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Do riparian evaluation tools reflect riparian vegetation functioning and relevance of this approach under global changes?

Est-ce que les indices d'évaluation des ripisylves reflètent la fonctionnalité de la végétation riparienne et quel est l'intérêt de cette approche dans un contexte de changement global ?

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Abstract: This interdisciplinary study investigates whether riparian assessment indices (IBCR and RipaScan) accurately reflect the ecophysiological responses of hygrophilous trees (Alnus glutinosa and Fraxinus excelsior) under water stress, in the Loire Rhône-Alpes watershed context. Fieldwork involved measuring functional traits (SLA, LDMC, water potential, stomatal conductance) across five sites with varying degrees of restoration and land use. Results show that leaf water potential significantly correlates with IBCR quality classes, especially under stable dry conditions, but this relationship weakens following rainfall events. Restored sites generally exhibit improved ecophysiological conditions, though responses vary by species and session. A complementary sociological survey revealed barriers to tool adoption among practitioners, including lack of time, conceptual ambiguity, and mismatch between scientific tools and field constraints. The study highlights the need to co-design simplified, function-oriented indices to better guide adaptive riparian management under climate stress.

Key words: Riparian zone, riparian vegetation, water stress, ecophysiology, IBCR, RipaScan, restoration, local policy.

Résumé : Cette étude interdisciplinaire évalue la capacité des indices d'évaluation de la ripisylve (IBCR et RipaScan) à refléter les réponses écophysiologiques d'arbres hygrophiles (Alnus glutinosa et Fraxinus excelsior) soumis au stress hydrique, dans le contexte du SAGE Loire Rhône-Alpes. À travers des mesures de traits foliaires (SLA, LDMC, potentiel hydrique, conductance stomatique) sur 5 sites contrastés, les résultats montrent que le potentiel hydrique varie significativement selon la qualité écologique évaluée par les indices, mais que cette correspondance dépend fortement du contexte hydrométéorologique. Les arbres en sites restaurés présentent une meilleure résistance hydrique dans des conditions modérées, mais ce signal s'atténue après des événements pluvieux. En parallèle, une enquête auprès des gestionnaires révèle un manque d'appropriation des outils, dû à leur complexité, à une communication insuffisante et à un décalage entre attentes opérationnelles et objectifs scientifiques. L'étude propose des pistes pour améliorer l'intégration de critères fonctionnels dans la gestion adaptative des ripisylves.

Mots clés : ripisylve, zone riparienne, stress hydrique, écophysiologie, IBCR, RipaScan, restauration, gestion locale.

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1. Introduction

In the context of global change (Calvin et al., 2023)—largely driven by direct and indirect human activities—freshwater systems are increasingly under pressure, and water resources have become a critical concern (Delpla et al., 2009; Haddeland et al., 2014; Johnson et al., 2009). Recent climatic events highlight the tangible reality of climate change, with increasingly unstable weather patterns leading to longer, more frequent, and more intense droughts. At the same time, heavy rainfall often falls on dry, compacted soils, reducing infiltration and groundwater recharge. These trends negatively affect both the quantity and availability of freshwater resources, which are essential to life, ecosystems, and well-being (Calvin et al., 2023; Haddeland et al., 2014; Johnson et al., 2009). Simultaneously, urban sprawl and intensified agricultural practices contribute to pollution, landscape fragmentation, and biodiversity loss—further degrading the quality and resilience of hydrosystems, especially rivers as their central components (Astaraie-Imani et al., 2012; Delpla et al., 2009; Li et al., 2023).

The inherent complexity of fluvial systems demands an interdisciplinary and cross-sectoral approach. These systems can be analysed at multiple spatial and temporal scales, integrating hydrological, ecological, morphological, and geographical dynamics (Dufour et al., 2019a; Piegay and Maridet, 1994). More than just physical systems, rivers today are socio-hydrosystems—shaped by and shaping human activities—making it essential to include social policy sciences in their study and management (Cottet et al., 2023; Riviere-Honegger et al., 2015).

A fundamental component of riverine landscapes is the riparian zone and its associated vegetation, which delivers numerous ecological services. These include pollutant filtration, water surface shading, habitat provisioning, bank stabilization, and flood attenuation (Chase et al., 2016; Dufour et al., 2019b; Riis et al., 2020; Rodríguez-González et al., 2022; Vidal-Abarca et al., 2016). Riparian vegetation also plays a pivotal role in fluvial dynamics by contributing to sediment transport, input of woody debris, soil water retention, evapotranspiration, primary productivity, and flow regulation (Corenblit et al., 2009; Corenblit and Steiger, 2023; Piegay and Maridet, 1994; Steiger et al., 2005).

Despite their importance, riparian zones and associated vegetation remain inconsistently defined. Discrepancies exist between scientific frameworks and field applications—some based on structural versus functional characteristics, others on communities or ecological processes. Moreover, terminology varies across scales: terms like "vegetation," "forest," "area," "zone," or "corridor" may refer to overlapping or distinct concepts also depending on disciplinary interpretation (Dufour et al., 2019b; Rodríguez-González et al., 2022). Here, we adopt a composite definition drawing from fluvial, ecological, and geographical perspectives: riparian vegetation comprises hydrophytic plant communities located between the high-water mark and adjacent uplands, influenced by freshwater proximity (e.g., flooding, water table) and in turn influencing hydrological dynamics (e.g., evapotranspiration), typically within a ~30-meter buffer. Beyond this zone lies the alluvial forest.

Anthropogenic pressures such as clear-cutting, land-use changes, and riverbed incision directly impact riparian vegetation, often reducing these zones to narrow strips of trees—or eliminating them altogether. Additionally, the spread of invasive alien species, while still debated, undeniably alters riparian plant community composition. Consequently, the ecological functions provided by these communities are diminished: degraded riparian vegetation supports fewer services and at reduced capacities compared to intact, natural stands (Aguiar et al., 2009; Boggs et al., 2015; Cornejo-Denman et al., 2018; Johnson et al., 2020; Richardson et al., 2007; Zermeño-Hernández et al., 2020).

Riparian vegetation communities are central to the delivery of ecosystem services. Moreover, diverse riparian types exist—for instance, in France, Mediterranean communities in the Rhône-Méditerranée-Corse watershed are different than inland assemblages in the Massif Central. The National Botanic Conservatory in the Massif Central has identified 13 phytosociological groups, reflecting environmental heterogeneity and functional diversity (LABROCHE et al., 2021). From a species perspective, various hygrophilous trees dominate, including *Salix* spp*., Fraxinus excelsior, Betula pubescens, Populus nigra,* and *Alnus glutinosa*. From an ecological succession viewpoint, riparian zones may transition from pioneer species (e.g., *Salix, Alnus, Populus*) to more advanced stage (*Fraxinus, Ulmus minor,* and eventually *Quercus robur* or *Acer pseudoplatanus*) (Dufour and Piégay, 2006). Understanding these assemblages helps interpret finer-scale ecological and physiological dynamics.

