, and resting.
- Maintaining natural vegetation and habitat heterogeneity in riparian zones is essential to support both aquatic larvae and terrestrial adults, thus ensuring the full life cycle of these species.
- Conservation efforts should focus not only on water quality and aquatic habitat but also on protecting the adjacent terrestrial environment, especially within at least 100 to 500 meters from the river, to sustain viable populations of diverse Trichoptera species.
- For species with conservation concern, such as Drusus sharrensis and Rhyacophila sarplana, strict protection of their known habitats including the riverbank zone is vital due to their limited dispersal and rarity.
- There is strong correlation between dispersal ability vs. rarity and endemicity of species in terms that species which are rare and/ or endemic tend to have less dispersal ability contrary to species which are widespread which tend to have high dispersal ability. This means that in terms of vulnerability to extinction rare and/or endemic species will be first to be impacted in scenarios of habitat deterioration and/or other factors such as pollution and climate change. Thus, maintaining their habitats in current form is crucial for their existence.

Table 1. Composition of the aquatic insect fauna at study area 1.

Species	IUCN status in Kosovo	Rarity in Kosovo	Endemism	No. of specimens/Distance from the river in meters							
				0	50	100	150	200	300	400	500
Drusus discolor	Not Evaluated	Rare	Europe	52	25	12	5		2		
Drusus sharrensis	Critically Endangered	Rare	Kosovo	1							
Hydropsyche sp.	Not Evaluated	Widespread	Europe	13	41	19	8	12	5	3	1
Limnephilus lunatus	Not Evaluated	Rare	Europe	12		1			1		
Limnephilus vittatus	Not Evaluated	Rare	Europe	3	4	1		1			
Micropterna sequax	Not Evaluated	Relatively widespread	Europe	13	3	3					
Philopotamus montanus	Not Evaluated	Widespread	Europe	21	8	4					
Philopotamus variegatus	Not Evaluated	Rare	Europe	23	13						
Plectrocnemia brevis	Not Evaluated	Relatively widespread	Europe	33	21						
Plectrocnemia conserpsa	Not Evaluated	Relatively widespread	Europe	32	25	2		1			
Potamophylax pallidus	Not Evaluated	Widespread	Europe	14	3	1					
Rhyacophila balcanica	Near Threatened	Rare	Southeastern Europe	41	12	4	2				
Rhyacophila loxias	Not Evaluated	Rare	Europe	24	14	3		2	1		
Rhyacophila sarplana	Vulnerable	Rare	Western Balkans	3	1						
Wormaldia subterranea	Data Deficient	Rare	Europe	15	2			1			

Figure 10. Study Area 1 — UV light-trap sampling of caddisflies (Trichoptera). Bubble size shows specimens recorded per species at trap stations set 0–500 m from the river (0 m = river edge). Marker fill shows rarity in Kosovo (Rare, Relatively Widespread, Widespread); IUCN status is noted where evaluated (CR, VU, NT).

Abundance and richness peak within 0–100 m, led by taxa such as Drusus discolor, Drusus sharrensis, and Rhyacophila balcanica. Detections drop sharply beyond ~200–300 m, indicating most adults remain near the channel. The concentration of nationally rare taxa near the water underscores the need to protect the riparian corridor.

8.3.2 Study area 2: Stream ecosystem inside a beech forested area inside Sharr Mountain National Park

Description of the site: Upper reach of the Lepenc River surrounded by forested area inside National Park. The site is concentrated around these coordinates 42.172804N, 20.969464E.

Sampling method: Ultraviolet light traps placed at different distances from the river.
This dataset (Table 2) highlights the distribution of adult Trichoptera species relative to the riverine environment and shows that the surrounding terrestrial habitats play a significant role in their ecology.

- Most species have the highest number of specimens found directly at the river edge (0 m), which aligns with their aquatic larval stages that develop in the river or stream.
- However, many species also have notable numbers of adult individuals found at increasing distances from the riverbank (up to 500 m). For example, Plectrocnemia conspersa shows a broad distribution, with adults present from 0 m all the way out to 500 m, including large numbers at 50 m (32 specimens) and 100 m (16 specimens). This indicates that adults of this species disperse quite far from the aquatic habitat, utilizing the surrounding terrestrial zones. Plectrocnemia conspersa is otherwise widespread and not considered rare or endemic.
- Other species such as Hydropsyche instabilis, Hydropsyche saxonica, and Silo graellsii also have a considerable number of adults found at 50 m and 100 m distances, suggesting these riparian zones are important for adult activities such as mating, feeding, or shelter.
- The critically endangered species Drusus sharrensis with only two specimens and strictly at the river edge (0 m), indicating either a very restricted distribution or low dispersal ability, emphasizing its vulnerability. The species' main habitat is however not the riverine ecosystem but small creeks in vicinity.
- Species with fewer specimens found farther from the river, such as Glossosoma intermedium, Rhyacophila sarplana, and Synagapetus iridipennis, might be more closely tied to the aquatic habitat or less capable of dispersal.
- The presence of adults at distances up to 500 m shows the importance of buffer zones and intact riparian vegetation for maintaining healthy populations of Trichoptera. These areas provide shelter, and microhabitats critical for the adult terrestrial phase.

Importance of surrounding habitats for Trichoptera

- The riparian terrestrial zone surrounding rivers and streams is crucial for adult caddisflies. These habitats support behaviors like dispersal, reproduction, and resting.
- Maintaining natural vegetation and habitat heterogeneity in riparian zones is essential to support both aquatic larvae and terrestrial adults, thus ensuring the full life cycle of these species.
- Conservation efforts should focus not only on water quality and aquatic habitat but also on protecting the adjacent terrestrial environment, especially within at least 100 to 500 meters from the river, to sustain viable populations of diverse Trichoptera species.
- For species with conservation concern, such as Drusus sharrensis and Rhyacophila sarplana, strict protection of their known habitats including the riverbank zone is vital due to their limited dispersal and rarity.
- There is strong correlation between dispersal ability vs. rarity and endemicity of species in terms that species which are rare and/or endemic tend to have less dispersal ability, contrary to species which are widespread which tend to have high dispersal ability. This means that in terms of vulnerability to extinction, rare and/or endemic species will be first to be impacted in scenarios of habitat deterioration and/or other factors such as pollution and climate change. Thus, maintaining their habitats in current form is crucial for their existence.

