



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



Impact of Climate on Biodiversity

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2025

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 investigates the interplay between climate change and biodiversity in the Sharr Mountains, Prizren, and surrounding areas, situating local ecological systems within broader climatic pressures. It develops a methodological framework centered on aquatic ecosystems, using aquatic insects as sensitive bioindicators of ecosystem vulnerability.

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BACKGROUND

Kosovo's ecosystems are already experiencing measurable climate change: rising temperatures, declining snowfall, shifting precipitation regimes, and more frequent extremes. These shifts threaten biodiversity—especially in mountainous and hydrologically sensitive areas—while also disrupting agriculture, water availability, and forest resilience. In the Sharr Mountains, Prizren, and surrounding areas, long-term observations show warming trends, more winter rain (less snow), and intensification of extreme events, all of which cascade into altered flows, thermal stress in rivers, and habitat fragmentation.

Within this regional picture, freshwater systems are pivotal. The White Drin/Drini i Bardhë, Lumbardhi i Prizrenit, and Toplluha support rich aquatic and riparian assemblages but are increasingly exposed to pollution, altered hydrology, heat stress, and erosion—pressures expected to intensify with climate change. These rivers also host sensitive taxa whose responses provide early warnings of systemic stress, making them strategic entry points for climate-aware biodiversity planning.

To move beyond static species lists and reactive risk registers, the project adopts a habitat-centred approach that treats biodiversity as relationships embedded in space. We use aquatic insects—notably mayflies, caddisflies, and stoneflies—as bioindicators spanning aquatic and terrestrial phases. Their ecological specificity (clean, oxygenated waters; intact riparian edges; shaded forest buffers) makes them sensitive sentinels of changing temperature, flow, and water quality. Tracking their abundance, diversity, and distribution offers a scalable way to detect early signals, visualize vulnerability, and prioritize conservation in places where pressures are converging.

Concretely, the mapping framework focuses on three linked habitat types that underpin these life cycles: (1) riverbeds and secondary tributaries, (2) riparian edge zones, and (3) forested buffer zones. By identifying where these habitats overlap—and how they intersect with land use and projected climate shifts—the analysis reveals sensitive zones, guides restoration, and supports adaptive water and habitat management across the Sharr–Prizren landscape.

INTRODUCTION

The interplay between climate and biodiversity is both intricate and increasingly urgent. Climate change stands as one of the principal drivers of biodiversity loss, reshaping habitats, altering species distributions, disrupting ecological balances, and threatening the survival of vulnerable organisms. As ecosystems respond to rising temperatures, shifting precipitation regimes, and the intensification of extreme events, species are forced to adapt, migrate, or face extinction. These transformations ripple beyond individual species, undermining ecological functions and the ecosystem services upon which both human and non-human communities depend.

This report examines the impacts of climate change on biodiversity in the Sharr Mountains, Prizren, and surrounding areas—a region of high ecological value and cultural significance. Drawing from international and local scientific assessments, legislative frameworks, and field-based research, it highlights the urgent need to understand vulnerability not only at the level of individual species but also within the broader ecological systems that sustain them. By situating biodiversity within the context of climate pressures, the report underscores the necessity of integrated approaches that merge scientific evidence, spatial analysis, and socio-ecological perspectives to inform conservation and policy.

A key contribution of the report is the development of a methodological framework for assessing ecosystem vulnerability. Moving beyond broad-scale projections, it proposes a focused approach centered on freshwater ecosystems, with particular attention to aquatic insects. These organisms serve as highly sensitive bioindicators of ecological health, responding rapidly to environmental changes such as temperature fluctuations, altered hydrological regimes, and water quality degradation. By examining their diversity, abundance, and distribution patterns, it becomes possible to detect early warning signs of ecological stress and to evaluate the resilience of freshwater habitats under different climate scenarios.

Through this lens, the report not only advances a methodology for vulnerability assessment but also contributes to a broader understanding of how species-level indicators can reveal systemic risks. In doing so, it aims to guide long-term strategies for biodiversity conservation and adaptive management, offering insights that are critical for sustaining ecosystems in the face of accelerating climate change.

MAPPING THE MORE-THAN-HUMAN

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MAPPING IS AN ACTIVE PRACTICE THAT GOES BEYOND DESCRIPTION, FUNCTIONING AS BOTH A COGNITIVE AND AESTHETIC TOOL FOR GENERATING NEW FORMS OF KNOWLEDGE. IT CHALLENGES ANTHROPOCENTRIC VIEWS BY RECOGNIZING NONHUMAN BEINGS AS VITAL SUBJECTS, EMPHASIZING RELATIONAL COEXISTENCE, AND FOSTERING NOVEL WAYS OF UNDERSTANDING AND REPRESENTING THE WORLD IN THE CONTEXT OF ECOLOGICAL CRISES.

3. Mapping the more-than-human

Mapping: the Aesthetics of Experience and the Representation of a New Knowledge.

It is 1966 when Michel Foucault, in the preface to his text *Les mots et les choses*¹, articulates the question of a new epistème. His essay opens with a reference to “a certain Chinese encyclopedia” written by Borges, wherein beings—mostly animals—are catalogued in idiosyncratic, an “unusual” manner, dividing themselves into: “(a) belonging to the Emperor, (b) stuffed, (c) domesticated, (d) suckling pigs, (e) mermaids, (f) fabulous, (g) dogs in the wild, (h) included in the present classification, (i) madly flitting about, (j) innumerable, (k) drawn with a very fine brush of camel hair, (l) et caetera, (m) making love, (n) looking like flies from a distance.”

This list, deliberately incongruous, dismantles the possibility of containing multiplicity within the one-directional logic of universal reason. Instead, it invites openness to heterogeneous modes of being, generating novel planes of consistency and meaning—effectively enacting a reversal of epistemology itself. It suggests that altering the subjects of philosophical discourse, together with their modes of ordering or classification, might engender entirely new constructions and a reshaping both our comprehension of the world and our representations of knowledge, with its classification and codification.

Foucault’s reflections prefigure certain essential conditions of what would later be termed post-critical² or contemporary thought: the rupture of synthetic logic, the acceptance of new subjects of experience, and the resulting epistemological questions about method, as well as about the incidence of the observed subject upon thought—particularly the questions of “who speaks”³ and how inquiry, organization, and representation of knowledge are structured.

It is an original question that ferries thought from the synthetic processes of the previous century toward the heterogeneous present: from uniformity to multiformity, from the visible to the invisible. The codification of reality, once centered on “the individual elevated to generality,” now shifts toward a plural mode of thought. No longer is there an exclusive Hermes to declare, as Protagoras did, *Pántōn chrēmātōn métron esti anthrōpos*—“Man is the measure of all things.”⁴ This Foucauldian unreason, this “disruption of all familiarity of thought,”⁵ signals the end of anthropocentrism. Man, for Foucault, is not a historical *a priori* but a recent invention. Borges’ animals, by fracturing language—that is, shared representation—dismantle epistemology and its systems of order through the very act of representation.

Within this framework of rupture, and in light of the ongoing “Ecological Trauma”⁶ that places Nature at the center of contemporary phenomenology, two priority questions emerge in the present inquiry. The first concerns the rotation of subjects: the emergence of “new speaking beings.”⁷ The second concerns the relationship between thought and its organization and representation—between praxis and aisthesis, that is, between experience and language.

¹ M. Foucault (1966), *Les mots et les choses (une archéologie des sciences humaines)*, Gallimard, Paris;

² cf. M. Croce (2019), *Postcriticism. Asignificance, matter, affects, Quodlibet*. As reported, “it in fact looks at the minute, the interstice, the ties that weave the web of ordinary life, and rejects the ‘structural projection’ of general theories.”

³ cf. A. Florio (2012), “Michel Foucault, Words and Things. An Archaeology of the Human Sciences,” in *The Philosophical Knowledge Club*;

⁴ P. Carravetta in “Postmodernism and ecocriticism: problems, paradoxes, perspectives,” In *Notos. Espace de la création. Arts Ecritures utopies* no. 3;

⁵ M. Foucault (1966), *Op. Cit.*;

⁶ cf. The research of Timoty Morton and Bruno Latour;

⁷ M. Croce, *Op. Cit.*;

Experience, Nature, and the Representation of Knowledge

This second question—concerning the relationship between thought, experience and its organization—posits mapping not merely as a form of restitution, but as a structuring principle of new knowledge. As both the organization and representation of knowledge, mapping, within this epistemological short-circuit generated by the emergence of new ecological emergences and subjects, reclaims priority in its relation to experience—that is, to the scientific or cognitive experiment itself. In this capacity, mapping becomes a device for “learning, for educating sensibility toward experimental modes of interchange with the world.”⁸ In this sense, it assumes a status equal and correlative to the experimental act, disengaging itself from the procedures of mere description or the finality of results. Instead, it is re-situated within a logic of non-subordination. This recalls the framework of American pragmatism, which situated the nexus of experience, nature, and art in a dynamic reciprocity. For John Dewey, the aesthetic dimension—in our case, representation—constitutes an aesthetic of experience, inseparable from operative purpose. As in the introduction to Dewey’s *Experience, Nature, and Art*, such a perspective ensures the regeneration of aisthesis in the service of acquiring novel operational and cognitive patterns.⁹

As a cognitive and operational instrument of experience, mapping thus acquires an aesthetic valence, capable of expressing itself as a cognitive and exploratory science, liberated from the confines of a mere a posteriori restitutive image of experiment or project. Its aesthetic (the grammar of its language) correlates nature (the object of exploration) with experience (the act of exploration) according to two primary conditions. First, it reframes experience as a process of meaning that exists only in relation to its restitution through a specific language, and not solely as a technocratic-scientific *in vitro* examination. Second, it posits the map as a “passage of interchange with the world toward another model of interchange”¹⁰: a language and representation capable of being both a nodal point within an experiential process and a generator of epistemological leaps—abandoning its immediate context and process to become a more general instrument of knowledge.

With respect to the first of these conditions, it is clear that contemporary mapping’s underlying assumptions can only be understood within a framework that is simultaneously operational and abstract, embedded in the new phenomenologies and metanarratives of the present. As an apparatus mediating the exchange between heterogeneous and complex entities, mapping functions as both a cognitive/experiential and a linguistic/aesthetic device. The maps in question do not necessarily aspire to synthesis; rather, they propose a method that situates experience beyond dualism and rigid scientism—outside frames that rely exclusively on associative or subordinating principles.

⁸ D. Cecchi, *Introduction to J. Dewey (2015), Experience, Nature and Art, Mimesis editions*, p. 16;

⁹ D. Cecchi, *Introduction, Op. Cit*;

¹⁰ D. Cecchi, *Introduction, Op. Cit*;

As Franco Farinelli has observed, mapping, in its engagement with “the dark space of our intellect,”¹¹ distances itself from cartographic vigilance and from the dialectics of true/false, literal/symbolic, descriptive/interpretive. Jean Baudrillard articulates a similar radicalism of rupture: “Simulation is no longer that of a territory, a referential being, or of substance.”¹² . The map, then, is not merely a locus physicus but a theoretical-potential instrument of experience. As Gilles Deleuze cautions: “Make maps, not tracings... The map is entirely oriented toward experimentation in contact with the real. It does not reproduce an unconscious closed in upon itself; it constructs the unconscious. It fosters connections between fields, removes blockages from bodies without organs, opens them maximally onto a plane of consistency... The map is about performance, whereas the tracing always invokes an alleged competence.”¹³

But map can also expel reality. In the capacity to produce epistemological leaps—entrusting representation with a function beyond that of mere experience—it reveals its fullest potential. As Dewey writes, the vision thus obtained “releases energies that remain diffuse and nascent, raising the overall level of our existence.” Representation thus becomes a signifying art, “the organization of forms in such a way as to enrich, prolong, and purify experience.”¹⁴ In this light, mapping simultaneously follows an autonomous trajectory—educating toward new languages (that is, new shared systems of classification) and toward novel expressions of the world, conceived not solely in relation to a specific experience. Mapping, as Farinelli argues, “possesses the power to amputate the represented—which coincides, as with any nominalist exercise, with the abolition of the very question of the essence of things and the reduction of existence to mere presence.”¹⁵

The Organization of Knowledge: The New Speaking Subjects

The emergence of these new speaking subjects within the aesthetics of experience introduces an additional layer of complexity to the proposed mapping—one that distinguishes it sharply from the cartographic traditions of the classical sciences. These subjects may be situated within a renewed conception of the living,¹⁶ a notion that departs from twentieth-century biocentrism and reorients itself toward the primacy of biodiversity—etymologically, the “variety of life.” From this vantage point, the question of plurality and dissimilarity among the agents populating this still-uncharted cartographic realm gains a decisive weight.

The entities under investigation are living beings marked by a dynamic ecosystem — multiplied, yet necessarily interrelated—and, by virtue of being alive, in constant motion. Their representation does not follow the taxonomic or Linnaean paradigm of nature, but instead addresses vital coexistence: the relationships among parts, the presence of multiplicities of time—those of geological and geographical epochs, of specific species, of ecosystems, of circadian or chosen moments of observation, among others.

¹¹ F. Farinelli (1992), *The Signs of the World. Cartographic image and geographical discourse in the modern age*, ed. La nuova Italia;

¹² J. Baudrillard (1981), *Simulacra and Simulations*, Éditions Galilée;

¹³ G. Deleuze, F. Guattari (1980), *Mille Plateaux. Capitalisme et schizophrénie*, Minuit;

¹⁴ J. Dewey, *Op. Cit.*, p. 42-44;

¹⁵ F. Farinelli, *Op. Cit.*;

¹⁶ E. Coccia (2018), *Plant life. Metaphysics of mixing*, Il Mulino;

Within this research, the new speaking subjects are defined, in particular, through three intertwined theoretical-methodological logics: the first, is a reversal of our idea of technology, as they become “technological” devices in relation to the environmental conditions in which they exist, thereby rendering obsolete the use of artificial instruments as mere tools of detached observation. The second, is a reversal of vantage, since they invert the traditional relation between observer and observed: mapping is undertaken from a relational perspective rather than from the canonical stance of the detached scientist examining inert objects. The third, is a kind of submersion in the unseen: they inhabit domains neglected by the prevailing ecological gaze, belonging to a “third world” that lies outside immediate visibility and recognizability, thus necessitating novel instruments and an inverted tools of observation.