Indirect threats also jeopardize riparian vegetation. For instance, channel incision can disconnect plant roots from groundwater, leading to a shift from hygrophilous to mesophilous species (Nadal-Sala et al., 2017; Rohde et al., 2021; Williams et al., 2022). Climate-facilitated diseases, such as Phytophthora (affecting alders) and ash dieback (Hymenoscyphus fraxineus), further impair dominant species. As a result, key ecological functions are compromised: lower organic matter input weakens trophic networks, and species loss erodes the functional integrity of riparian ecosystems. Even when total vegetation loss is avoided, changes in species composition can drastically reduce ecosystem services (Alimpić et al., 2022; Corbacho et al., 2003; Janssen et al., 2020).

At the local level, riparian vegetation is shaped by a multitude of factors—soil conditions, biotic interactions, plant health, and environmental variables such as temperature, hydrological regime, and river dynamics(Chase et al., 2016; Corbacho et al., 2003; Corenblit and Steiger, 2023; Steiger et al., 2005). Among these, water availability is critical. Riparian tree species adapted to periodic flooding and high-water tables are especially vulnerable to drought. Stressors such as channel incision, reduced precipitation, and drought events lower soil moisture and water table depth, thereby degrading tree physiological condition, less biotic competition and resilience(Chen et al., 2013; Nadal-Sala et al., 2017; Portela et al., 2023; Williams et al., 2022).

Water stress impacts individual fitness, affecting the three components; growth and survival (Alizadeh et al., 2021; Feld et al., 2018; Pérez-Harguindeguy et al., 2013). These effects are typically assessed through ecophysiological markers. In response to drought, trees exhibit adaptive responses—morphological (e.g., reduced leaf area), physiological (e.g., increased water retention, reduce stomatal conductance), and biochemical (e.g., lower water potential)—that vary by species and individual traits (Alizadeh et al., 2021; Chen et al., 2013; Portela et al., 2023).

In response to mounting environmental challenges, the European Union has progressively integrated ecological and hydrological considerations into its policy framework. A key milestone in this effort was the adoption of the Water Framework Directive (WFD) in 2000, inspired by the French Water Law (EU, 2024, 2000). The WFD represented a turning point in the coordinated management of water quality and quantity across EU member states, establishing the objective of achieving “good status” for all water bodies through systematic monitoring, assessment, and restoration (Rodríguez-González et al., 2022; Vidal-Abarca et al., 2016).

Within this framework, riparian zones have been increasingly acknowledged as essential for supporting the ecological integrity of freshwater systems and its fluvial dynamic (Riis et al., 2020). However, riparian vegetation itself is not explicitly defined or prioritized in the WFD, resulting in limited integration in both assessment and management protocols. This underrepresentation persists despite growing scientific evidence highlighting the pivotal role of riparian vegetation in providing ecosystem services—often exceeding the indicative power of traditional biological elements like diatoms, macroinvertebrates, or fluvial geomorphology (González del Tánago et al., 2020; Rodríguez-González et al., 2022; Urbanič et al., 2022; Vidal-Abarca et al., 2016).

The development and application of riparian forest quality indices have demonstrated strong potential in linking vegetation condition to a wide array of ecosystem functions. Nevertheless, few current indices are designed specifically to assess riparian vegetation for its own sake (see Table 1). Many researchers advocate for better integration of riparian considerations across sectoral policies—particularly in agriculture, energy, water, and land-use planning—as well as a more collaborative approach among scientists, policymakers, and practitioners. In this regard, the establishment of a legal status and a dynamic, context-sensitive definition of riparian vegetation could empower local governance structures to implement more effective protection and management measures (González del Tánago et al., 2020; Rodríguez-González et al., 2022; Urbanič et al., 2022).

To evaluate and monitor the condition of riparian zone or the fluvial system, several countries—particularly in Europe and arid regions—have developed specialized assessment tools. These tools use a range of metrics to capture diverse aspects of riparian ecosystems, including vegetation structure, ecological integrity, and bank stability. However, the diversity and lack of standardization among these tools create challenges for comparison and integration (see Table 1). This methodological heterogeneity contributes to fragmented and often inefficient assessments, ultimately limiting the effectiveness of riparian restoration and management efforts at both local and broader scales.

***Table 1**: Assessment tools for riparian zone*

Protocol / Tool / Index	Reference	Localisation	Subject
Riparian Health Assessment (Cows and Fish)	Hansen et al., Adams et Hale, 2000 / 2009	Canada	Riparian zone
Índice de Vegetación Fluvial (IVF)	Gutiérrez, Salvat, Sabater, 2001	Spain	Fluvial environment
Riparian Forest Quality Index (QBR)	Munné et al., 2003	Spain	Riparian habitats
Riparian Quality Index (RQI)	González del Tánago, García de Jalón et al., 2006 / 2011	Spain	Vegetation disturbances
Riparian Vegetation Index (RVI)	Aguiar, Ferreira, Albuquerque, Rodríguez-González, 2008 / 2009	Portugal	Riparian vegetation

Stream Visual Assessment Protocol (SVAP)	Bjorkland al.,1998 / 2001	USA	Visual riparian evaluation
River Habitat Survey (RHS)	Environment Agency (UK), 1996 / 1997	UK, Italia	Physical aspects of river, vegetation and habitats
Index of Stream Condition (ISC)	Ladson et al., 1999	Australia	Global stream quality
Tropical RARC	Dixon, Douglas, Dowe, Burrows, 2006	Australia	Riparian condition
RVD & RVCT	Macfarlane et al., 2017	USA	Riparian vegetation and disturbances
Riparian Forest Evaluation (RFV)	Magdaleno, Martínez, 2014	Spain	Connectivity of riparian zone
IBI basé sur les plantes	Miller et al., 2006	Pennsylvania, USA	Riparian biotic integrity
RCE (Riparian, Channel, Environmental Inventory)	Petersen, Petersen Jr., 1992	Italia	River and riparian zone

In France, implementation of the WFD is supported through decentralized governance structures known as “Schémas d’Aménagement et de Gestion des Eaux” (SAGE). These watershed-based frameworks are designed to guide restoration, management, and planning efforts by establishing shared objectives tailored to the specific environmental, geographical, and anthropogenic characteristics of each river basin. SAGEs play a key role in integrating riparian zones into the broader pressure–management–restoration framework, helping to address both water and biodiversity crises more effectively.

This study is part of an interdisciplinary research initiative led by H2O’Lyon in collaboration with the SAGE “Loire en Rhône-Alpes.” The region faces multiple challenges stemming from anthropogenic pressures, most notably climate change. As the territory depends heavily on surface water, it is particularly vulnerable to drought. Between 2017 and 2022, nearly 70% of days were subject to either crisis-level or reinforced restriction measures. Agricultural irrigation increased by 50% between 2010 and 2020, and climate projections forecast a 20.5% reduction in river flows by 2050, alongside a 1.8°C rise in temperature and a decrease in precipitation—conditions that will place additional stress on both water resources and ecosystems.