Table 2. Composition of the aquatic insect fauna at study area 2.

Species	IUCN status	Rarity in Kosovo	Endemism	No. of specimens/Distance from the river in meters							
				0	50	100	150	200	300	400	500
Drusus discolor	Not Evaluated	Rare	Europe	32	12	8		4	1		
Glossosoma bifidum	Not Evaluated	Rare	Europe	38	12	6	7	3			
Glossosoma intermedium	Not Evaluated	Rare	Southeastern Europe	4							
Glossosoma klotho	Not Evaluated	Rare	Balkans	5	1						
Hydropsyche instabilis	Not Evaluated	Relatively widespread	Europe	29	23	21	8	8	2		4
Hydropsyche saxonica	Not Evaluated	Widespread	Europe	31	23	14	8	8	5	2	2
Limnephilus auricula	Not Evaluated	Relatively widespread	Europe	4	1	1					
Micropterna sequax	Not Evaluated	Relatively widespread	Europe	5				3			
Philopotamus montanus	Not Evaluated	Widespread	Europe	21	8	4					
Plectrocnemia conspersa	Not Evaluated	Widespread	Europe	42	32	16	8	2	4	2	1

Plectrocnemia geniculata	Not Evaluated	Rare	Europe	7	2	4					
Potamophylax luctousus	Not Evaluated	Relatively widespread	Europe	7	2	1					
Rhyacophila fischeri	Near Threatened	Rare		12	4	2					
Rhyacophila loxias	Not Evaluated	Relatively widespread	Europe	12	4						
Rhyacophila tristis	Least Concern	Widespread	Southeastern Europe	5	2						
Sillo graellsi	Not Evaluated	Relatively widespread	Europe	29	19	12	7	5	3	2	
Synagapetus iridipennis	Not Evaluated	Relatively widespread	Europe	12	3	1					
Tinodes pallidulus	Not Evaluated	Relatively widespread	Europe	9	4	1					
Rhyacophila sarplana	Vulnerable	Rare	Western Balkans	4	1						
Drusus sharrensis	Critically Endangered	Rare	Kosovo	2							