As instruments and devices, these living beings—often linked to systems of scalar proximity—compel representation to confront two additional conditions specific to contemporary ecology. First, in the context of “new climate regimes”¹⁷ and environmental phenomena that Timothy Morton terms hyperobjects—entities whose effects are perceptible though their causes remain concealed—they force a reconsideration of the scale of global interrelation, even when the mapped subject appears volatile or minute. Second, insofar as mapping is a geopolitical act, it necessarily intersects with the question of the right of these new speaking beings to autonomous existence—as living subjects in their own right. The mapped subjects themselves emerge as technological agents, dissolving the dichotomy between nature and artifice until it vanishes entirely. The living matter under investigation becomes, in and of itself, a vehicle of information, destabilizing the notion that information belongs exclusively to the technocratic domain—falsely construed as separate from the living. In so doing, they instantiate a relational principle: a “deep and broad empiricism, in which empiricism is understood as the study of the relationships between things, and of things as systems of relations, rather than as isolated, solid objects separated by ostensibly empty space.”¹⁸

As devices, given the global ecological traumas to which they refer, these beings necessarily inhabit a worldview in which nature is recognized as both a resource and a good. In so doing, they position themselves as acts of resistance against the dynamics of planetary urbanization,¹⁹ that is, against the human tendency toward voracious consumption of the Earth’s resources. Inevitably, this stance aligns them with the principles of Object-Oriented Ontology (OOO), wherein the ontological—and thus physical—boundary between things is dissolved, opening the question of co-existence between subjects of representation, and of how such parity of relation might itself be represented. From this perspective, mapping is forced to grapple with the selection between cause and effect, with the dismantling of scale-bound consequentialities, with the codification and representation of heterogeneous elements within a shared frame of reference—and, crucially, with the absence of any single, metric unit by which that frame might be measured.

Simultaneously—and at times in tension with the previous point—these new speaking subjects do not conform exclusively to a principle of efficiency calibrated to human necessity.

17 B. Latour (2020), *The Gaia Challenge. The new climate regime*, Meltemi;

18 T. Morton (2023), *Ecology as Text, Text as Ecology*, Crisis Publishing, 31;

19 Cf. Neil Brenner’s *Research*;

Instead, they generate new measures and logics of efficiency, determined by circumscribed environmental conditions, survival imperatives, and the creation of a self-sustaining habitat. In so doing, they depart from the logic of planetary performativity and from any purely anthropocentric observational stance. If the observer functions as the classifying gaze, the result of classification does not serve the mapper, but resides within the rights of the observed subject.

This shift demands new metrics, new orientations, and new instruments—ones capable of establishing a principle of necessity distinct from that of the external observer, and even from ecology as an ideology tasked with “saving” the world. It moves toward a logic beyond culture, wherein the principle of natural order is liberated from the teleological designs of humankind.²⁰ Consequently, the maps here proposed are rooted in an anti-speciesist ethic—an ethics of equivalence—which requires a new vocabulary. As Robin Wall Kimmerer cautions: “Science can be a language of distance which reduces a being to its working parts; it is a language of objects. The language scientists speak, however precise, is based on a profound error in grammar, an omission, a serious loss in translation.”²¹

Their minuteness, apparent fragility, and ephemeral nature—their capacity to inhabit the thickness of water in accordance with reproductive and life cycles—remove them from a teleological or Darwinian reading of evolution. Instead, they belong to that unseen contingency capable of reshaping classifications of knowledge, keeping them open to the multitude.

From this position, the problematics of transparency and opacity in representation become inseparable from the question of the rights of the other or, quoting Glissant, their right to be opaque.

The origins of this positionality—one grounded in the rights of Nature—can be traced to the epistemic and cultural transformations of the 1970s.²² In truth, its roots lie earlier, in the modern-era shift from conceiving the Earth as organism to conceiving it as machine.²³ Carolyn Merchant has described this as the transition from a *natura naturans*—generative, relational, and “feminine” in its creative potency—to a *natura naturata*—exploited, consumed, and subsumed under the instrumental logics of “progress.”

It is within this reorientation that several pivotal currents emerged: Rachel Carson’s ecological critique in *Silent Spring*, the anti-imperialist and anti-biocolonial positions of Vandana Shiva expressed in her *Terra Viva* manifesto, and the foundational works of Donna Haraway. These genealogies extend forward into the more recent contributions of Bruno Latour, Vinciane Despret, Bruce Albert, and Eduardo Kohn, among others.²⁴

This orientation toward the rights of the mapped subject is reinforced within the geographical frame of the research —specifically and particularly evident in the distinction between

²⁰ T. Morton, *Op. Cit.*, p. 33;

²¹ T. Morton, *Op. Cit.*, p. 33;

²² The last year in which mankind was not indebted to its global footprint, 1970 was also the year during which the North American oil crisis began, through which the double implication for interest in ecology was revealed: on the one hand, resource-related economic developments linked to embargoes and the Yom Kippur War (1973); on the other, North American protest movements which, by unmasking this process, induced a shift in general opinion toward a new culture of the earth, moving away from a deterministic and exploitative approach toward a geo-ethical or geo-ontological one. In fact, in 1970 itself, Earth Day was introduced: the day of the Earth.

²³ Carolyn Merchant (1980), *The Death of Nature*, Editrice Bibliografica;

²⁴ E. Coccia (2023), *We are Forest*, Interview;

territory and land. Territory is conceived as an area of domination and geopolitical boundary: a jurisdictional entity defined by the relationship between space and politics, underpinned by the juridical concept of *nomos*. In its most precise sense, *nomos* denotes the unity between ordering (*Ordnung*) and localization (*Ortung*)—the material precondition of law.²⁵ Etymologically and historically, *nomos* first signifies taking or appropriation (*Nehmen*); second, the act and process of division and distribution, thereby linking law to property and to each person's share in the goods of life; and finally, cultivation and production,²⁶ where the notions of measure and equality dominate.

By contrast, land—as approached in this work—becomes the central locus of the proposed mappings. The intelligibility of space through mapping must be able to embrace a continuous, liminal, and circumstantial condition—its right deriving from nature itself. Mapping must therefore define as its operative interval a “third space,” one that is in perpetual oscillation between scales, and whose sense emerges from this constant rethinking. In so doing, it shifts the terms of classical geography and necessarily intersects with disciplines beyond those traditionally concerned with spatial description. The cartographic quadrant chosen here thus rejects the ancient concepts of boundary, limit, and barrier in favor of the threshold—a conceptual move toward a co-evolutionary and relational understanding of the world.

This is the stance, for instance, of Bruno Latour, whose notion of Gaia is “a network that precipitates into nodes: unique events in which things are condensed from time to time.” In Gaia, the world is mixture: the central challenge is one of composition, of discerning the assemblages that have given rise to present conditions. Latour's related concept of the Critical Zone operates as both a specific and an a-scalar spatial interval in which the interplay of global and local, law and relation, unfolds. It is only within this intricate and parabolic “third space” that mapping can generate intrusions and disclose the unexpected—where, for example, the subject of investigation may also become the observing subject.

Mapping as Epistemological Instrument

In breaking the circuit of mere description, mapping assumes the role of an epistemological instrument—one that engages reality through interrelation with experience, yet equally through a vision in *potentia*: a capacity to return to, and correlate with, the real, acquiring meaning only in relation to it. At the same time, mapping becomes an *oligopticon*: a locus where practices circulate without fixing into permanence, conscious of their own mutability.

In the generative power of these new mappings—in the ordering, as Foucault might say, of the epistemology of an era; in the multiplicity of subjects and the interrelated codes they bring forth—this research ultimately restores aesthetics as a mode of knowing. It does so through channels of organizing knowledge that exceed the limits of language, incorporating what might be called the non-linguistic character of life in contemporary forms.

²⁵ G. Battiston (2007), *Interview with E. Glissant: Every poetic act is knowledge of the real*, in *The Manifesto*, May, 2007;

²⁶ E. Glissant, *op. cit.*

BIODIVERSITY HOTSPOTS IN TRANSITION: THE SHARR MOUNTAINS AND THE DRINI I BARDHË BASIN

4

THE SHARR MOUNTAINS AND DRINI I BARDHË BASIN ARE MAJOR BIODIVERSITY HOTSPOTS IN KOSOVO, RICH IN ENDEMIC SPECIES AND VITAL ECOSYSTEMS THAT ACT AS ECOLOGICAL CORRIDORS AND PROVIDE KEY SERVICES LIKE WATER REGULATION. HOWEVER, THEY FACE GROWING THREATS FROM LOGGING, POLLUTION, UNREGULATED DEVELOPMENT, AND WEAK GOVERNANCE, WHILE CLIMATE CHANGE INTENSIFIES RISKS THROUGH REDUCED SNOW COVER, ALTERED FLOWS, AND EXTREME EVENTS. URGENT, CLIMATE-INFORMED CONSERVATION IS NEEDED TO PROTECT THEIR RESILIENCE AND ECOLOGICAL VALUE.

4. Biodiversity Hotspots in Transition: The Sharr Mountains and the Drini i Bardhë Basin

Kosovo sits at a biogeographic crossroads where continental and Mediterranean influences overlap, producing a dense mosaic of mountains, forests, grasslands, wetlands, and rivers. Within this setting, our analysis focuses on two biodiversity hotspots that are both exceptionally rich and increasingly vulnerable: (i) the Sharr Mountains protected area and surrounding landscape, and (ii) the river network of the Drini i Bardhë basin, including Lumbardhi i Prizrenit and the Toplluha/Tophulla stream in Suharekë/Suhareka.

The Sharr Mountains National Park is among Southeast Europe's most significant biodiversity reservoirs. Altitudinal gradients from roughly 800 to over 2,700 meters support alpine and subalpine meadows, glacial and periglacial lakes, karst formations, dense beech and conifer forests, and riparian corridors. The park hosts over 1,800 vascular plant species—one of the highest counts in the Balkans—alongside at least 32 mammal species and more than 147 recorded bird species, including raptors of conservation concern. The massif functions as a climatic refugium preserving glacial relicts and as a connective corridor between the Dinaric Alps and the Rhodopes, enhancing gene flow across regional scales.

Downstream, the Drini i Bardhë—Kosovo's longest river and part of the wider Drin basin draining to the Adriatic—sustains critical aquatic and riparian habitats and delivers essential ecosystem services such as water purification, sediment regulation, and flood mitigation. Its tributary, Lumbardhi i Prizrenit, rises in the Sharr Mountains and maintains cold, oxygen-rich waters that support diverse macroinvertebrate communities; a 2009 survey recorded 28 families across a 33-km reach. The smaller Toplluha/Tophulla stream, although less studied, contributes to local agro-ecological resilience through its riparian vegetation, pollinator support, and microclimate regulation. Together, these waters form ecological lifelines linking headwaters to lowlands and cities.

Yet both hotspots face mounting pressures. In the Sharr Mountains, illegal logging, fragmented enforcement, and unregulated tourism infrastructure erode habitat connectivity and disturb sensitive alpine and subalpine zones; governance fragmentation across the transboundary Sharr–Korab complex further complicates coordinated protection. In the Drini i Bardhë basin, pollution from agriculture and settlements, altered flows from hydropower and abstraction, and cumulative catchment modifications degrade aquatic habitats. Superimposed on these drivers, climate change amplifies thermal stress, shifts snowfall and runoff timing, and increases the likelihood of droughts, flash floods, erosion, and landslides—threatening cold-water biota, riparian systems, and conservation assets alike.

This chapter establishes the ecological baseline and risk context for these two hotspots, clarifies their role as regional corridors and refugia, and synthesizes current pressures—including climate-related hazards—most relevant to biodiversity persistence.

The area under study can be broadly categorized into two biodiversity-related hotspots—both rich in ecological value yet increasingly vulnerable. These include:

- The Sharr Mountains protected area and its surrounding landscape, and
- The network of rivers forming part of the Drini i Bardhë basin, including Lumbardhi i Prizrenit, Drini i Bardhë, and the river in Suhareka.

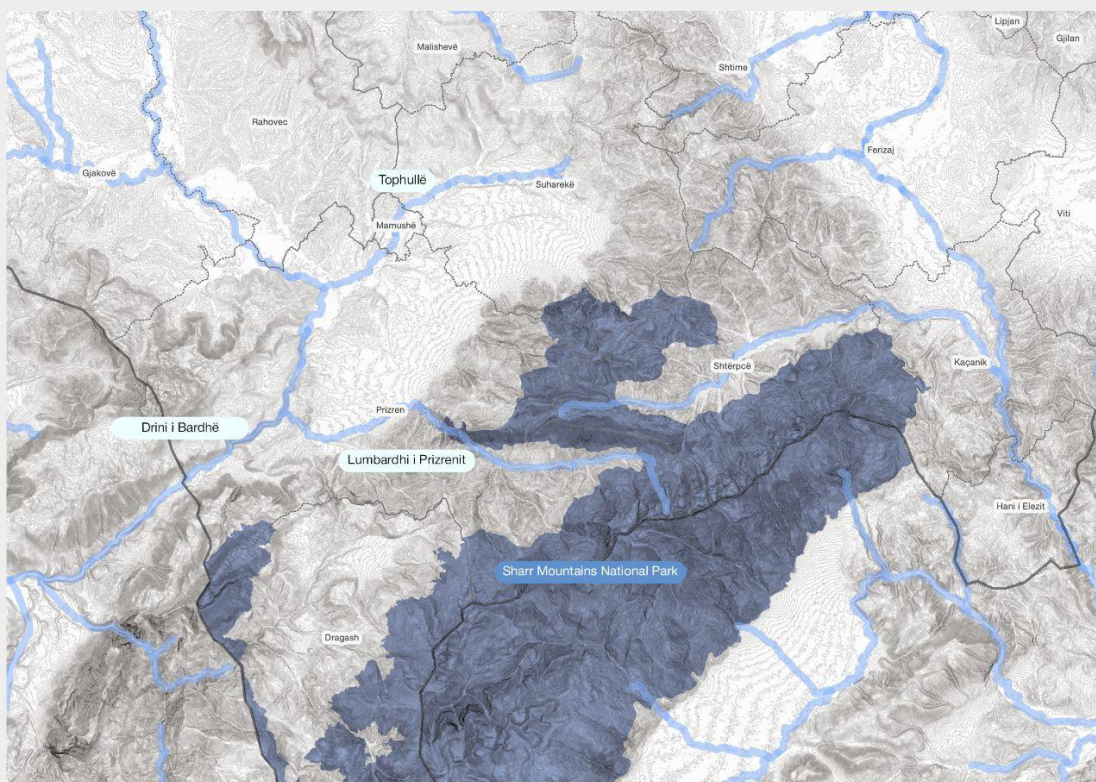


Figure 1. Map of the study area, focusing on Sharri Mountains National Park and the surrounding landscape, including key river systems such as the Drini i Bardhë, Lumbardhi i Prizrenit, and Toplluha, in proximity to the settlements of Prizren and Suharekë.