These alarming trends underscore the urgent need for integrated research frameworks that bring together scientists, stakeholders, and policymakers (Dufour et al., 2019; Rodríguez-González et al., 2022; Urbanič et al., 2022). Addressing the complexity of riparian zone assessment under global change requires both large-scale hydrological and geographical analyses, and fine-scale ecological understanding based on river-specific conditions and species compositions. In response to this need, the interdisciplinary cluster project from which this study emerges aims to offer a new perspective on the functioning and assessment of riparian zones. The project is structured around three core axes: (i) hydrology, focusing on the evolution of water temperature in different vegetation contexts—given the essential shading function of riparian vegetation, especially under low-flow and high-temperature conditions; (ii) geomatics, aimed at developing methods to characterize the complex structure of riparian vegetation using spatial databases, a crucial step toward prioritizing restoration and tracking ecosystem change; and (iii) ecology, which assesses whether riparian evaluation indices accurately reflect tree-level ecophysiological conditions and their relevance to ecosystem functioning.

The project embraces the multi-scale complexity of riparian ecosystems, spanning watershed-scale patterns down to reach and individual tree levels. It explores a wide range of interactions, from vegetation structure and spatial representation to ecological functions such as shading, thermal regulation, water stress mitigation, and overall vegetation health. The present disciplinary report focuses on the ecological axis of this interdisciplinary cluster project.

Within the Auvergne–Rhône–Alpes (AuRA) region, and under the leadership of the Rhône-Méditerranée-Corse water agency, several initiatives have emerged to assess riparian zones. One such effort was the development of the Index of Biodiversity and Connectivity of Riparian Vegetation (IBCR or IBC Ripisylve) in 2018, coordinated by France Nature Environnement AuRA (FNE AuRA). This index has served as a key operational and scientific tool for evaluating riparian condition. Our project aligns closely with the IBCR framework, although it places greater emphasis on biodiversity-related functions, with potential extensions to other ecosystem services. IBCR integrates four subcomponents that evaluate forest stand characteristics, territorial context, anthropogenic and biological disturbances, and ecological connectivity—offering a composite score that reflects the riparian zone's capacity to support biodiversity and provide habitat.

The index also benefits from long-term outreach and implementation efforts led by ARRA² (Association Rivière Rhône-Alpes Auvergne), leveraging an extensive operational network. In parallel, the Index of Potential Biodiversity (IBP), developed by the CNPF in 2016 for forest managers, complements the IBCR by addressing adjacent forest ecosystems. These two indices, together, provide a comprehensive approach to managing riparian ecotones, from riverbank corridors to alluvial forests. The IBCR typically assesses vegetation within 10 meters from the riverbank (or up to the bankfull top), while the IBP applies beyond this range. The IBCR has demonstrated strong predictive value for biodiversity across taxonomic groups. However, it has not been uniformly adopted by river managers. Many practitioners continue to use other indices, create localized tools, or rely on subjective field assessments.

As a result, various regional alternatives have emerged to address perceived limitations. These include a regional index in Artois-Picardie (Bruno, 2018), the Loire-Forez agglomeration guide co-developed with the CBNMC (LABROCHE et al., 2021), and more recently, RipaScan [https://ripascan.org/], which is being developed in the Grand Est region (Staentzel, 2024). We chose to focus on IBCR and RipaScan for this study due to their relevance to our spatial scale (500 m river segments and 150 m reach length) and their growing visibility in operational contexts, which enhances the transferability of our findings. RipaScan is closely tied to IBCR and offers a streamlined format for broader adoption by river managers. It provides more detailed evaluations of vegetation communities and their functional roles, based on field-based proportional assessments. The results are presented in the form of radar charts, offering a clear visualization of the strengths and weaknesses of the evaluated reach in terms of riparian functions, going beyond biodiversity support alone.

Another important aspect emerging in riparian vegetation assessment is the role of citizen science (Gumiero et al., 2023). For some, it is seen as a valuable tool to reconnect local communities with riparian ecosystems and enhance perception of ecological quality. Others remain cautious due to concerns about bias and scientific rigor. Nonetheless, Italian researchers have developed a riparian vegetation assessment method based on citizen participation, which is currently being tested and disseminated across Europe.

Meanwhile, remote-sensing-based tools—such as those relying on NDVI (Normalized Difference Vegetation Index) or infrared imagery—offer large-scale perspectives and are widely used to assess long-term vegetation changes using historical or geospatial data (Godfroy et al., 2022; Huylenbroeck et al., 2020; Lochin et al., 2024a; Macfarlane et al., 2017). While promising, these approaches require high-resolution data and involve numerous calculations and potential detection biases, making them less accessible or relevant to on-the-ground river management efforts. Ultimately, while all these tools can be complementary, their operational adoption depends on their practicality and the clarity of the ecological functions they assess. For this reason, our work focused specifically on IBCR and RipaScan to bridge ecological accuracy with practical utility in riparian zone evaluation.

Focusing here on the ecological approach, the project specifically explored whether scientists, river managers, and practitioners can evaluate the same ecological object using shared assessment tools, thereby reducing fragmentation in riparian management under climate change.

Riparian zones and their vegetation are composed of characteristic tree genus such as Populus, Salix, Quercus, Alnus, and Fraxinus. Given their ecological relevance, sensitivity to hydrological change and the ask from river managers, this study focuses on Alnus and Fraxinus-dominated riparian communities (LABROCHE et al., 2021). Through an ecophysiological lens, we aim to better understand their responses to water stress, contributing to broader insights on riparian forest resilience.

Riparian tree species are highly dependent on water availability and are particularly vulnerable to drought (Portela et al., 2023; Rohde et al., 2021). Water stress directly affects individual fitness, such as growth, and survival (Chen et al., 2013; Posch et al., 2024). These aspects are commonly assessed through ecophysiological traits (Godfroy et al., 2022; Lochin et al., 2024a; Pérez-Harguindeguy et al., 2013; Rood et al., 2003). In response to water scarcity, trees exhibit a variety of morphological and physiological adaptations that differ among species and individuals. Documented responses include reduced leaf area, increased leaf water retention, altered stomatal conductance, and changes in water potential (Bhaskar and Ackerly, 2006; Carrière et al., 2020; Martínez-Vilalta and Garcia-Forner, 2017; Osem and O'Hara, 2016; Pérez-Harguindeguy et al., 2013; Smart et al., 2017).

The central research question guiding this study was: Does riparian zone evaluation tools reflect riparian tree functioning in their assessment, and how relevant are these tools to both scientific research and operational management? This question reflects a dual ambition—to assess ecological integrity through measurable vegetation responses and to ensure that resulting tools are usable in real-world river management contexts.

To address this overarching question, the investigation was structured around three sub-questions:

1. Which riparian evaluation tools currently exist, and what are their primary design objectives? This sub-question aimed to assess the scope, structure, and intended use of existing scientific and technical tools used for riparian assessment, such as IBCR and RipaScan.
2. To what extent do local management practices and riparian landscape characteristics influence tree-level ecophysiological functioning? This question explores the impact of topographical, hydrological, and land-use factors—along with restoration practices—on physiological stress responses in riparian trees.
3. Is there a measurable correlation between riparian zone assessments and tree ecophysiological traits? Here, the objective is to test whether commonly used riparian indices accurately reflect physiological functioning (e.g., water status, leaf traits) and whether they can serve as reliable proxies for riparian vegetation health.

In addressing these questions, a targeted ecophysiological study was conducted in close collaboration with local practitioners, including river managers and policy actors. This participatory approach was central to the project's aim of producing knowledge that is not only scientifically rigorous but also operationally relevant. By integrating field measurements of tree function with current riparian evaluation practices, the study sought to bridge the gap between ecological theory and applied river management under changing environmental conditions.