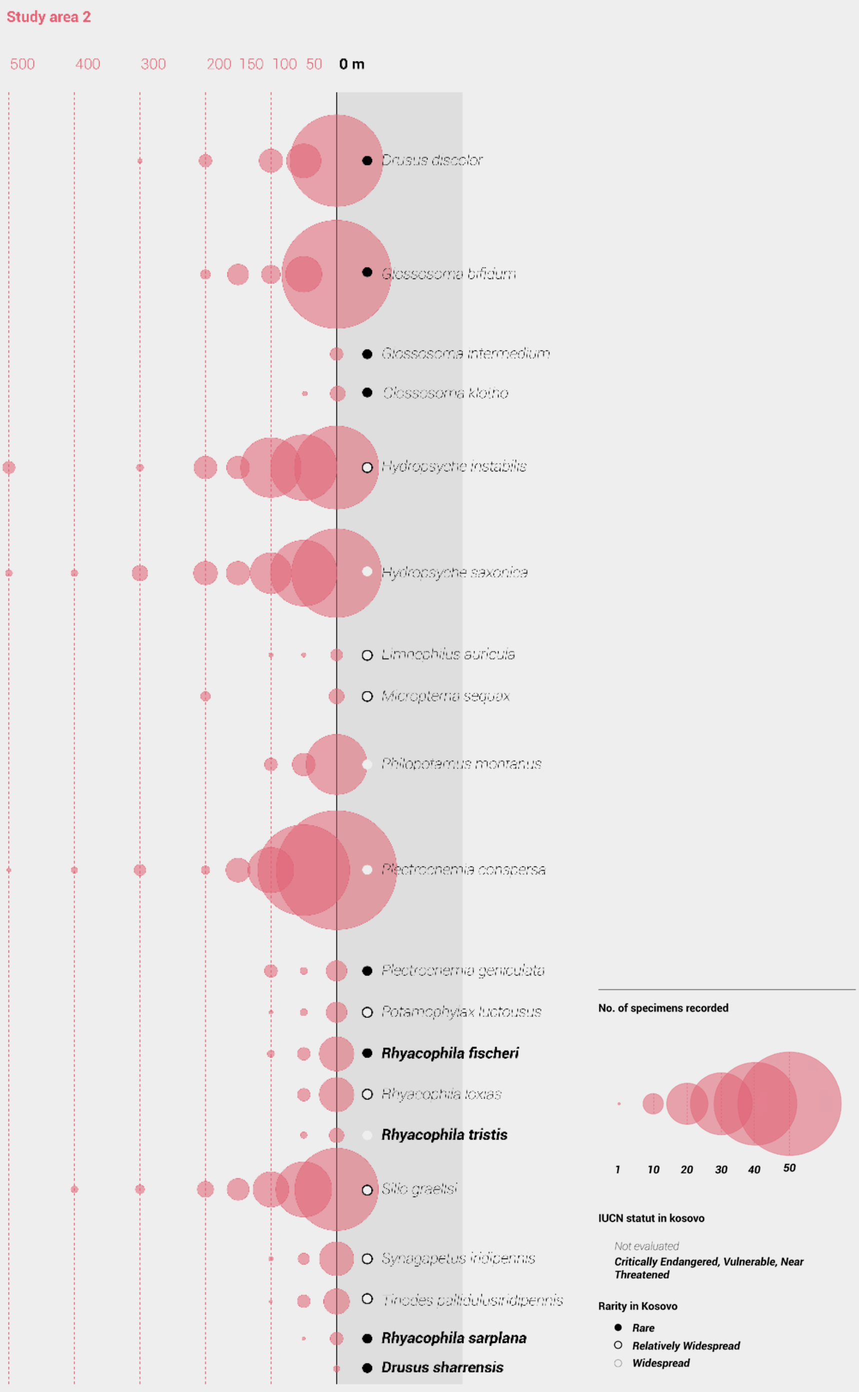


Figure 11. Study Area 2 — UV light-trap sampling of caddisflies (Trichoptera). Bubble size shows specimens recorded per species at trap stations set 0–500 m from the river (0 m = river edge). Marker fill shows rarity in Kosovo (Rare, Relatively Widespread, Widespread); IUCN status is noted where evaluated (CR, VU, NT).
Diversity is high close to the river and features several rheophilic Rhyacophila species (e.g., R. fischeri, R. tristis, R. sarplan), with Drusus sharrensis also present. While captures still occur up to 400–500 m for a few strong-flying taxa, overall abundance decreases with distance. Results point to high-quality flowing-water habitat and emphasize safeguarding near-channel zones.

8.3.3 Study area 3: Small creek inside forested area inside Sharr Mountain National Park

Description of the site: A small creek in vicinity of Lepenc River surrounded by forested area inside National Park. The site is concentrated around these coordinates 42.172216N, 20.988126E. Such creeks exist all along the river. Several such small creeks, tributaries of Restelica River were also studied in an open area without surrounding forested site and they exhibit generally similar composition of species.

Sampling method: Entomological nets.
This dataset (Table 3) provides important insights into the ecological value of small creeks for supporting sensitive and rare caddisfly species in Kosovo and the Western Balkans region. It focuses on a group of species with varying conservation statuses, rarity levels, and endemism patterns, highlighting key aspects of their ecology and conservation importance.

- Small creeks serve as critical refuges for rare and localized caddisfly species. Species such as Drusus sharrensis, Rhyacophila sarplana, Chaetopteryx stankovici, and Wormaldia subterranea are all classified as rare in Kosovo, with distributions largely restricted to particular geographic regions like Kosovo or the Western Balkans. These species often depend on clean, well-oxygenated headwaters with intact surrounding habitat. Their presence in small creeks underlines the ecological significance of these microhabitats.
- Most species listed are endemic or regionally restricted, reinforcing the need to protect their specific habitat types. For instance, Drusus sharrensis is a Kosovo endemic and listed as Critically Endangered, while Odontocerum hellenicum and Rhyacophila sarplana are Western Balkan endemics, both showing limited ranges and vulnerability to habitat changes.
- These species generally exhibit low dispersal ability, particularly those in the families Limnephilidae, Rhyacophilidae, and Philopotamidae. Their life history traits are typically associated with short adult lifespan, limited flight capacity, and strong affinity to localized breeding sites. As such, even minor habitat disturbances in these small creeks could isolate or eliminate local populations.
- A majority of these caddisflies are diurnal, meaning they are active during the day, unlike most caddisflies that are nocturnal. This is particularly true for species in the genus Drusus and Rhyacophila, which are commonly observed flying or mating in daylight, especially on sunny days in spring and early summer. Their diurnal activity has implications for survey timing and conservation monitoring.
- Despite their rarity, the dataset shows relatively high numbers of some species. For example, Drusus sharrensis (19 specimens) and Rhyacophila sarplana (5 specimens) were encountered in numbers that suggest viable local populations, though still vulnerable due to their narrow ranges. In contrast, Chaetopteryx stankovici was represented by only one individual, highlighting its extreme rarity and possibly fragmented population.
- The presence of widespread species like Rhyacophila tristis and Thremma anomalum (21 and 15 specimens, respectively) reflects a broader distribution and greater ecological toler-

ance. However, their co-occurrence with rare and endemic taxa emphasizes the biodiversity richness of these small freshwater systems and their role in supporting both generalist and specialist species.

In conclusion, this dataset underscores the high conservation value of small creeks, especially for endemic and range-restricted Trichoptera species with low dispersal and specific habitat requirements. Conservation strategies must prioritize the protection of these microhabitats, including preserving riparian vegetation, ensuring water quality, and mitigating local disturbances such as road construction, pollution, or deforestation. These efforts are particularly urgent for diurnal species and habitat specialists, whose survival depends on maintaining undisturbed aquatic-terrestrial linkages at the landscape scale.
During our study such small creeks were found at Restelica River as well outside and inside national park boundaries.

Table 3. Composition of the aquatic insect fauna at study area 3.

Species	IUCN status	Rarity in Kosovo	Endemism	No. of speci-mens
Drusus sharrensis	Critically Endan-gered	Rare	Kosovo	19
Rhyacophila tristis	Least Concern	Widespread	Southeastern Europe	21
Rhyacophila sarplana	Vulnerable	Rare	Western Balkans	5
Chaetopteryx stankovici	Near Threatened	Rare	Southeastern Europe	1
Wormaldia subterranea	Not Evaluated	Rare	Southeastern Europe	3
Thremma anomalum	Not Evaluated	Widespread	Southeastern Europe	15
Odontocerum hellenicum	Critically Endan-gered	Relatively wide-spread	Western Balkans	4