4.1 Biodiversity in the Sharr Mountains National Park

The Sharr Mountains National Park is widely recognized as one of the most important biodiversity hotspots in Southeast Europe, owing to its exceptional range of ecosystems, species richness, and high conservation value. According to the Law on the Sharr National Park, the area hosts over 1,800 species of vascular plants, making it one of the floristically richest regions in the Balkans. This includes a significant number of endemic, sub-endemic, and glacial relict species, many of which are listed under the Red List of Flora and Fauna of Kosovo, the Bern Convention, the EU Habitats Directive, and other international conservation frameworks.

The park's complex topography, with altitudes ranging from 800 to over 2,700 meters, supports an extraordinary diversity of habitats: alpine and subalpine meadows, glacial and periglacial lakes, karst formations, dense beech and conifer forests, and riparian ecosystems. These habitats offer vital ecological niches that support a remarkable array of life forms and ecological communities.

Faunal diversity is equally impressive. The park provides habitat for 32 species of mammals, including flagship and umbrella species such as the Balkan lynx, brown bear, wolf, and chamois. Avifauna is particularly rich, with more than 147 bird species recorded, including large raptors like the golden eagle, short-toed snake eagle, and eagle owl, as well as numerous species of conservation concern. The presence of diverse amphibian and reptile species further underscores the region's ecological significance.

A number of rare and endangered plant and animal species found within the park are included in the Red List of Flora and Fauna of Kosovo, highlighting their national conservation importance. Among the vascular plants listed are *Gentiana lutea*, *Achillea alexandri-regis*, and various endemic orchids, while the fauna includes rare butterflies like *Euphydryas aurinia*, as well as endemic freshwater invertebrates and regionally threatened amphibians. The inclusion of these species underlines the urgency of safeguarding their habitats and monitoring population trends.

Notably, the park is also home to species protected under international conservation frameworks, such as the Bern Convention, the EU Habitats Directive, and the Convention on International Trade in Endangered Species (CITES). Species listed under these agreements and found in the park include:

- The Balkan lynx (*Lynx lynx balcanicus*) – critically endangered and a flagship species for conservation in the region.
- Brown bear (*Ursus arctos*), wolf (*Canis lupus*), and chamois (*Rupicapra rupicapra*), all of which are listed in Annexes of the Habitats Directive.
- Several bird species like the golden eagle (*Aquila chrysaetos*), Eurasian eagle-owl (*Bubo bubo*), and multiple woodpecker species protected under the EU Birds Directive.
- Endemic amphibians and reptiles, including the Sharri salamander (*Mertensiella luschani*) and *Vipera ursinii*, listed in Annex II of the Habitats Directive.
- Over 200 species of fungi, and numerous invertebrates, such as rare Lepidoptera (butterflies)

and moths) and beetles, many of which enjoy strict protection status across international agreements.

Situated at the crossroads of the Central European, Mediterranean, and Alpine biogeographic zones, the Sharr Mountains function as a transitional zone and evolutionary melting pot, fostering both species overlap and divergent evolutionary processes. The park is also considered a climatic refugium, having preserved glacial relict species since the last Ice Age, thereby serving as a living archive of ecological resilience and adaptation. In addition, the Sharr Mountains form part of a wider ecological corridor that connects the Dinaric Alps to the Rhodope Mountains, enhancing landscape connectivity and gene flow across broader geographic scales. This function is critical in supporting long-term ecosystem stability and regional biodiversity.

4.2 Biodiversity across Drini i Bardhë, Lumbardhi i Prizrenit, and Tophulla

The Drini i Bardhë is the longest river in Kosovo, originating near Radavc and flowing westward through the country before joining the Black Drin in Albania. As a major component of the Drin River Basin—the most expansive water system in the Western Balkans shared among Albania, Kosovo, North Macedonia, and Montenegro—Drini i Bardhë drains into the Adriatic Sea and supports significant aquatic and terrestrial biodiversity. Its varied topography and climate gradients provide critical habitats for numerous species, making it a vital ecological corridor in the region.

The river plays a key role in migratory pathways for fish, while its riparian zones host a diversity of flora and fauna, including amphibians, birds, and mammals that depend on wetlands and floodplain ecosystems. Furthermore, the Drini i Bardhë contributes essential ecosystem services such as water purification, sediment regulation, and flood mitigation, making it not only ecologically significant but also indispensable to regional environmental health.

Flowing into this system is the Lumbardhi i Prizrenit (Prizren Bistrica), a left-bank tributary that originates in the Sharr Mountains—a recognized biodiversity hotspot. The river cuts through forested gorges and flows into the urban heart of Prizren. Particularly in its upper and mid-sections, the river sustains cold, oxygen-rich waters that support diverse communities of macroinvertebrates, aquatic insects, and amphibians.

A detailed study conducted in 2009 recorded 28 families of macroinvertebrates, including sensitive taxa such as Ephemeroptera, Trichoptera, Odonata, and Plecoptera, across a 33 km stretch of the river. These findings reveal high ecological complexity and make the Lumbardhi an important ecological corridor between mountain and lowland habitats. In addition to its ecological role, the river enhances urban biodiversity and offers potential for community-based conservation and monitoring.

Further downstream, in the municipality of Suhareka, lies the Tophulla stream, a smaller but ecologically valuable tributary that also connects to the Drini i Bardhë system. Although less extensively studied, Tophulla plays an important role in local biodiversity and agro-ecological balance. Its surrounding mosaic of traditional agricultural fields, semi-natural grasslands, and hedgerows supports pollinators, soil organisms, and riparian vegetation crucial for ecosystem health.

4.3 Challenges Facing the Sharr Mountains National Park

The Sharr Mountains National Park is one of the most ecologically important areas in Kosovo, forming a key part of the Drin River Basin and the wider Dinaric–Balkan mountain corridor. This mountainous landscape, shared with Albania and North Macedonia, harbors high levels of biodiversity, including endemic, rare, and protected species. Despite its designation as a national park, the area is under significant pressure from both non-climatic and climate-induced challenges that threaten its ecological integrity and long-term resilience.

Among the non-climatic challenges, illegal logging remains one of the most damaging activities. It is driven by weak enforcement capacities, unresolved land tenure issues, and limited economic alternatives in local communities. This unsanctioned extraction of timber contributes to the degradation and fragmentation of forest ecosystems, which are vital for species such as the brown bear (*Ursus arctos*), wolf (*Canis lupus*), and the critically endangered Balkan lynx (*Lynx lynx balcanicus*). The loss of habitat and biodiversity is exacerbated by the resulting soil erosion and the disruption of hydrological cycles²⁷.

A further significant concern is the proliferation of unregulated infrastructure development, especially in connection with tourism. Road expansions, ski resort construction, and related recreational facilities are frequently undertaken without adequate environmental impact assessments. Such interventions reduce habitat connectivity and increase human disturbance, posing long-term threats to the park's ecological corridors and sensitive alpine and subalpine zones²⁸.

Transboundary governance weaknesses also hinder effective conservation of the broader Sharr–Korab region. While the protected areas in Kosovo (Sharri National Park), North Macedonia (Šar Planina and Mavrovo National Parks), and Albania (Korab-Koritnik Nature Park) form a connected ecological landscape, they are governed by different legal regimes, planning instruments, and institutional structures. The absence of formal coordination mechanisms undermines joint management, limits data sharing, and restricts collective responses to shared environmental threats such as forest fires, poaching, and disease outbreaks^{29,30}.

4.4 Current Challenges for Biodiversity across Drini i Bardhë, Lumbardhi i Prizrenit, and Tophulla

4.4.1 Drini i Bardhë: A Shared Watershed Under Stress

The Drini i Bardhë, Kosovo's longest river and part of the broader Drin River Basin, faces significant ecological pressures despite its vital hydrological and ecological functions. Flowing from the Radavc spring near Peja and eventually joining the Black Drin in Albania, the river supports rich biodiversity and offers essential ecosystem services such as water supply, sediment transport, and flood regulation.³¹

²⁷ OSCE & adelphi. (2023). *Joint Co-operation Strategy on Climate Change and Security in the Shar/Šara Mountains and Korab Massif Area*. Vienna: Organization for Security and Co-operation in Europe (OSCE).

²⁸ OSCE & adelphi. (2023). *Joint Co-operation Strategy on Climate Change and Security in the Shar/Šara Mountains and Korab Massif Area*. Vienna: Organization for Security and Co-operation in Europe (OSCE).

²⁹ OSCE & adelphi. (2023). *Joint Co-operation Strategy on Climate Change and Security in the Shar/Šara Mountains and Korab Massif Area*. Vienna: Organization for Security and Co-operation in Europe (OSCE).

³⁰ OSCE. (2022). *Collaborative Approaches to Addressing Illegal Logging in Shar/Šara Mountains and Korab Massif Area*

³¹ RCC. (2020). *Drin River Basin Transboundary Diagnostic Analysis*. Regional Cooperation Council. <https://www.rcc.int/docs/487/drin-riv->

However, the river is increasingly affected by pollution from agriculture and urban sources, notably nutrient runoff and untreated wastewater entering the water system. Sediment overload caused by deforestation and construction along its catchment has led to the degradation of aquatic habitats, affecting fish spawning and reducing water quality.

Further, hydrological modification, especially in the Albanian section of the river basin, has altered natural flow regimes due to water abstraction for hydropower and irrigation. The river also suffers from governance challenges, as it is shared between Albania, Kosovo, North Macedonia, and Montenegro, making coordinated water management difficult.³² Climate change poses an additional risk, with rising temperatures³³ and increasingly erratic rainfall patterns threatening its role as a migratory corridor for fish and wetland species.

4.4.2 Lumbardhi i Prizrenit: A Mountain Stream at Risk

Originating in the Sharr Mountains, the Lumbardhi i Prizrenit is a tributary of Drini i Bardhë and a vital ecological artery in southern Kosovo. The river descends through gorges and forests before passing through the historic city of Prizren, supporting mountain ecosystems rich in macroinvertebrates and amphibians.

Upstream, the river maintains relatively high ecological integrity, with cold, oxygen-rich waters that sustain aquatic insects such as Ephemeroptera, Trichoptera, Plecoptera, and Odonata, as identified in a 2009 study that recorded 28 families of macroinvertebrates across six monitoring sites³⁴. However, urban encroachment in Prizren has led to the channelization of the river and a loss of natural flow dynamics³⁵. Solid waste dumping and sewage discharge remain persistent problems, particularly in downstream segments where water quality and biodiversity are declining.

Increased tourism in the Sharr region also places stress on the river through trail erosion, waste accumulation, and pressure on riparian vegetation. These cumulative impacts threaten its role as a natural corridor between mountainous and lowland ecosystems.

4.4.3 Toplluha in Suhareka: A Neglected Tributary Ecosystem

Toplluha, a small river flowing through the municipality of Suhareka, also contributes to the Drini i Bardhë system, though it is far less studied. Despite its modest size, Toplluha supports riparian flora, native amphibians, and insect species³⁶, especially within agro-ecological mosaics composed of hedgerows, grasslands, and semi-natural fields. These features make it important for pollination, microclimate regulation, and soil health.

Unfortunately, Toplluha is considered one of the most polluted tributaries in Kosovo. It is subject to severe environmental stress, including high nutrient and contaminant loads from household sewage³⁷, agrochemical runoff, and industrial effluents. The stream banks are frequently impacted by flooding and erosion, and the surrounding habitats are degraded due to land use

er-basin-transboundary-diagnostic-analysis

32 WWF Adria. (2020). WWF launches Drin River Basin project. <https://adria.wwf.org/?358751/WWF-launches-Drin-River-Basin-project>

33 IUCN. (n.d.). Project Drin River Basin. <https://www.iucn.org/our-work/project-drin-river-basin>

34 Gashi, N. (2012). Ecological assessment of Prizren Lumbardhi River using macroinvertebrates. <https://www.researchgate.net/publication/265220537>

35 UN-Habitat Kosovo. (2019). Strategic Environmental Assessment – Prizren Region. https://unhabitat-kosovo.org/wp-content/uploads/2019/06/SEA_Prizren_draft_786745.pdf

36 UN-Habitat Kosovo. (2019). Strategic Environmental Assessment – Prizren Region

37 Kosovo Environmental Protection Agency. (2023). Water Polluters Cadastre in Kosovo. https://www.ammk-rks.net/assets/cms/uploads/files/Publikime-raporte/Water_Polluters_Cadastre_eng.pdf

changes, including overgrazing, informal construction, and the lack of vegetated buffers. Unlike Drini and Lumbardhi, Toplluha has not been the subject of detailed ecological monitoring, which complicates restoration efforts. However, studies such as the 2025 Journal of Ecological Engineering article have begun exploring potential nature-based and engineering solutions³⁸ to restore and stabilize its banks, indicating the need for urgent, integrative ecological action.