During the initial review of existing riparian indices, a key challenge emerged: although numerous assessment tools have been developed and discussed in scientific literature, very few have been translated into operational frameworks or integrated into local management plans. This gap persists despite the fact that many of these tools are supported by public funding and are intended for practical use. The lack of operational uptake raises critical questions about the design, accessibility, and relevance of scientific indicators when faced with on-the-ground constraints.

In response, the ecological component of this study was explicitly designed to align physiological measurements of tree functioning with current riparian evaluation methods. Specifically, the study focused on stress indicators such as leaf water potential (LWP), specific leaf area (SLA), leaf dry matter content (LDMC), and stomatal conductance—traits recognized for their sensitivity to water availability and vegetation functioning under environmental stress.

Based on this framework, four key ecological hypotheses were formulated:

1. Sites with higher riparian quality scores (based on IBCR or RipaScan indices) will exhibit improved ecophysiological functioning, reflected in higher LWP, lower LDMC, and more favorable trait profiles, indicating reduced stress.
2. Over time, water stress will intensify more severely in low-quality riparian zones, where vegetation may be more exposed to hydrological disconnection, degraded buffer function, or fragmented forest structure.
3. Restored sites are expected to show better ecophysiological performance than unrestored sites, due to improved structural and functional characteristics. However, some unrestored sites may exhibit similar functioning if hydrological connectivity remains intact, particularly in systems where groundwater access buffers drought effects.
4. Topographic descriptors (e.g., elevation above water table, distance to river) will provide stronger explanations for observed ecophysiological variability than surrounding land use or land cover classifications, especially when considered at fine spatial scales.

These hypotheses provided the foundation for experimental design, variable selection, and statistical testing throughout the ecological portion of the study. The results were interpreted not only in relation to riparian condition, but also in the broader context of land-use dynamics, topographic heterogeneity, and the increasing urgency of climate adaptation in riverine environments.

To complement the ecological assessment, a sociological survey (Cottet et al., 2023; Riviere-Honegger et al., 2015) was conducted with the overarching research question: Do river managers' perceptions of riparian vegetation and their understanding of scientific assessment tools explain the limited adoption of these tools in operational practice?

This question was developed in response to observed discrepancies between the availability of scientifically developed riparian assessment frameworks and their actual application by local river managers. Based on this, three working hypotheses were formulated to guide the qualitative inquiry:

1. Unclear conceptual frameworks and insufficient communication regarding riparian vegetation hinder the local implementation of scientifically developed assessment tools. This hypothesis addresses the idea that limited knowledge transfer, and a lack of shared definitions or standards make it difficult for practitioners to confidently apply formal tools such as IBCR or RipaScan. It also explores how ambiguous spatial and functional definitions of the riparian zone may undermine field-based application.
2. A misalignment between scientific and operational objectives, combined with temporal and spatial mismatches, complicates the co-development and integration of assessment tools. This assumption focuses on institutional and structural barriers: the different goals, timelines, and working scales of scientists and managers may prevent meaningful adoption or adaptation of ecological assessment tools in everyday practice. It also highlights the tension between the need for detailed, long-term monitoring and the reality of short-term, context-specific action plans.
3. The integration of riparian vegetation functioning—particularly physiological status—as a core criterion for climate change adaptation is still insufficiently considered in current practices. This final hypothesis proposes that despite the growing awareness of climate impacts on river ecosystems; vegetation condition and functional traits are not yet fully embedded in restoration planning or evaluation protocols. The underlying question is whether focusing more explicitly on vegetation functioning could provide a stronger rationale for assessment and management, particularly under conditions of accelerating environmental change.

These hypotheses provided the foundation for the structure of the interviews and thematic analysis. The results are presented in alignment with these three conceptual assumptions, aiming to clarify the barriers, contradictions, and opportunities for improving the implementation of riparian vegetation assessment tools in practice.

2. Material and methods

2.1. Study site

2.1.1. Global presentation

The SAGE Loire Rhône-Alpes (LRA) encompasses a hydrographic area of approximately 4,000 km², including 1,258 km of river networks, 67 surface water bodies, and 6 groundwater bodies. This territory faces major hydrological challenges, notably low and irregular rainfall, limited soil water retention, and poorly characterized groundwater resources. The region relies heavily on surface water (75%) for its supply, sustained by long-standing infrastructure such as the Forez Canal and the Lavalette Dam. Water demand is primarily driven by drinking water needs (65%), followed by agriculture (25%) and industry (10%). Notably, irrigated agricultural land increased by 50% between 2010 and 2020. The area is particularly vulnerable to drought, with nearly 70% of days between 2017 and 2022 classified under crisis or reinforced restriction levels. Climate projections forecast a 20.5% decrease in river flows by 2050, coupled with a 1.8°C rise in temperature and a decline in precipitation—exacerbating stress on both water resources and ecosystems. More than 70% of water bodies in the territory currently fail to achieve good ecological status, underscoring the need for adaptive and integrated water management as promoted by the SAGE framework. The ecological component of the study was carried out on the Lignon River, specifically its downstream reach between Boën-sur-Lignon and Feurs, where it converges with the upper Loire River (Fig. 1). This section includes key Natura 2000 sites within the Lignon du Forez catchment, a sensitive watershed exposed to hydrological pressures, biodiversity loss, and climate change. The area functions as a "climate open-air laboratory", where ecological resilience, riparian restoration, and water quality protection are at the forefront of management efforts.