Sampling method: Entomological nets

Study area 3

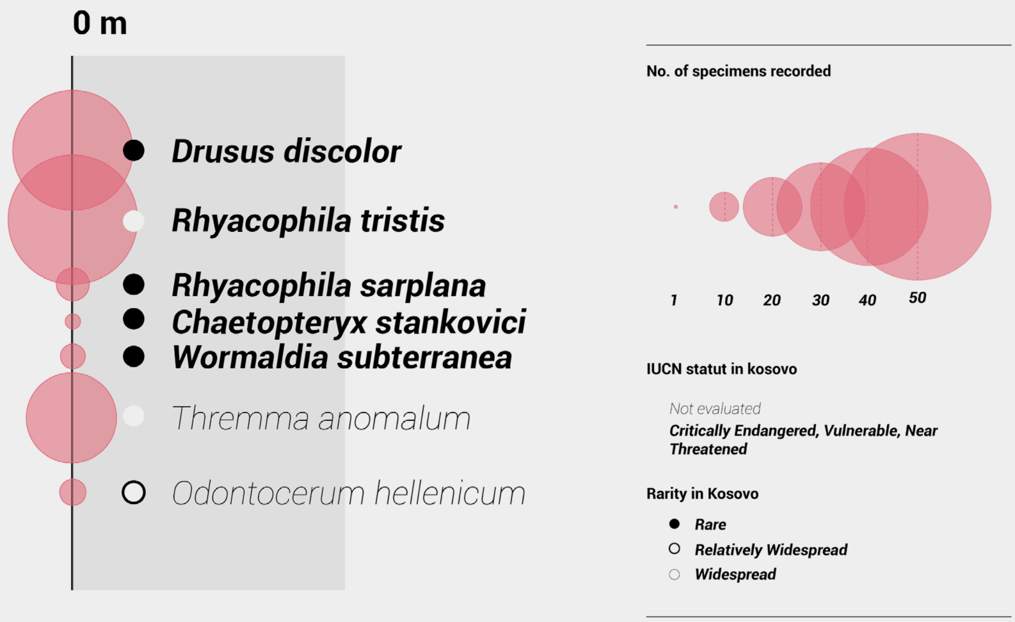


Figure 12. Study area 3 — entomological net sampling of caddisflies (trichoptera). bubble size shows specimens recorded (1–50), marker fill shows rarity in kosovo (rare, relatively widespread, widespread), and iucn status is noted where evaluated (cr, vu, nt).

In Study Area 3, the catch is skewed toward two taxa—Drusus discolor and Rhyacophila tristis—with other species present in low numbers. Most recorded taxa are rare in Kosovo, and the few with IUCN assessments fall into threatened categories (CR, VU, NT). This indicates high conservation value; continued seasonal monitoring and habitat protection are recommended to track trends and address assessment gaps.

8.3.4. Study area 4: Riverine ecosystem in an open area without surrounding forested area outside Sharr Mountain National Park

Description of the site: Upper reach of the Restelica River in an open area without forested surrounding environment. The site is concentrated around these coordinates 42.172216N, 20.988126E. The site is in the outskirts of the Restelica village, few kilometers from Sharr National Park borders.
Sampling method: Ultraviolet light traps placed at different distances from the river.
This dataset (Table 4) highlights the distribution of adult Trichoptera species relative to the riverine environment and shows that the surrounding terrestrial habitats play a significant role in their ecology.

- Most species have the highest number of specimens found directly at the river edge (0 m), which aligns with their aquatic larval stages that develop in the river or stream.

- However, many species also have notable numbers of adult individuals found at increasing distances from the riverbank (up to 500 m). For example, Hydropsyche peristerica and Glossosoma conformis show a relatively broad distribution, with adults present from 0 m all the way to 500 m. Hydropsyche peristerica, a widespread European species, was found up to 500 m with substantial counts at 0 m (14 specimens), 50 m (4), 100 m (3), and even 300 m and 500 m (6 and 4 specimens respectively), indicating good dispersal capacity and tolerance for surrounding habitats. Similarly, Glossosoma conformis was found at all distances up to 500 m, with a notable number of individuals at 0 m (21), 50 m (18), 100 m (5), and smaller numbers even at 200 m and 500 m, suggesting a relatively high terrestrial dispersal ability.

- Other species such as Silo graellsii, Philopotamus montanus, and Plectrocnemia conspersa also had considerable numbers of adults at 50 m and 100 m distances, indicating these riparian zones are important for adult behaviors such as mating, dispersal, or shelter. Silo graellsii had 32 specimens at 0 m, 8 at 50 m, and 2 at 100 m. Philopotamus montanus had 19 specimens at 0 m and 12 at 50 m, showing a preference for near-river zones but still utilizing the buffer zone.

- Rare and endemic species such as Glossosoma clotho, Notidobia vaillanti, and Rhyacophila cf. palmeni were found only within the first 50 m from the river. For instance, Notidobia vaillanti, a critically endangered species endemic to the Western Balkans, was found exclusively at 0 m (4 specimens), indicating very limited dispersal and a strong reliance on immediate riverbank habitat. Likewise, Glossosoma clotho (Western Balkans endemic) was only found at 0 m, and Rhyacophila cf. palmeni (also endemic to the Western Balkans) was found in low numbers within the 0–150 m range, emphasizing the vulnerability of such taxa to any habitat disturbance near the stream.

- Species like Hydropsyche tabacarrui and Drusus discolor, although also rare or endemic to Europe, showed somewhat broader distributions. Drusus discolor had its highest numbers close to the river (0 m: 19; 50 m: 13) but was still present up to 150 m (12 at 100 m, 3 at 150 m), suggesting moderate dispersal capacity. Hydropsyche tabacarrui, despite its rarity, reached up to 500 m, though in small numbers (2 individuals), hinting at the possibility of occasional longer-range adult movement.

- The presence of adults at distances up to 500 m in species like Glossosoma conformis, Hydropsyche peristerica, and Potamophylax luctuosus shows the importance of buffer zones and intact riparian vegetation for maintaining healthy populations of Trichoptera. These zones provide not only resting and mating sites but also shelter and microhabitats for various stages of the adult phase.