4.4.4 Key Aquatic and Riparian Biodiversity in the Prizren–Suharekë–Rahovec Region and Their Water Management Implications

1. Brown Trout (*Salmo* spp.) and Native Fish in Mountain Streams

Description and Presence: Found in cold headwaters, such as Lumbardhi i Prizrenit (Sharr Mountains) and Lepenc headwaters; indicator of high water quality.

Threats: Reduced flows due to water abstractions and hydropower diversions; rising temperatures; pollution and sedimentation harming spawning grounds.

Management Implications: Maintain ecological flow requirements; regulate water abstraction; prevent pollution to preserve cold, oxygenated conditions.

2. White Drin Main Stem Ecosystem

Description and Presence: Larger river habitat supporting species like barbel (*Barbus*), nase (*Chondrostoma*), European chub, otters, and water birds; influenced by tributaries and irrigation return flows (e.g., near Rahovec).

Threats: Untreated wastewater discharge reducing oxygen levels and spreading disease; gravel extraction disrupting aquatic habitats.

Management Implications: Complete and maintain wastewater treatment plants (WWTPs); enforce effluent standards and riverbed mining regulations; conserve riparian vegetation buffers.

3. Mirusha River Canyon (Protected Landscape)

Description and Presence: Karst canyon with waterfalls, pools, endemic plants, bats, cave fauna, and pool-dwelling fish; protected since 1982.

Threats: Reduced water flows from drought or upstream usage; tourism pressure and littering.

Management Implications: Guarantee environmental flows to maintain waterfalls; limit upstream abstractions; improve park infrastructure and waste management; explore ecologically safe small upstream reservoirs to sustain flow during dry seasons.

4. Wetlands and Marshes (e.g., around Rahovec)

Description and Presence: Small wetlands fed by irrigation or oxbows; support frogs, newts, migratory birds; remnants found near Radoniqi Reservoir and Drin River banks.

Threats: Drainage, agricultural conversion, and summer water shortages.

Management Implications: Map and protect critical wetland patches as reserves; coordinate irrigation releases to sustain wetland water levels; pilot artificial wetlands for nature-based wastewater purification.

5. Sharri National Park Headwaters

Description and Presence: Alpine streams, bogs, and glacial lakes that source the Lumbardhi i Prizrenit and Lepenc rivers; home to endemic invertebrates and rare plants; critical for mammals like the Balkan lynx.

Threats: Climate change impacts including glacial melt and altered snowpack; potential hydropower development and overgrazing.

Management Implications: Enforce no-hydropower and no-extraction rules in the national park; monitor climate effects; protect upstream forests to improve water retention capacity.

³⁸ Osmani, B., & Vokshi, K. (2025). Integrating bank reinforcements and natural solutions for the regulation and protection of Toplluha River. *Journal of Ecological Engineering*, 26(2). <https://www.jeeng.net/Integrating-bank-reinforcements-and-natural-solutions-for-the-regulation-and-protection%2C208290%2C0%2C2.html>

6. Agricultural Landscape Biodiversity

Description and Presence: Irrigation canals and farm ponds, while artificial, support biodiversity like the European pond turtle and migratory birds; especially relevant in Rahovec vineyards.

Threats: Agricultural intensification and pesticide runoff.

Management Implications: Promote buffer strips along canals; reduce agrochemical use; encourage small water retention ponds for combined irrigation and ecological benefit.

Climate Change Trends and Their Implications for Biodiversity

The Prizren–Suharekë–Rahovec region is already experiencing measurable climatic shifts, including rising temperatures, declining snowfall, and changes in precipitation patterns. Analysis of historical data from 1961–2020 reveals a significant warming trend, especially in spring and summer months, with annual average temperatures rising by 1.2°C to 1.4°C. At the same time, winter precipitation is increasingly falling as rain instead of snow, and overall snow cover has declined, threatening seasonal water availability.

Future climate scenarios further project that these trends will intensify. Under high-emission scenarios (SSP5-8.5), summer temperatures may increase by over 4°C by the end of the century, while even the low-emission scenarios (SSP1-2.6) indicate warming of more than 2°C. The frequency and intensity of extreme weather events—such as heatwaves, droughts, and torrential rainfall—are also expected to increase. These changes will disrupt hydrological regimes, shift vegetation zones, and stress sensitive ecosystems.

Given the region's rich ecological tapestry—ranging from high mountain headwaters in the Sharr Mountains to wetland remnants and vineyard agro-landscapes—these shifts pose serious threats to both aquatic and terrestrial biodiversity. Altered flow regimes, habitat desiccation, phenological mismatches, and invasive species proliferation are among the most critical risks. Understanding and addressing these climate-induced changes is vital for maintaining the region's ecological integrity and adaptive capacity.

According to the Regional Assessment for South-Eastern Europe (OSCE), both the Drin/Drim River Basin and the Sharr Mountains are recognized as major biodiversity hotspots due to their exceptional ecological richness, high levels of endemism, and essential ecosystem services. However, these regions are simultaneously under serious threat, particularly from climate change, unsustainable land use, and infrastructure pressures. This dual status—ecologically vital yet critically vulnerable—makes targeted, climate-informed action across the region both urgent and necessary.

4.5 Climatic Challenges and Ecosystem Vulnerability in Sharr Mountains National Park

Climate change presents a series of escalating challenges for Sharr Mountains National Park (Sharri), a biodiversity hotspot in Kosovo renowned for its endemic alpine flora and glacial hydrology. The park's ecosystems, particularly those in high-altitude zones, are acutely vulnerable to warming temperatures, altered precipitation patterns, and extreme weather events, all of which are expected to intensify in the coming decades.

One of the most critical threats is the retreat of glacial and snow-dependent ecosystems. With rising average temperatures, there is a projected reduction in snow cover and earlier spring snowmelt, which in turn diminishes the volume and duration of spring flows feeding mountain

streams. These hydrological changes directly impact coldwater habitats and species such as trout, amphibians, and invertebrates adapted to high oxygen and low-temperature conditions. The shrinking of alpine wetlands and bogs could also affect rare plant communities and alter soil moisture regimes crucial for ecosystem function .

Furthermore, the park's endemic species, many of which are adapted to narrow ecological niches, may find it difficult to migrate to suitable habitats as conditions shift. This includes both floral and faunal species, some of which are already listed as vulnerable or endangered. Warmer winters may additionally encourage the spread of pests and invasive species into previously inhospitable zones, further destabilizing the ecological balance .

Extreme weather events, such as intense storms and droughts, are projected to become more frequent due to increased atmospheric moisture. In a terrain as steep and rugged as Sharri, this raises the risk of landslides, erosion, and flash floods, which can degrade habitats and undermine conservation infrastructure. In tandem, reduced summer flows and elevated temperatures could lead to thermal stress in aquatic ecosystems, causing die-offs of sensitive species, altering reproductive cycles, and concentrating pollutants in rivers and streams.

The alpine streams in the upper Sharr Mountains are particularly sensitive to the impacts of climate change due to their dependence on snowmelt and stable spring flows. These high-elevation water bodies are characterized by cold temperatures, high oxygen levels, and steep gradients, providing habitats for many specialist species that rely on precise thermal and hydrological conditions. Rising temperatures and reduced snow accumulation threaten to disrupt these delicate balances by diminishing flow volumes and altering seasonal water availability. During summer, lower flows and increased evaporation can lead to elevated water temperatures and higher concentrations of pollutants, while intensified winter rainfall may cause flash floods, sedimentation, and physical scouring of streambeds. Such changes risk degrading habitat quality and could lead to the retreat or loss of species that cannot adapt or relocate. Preserving the ecological integrity of these alpine stream systems will require close monitoring and adaptive conservation strategies that account for both hydrological and thermal stressors.

Adaptation efforts will require strict enforcement of conservation rules within the park, particularly in relation to hydropower development and water abstraction. Ongoing monitoring of indicator species and glacial retreat, as well as the development of climate-smart conservation strategies—such as protecting upstream forests for water retention and establishing ecological corridors for species migration—will be essential for maintaining ecosystem resilience in the face of a warming climate.

Climatic Challenges in Sharr Mountains National Park (Sharri) – Key Points

Sharri as a biodiversity hotspot:

- High-altitude park in Kosovo, home to endemic alpine flora and glacial hydrology.
- Particularly vulnerable to warming temperatures, altered precipitation, and extreme weather events.

Retreat of snow- and glacial-dependent ecosystems:

- Rising temperatures reduce snow cover and cause earlier spring melt.
- Results in shorter and weaker spring flows feeding mountain streams.
- Threatens coldwater habitats and species like trout, amphibians, and high-altitude invertebrates.

Loss of alpine wetlands and soil moisture:

- Shrinking of alpine bogs affects rare plant communities.
- Alters soil moisture regimes, disrupting essential ecosystem functions.

Habitat fragmentation and migration barriers for endemic species:

- Many species have narrow ecological niches and limited ability to shift ranges.
- Includes both vulnerable plant and animal species already under conservation concern.

Increased pest and invasive species pressure:

- Warmer winters enable spread of species into higher elevations.
- Poses additional threat to ecological stability and native biodiversity.

More frequent extreme weather events:

- Intensified storms and droughts due to increased atmospheric moisture.
- Steep terrain increases risks of landslides, erosion, and flash floods.
- These phenomena degrade habitats and can damage conservation infrastructure.

Thermal stress on aquatic systems:

- Reduced summer flows combined with higher temperatures stress aquatic life.
- Can lead to fish die-offs, disrupted breeding cycles, and increased pollutant concentrations.

4.6 Climate Risks to Biodiversity Across Drini i Bardhë, Lumbardhi i Prizrenit, and Toplluha

The watersheds of Drini i Bardhë, Lumbardhi i Prizrenit, and Toplluha represent ecologically valuable systems that are increasingly vulnerable to the cascading impacts of climate change. These changes—manifesting in altered hydrological regimes, increased frequency of extreme events, and shifts in seasonal patterns—are expected to exacerbate existing biodiversity challenges and potentially trigger new ecological instabilities.

Drini i Bardhë, as Kosovo's largest river basin, plays a pivotal role in sustaining lowland aquatic habitats, agricultural systems, and riparian ecosystems. Climate models project increased variability in precipitation and prolonged summer droughts, which may reduce base flows, concentrate pollutants, and elevate water temperatures³⁹. These changes threaten aquatic species already under pressure from water abstraction, agricultural runoff, and illegal gravel extraction⁴⁰. The reduction in snow accumulation in the surrounding mountains further limits spring recharge, weakening seasonal water availability vital to wetlands and amphibian habitats⁴¹.

Lumbardhi i Prizrenit, originating from the high-elevation zones of the Sharr Mountains, is characterized by steep gradients, glacial hydrology, and diverse high-altitude flora and fauna.

The retreat of snow cover and earlier snowmelt cycles have serious implications for coldwater

³⁹ IUCN ECARO & ADAPT (2023). *Regional Assessment: Climate & Biodiversity Resilience in the Western Balkans*.

⁴⁰ Zhushi, F. et al. (2020). Correlation between water parameters and macroinvertebrate indices in the White Drin river basin, Kosovo. *Journal of Water and Land Development*. Retrieved from: <https://journals.pan.pl/Content/117620>

⁴¹ World Bank (2019). *Water-Security Outlook for Kosovo*. Retrieved from: <https://documents1.worldbank.org/curated/en/496071548849630510/Water-Security-Outlook-for-Kosovo.pdf>

aquatic ecosystems and endemic mountain species, many of which depend on precise seasonal cues for breeding and migration⁴². Intense rainfall events, now expected to increase, could further accelerate erosion, sedimentation, and habitat fragmentation in this narrow valley system⁴³.

Toplluha, a hilly catchment in the Suhareka municipality, faces erosion-prone soils, shallow vegetation layers, and seasonal flow irregularities. While it does not exhibit karstic features, it is susceptible to localized biodiversity loss due to surface runoff, sediment transport, and soil degradation⁴⁴. Reduced precipitation during critical growth periods, coupled with intense downpours, is likely to destabilize already fragile plant assemblages and threaten aquatic microhabitats reliant on consistent moisture availability⁴⁵. These climate impacts compound existing anthropogenic pressures such as land conversion and upstream pollution¹. Together, these climate-driven threats reinforce pre-existing vulnerabilities in each basin. For example, temperature increases and reduced summer flows may intensify eutrophication and oxygen depletion in river segments already affected by nutrient inputs⁴⁶. Likewise, projected flood events could compromise restoration efforts and overwhelm existing conservation infrastructure⁴⁷. Without climate-informed biodiversity management, species decline and habitat loss in these watersheds will likely accelerate, particularly for endemic and sensitive species.

Moreover, additional climate-related stressors are projected to affect both human water needs and ecosystem integrity. Less summer rain and hotter temperatures will reduce streamflows in July–August and increase irrigation demand. This exacerbates competition between agricultural, urban, and environmental water needs. We can expect more frequent imposition of water saving measures, expansion of drip irrigation (to use water more efficiently), and possibly conflict or the need for allocation rules in extreme drought years. Kosovo’s Water Strategy calls for building new storage reservoirs to capture winter runoff for summer use. In the White Drin basin, potential projects include expansion of the Lepenc Canal (transfers water from Lepenc basin into Drenica/Ibër) to bring more water into the drier central areas, and construction of Firaja Dam (in the Lepenc basin) which might indirectly relieve pressure on other basins. While these are outside the immediate Prizren region, they form part of Kosovo’s adaptation strategy to boost water security nationally.