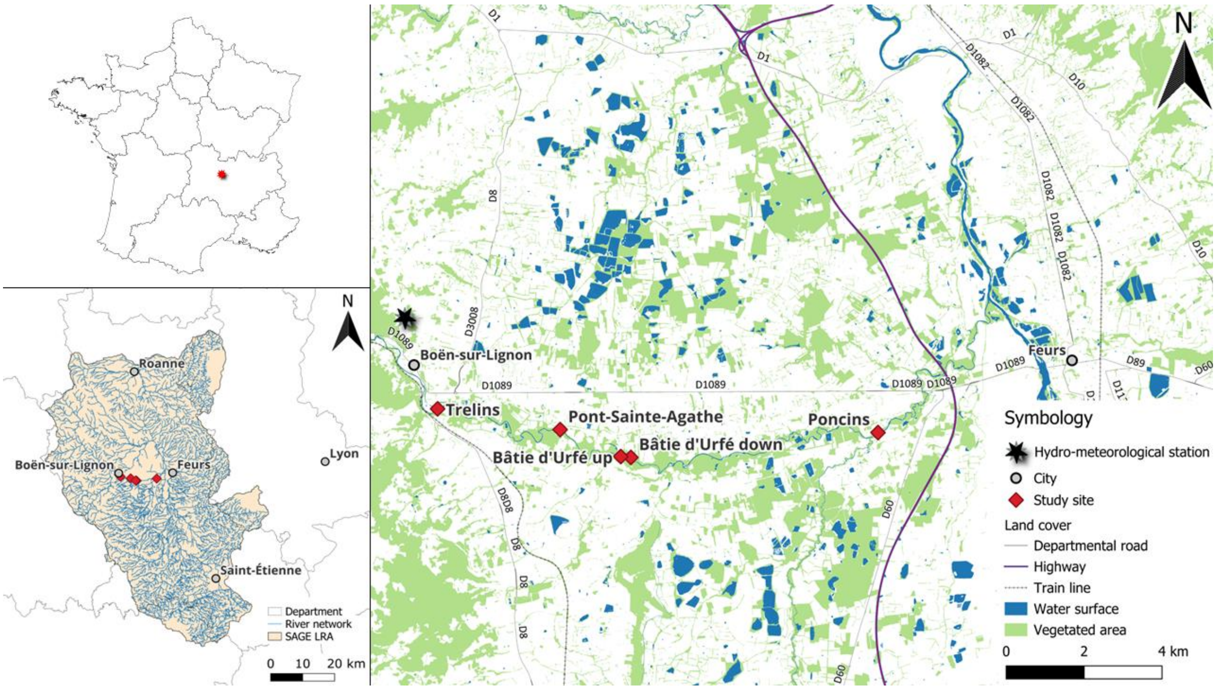

Figure 1: *Map of the site location - top left France, bottom left Loire department and SAGE, right study sites.*

2.1.2. Site presentation

The study area was selected due to the comparability of five sampling sites; all subject to similar meteorological and hydrological conditions but exhibiting different levels of management and anthropogenic disturbance. From upstream to downstream, the sites include: Trélins, Pont-Sainte-Agathe, Bâtie d'Urfé upstream, Bâtie d'Urfé downstream, and Poncins (Fig. 1 and Table 2). All reaches flow west to east, providing a coherent spatial gradient for ecological comparison. The sociological analysis was conducted at the broader SAGE territorial scale, allowing integration of local perceptions and governance dynamics into the understanding of riparian ecosystem management.

Trélins is the most anthropized, with a confined river corridor bordered by a railway line and a departmental road, and an urbanized floodplain hosting commercial facilities. It shows visible bank erosion and includes a downstream weir. Pont-Sainte-Agathe presents an intermediate setting, with upstream forest cover transitioning to agriculture; a mid-reach weir diverts water for livestock, and pastures extend along the left bank. Bâtie d'Urfé upstream is mainly forested, aside from a small anthropized section protecting a wastewater treatment plant. Downstream, Bâtie d'Urfé is fully forested with a mobile channel; both reaches have been restored since 2023 through hydromorphological interventions, while still supporting recreational activities like walking, cycling, and horse riding. Finally, Poncins is a recreational and agricultural site with extensive public access infrastructure on the downstream end, making it a highly managed area designed to meet citizen demand. This gradient of disturbance and restoration status provides a valuable framework for assessing riparian ecological responses under varying land-use and management conditions.

Table 2: *Study sites locations and description*

Site name	Location	Description
Trelins	45.734453,4.013819	Anthropized and agricultural
Pont-Sainte-Agathe	45.730688,4.052292	Agricultural and forested
Bâtie d'Urfé upstream	45.723790,4.075249	Forested and restored
Bâtie d'Urfé downstream	45.723790,4.075249	Forested and restored
Poncins	45.728500,4.158276	Recreational and agricultural

2.2. Tree sampling

Each site was identified as *Alnus-Fraxinus* dominated riparian zone, where we selected 20 trees for each site — 10 alders (*Alnus glutinosa*) and 10 ashes (*Fraxinus excelsior*). We were looking for well-being trees, big enough to do not be affected by the measurements (we spotted sites without detected diseases) and from the water mark to the bank top, close to the river. They also should develop accessible branch to be sampled (5 m height maximum) allowing 3 samplings. In the same time, all trees were tagged with the GPS (Trimble geo 7x ± 1m) from EVS team (UMR 5600, "Environnement Ville et Société").

2.2.1. Morphological traits

We measured morphological traits, circumference using a measuring tape (± 0.001 m) at approximatively 1.3 m height or before ramification. Top canopy heights using a clinometer (± 0.1 m) was used to calculate tree heights from an angle ration between the base and the top of the tree knowing the distance from the tree, approximately equal at the tree height estimation (limit calculation errors).

2.2.2. Ecophysiological sampling

Ecophysiological sampling was carried out over three campaigns in Aril and May, when leaves were developed, each conducted across two consecutive days: April 24–25, May 4–5, and May 19–20, 2025. Each campaign followed a consistent protocol. On the first day, measurements were taken at three sites: Bâtie d'Urfé upstream, Bâtie d'Urfé downstream, and Poncins. The second day of each campaign was dedicated to the Trelins and Pont-Sainte-Agathe sites. All samplings were conducted between 10:30 a.m. and 2:30 p.m., corresponding to the solar zenith period, to ensure consistency in light and temperature conditions. For each tree, one sun-exposed branch from the lower canopy (under 6 meters in height) was collected using pruning shears. Branches were selected to contain at least 10 mature leaves for alders and as close as possible to 10 for ashes. Immediately after cutting, samples were placed in a cooler with a moistened wipe, protected from light and dehydration, and transported to the laboratory for analysis.

2.2.3. Leaf Water Potential

After at least 2 hours in the cooler, we used a pressure chamber (Model 1505D Pressure Chamber Instrument - PMS Instrument Company) to measure minimal leaf water potential (±0.01

bar) for one leaf per branch (LWP, in MPa). Minimal water potential is a negative value showing the leaf water potential (the more negative the value is, higher is the resistance of the leaf to release water). The leaf was cut at the insertion of the petiole on the branch for the Alders and 1cm above for the Ashes due to the triangle shape causing troubles in the pressure chamber sealing.

2.2.4. Stomatal conductance

Stomatal conductance measurements were only performed at Bâtie d'Urfé both sites and Poncins, due to equipment constraints. A different leaf than the one used for LWP was used for stomatal conductance, measured with a porometer (AP4 ref system). A leaf per tree were inserted in the porometer after device calibration. Stomatal conductance value was saved after measure stabilisation $mmol_{H2O}\ m^{-2}\ s^{-1}$. We measured one leaf per tree for the three sites sampled. Stomatal conductance is the quantity of moles of water (H2O) exchanged per area and second, reflecting the stomatal openness and the level of activity in the leaf.

2.2.5. Functional leaf traits

For each tree, not exceeding 10 leaves were collected and grouped for mass measurements using a precision scale (Model Denver TP-214; ±0.0001 g). Leaves were weighed at three steps: fresh (on the day of sampling), turgid (after soaking the petioles in water for at least 24 hours), and dry (after 48 hours in a drying oven at 60 °C).

Prior to drying and immediately after recording the turgid mass, the leaves were scanned to determine leaf area using the WinFOLIA software (accuracy ±0.01 cm^2). During the first campaign, all sampled leaves from all selected trees were scanned and measured. In campaigns 2 and 3, the protocol was adjusted: only 5 trees per species were analysed per site, with 10 leaves per alder and 3 leaves per ash. For ashes, the scanned leaves were dried individually to enable the calculation of Specific Leaf Area (SLA). Using mean values, we calculated 4 leaves traits: SLA that identify the ratio between leaf area and dry mass, reflecting the investment done between growth and loses (1); leaf dry-matter content reflects the investment given in the leaf resistance, often affecting leaf longevity, primary productivity, evapotranspiration or water retention (2); relative water content is the quantity of water store at the sample date compared to the maximum water retention at turgescence (3); and absolute water content is the ratio between water in the leaf and the dry matter (4).