Importance of surrounding habitats for Trichoptera

- The riparian terrestrial zone surrounding rivers and streams is crucial for adult caddisflies. These habitats support behaviors like dispersal, reproduction, and resting.
- Maintaining natural vegetation and habitat heterogeneity in riparian zones is essential to support both aquatic larvae and terrestrial adults, thus ensuring the full life cycle of these species.
- Conservation efforts should focus not only on water quality and aquatic habitat but also on protecting the adjacent terrestrial environment, especially within at least 100 to 500 meters from the river, to sustain viable populations of diverse Trichoptera species.
- For species with conservation concern, such as Notidobia vaillanti and Rhyacophila cf. palmeni, strict protection of their known habitats including the riverbank zone is vital due to their limited dispersal and rarity.
- There is strong correlation between dispersal ability vs. rarity and endemicity of species in terms that species which are rare and/or endemic tend to have less dispersal ability, contrary to species which are widespread which tend to have high dispersal ability. This means that in terms of vulnerability to extinction, rare and/or endemic species will be first to be impacted in scenarios of habitat deterioration and/or other factors such as pollution and climate change. Thus, maintaining their habitats in current form is crucial for their existence.
- This site is outside National Park boundaries, indicating that there are crucial habitats for species conservation outside protected areas.

Table 4. Composition of the aquatic insect fauna at study area 4.

Species	IUCN status	Rarity in Kosovo	Endemism	No. of specimens/Distance from the river in meters							
				0	50	100	150	200	300	400	500
Drusus biggutatus	Not Evaluated	Rare									
Drusus discolor	Not Evaluated	Rare	Europe	19	13	12	3				
Glossosoma clotho	Not Evaluated	Rare	Western Balkans	2							
Glossosoma conformis	Not Evaluated	Relatively widespread	Europe	21	18	5	2		4		2
Hydropsyche peristerica	Not Evaluated	Widespread	Europe	14	4	3	3		6		4
Hydropsyche tabacarrui	Not Evaluated	Rare	Europe	12	7			3			2
Limnephilus extricatus	Not Evaluated	Rare	Europe		1						
Notidobia vaillanti	Critically Endangered	Rare	Western Balkans	4							
Philopotamus montanus	Not Evaluated	Widespread	Europe	19	12						
Plectrocnemia brevis	Not Evaluated	Widespread	Europe	9	12						
Plectrocnemia conspersa	Not Evaluated	Relatively widespread	Europe	13	9	1	1				
Potamophylax latipennis	Not Evaluated	Relatively widespread	Europe	9	5						
Potamophylax luctousus	Not Evaluated	Relatively widespread	Europe	21	7	2	2				
Rhyacophila cf. palmeni	Endangered	Rare	Western Balkans	2		1	1				
Rhyacophila loxias	Not Evaluated	Relatively widespread	Europe	29	6						
Rhyacophila mocsaryi	Not Evaluated	Rare	Europe	16	2						
Sillo graellsi	Not Evaluated	Relatively widespread	Europe	32	8	2					
Stenophylax meridiorientalis	Not Evaluated	Relatively widespread	Europe	5	2	3	3				

Figure 13. Study Area 4 — UV light-trap sampling of caddisflies (Trichoptera). Bubble size shows specimens recorded per species at trap stations set 0–500 m from the river (0 m = river edge). Marker fill shows rarity in Kosovo (Rare, Relatively Widespread, Widespread); IUCN status is noted where evaluated (CR, VU, NT).
Assemblages near 0–100 m are most abundant, mixing widespread net-spinners and cased caddis (Hydropsyche, Glossosoma) with noteworthy rare records—especially Notidobia vaillanti and Rhyacophila cf. palmeni. Farther from the river, catches are sparse and dominated by common species. Protecting riparian vegetation and microhabitats is key to retaining the rare, river-dependent fauna.

8.3.5 Study area 5. Lumbardhi i Prizrenit River, from one of the spring areas downwards to the middle reach of the river

Description of the site: Three localities along the Lumbardhi i Prizrenit River (L1 small spring of the river at 42.152402°N, 20.995024°E; L2 upstream area of Lumbardhi i Prizrenit River at 42.161N, 20.9533E; and L3 at 42.1708N, 20.8623E).

Sampling method: Ultraviolet light traps placed at different longitudinal distances from the river. The dataset (Table 5) illustrates a clear ecological pattern in the distribution of Trichoptera species along a thermal gradient within a river system. This gradient, defined by increasing water temperatures from cold spring habitats (L1: 5 °C) to warmer downstream sections (L2: 7.5 °C and L3: 10.5 °C), strongly influences species composition and abundance.

In the coldest upstream sections (L1, 5 °C), the fauna is dominated by cold-adapted, stenothermic species, many of which are rare or endemic. These include Drusus sharrensis (Critically Endangered, endemic to Kosovo, 35 specimens), Rhyacophila obtusa (Vulnerable, Southeastern European endemic, 29 specimens), and Thremma anomalum (26 specimens), among others. These taxa exhibit narrow thermal tolerances and are typically restricted to spring-fed habitats characterized by stable and low water temperatures.

As water temperature increases toward mid-reaches (L2, 7.5 °C), the abundance of these cold-specialist species declines sharply, and a transition begins toward more thermotolerant fauna. Species such as Drusus discolor, Rhyacophila obliterata, and Micropterna sequax begin to appear more frequently, reflecting a shift in ecological conditions and community composition.

In the warmest sites (L3, 10.5 °C), the community is increasingly dominated by widespread, eurythermic species that are adapted to a broader range of environmental conditions. These include members of the genera Hydropsyche (32 specimens), Cyrnus tremaculatus (45 specimens), and Psychomyia pusilla (32 specimens). These species are typically generalists, capable of thriving in various habitats and are often indicators of more common riverine conditions downstream.