Warmer air holds more moisture, so when storms occur, they can dump larger amounts of rain in short time. The Drin basin’s steep terrain is prone to flash floods and landslides. Climate projections indicate flood events that used to happen once in 50 years might occur more often

42 RCC & GWP-Med (2018). *Nexus Mapping and Climate Risk Assessment – Kosovo*. Retrieved from: https://www.gwp.org/globalassets/global/gwp-med-files/list-of-programmes/see-nexus/mapping-studies-reports/nexus-mapping-study_report-for-kosovo.pdf

43 UNDP Kosovo (2023). *Cross-Sectoral Intervention Plan for Climate Change in Suhareka*. Retrieved from: <https://www.undp.org/sites/g/files/zskgke326/files/2023-05/Climate%20Change%20Cross-Sectoral%20Intervention%20Plan%20of%20Suharek%C3%AB%20-%20Suva%20Reka.pdf>

44 Shehu, I. (2019). *Water and Sediment Quality Status of the Toplluha River, Kosovo*. *Journal of Ecological Engineering*. Retrieved from: <https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-0066ebcf-785a-4ada-b292-77192071163c>

45 ESIA (2024). *Kosovo Improvement and Rehabilitation of Irrigation Systems Project*. Retrieved from: https://kruradoniqi-dukagjini.com/wp-content/uploads/2024/08/ESIA_Kosovo-Improvement-and-Rehabilitation-of-Irrigation-Systems-P179737_Final_June-2024-1.pdf

46 Zhushi, F. et al. (2020). *Correlation between water parameters and macroinvertebrate indices in the White Drin river basin, Kosovo*. *Journal of Water and Land Development*.

47 UNDP Kosovo (2023). *Cross-Sectoral Intervention Plan for Climate Change in Suhareka*.

(e.g. a severe flood every 20 years or less). Municipalities will need to update flood hazard maps periodically and possibly revise building codes (e.g. elevating structures in floodplain, providing floodproofing for infrastructure). The Flood Risk Maps being developed will incorporate climate change scenarios to delineate future risk zones.

Aquatic ecosystems will be under thermal stress – coldwater species may retract to higher elevations as downstream reaches get too warm. Lower summer flows also concentrate pollutants (less dilution), which could lead to more frequent fish kills or algal blooms in slow-moving waters. Conversely, heavier winter flows could scour riverbeds and alter habitat structures, affecting spawning grounds. Wetland habitats might dry out earlier in the year, affecting amphibian breeding cycles. In Sharri NP, climate change could threaten snow-dependent species and reduce spring flows that many streams rely on. Conservationists are keeping an eye on climate indicator species; for example, any disappearance of trout from mid-elevation streams would be a red flag.

MAPPING VULNERABILITY: FROM ENDANGERED SPECIES TO LANDSCAPES IN TRANSITION

5

BIODIVERSITY IN KOSOVO FACES PRESSURES FROM CLIMATE CHANGE, HABITAT LOSS, POLLUTION, AND WEAK PROTECTION, MAKING TRADITIONAL SPECIES LISTS LIKE THE RED BOOK INSUFFICIENT FOR GUIDING ACTION. A NEW APPROACH USES AQUATIC INSECTS—HIGHLY SENSITIVE BIOINDICATORS WHOSE LIFE CYCLES SPAN RIVERS, RIPARIAN ZONES, AND FORESTS—TO MAP HABITAT VULNERABILITY AND DETECT EARLY SIGNS OF ECOLOGICAL STRESS. BY LINKING SPECIES NEEDS TO SPATIAL HABITATS, THIS METHOD IDENTIFIES WHERE CRITICAL FUNCTIONS ARE BREAKING DOWN, ENABLING MORE PROACTIVE, LANDSCAPE-BASED CONSERVATION STRATEGIES THAT SUSTAIN ECOLOGICAL RESILIENCE.

5. Mapping Vulnerability: From Endangered Species to Landscapes in Transition

Biodiversity in Kosovo is under simultaneous pressure from climate variability, habitat fragmentation, water-quality degradation, and uneven protection and enforcement. Listing threatened species remains essential for national accountability, but it is no longer sufficient to anticipate ecological change or to guide spatially precise action. This chapter reframes vulnerability from a static catalogue of endangered taxa to a landscape-based, spatially explicit assessment of the conditions that sustain life—and the places where those conditions are unraveling.

The analysis is anchored in field observations and ecological expertise, with a focal group that is both vulnerable and highly informative for the broader system: aquatic insects (e.g., sensitive Ephemeroptera, Plecoptera, Trichoptera). As bioindicators whose life cycles bridge water and land, aquatic insects translate diffuse environmental stress into measurable biological signals. Their presence, abundance, and community composition reveal shifts in water quality, temperature, flow, riparian structure, and sediment dynamics—often before impacts are visible on larger fauna or vegetation.

To render vulnerability actionable, life-cycle requirements are translated into mappable habitats and assessed for condition and pressure across scales:

- Riverbeds and secondary tributaries (aquatic breeding and larval development)
- Riparian edge zones (emergence and transition)
- Forested buffer zones (adult dispersal and reproduction)

This life-cycle-to-habitat mapping detects where critical functions are compromised and identifies **sensitive zones** where multiple habitat requirements coincide.

The workflow integrates (i) field surveys (biotic and physicochemical), (ii) GIS-based habitat mapping (hydrological network and tributaries, riparian belts, forest buffers), and (iii) land-use and canopy datasets for pressure diagnostics.

In short, mapping is repositioned as an operative instrument: a means to learn from living systems, localize risk, and design interventions that sustain the hydrological, thermal, trophic, and structural relationships on which biodiversity persistence depends.

5.1. Background and the Need for a New Approach to Biodiversity Mapping

Among the key national documents related to biodiversity in Kosovo is the Red Book (Libri i Kuq), which serves as an official register of threatened species. Developed in alignment with the methodology of the International Union for Conservation of Nature (IUCN), the Red Book provides a scientific framework for assessing the conservation status of species based on risk criteria. It is part of Kosovo's broader effort to align with international environmental standards and to identify conservation priorities at the national level.

The Red Book of Kosovo (Libri i Kuq) plays a crucial role in documenting species that are under threat within the country, following a model derived from the global IUCN Red List. It categorizes species according to their level of risk—such as endangered, critically endangered, or vulnerable—and serves as a national inventory of flora and fauna facing extinction. As such, it functions as a foundational tool for conservation efforts and environmental policy, helping to set national priorities for species protection.

However, while Libri i Kuq is a key reference for identifying species already recognized as threatened, it remains limited in its scope and application when it comes to understanding broader biodiversity dynamics. First, it is important to emphasize that Libri i Kuq is not a biodiversity inventory. It does not provide a comprehensive picture of all species, nor does it account for the richness and complexity of ecosystems, genetic diversity, or habitat functionality. Moreover, it is not spatialized—it does not map where these species live, how their habitats are changing, or where ecological pressures are most concentrated.

The Red Book is also reactive by nature: it registers species that are already at risk of extinction but does not systematically analyze the causes of endangerment, such as habitat fragmentation, pollution, or climate-induced shifts. It largely overlooks the ecological interactions between species, the processes of habitat degradation, and the migration or adaptation strategies of species responding to new environmental conditions. In this sense, Libri i Kuq offers a snapshot of biodiversity loss, but not a broader, proactive understanding of biodiversity or its spatial and ecological dynamics.

This project aims to build a more systemic and spatial understanding of biodiversity vulnerability in Kosovo. It does so by integrating a multi-scalar methodology that includes spatial analysis of land use and habitat change, climate vulnerability assessments, species migration patterns, and the identification of ecologically significant zones that are not yet under formal protection. It also incorporates local ecological knowledge and field-based observations, helping to identify subtle or early-stage ecological shifts that may not yet be reflected in formal databases.

By expanding the focus beyond what is already endangered, this project contributes to a more proactive approach—one that seeks to understand and respond to underlying ecological pressures before they result in irreversible biodiversity loss. In doing so, it bridges the gap between species-based risk documentation and landscape-based vulnerability analysis, supporting more informed conservation strategies and long-term ecological resilience.

5.2 Methodological Approach: From Aquatic Insects to Sensitive Zones

To move from species-at-risk lists to a more nuanced, spatial, and anticipatory understanding of biodiversity, this project proposes a shift in both perspective and methodology. Rather than taking all biodiversity as an abstract totality, we begin from the specific ecological role and habitat of a particular group of organisms: aquatic insects—more precisely, insects that are born or develop in rivers and wetlands but later emerge and live part of their lifecycle on land. These organisms are known in ecology as specialist species, meaning they have narrow habitat

requirements and specific ecological functions, making them highly sensitive to environmental changes.

Selected as the focal lens for this methodology, aquatic insects—particularly EPT taxa (Ephemeroptera, Plecoptera, Trichoptera)—function as sensitive bioindicators whose life cycles span water and land. Their community structure and timing provide early, spatially specific signals of stressors such as water-quality decline, thermal anomalies, altered flows, and riparian disturbance.

5.2.1 A Habitat-Centered Definition of Biodiversity

For the purpose of this study, biodiversity is approached not as a static list of species, but as an interplay of ecological relationships and spatial conditions. It is defined through the habitat needs and vulnerabilities of these riverine insects. By starting from the specific requirements of these species and tracing how their habitat is shifting, fragmenting, or adapting due to climatic and anthropogenic pressures, we aim to construct a more actionable and grounded understanding of biodiversity in transition.

This methodological entry point allows to:

- Anchor abstract biodiversity discussions in concrete species-habitat relationships.
- Bridge scales, moving from micro-habitats (like riparian plant assemblages or soil moisture conditions) to landscape-level transitions (such as river course alterations, land use change, or deforestation).
- Visualize vulnerability, by mapping where these specific ecological conditions are disappearing, shifting, or under threat.
- Identify early-warning signals, since aquatic insect populations often reflect subtle environmental stress before it becomes visible in larger fauna or ecosystem collapse.

5.2.1.1 Why start from Aquatic insects?

Aquatic insects—such as certain mayflies, caddisflies, and stoneflies—are key indicators of ecological health. Their lives span both aquatic and terrestrial systems, which means their survival depends on the integrity of both. These species require clean, oxygenated water for reproduction, stable microclimates for emergence, and undisturbed riparian habitats for shelter and feeding. Because of this ecological specificity, they act as a lens through which we can observe broader ecosystem dynamics: degradation in water quality, temperature shifts due to climate change, or even small changes in vegetation cover can result in large population changes or local extinctions.

Aquatic insects are vital because they serve as:

- **Indicators** (of ecosystem health),
- **Connectors** (between land and water),
- **Supporters** (of food webs),
- **Specialists** (highlighting fragile conditions),
- and **Catalysts** (for nutrient cycles and biodiversity resilience).

Indicators of ecosystem health

Aquatic insects are among the most widely used bioindicators in freshwater ecosystems. Their sensitivity to changes in water quality, oxygen levels, pollution, and habitat disturbance allows for early detection of ecological stress. Monitoring their population trends offers insight into both short- and long-term impacts on river systems, providing a scientifically grounded method for assessing ecosystem integrity. Their presence or absence reflects the cumulative effects of environmental pressures that may not yet be visible through other forms of observation.

Connectors between aquatic and terrestrial environments

Many aquatic insect species undergo a lifecycle that spans both aquatic and terrestrial domains. Larval stages typically develop in rivers, streams, or wetlands, while adult stages emerge and function in terrestrial environments. This dual existence enables the transfer of energy and nutrients between ecosystems and plays a key role in maintaining ecological continuity across spatial boundaries. Their population dynamics are thus shaped by the conditions of both the aquatic habitats they originate from and the terrestrial environments into which they emerge.

Supporters of food webs

Aquatic insects occupy foundational positions in both aquatic and terrestrial food chains. As primary consumers, they contribute to the breakdown of organic material and regulate microbial populations in freshwater systems. In their adult forms, they become an essential food source for a wide range of species, including fish, amphibians, birds, and bats. Their abundance and diversity are closely tied to the health and stability of trophic interactions across multiple ecosystems.

Specialists with narrow habitat requirements

A significant number of aquatic insect species are ecological specialists, meaning they depend on very specific environmental conditions to survive and reproduce. These may include clean, fast-flowing waters, particular substrate compositions, or shaded and stable riverbanks. As a result, they are among the first organisms to respond to habitat degradation, fragmentation, or climatic shifts. Their specialist nature makes them highly valuable for detecting emerging vulnerabilities within ecosystems that may not yet be formally recognized or protected.

Catalysts for ecosystem processes and biodiversity resilience

Beyond their role in trophic dynamics, aquatic insects contribute directly to essential ecosystem processes. Larval stages engage in bioturbation—restructuring sediments and enhancing oxygen flow—while feeding behaviors contribute to the decomposition of organic material and nutrient cycling. These functions support the long-term resilience of aquatic systems, enabling them to better withstand and recover from environmental disturbances. Their presence contributes to ecosystem multifunctionality, particularly in dynamic or transitional landscapes.

5.2.1.2 What the Loss of Aquatic Insects Signals – And Why It Matters

The disappearance of aquatic insects is not merely a biological concern—it signals a wider ecological and systemic crisis. Their loss disrupts food webs, weakens ecosystem functionality, and undermines the capacity of environments to sense and respond to change. The implications span from the breakdown of localized ecological processes to the broader failure of

environmental governance.

1. Ecological breakdown at the base of food webs

- Fish populations decline due to lack of food (especially species that feed on larvae).
- Amphibians, birds, and bats lose critical protein sources during reproductive seasons.
- Reduced prey availability forces predators to relocate, potentially destabilizing surrounding ecosystems.

Aquatic insects form the foundation of many freshwater and riparian food chains. Larvae serve as a primary food source for fish, while adult insects support amphibians, birds, and bats—particularly during key seasonal windows such as breeding or migration. When insect populations decline, these feeding relationships begin to collapse. Fish experience reduced growth and reproductive success, while terrestrial predators lose essential protein-rich resources. This ripple effect destabilizes trophic relationships, weakening the broader ecosystem and its capacity to maintain balance across species.

2. Collapse of nutrient cycling and ecological functions

- Aquatic insects decompose organic matter and regulate microbial communities.
- They contribute to sediment mixing (bioturbation), maintaining oxygen levels and water quality.
- Their lifecycle transports energy and nutrients between aquatic and terrestrial systems.