(1) $\text{SLA } (\pm\ 0.01\ mm^2\ mg^{-1}) = \frac{Leaf\ Area}{Dry\ mass}$;

(2) $\text{LDMC } (mg\ g^{-1}) = \frac{Dry\ Mass}{Fresh\ Mass}$;

(3) $\text{RWC} = \frac{Fresh\ Mass - Dry\ Mass}{trugescent\ Mass - Dry\ Mass}$;

(4) $\text{abWC} = \frac{Fres\ Mass - Dry\ Mass}{Fresh\ Mass}$

2.3. Site evaluation indexes

For the five sites we defined different evaluation reaches depending on the tool protocol (from 150m to 500m) on both banks, representative of the total length site. We always included sampled trees into the evaluation reach (Fig.X).

2.3.1. Index of Biodiversity and Connectivity of the Riparian zone (IBC Ripisylve or IBCR)

Following an introductory session with France Nature Environnement Auvergne-Rhône-Alpes (FNE AuRA), we used the IBC Ripisylve software (FNE AuRA; version 1.0.9 available on the Android Play Store). This index, developed in 2018, was designed to meet regional needs in Auvergne-Rhône-Alpes by standardizing the evaluation of biodiversity and connectivity in riparian zones. The tool is structured around four major factors, incorporating a total of 15 ecological and structural metrics, to generate a score out of 100 (see Table 3). The assessment was conducted on 500-meter river reaches, surveyed in one direction on both banks, extending from the water's edge up to 10 meters inland, or up to the top of the bank where applicable. The surveys took place between March 31st and April 18th, 2025, following the standard IBC Ripisylve protocol. Classification from “good” above 50/100, “medium” between 50/100 and 40/100 and “weak” under 40/100 was done.

Table 3: *Summary presentation of the IBC Ripisylve factors and metrics.*

Factor (score)	Metric (score)
Forest stands and management /35	A – Autochthonous woody /5
	B – Vertical vegetation structure /5
	C – Standing dead wood /5
	D – Ground dead wood /5
	E – Large and very large living wood /5
	F – Living tree-related microhabitats/5
	G – Root shelters /5
Context /15	H – Temporal Forest continuity /5
	I – Complementary wetlands /5
	J – Associated minerals lands /5
Land perturbation /10	K - Exotics and invasives species /5
	L – Land deterioration and perturbation /5
Connectivity / 40	M – Longitudinal connectivity /10
	N – Transversal connectivity /15
	O – Landscape connectivity /15

2.3.2. RipaScan

We applied the new developed index RipaScan on 2nd and 13th of May. This index consists of 3 types of data – vegetation cover and identification, site evaluation based on IBCR and Digital Elevation Model. To go deeper, on field days, we identified vegetation cover and map it on Qfield, registering percentage cover, type of vegetation and percentage of each group in the patch, on a reach from 155 m to 220 m long. Then, for each reach, we summarized the categories of dead wood stand and fallen, tree-related microhabitats, roots shelters, longitudinal and lateral continuity, and width (Fig. 11). Finally, all parameters are run in the RipaScan soft were under development by Cybill STAENZEL [https:// ripascan.org/]. It proposes a more detailed result of riparian functions, on different taxonomical groups and epuration, bank stabilisation, shading. Classification from “high” above 6/10, “medium” between 6/10 and 40/10 and “low” under 4/10 was done.

2.4. Geographic Information System (GIS)

2.4.1. Land use and land cover

GIS data extraction was used to calculate several metrics using the current available LTR version of QGIS 3.40.7. To extract land cover and land use we used the free available last OCSGE data from 2022 of the IGN websites (https://geoservices.ign.fr/ocsge), cut in a 30 m and 100 m round buffer from the upstream to the downstream tree. We selected this 30 m buffer from the definition, above it is alluvial forest but also used 100 m buffer width that was well recognized in the literature.

2.4.2. Tree distance and tree height from water table

Tree distance from the river (±0.1m) and differential height between tree base and water table (±0.1m) were calculated using field tree GPS tagging (ref GPS EVS ± 0.6m). Once tree location exported, we first executed the vector-based analysis of the shortest distance between entities to obtain the distance metric between tree GPS tag and the previous OCSGE water layer. Then, from the intersection of the distance line and the OCSGE water layer, elevation was extracted for tree GPS location and nearest water table. Elevation was based on a 0.5m digital elevation model (DEM) produced by LiDAR location thanks to EVS laboratory (UMR 5600). Some points were manually corrected due to mismatches between DEM and OCSGE water layer due to latest hydrogeomorphological restoration and data quality. Finally, we used the EVS work production to know the proportion of riparian zone contained in the valley bottom as the definition of our riparian zone and to the flooded connectivity it represents.

2.5. Sociological study

2.5.1. Survey design

The qualitative survey was construct on individual semi-directive interviews. We first identified our target population and key questions. To aim our survey on practitioners needs, we selected river management technicians and water and biodiversity project officers. The survey guide was constructed on 4 themes, i) Professional background, field work, financial structure and territory; ii) Riparian vegetation and zone definition; iii) Temporal objectives and management; iv) Riparian evaluation method and future needs.

2.5.2. Recruitment and interviews

The recruitment was done by mailing list of project officer involved in the territorial policy of the SAGE LRA. Then, some project officers linked us to river management technicians. Using this approach, we realized 5 interviews on 8 people contacted. We also reached the objective of interviewing both project officers (2 on 5) and river management technicians (3/5). However, we recognize that the population can be misrepresented with numerous biases (e.g. gender bias) due to the technical approach and construction time allowed to the survey.

Interviews were on videoconferences from 15th to 23rd of May using Janghorban et al., 2014 methodology and took in average 51 minutes (43 to 65 minutes). We asked for feedback of the videoconference modality and no interviewee was affected by this modality in is capacity to answer. All were asked before interview, during mail communication, to record audio then confirmed during the interview and were informed of anonymization each time.

2.5.3. Qualitative analysis

Interviews were fully transcribed, and a theme grid was developed from previous hypothesis and reading of interviews allowed to ad unidentified theme to valid or not our hypothesis. This theme grid was based on the principles of content thematic analytics principles defined as “a method to identify, analyse and report patterns (themes) in the data” (Braun and and Clarke, 2006). So, we followed our hypothesis selecting citations from transcribed interviews to illustrate some patterns or themes. This method of classification, highlight patterns overlaping, grouping, divergent or completing to illustrate theme in the population (Paillé and Mucchielli, 2012).

2.6. Statistical analysis

The analyses were performed on Rstudio version 4.4.32 (RStudio 2024.09.0+375 "Cranberry Hibiscus"). The repeated analysis (between sessions) was performed using a linear mixed-effects model from package nlme, with tree identity included as a random effect (due to repeated measurement on same trees) and species, sampling session, and IBCR class as fixed effects and all their interactions. Topographic and morphological analysis were performed using ANOVA model between group from basic R packages, and correlations were performed using spearman method from corrplot package.