Overall, the dataset demonstrates that water temperature is a key environmental gradient structuring the distribution of Trichoptera species. Cold spring habitats harbor rare and often endemic taxa with conservation importance, while warmer sections of the river favor widespread and generalist species. This pattern highlights the ecological significance of thermally stable spring ecosystems and underscores their role in preserving regional aquatic biodiversity.

Table 5. Composition of the aquatic insect fauna at study area 5.

Species	IUCN status	Rarity in Kosovo	Endemism	L1 (water t 5 °C)	L2 (water t 8.5 °C)	L 3 (water t 14.5 °C)
Drusus sharrensis	Critically Endangered	Rare	Kosovo	35	3	
Rhyacophila obtusa	Vulnerable	Rare	Southeastern Europe	29	1	
Rhyacophila sarplana	Vulnerable	Rare	Western Balkans	9	2	1
Chaetopteryx stankovici	Near Threatened	Rare	Southeastern Europe	14	2	1
Thremma anomalum	Not Evaluated	Widespread	Southeastern Europe	26		
Odontocerum hellenicum	Critically Endangered	Relatively widespread	Western Balkans	19		
Drusus biggutatus	Not Evaluated	Rare	Western Balkans	15		
Rhyacophila balcanica	Near Threatened	Rare	Southeastern Europe		13	
Drusus discolor	Not Evaluated	Rare	Europe		14	8
Rhyacophila fischeri	Near Threatened	Rare	Southeastern Europe		12	2
Rhyacophila obliterata	Near Threatened	Rare	Europe		17	18
Philopotamus montanus	Not Evaluated	Widespread	Europe		25	19
Hydropsyche	Least Concern	Widespread	Europe		26	32
Psilopteryx montanus	Not Evaluated	Rare	Western Balkans	14	2	
Micropterna sequax	Not Evaluated	Relatively widespread	Europe		14	7
Potamophylax pallidus	Not Evaluated	Widespread	Europe		27	9
Psychomyia pusilla	Not Evaluated	Widespread	Europe			32
Cyrnus tremaculatus	Not Evaluated	Widespread	Europe			45

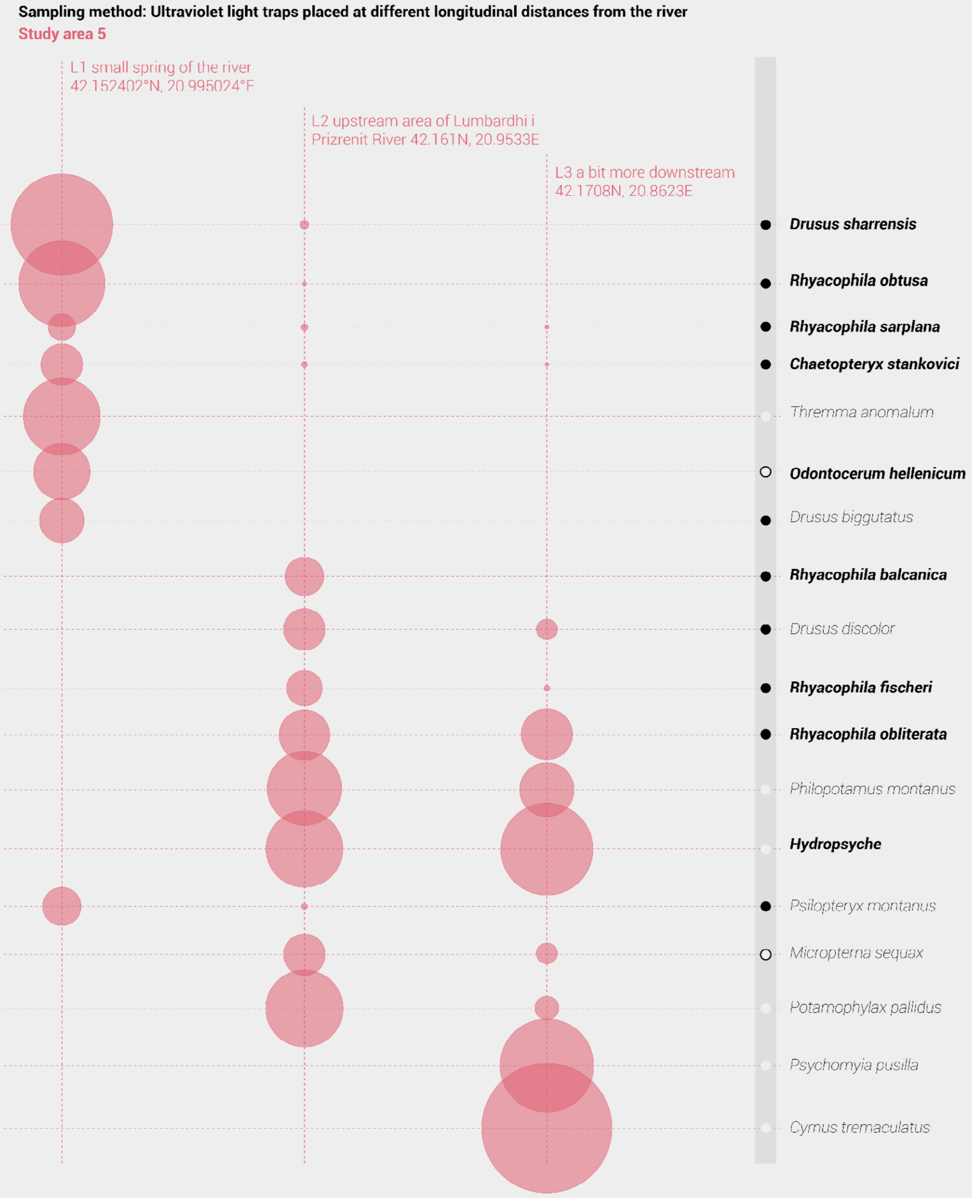


Figure 14. Study Area 5 — Ultraviolet light-trap sampling of caddisflies (Trichoptera). Bubble size shows specimens recorded per species at each station; columns L1 (spring), L2 (upstream), and L3 (downstream) indicate longitudinal position along the Lumbardhi i Prizrenit River. Marker fill shows rarity in Kosovo (Rare, Relatively Widespread, Widespread), and IUCN status is noted where evaluated (CR, VU, NT).