Many aquatic insects play critical roles in maintaining freshwater ecosystem functions. As detritivores and herbivores, they help break down organic material, regulate microbial populations, and keep nutrient cycles in motion. Larvae that burrow and stir sediments (a process called bioturbation) improve oxygen penetration and prevent stagnation. Their life cycle also links aquatic and terrestrial systems: nutrients consumed in the river are released on land as the insects emerge, mate, and die. The loss of these organisms interrupts these cycles, leading to organic accumulation, slowed nutrient turnover, and potentially harmful imbalances like algal blooms or dead zones.

3. Disruption of ecological indicators and early warning systems

- Aquatic insects are bioindicators—sensitive to water quality, pollution, and temperature changes.
- Their loss removes a key early warning signal of ecosystem stress.
- Without them, management becomes reactive rather than proactive.

Because of their sensitivity to environmental variables—like pollutants, dissolved oxygen, pH, and flow—many aquatic insects are used as biological indicators of freshwater ecosystem health. Their disappearance removes a critical feedback system from the landscape. Without this “living data,” environmental stressors go undetected until they reach critical levels. This delays intervention, leading to reactive (often costly and ineffective) responses. The absence of insects means a loss of ecological sensing—the capacity of ecosystems to indicate stress

through the lived responses of their inhabitants.

4. Loss of specialist species and homogenization of ecosystems

- Specialist insects disappear due to habitat alteration and pollution.
- Generalist or disturbance-tolerant species (e.g. midges, mosquitoes) take over.
- Unique ecological identities of rivers are erased—ecosystems become biologically similar.

Many aquatic insects are ecological specialists: they depend on specific conditions such as clean, fast-flowing water, shaded banks, or particular substrates for their development. These are the first species to disappear when rivers are modified or degraded. In their absence, ecosystems are increasingly dominated by generalist species that tolerate or even benefit from disturbance, including some with negative implications for human health (e.g., invasive mosquitoes). Over time, this shift results in the **homogenization** of biodiversity—different rivers begin to resemble each other ecologically, regardless of their natural or cultural distinctiveness. This loss of ecological identity undermines both resilience and regional uniqueness.

5. Indicator of broader socio-environmental failure

- Declines often reflect failures in water governance and pollution control.
- Linked to unsustainable agriculture, pesticide runoff, river engineering, and climate stress.
- Their disappearance reveals the dysfunction of environmental management systems.

The decline of aquatic insect populations rarely occurs in isolation—it often reflects deeper failures in how land and water are managed. Poor enforcement of pollution controls, unchecked agricultural runoff, heavy pesticide use, and widespread river modification (e.g., dams, channelization) all contribute. Climate change amplifies these impacts through altered flow regimes, increased temperatures, and droughts. The absence of these species therefore serves as a systemic warning: environmental governance structures are not functioning effectively, and ecological thresholds are being crossed—often unnoticed or unacknowledged in policy frameworks.

6. Irreversible losses in evolutionary and genetic diversity

- Many aquatic insects are endemic and exist only in specific microhabitats or watersheds.
- Their extinction erases millions of years of evolutionary adaptation.
- We lose unknown potentials for science, medicine, and ecological resilience.

Some aquatic insects have extremely narrow geographic ranges, adapted over millennia to very specific hydrological and microclimatic conditions. Their extinction constitutes an irreversible loss of evolutionary history—these species cannot be replaced or reintroduced once gone. This loss also narrows the genetic pool that ecosystems need to adapt to future environmental changes. Furthermore, many aquatic insects remain poorly studied; their disappearance forecloses unknown ecological functions and scientific opportunities, including biomimicry,

natural product discovery, or ecosystem-based design strategies. Their loss diminishes not only nature's resilience—but also our capacity to learn from it.

In short, the loss of aquatic insect biodiversity is not just about species numbers — it is about the loss of ecological function, environmental sensing, and relational balance between species and habitats. It reflects our inability to sustain interconnected systems. Protecting these species is thus not only about conservation, but about maintaining the livability and resilience of our landscapes.

5.2.1.3 Defining Biodiversity Through Habitat-Specific Vulnerability

To move beyond generalized notions of biodiversity loss, this study proposes a habitat-centered approach rooted in the ecological needs of aquatic insects. Rather than treating biodiversity as an abstract or purely species-based concept, we focus on the specific ecological requirements of organisms whose survival depends on the integrity of multiple, interconnected environments. Aquatic insects—whose life cycles span both aquatic and terrestrial ecosystems—offer a particularly effective and sensitive entry point for this type of analysis.

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.

1. 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.

2. 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.

3. 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.

5.3 Mapping Methodology: Multi-Scalar, Spatial, and Situated

This section operationalizes the habitat-based approach by assembling a concise set of spatial layers that reveal where ecosystem functions required by aquatic insects are present and under pressure. The hydrological foundation combines the official river network with DEM-derived secondary tributaries to capture small drainage lines that structure larval habitat and sediment dynamics. Riparian structure is represented through two functional buffers from the river centerline: 0–50 m as the critical emergence belt where bank disturbance, trampling, and vegetation removal most directly interrupt the aquatic–terrestrial life cycle; and 50–150 m as the protective buffer that supplies shade, moisture, microclimate, and short-range connectivity for adult dispersal. Beyond 150 m, influence declines but patches may still operate as stepping-stone corridors for limited-dispersal taxa.

Adjacent vegetation is mapped using tree and shrub canopy layers (e.g., Copernicus), interpreted for contiguity and edge effects to indicate the quality of forested buffers that shelter adult stages, stabilize banks, and regulate temperature. Land-use/land-cover layers provide a pressure backdrop—intensive agriculture, urban fabric, road density, extraction sites, and grazing areas—while channel-alteration features (bank hardening, straightening, rip-rap, gravel mining footprints) identify reaches where physical habitat has been simplified or fragmented. Pollution proxies are added where available (wastewater outfalls, settlement proximity, known dump sites), alongside field observations such as spot temperature, dissolved oxygen, and notes on channel condition, to ground-truth the spatial patterns.

These layers are intersected to highlight “sensitive zones”: places where multiple habitat requirements coincide and where pressures accumulate. The resulting maps make visible the fine tributary network that sustains larval development, the riparian belts that enable successful emergence, and the forested mosaics that support adult dispersal—together with the specific land-use and engineering pressures that compromise those functions. The outputs guide action by showing exactly where riparian restoration, ecological-flow protection, pollution control, or connectivity measures will yield the greatest benefit to biodiversity. Limitations remain where point-source inventories or monitoring are incomplete; the maps are therefore designed to be iteratively refined as new field data and improved exposure layers become available.

Building on the fieldwork insights and policy review, the mapping of biodiversity vulnerability in the Sharr region was carried out by spatially identifying and analyzing key habitats that support aquatic biodiversity. These include:

1. Riverbeds and secondary tributaries,

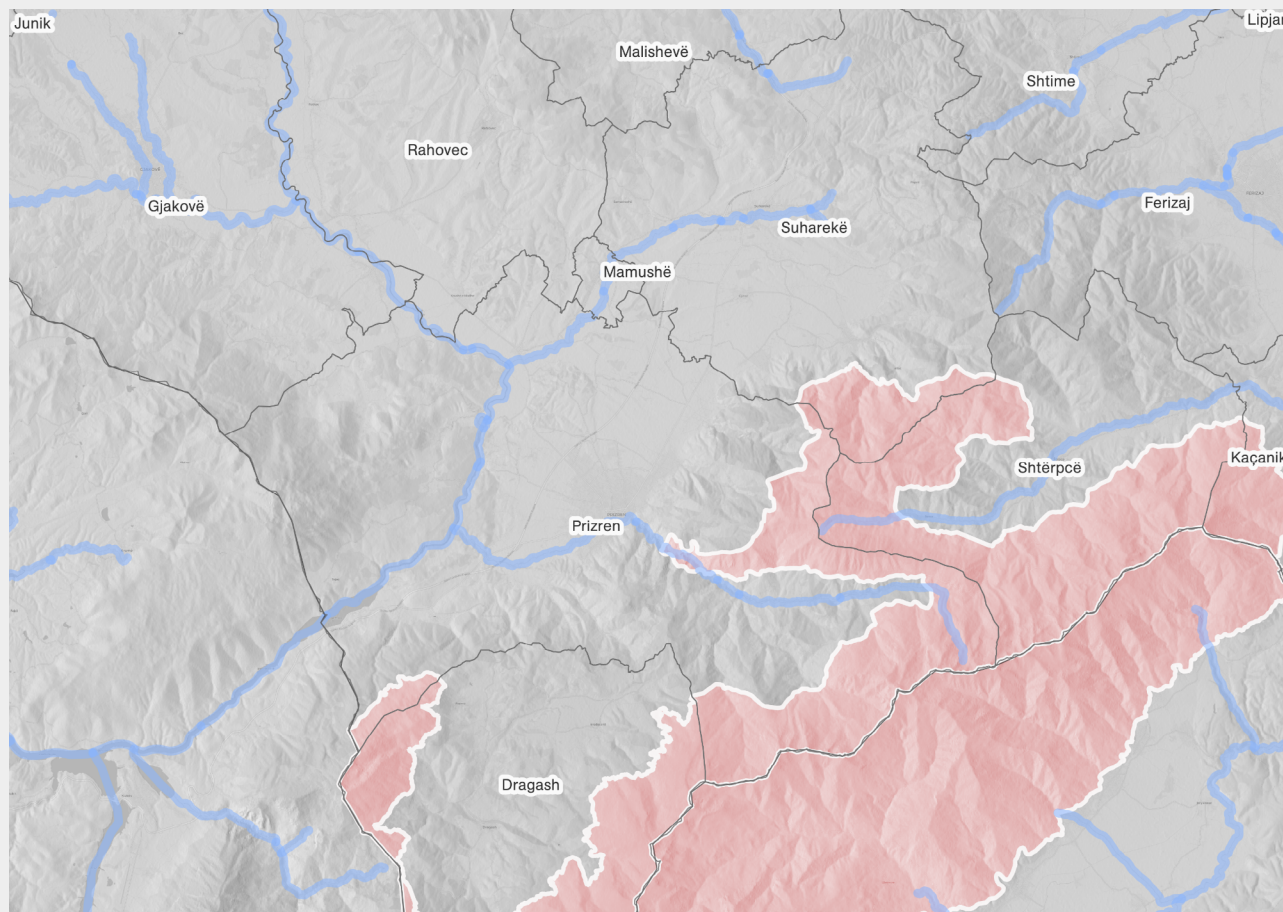


Figure 2. River network of the study area

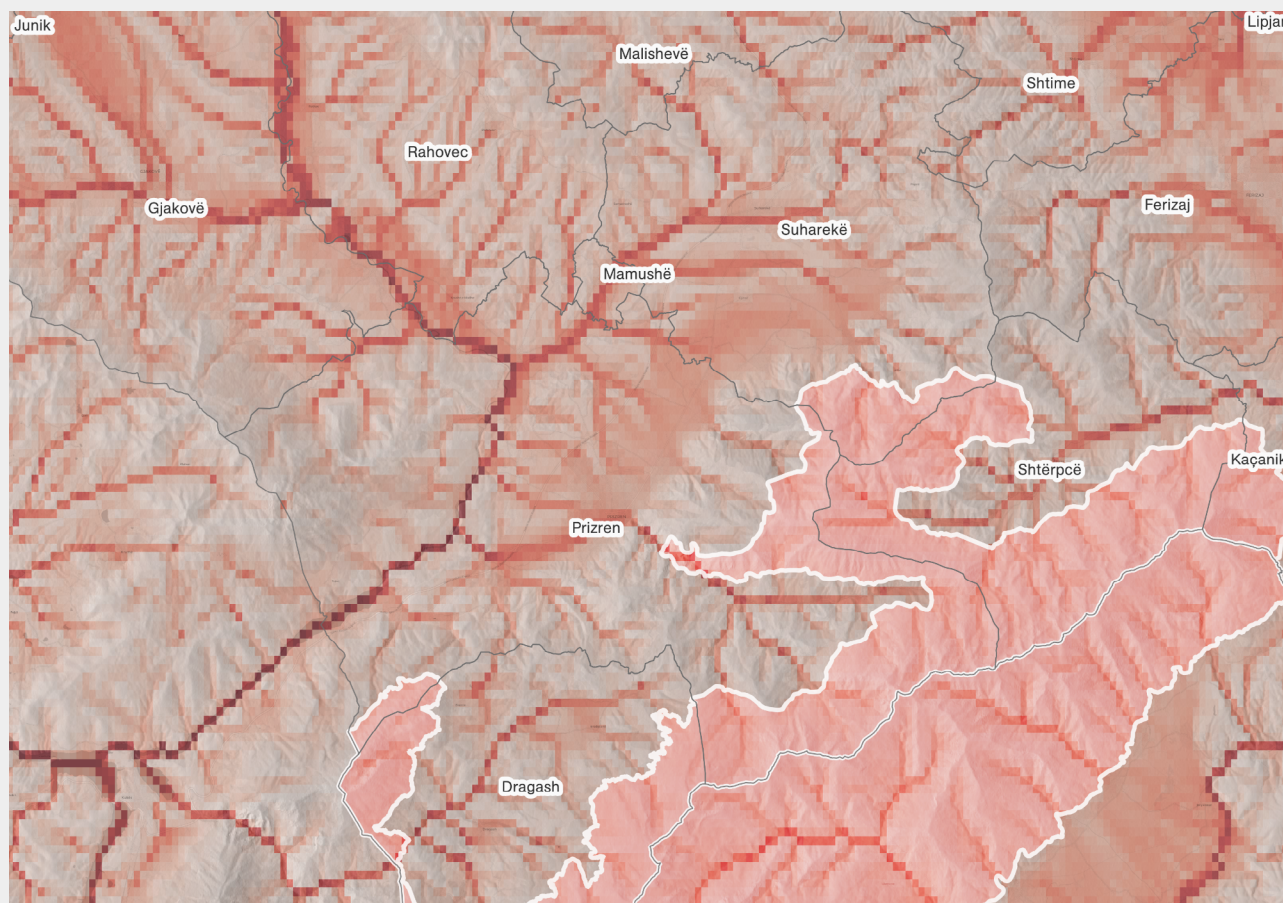


Figure 3. Tributary extraction from the DEM, showing drainage detail not present in base hydrography.