3. Results

3.1. Ecophysiological

Topographical and morphological data showed significant differences between sites (Fig. 2). Concerning topographical variables, namely tree distance to water (TDW) and tree height above the water table (THWT), significant differences were observed between sites (Fig. 2). Specifically, trees at Bâtie d'Urfé upstream were located significantly farther from the river than those at all other sites (all p-values < 0.0001, df = 295). Additionally, Bâtie d'Urfé downstream and Poncins displayed greater mean distances than Pont-Sainte-Agathe and Trelins (p = 0.008, p = 0.008, p = 0.0448, p = 0.0432; df = 295). In terms of THWT, significant differences were observed only in Ash trees. At Trelins, Ash trees had higher average heights above the water table compared to Bâtie d'Urfé (both upstream and downstream) and Pont-Sainte-Agathe (all p-values < 0.0001; df = 287), and Poncins had significantly higher values than Bâtie d'Urfé upstream (p < 0.0001; df = 287).

Regarding morphological traits (Fig. 2), Alder trees at Bâtie d'Urfé upstream had significantly smaller circumferences than those at Bâtie d'Urfé downstream and Pont-Sainte-Agathe (p = 0.0193, p = 0.0066; df = 295). For Ash trees, circumferences were significantly larger at Poncins compared to both Bâtie d'Urfé and Trelins (p < 0.001, p < 0.001, and p = 0.0234; df = 295).

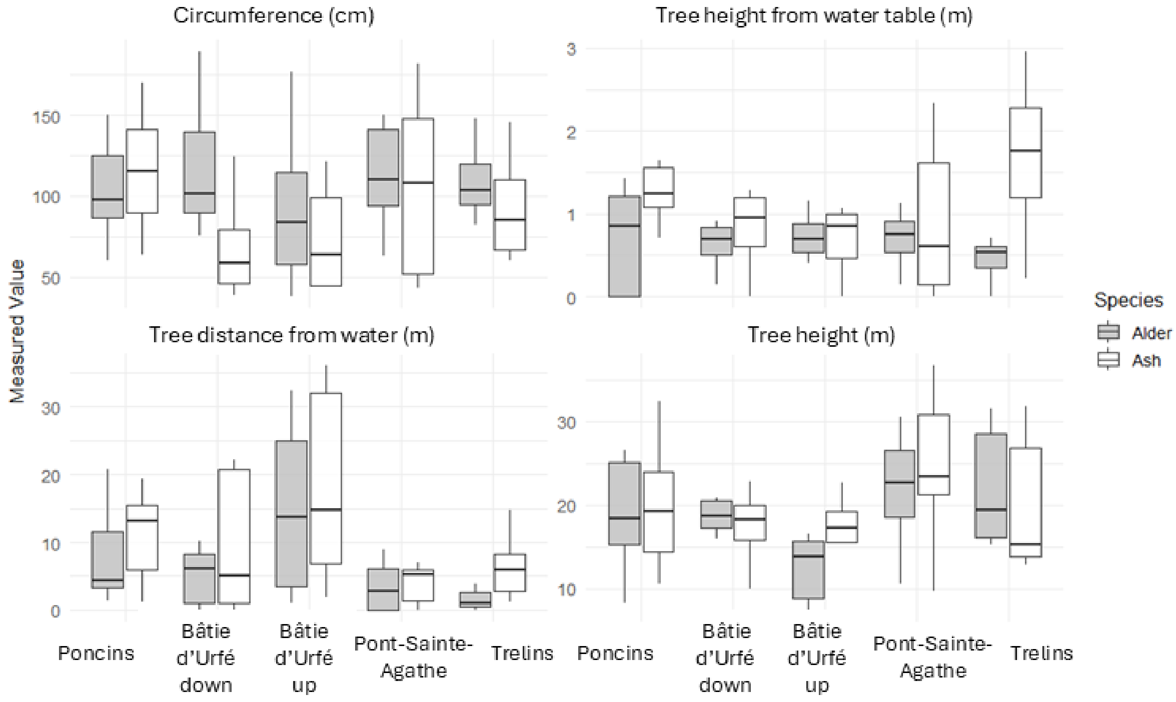

Figure 2: *Topographic and morphologic data per sites and species*

Correlations between morphological or topographical variables and global ecophysiological data were examined, but no strong or significant relationships were detected overall (Fig. 3 and 4). However, when analyzed by session, significant correlations emerged: leaf water potential (LWP) was negatively correlated with THWT during session 1 in both species (Ash: ρ = -0.3701, p = 0.0993; Alder: ρ = -0.3980, p = 0.0294).

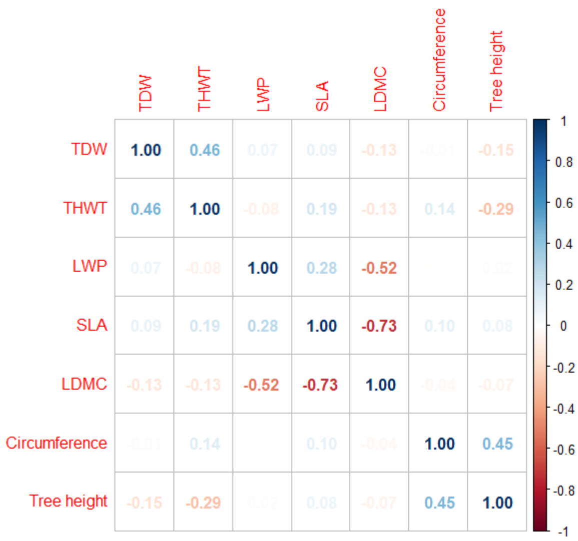

Figure 3: *matrix of spearman correlation for Alders*

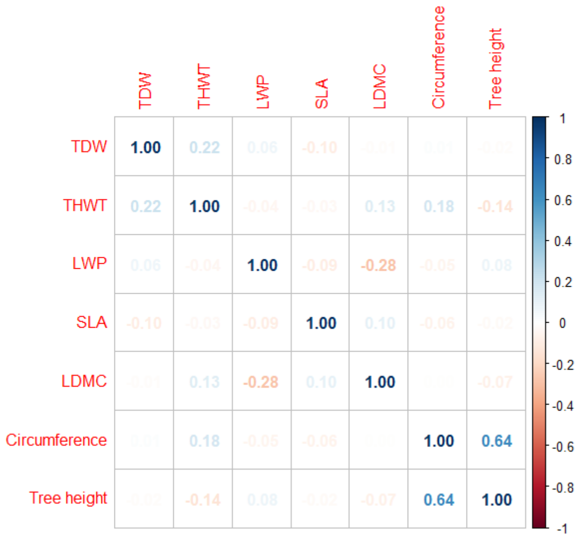

***Figure 4:** matrix of spearman correlation for Ashes*

A Principal Component Analysis (PCA) was conducted to explore associations between ecophysiological traits and land use/land cover variables, along with IBCR and RipaScan values calculated using 30 m (Fig. 7) and 100 m buffer zones (Fig. 5 and 6). No consistent patterns were detected overall. However, LWP was found to be associated with forest or silvicultural cover during sessions 1 and 3, and LDMC was associated with urban land cover classes such as built, unbuilt, mineral surfaces, and land use like roads, railways, and residential areas.