Conclusion: The assemblage shifts markedly along the river. L1 (spring) holds the greatest diversity of cold-water taxa (e.g., Drusus spp., Rhyacophila spp.), many of them nationally rare. L2 shows a mixed community with moderate abundances. L3 records the highest numbers but is dominated by a few widespread taxa (e.g., Hydropsyche, Cyrnus), while several headwater specialists are absent. These patterns highlight the conservation importance of protecting spring and upper-reach habitats and of sampling multiple longitudinal positions

CONCLUSIONS

9

THIS FIELDWORK REPRESENTS ONE OF THE FIRST SYSTEMATIC EFFORTS TO DOCUMENT AQUATIC INSECT BIODIVERSITY IN KOSOVO ACROSS BOTH PROTECTED AND NON-PROTECTED FRESHWATER ZONES. THE STUDY HAS GENERATED A PRELIMINARY SPECIES LIST, WITH PARTICULAR ATTENTION TO ECOLOGICALLY SENSITIVE TAXA, AND HAS BEGUN MAPPING THEIR SPATIAL DISTRIBUTION. EARLY FINDINGS SUGGEST A CLEAR DIFFERENCE IN BOTH DIVERSITY AND ABUNDANCE BETWEEN THE SHARR MOUNTAINS PROTECTED SITE AND THE NON-PROTECTED ZONE NEAR PRIZREN, REINFORCING THE ECOLOGICAL VALUE OF HABITAT PROTECTION AND THE POTENTIAL FOR TARGETED RESTORATION

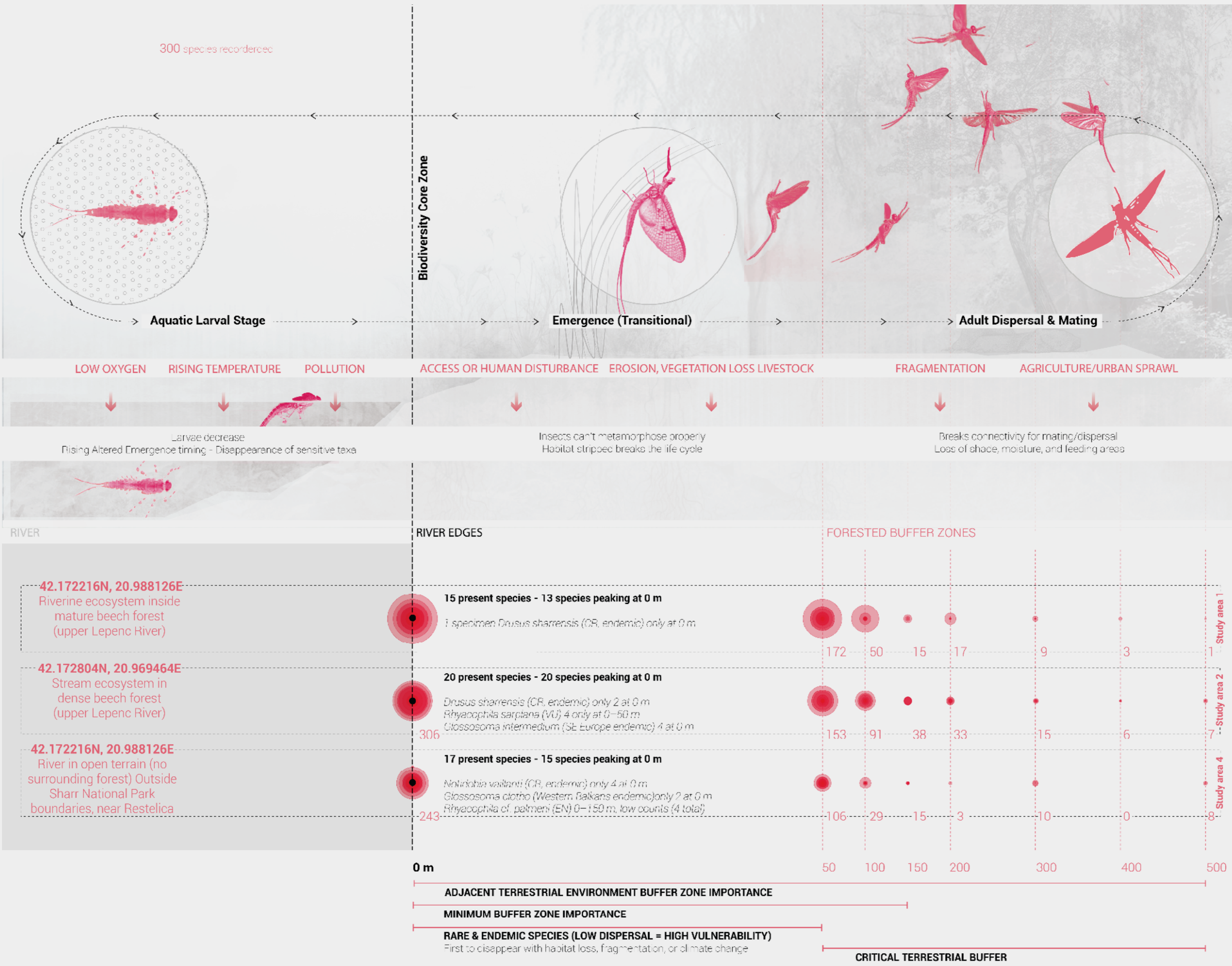


Figure 15. Bubble size shows total specimens at set distances from the river (0–500 m). Rows summarize three sites (with coordinates noted) and list the number of species present and how many peak at the river edge (0 m). Icons indicate rarity in Kosovo and IUCN status where available (CR, VU, NT). The top band diagrams the life cycle—from aquatic larva to emergence to adult dispersal—and the main stressors acting at each stage. Shaded zones mark the river edge (biodiversity core) and forested buffer areas.