2. Riparian edge zones, and

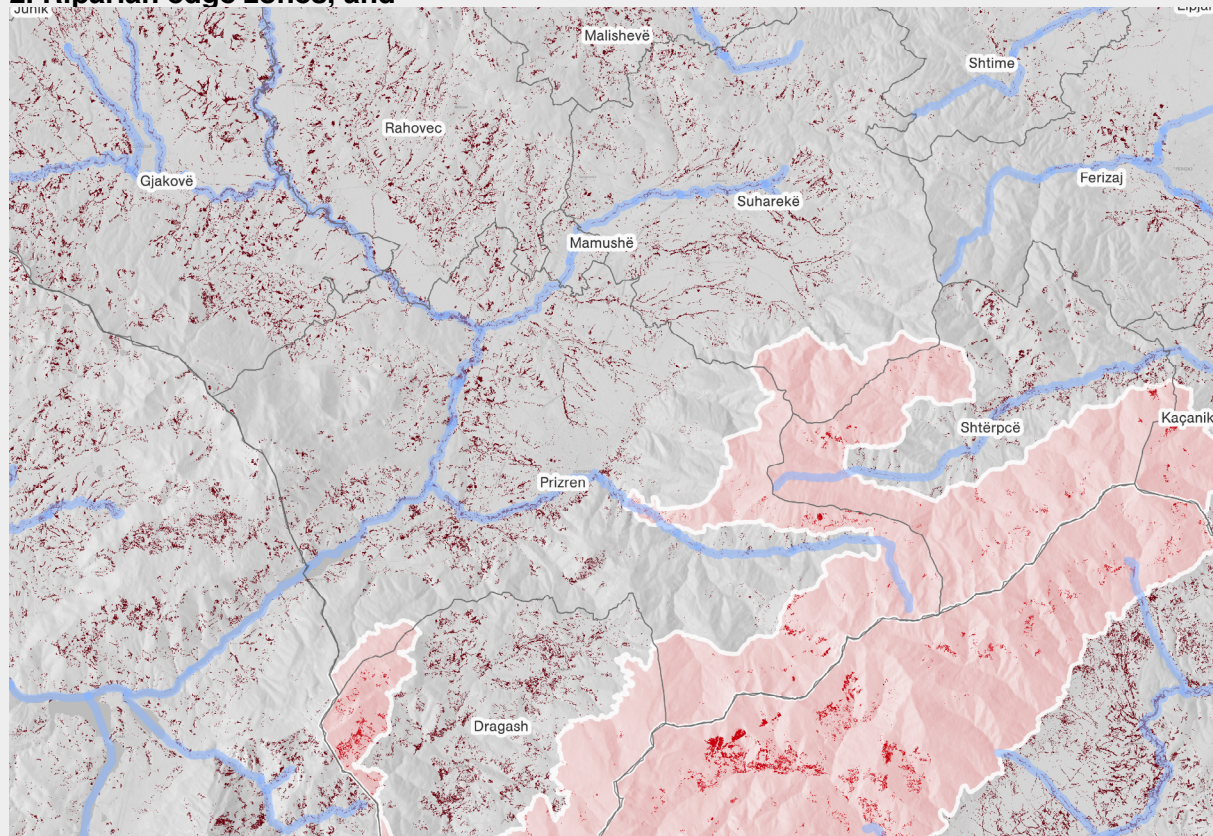


Figure 4. Low vegetation and shrub areas (source: Copernicus)

3. Forested buffer zones.

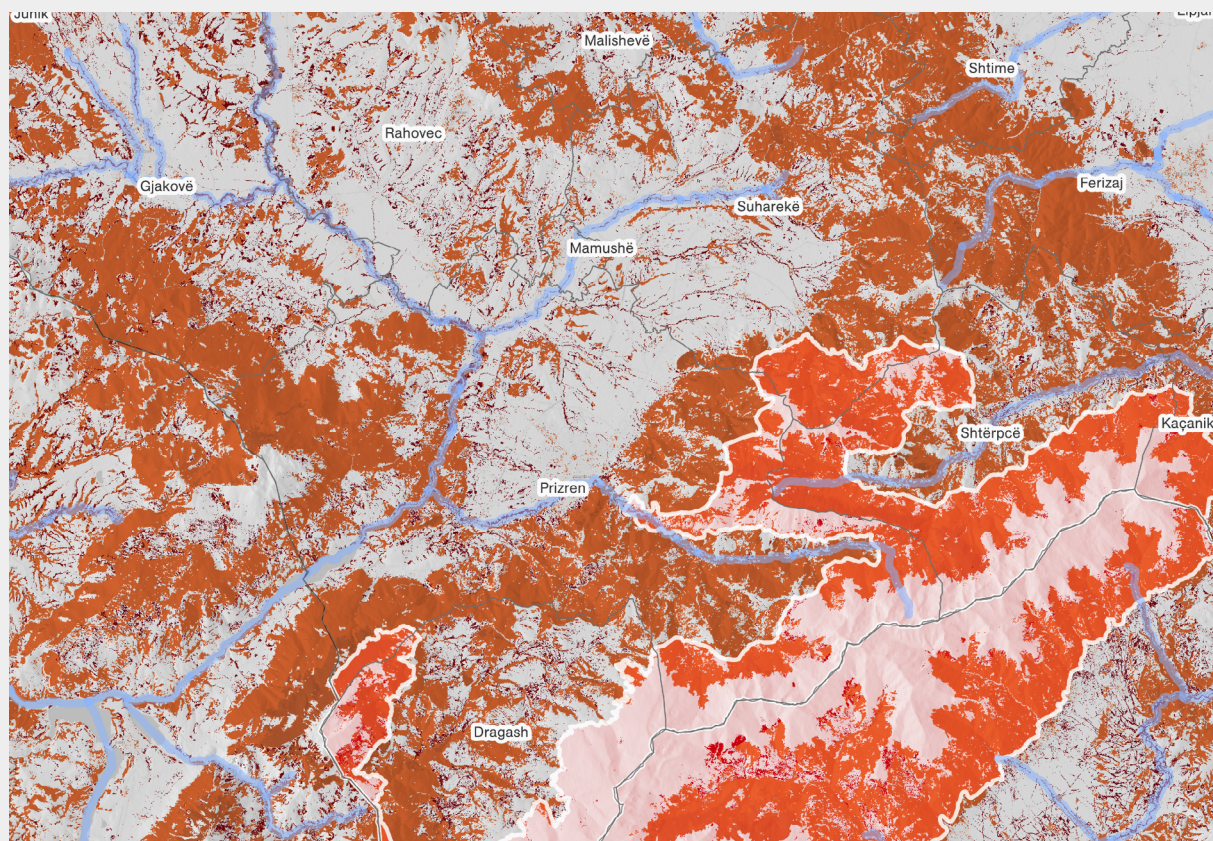


Figure 5. Forested buffers - tree-cover density. (source: Copernicus)

The aim is to develop a methodology for detecting ecologically sensitive areas and examining how these habitats intersect with existing land use patterns—both within and beyond protected areas. By identifying zones where all three habitat types coexist, the analysis highlights areas of high ecological value and vulnerability. This spatial overlap provides insight into current and emerging pressures on biodiversity, while also identifying where future opportunities for integrated landscape management may emerge. Ultimately, the goal is to use these findings to assess how such vulnerable areas are influenced by or exposed to changing climate patterns

Field evidence and spatial analysis confirm that the riparian belt is decisive for the life cycle of aquatic insects, especially within 150 meters of the water's edge. This area is not merely a physical boundary of the river but a functional space where transitions between aquatic and terrestrial phases occur, microclimate is maintained, and connectivity to adjacent habitats is secured.

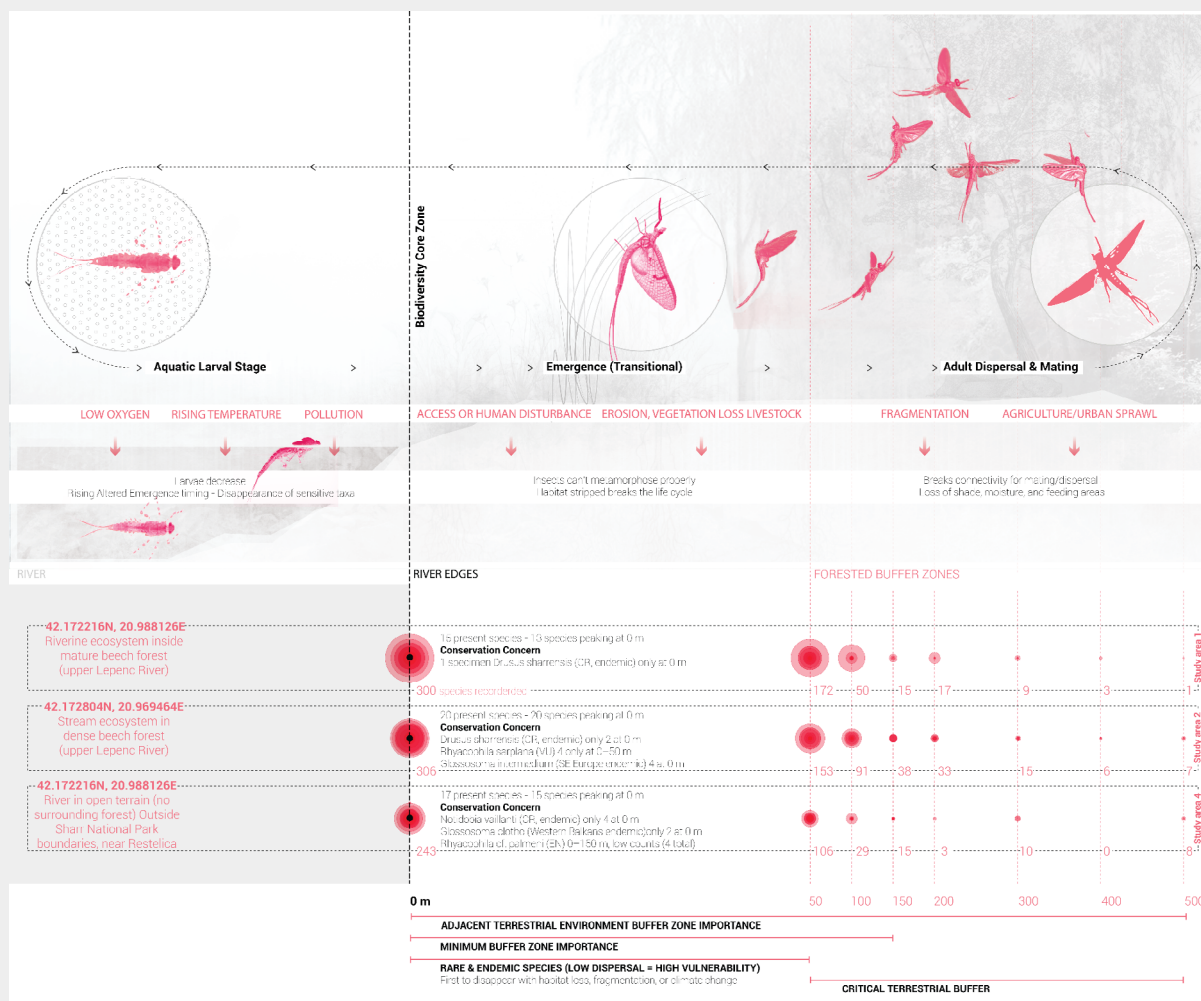


Figure 6. Riparian zone identified as important for the target aquatic system.

Within 150 meters of the channel, ecological functions change markedly with distance. The first 0–50 meters constitute the critical emergence belt, where the transition from water to land occurs; uncontrolled access, livestock trampling, vegetation removal, and bank armoring disrupt metamorphosis and sever the aquatic–terrestrial life cycle. From 50–150 meters, a protective buffer supplies shade, moisture, microclimate, and short-range connectivity that supports adult dispersal and reproduction. Beyond 150 meters, the direct influence of the river declines, yet forest and shrub patches can still operate as stepping-stone corridors for taxa with limited dispersal.

Accordingly, the riparian belt delineated above is adopted as the primary spatial unit for vulnerability analysis and for targeting management measures. Concentrating on this belt captures the processes that sustain bioindicator assemblages, mediates exchanges between channel, floodplain, and adjacent land uses, and provides the most cost-effective locus for restoration and protection (e.g., temperature moderation, bank stability, habitat continuity).

Because the riparian belt interacts directly with agricultural, urban, and forested zones, land-use/land-cover (LULC) analysis is used to diagnose tensions—such as shrub clearing, livestock crossings, and informal tracks cut to the river—and to identify opportunities—including riparian restoration, vegetated buffer establishment, and reconfigured public access—to mainstream biodiversity into sectoral management.

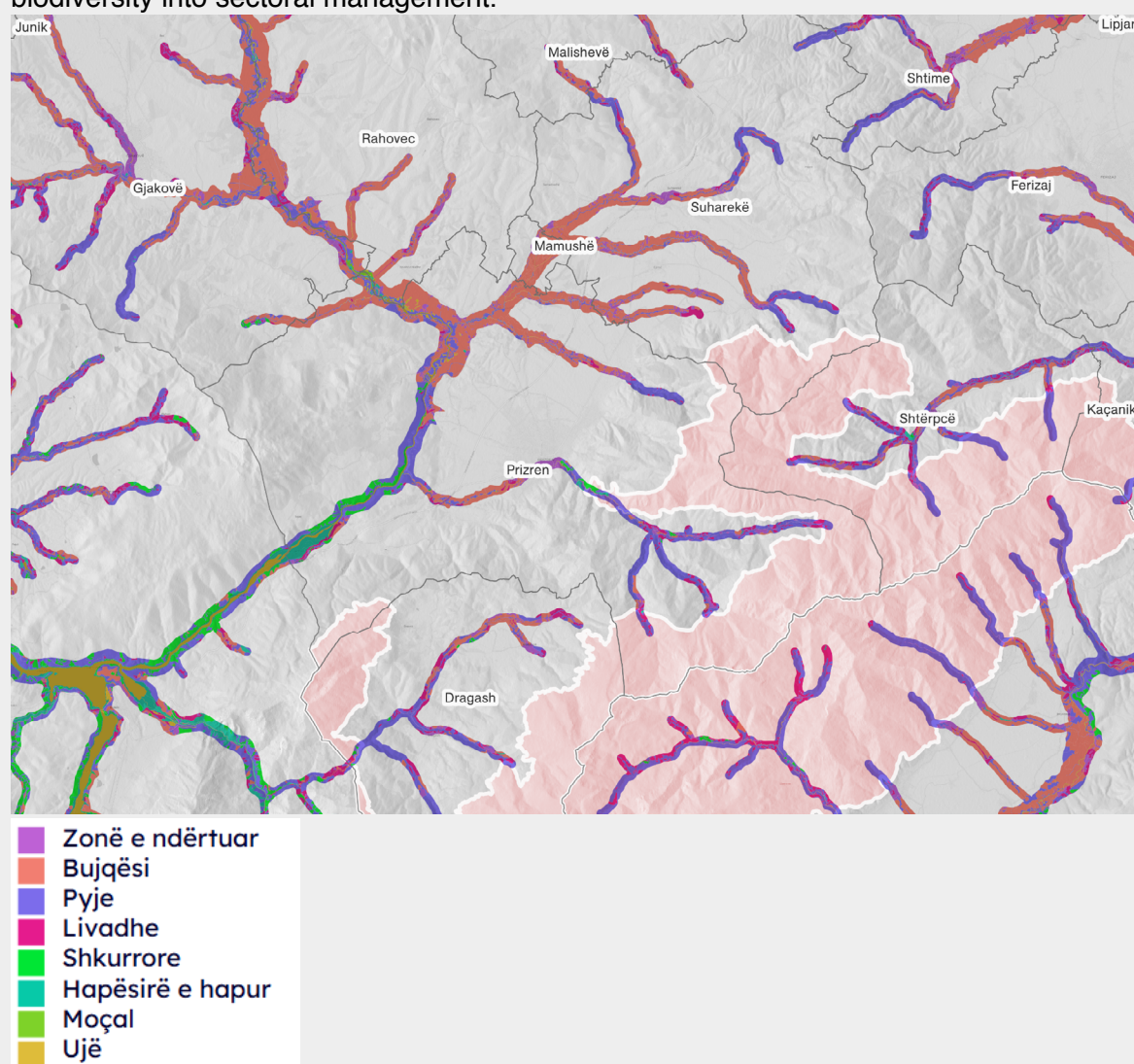


Figure 7. Landuse surrounding the riparian zone. Data source: Coopernicus

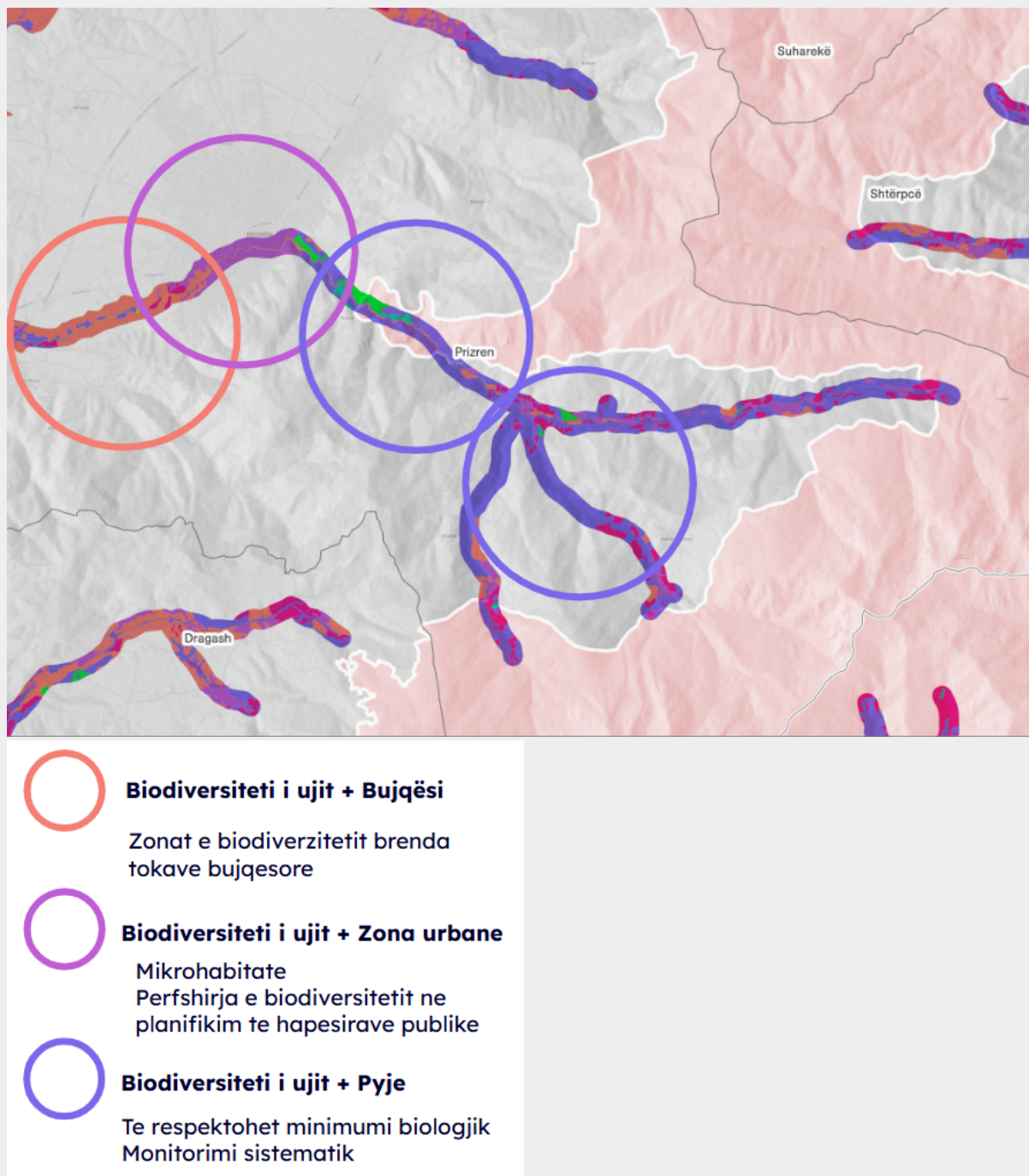


Figure 8. Three recurring configurations that are useful as a first step for spatial prioritization

The analysis highlights three recurring configurations that are useful as a first step for spatial prioritization:

1. **Upper forested reaches (Sharr) — forest–river complexes:** cold, oxygenated water and high larval-habitat sensitivity to disturbance in the 0–50 m belt. Orientation: maintain canopy cover, avoid bank hardening, control crossings.
2. **Peri-urban river corridor (Prizren) — river in contact with infrastructure/public access:** high risk of channelization, vegetation clearance, and diffuse pollution. Orientation: establish 0–50 m vegetated buffers, manage access points, remove physical barriers where feasible.
3. **Lowland agro-ecological mosaic (Suharekë/Rahovec) — river, fields, and irrigation canals:** pressures from agrochemicals, erosion, and livestock; strong potential for nature-based measures (e.g., filter strips, small ponds). Orientation: 50–150 m buffer with native shrubs/trees, managed drainage, and habitat-friendly canal retrofits.

Crossing the hydrological, riparian, vegetation, land-use, and modification layers yields sensitive zones—river segments and adjacent belts where multiple habitat requirements co-occur and pressures accumulate. The composite surfaces make visible three things at once: (i) the fine tributary network that sustains larval development, (ii) the 0–50 m and 50–150 m riparian functions that enable emergence and short-range dispersal, and (iii) the forest/shrub mosaics that support adult stages and corridor continuity. Read together, these maps indicate where interventions will deliver the highest ecological return—for example, riparian restoration in 0–50 m belts, protection of side channels and secondary tributaries, ecological-flow safeguards on sensitive reaches, targeted pollution control near discharge points, and patch-to-patch forest connectivity measures.

The outputs are intended as decision support for:

- **Prioritization and phasing:** ranking reaches by overlap of habitat functions and pressure intensity to stage near-term (0–2 years) vs. medium-term (3–5 years) actions.
- **Design targeting:** locating precise sites for vegetated buffers, bank naturalization, barrier removal or retrofitting, and habitat-friendly canal management.
- **Permitting and safeguards:** flagging high-sensitivity belts (especially 0–50 m) to guide setbacks, access control, and conditions on works near water.
- **Monitoring baselines:** proposing indicators (e.g., EPT assemblages, dissolved oxygen, canopy continuity, fine-sediment deposition) tied to each priority reach.
- **Co-benefits and risk reduction:** aligning biodiversity actions with flood mitigation, erosion control, water-quality improvements, and climate-refugia protection.

To aid implementation, priority clusters are identified both inside and outside protected areas, highlighting leverage points along peri-urban corridors and lowland agro-mosaics where nature-based measures can be integrated with existing land uses. Where point-source inventories or monitoring are incomplete, confidence is noted at map level; the products are designed for iterative refinement as new field data and improved exposure layers become available, ensuring that investments remain spatially precise, cost-effective, and ecologically justified.

Implementation also depends on cooperation across adjacent land uses. In the upper forested reaches (Sharr), coordination with the forestry service and the park directorate should secure

continuous canopy over the channel, prohibit bank hardening in the 0–50 m belt, and formalize a limited number of controlled crossings (with seasonal work windows to avoid emergence). Along the peri-urban river corridor (Prizren), municipal planning, public works, utilities, and transport agencies should align permits and capital works to establish 0–50 m vegetated buffers, regulate public access points, and remove or soften physical armoring and barriers where feasible, integrating stormwater retrofits. Within the lowland agro-ecological mosaic (Suharekë/Rahovec), agricultural authorities, water-user associations, and landowners should co-finance 50–150 m native buffers, filter strips and small ponds, managed drainage, and habitat-friendly canal retrofits tied to agri-environment incentives. Across all three settings, memoranda of understanding should specify setbacks, design standards, maintenance responsibilities, and monitoring (e.g., EPT indices, dissolved oxygen, canopy continuity), with enforcement and incentive mechanisms embedded in sectoral budgets and permits.

Conclusions

This report situates Kosovo's biodiversity within a changing climate and a complex land-use mosaic, focusing on two priority hotspots—the Sharr Mountains and the Drini i Bardhë basin—and reframes vulnerability from a static catalogue of species to a spatially explicit reading of habitats and functions. The analysis shows that pressures from warming, hydrological change, fragmentation, pollution, and uneven enforcement are converging on river corridors and their adjacent landscapes, where ecological processes are most tightly coupled and most easily disrupted.

A central contribution is methodological: treating mapping as an operative instrument rather than a posterior description. By starting from aquatic insects as sensitive bioindicators and translating their life-cycle requirements into mappable habitats—riverbeds and secondary tributaries, riparian edge zones, and forested buffers—the study identifies “sensitive zones” where multiple functions co-occur and where pressures accumulate. The riparian belt (0–50 m and 50–150 m) emerges as decisive for emergence, microclimate, short-range dispersal, and corridor continuity; beyond 150 m, forest and shrub patches still act as stepping stones for limited-dispersal taxa. These findings supply a practical geography for intervention.

The composite maps make three realities visible at once: the fine tributary network sustaining larval development; the riparian belts that enable transition from water to land; and the forest/shrub mosaics that stabilize banks, buffer temperature, and maintain connectivity. Read together, they indicate where restoration and protection yield the highest ecological return—riparian restoration in 0–50 m belts, safeguarding of side channels and secondary tributaries, ecological-flow protections on sensitive reaches, targeted pollution control near discharge points, and patch-to-patch forest connectivity.

Implementation depends on cooperation across adjacent land uses. In upper forested reaches (Sharr), forestry and park management should maintain continuous canopy, prohibit bank hardening within 0–50 m, and formalize controlled crossings. Along peri-urban corridors (Prizren), municipal planning, utilities, and transport should align permits and public works to establish vegetated buffers, manage access, retrofit stormwater, and remove or soften armoring. In lowland agro-mosaics (Suharekë/Rahovec), agricultural authorities, water-user associations, and landowners should co-finance 50–150 m native buffers, filter strips and small ponds, managed drainage, and habitat-friendly canal retrofits through agri-environment incentives. Memoranda of understanding should set setbacks, design standards, maintenance, monitoring, and enforcement across sectors.

The outputs are intended as decision support for prioritization and phasing (near-term versus medium-term action), design targeting (buffers, bank naturalization, barrier removal, canal retrofits), permitting and safeguards (flagging high-sensitivity belts), and monitoring baselines (EPT assemblages, dissolved oxygen, canopy continuity, fine sediments). They also align biodiversity gains with co-benefits in flood mitigation, erosion control, water quality, heat relief, and climate-refugia protection—inside and outside protected areas.

Two cross-cutting needs follow. First, governance: embed no-net-loss/net-gain standards in sectoral permits; reference mapped sensitive zones in approvals and performance conditions; create a multi-agency river-corridor task force with shared GIS layers; and fund community stewardship and citizen-science monitoring tied to clear indicators. Second, iteration: close data gaps on point sources and small tributaries, expand field validation, and periodically refresh the

maps with improved exposure layers and climate information so investments remain spatially precise, cost-effective, and ecologically justified.

In sum, safeguarding biodiversity under climate pressure requires shifting from lists to landscapes, from descriptions to operative maps, and from isolated conservation actions to sector-wide design and permitting standards.

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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."