- **Across sites, 15–20 species were recorded per transect, with 13–20 species peaking at 0 m.**
- **Rare/endemic taxa with low dispersal (e.g., Drusus sharrensis, CR) were found only at the river edge, while a few widespread, strong-flying taxa persisted farther away.**
- **Abundance and richness decline sharply beyond ~100–150 m; by 200–300 m assemblages are sparse and dominated by common species.**
- **The pattern matches the life-cycle logic: larval development depends on cool, oxygenated water; the emergence strip at the bank is easily broken by trampling, bank clearing, or livestock; adult dispersal relies on continuous riparian vegetation for shade, moisture, and feeding.**

The presence of sensitive taxa in the protected area (e.g., Heptageniidae, Perlidae) supports the site's high ecological integrity, while the dominance of more tolerant groups in non-protected areas (e.g., Chironomidae, Oligochaeta) may reflect anthropogenic stressors, altered hydrology, or pollution.

- **All habitats studied support populations of rare aquatic insect species,** underscoring their ecological value in maintaining the structure and function of freshwater ecosystems. These species often play vital roles in nutrient cycling, organic matter breakdown, and supporting trophic interactions within the aquatic food web.

- **Cold spring habitats and small headwater creeks act as critical refugia for rare and endemic species,** many of which exhibit narrow ecological tolerances and highly specialized life histories. Examples include Drusus sharrensis, Notidobia vaillanti, Rhyacophila sarplana, Rhyacophila obtusa, and Chaetopteryx stankovici, all confined to low-temperature spring areas with limited distribution.

- **These rare taxa are typically characterized by low dispersal ability, small population sizes, and high habitat specificity.** As such, they are particularly vulnerable to both short-term habitat disturbances and long-term environmental changes such as:
  - Climate change, which threatens to alter thermal regimes, hydrology, and precipitation patterns, potentially eliminating suitable microhabitats for cold-adapted species.
  - Habitat deterioration, including deforestation, water extraction, and land-use changes that disrupt ecological continuity.
  - Pollution, especially organic and chemical pollutants, which can drastically reduce water quality and affect sensitive species first.

- **Riparian zones and surrounding terrestrial habitats play a key role in sustaining aquatic insect communities.** Forested riverbanks, shaded areas, accumulations of rocks, and sparsely vegetated areas offer essential functions such as:
  - Shelter for emerging adults and ovipositing females
  - Microclimatic stability, which buffers against extreme temperature fluctuations
  - Dispersal corridors that facilitate gene flow among populations

- **Conservation strategies should not be limited to aquatic channels alone but must include the protection and restoration of adjacent riparian habitats.** Integrative conservation planning must account for the interplay between terrestrial and aquatic systems.

- **The discovery of Limnephilus extricatus as a new record for the fauna of Kosovo adds to the growing evidence that the country's freshwater biodiversity remains in-**

completely documented. Such findings highlight the need for continued surveys, long-term monitoring, and taxonomic expertise to detect cryptic or overlooked species.

- **Effective conservation and management of aquatic biodiversity require urgent action**, especially in light of the documented presence of regionally endemic and threatened species. Protection of cold-water habitats, enforcement of pollution control, and riparian habitat conservation must be prioritized in biodiversity hotspots.

- **This study reinforces the importance of small, thermally stable aquatic systems** as biodiversity reservoirs, particularly in karst and mountainous regions of the Balkans, and provides a scientific foundation for future conservation efforts in Kosovo and the wider Western Balkans region.

- **There are crucial habitats for species conservation located outside officially protected areas.** Many of the rare and endemic aquatic insect species identified in this study occur in areas that lie beyond the boundaries of designated nature reserves or national parks. These habitats often receive little formal conservation attention despite their high ecological value. As such, they represent conservation blind spots where biodiversity is highly vulnerable to land-use changes, agricultural runoff, and unmanaged development. Including these areas in regional conservation planning—either through habitat corridors, buffer zones, or targeted protection measures—is essential for maintaining ecological integrity and preventing further species decline.

Given the climate vulnerability of freshwater systems and the limited ecological data available in the region, the study strongly recommends the establishment of long-term monitoring programs for aquatic insects in both high-altitude and lowland watersheds. Monitoring should be aligned with seasonal emergence patterns and include attention to both established indicator taxa and potentially vulnerable species whose populations may signal early shifts in ecosystem resilience. Expanding this approach nationally would not only fill a critical biodiversity data gap but also support Kosovo's integration into broader regional and international conservation frameworks.

About EC

EC Ma Ndryshe is a community-based organization, established in 2006, committed to sustainable development through an inclusive approach.

EC's activism envisions a Kosovo where democratic governance is participatory, transparent, and accountable, ensuring that institutions, communities, and stakeholders work together towards sustainable development.

This vision promotes inclusive decision-making, stronger policies, and greater public participation, ensuring that sustainability is an integral part of governance at both local and national levels.

Through better institutional coordination, evidence-based policymaking, and citizen engagement, EC's work aims to bridge the gap between communities and institutions, ensuring that good governance leads to tangible and lasting change.

Vision statement

"Empowering a resilient and inclusive Kosovo, where communities actively shape sustainable, digitalized, and conscientious institutions."

Mission statement

"EC Ma Ndryshe supports democratic governance and sustainable development in Kosovo by fostering sustainable socioeconomic, cultural, and green growth through digital education, environmental stewardship, community mobilization, advocacy for participatory public decision-making, and the cultivation of strategic partnerships."