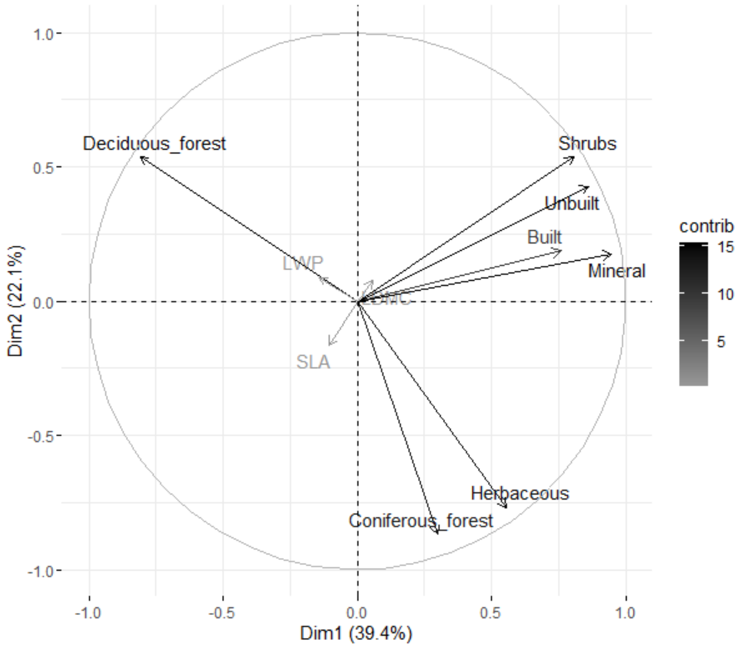

***Figure 5:** PCA of land cover in100m buffer zone and ecophysiological data*

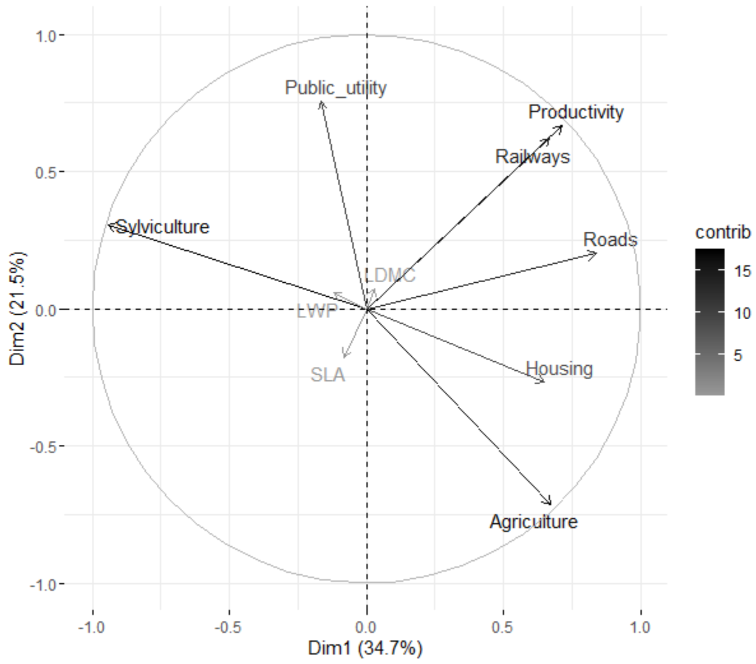

Figure 6: *PCA of land use in 100m buffer zone and ecophysiological data*

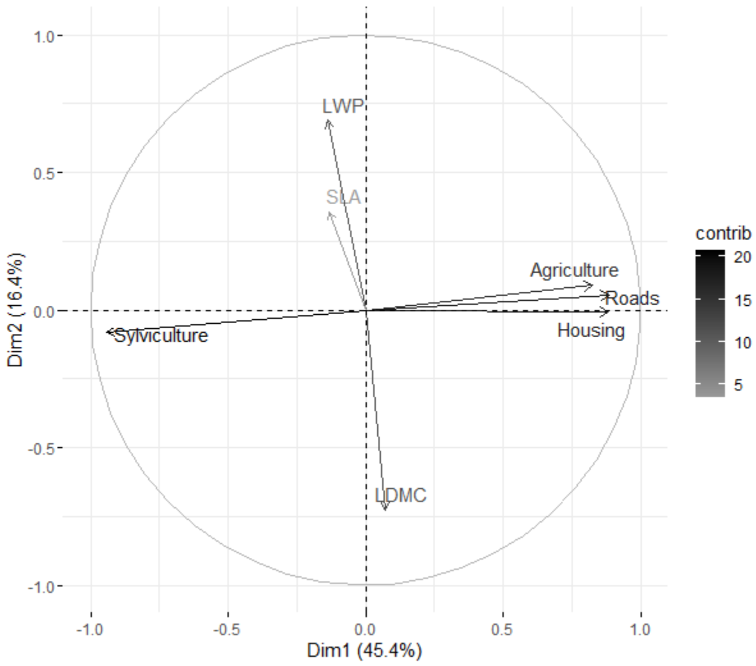

Figure 7: *PCA of land use in 30m buffer zone and ecophysiological data*

Concerning IBCR, only one ecophysiological trait showed significant differences across all sessions: LWP was significantly different between “good” and “weak” IBCR classes in both species ($p = 0.0187$; $df = 47$). Session-specific differences were also found for LDMC, SLA, and LWP, while stomatal conductance remained unaffected.

LDMC (Fig. 8) showed minimal variance attributable to random effects (SD ≈ 0.0118), indicating low inter-individual variability. Fixed effects explained 68.8% of the total variance (marginal R^2), with a residual standard deviation of 0.0305. LDMC increased significantly in session 3 (p <

0.0001; df = 223). Although IBCR class alone was not significant (p = 0.2750; df = 47), its interaction with session was (p < 0.0001; df = 223). Unlike other traits, LDMC appeared less sensitive to day-specific weather fluctuations, making session 3 particularly relevant. During this session, LDMC significantly decreased for both “medium” (p = 0.0002; df = 223) and “weak” (p = 0.0357; df = 223) IBCR classes. LDMC values ranged from 0.275 to 0.35 in Alders and from 0.17 to 0.275 in Ashes.

For SLA (Fig. 10), random effect variance was modest (SD = 7.74). Fixed effects explained 46.3% of the variance (marginal R^2), while the full model explained 48.7% (conditional R^2). SLA decreased significantly in session 3 (p < 0.0001; df = 123), and a significant interaction between species and session was identified (p < 0.0001; df = 123), particularly due to increased SLA in Ashes during session 2 (p = 0.0001). IBCR class had no significant main effect (p = 0.6359; df = 47), nor did it interact significantly with species or session.

Water potential (Fig. 9) showed negligible random effect variance (SD ≈ 1.38e−05), but fixed effects accounted for 38.3% of the variance (marginal R^2), with a residual SD of 0.324. A significant global effect of “weak” IBCR was found (p = 0.0001; df = 47), though this effect was inverted during session 3—likely due to rainfall on day two of sampling, affecting sites 4 and 5, which may have reduced expected water stress. For Ashes, a significant effect of “medium” IBCR status was observed (p = 0.0329; df = 231), while no such effect was found in Alders. Overall, water potential significantly decreased across sites in session 3 (p < 0.0001; df = 231), indicating intensifying water stress.

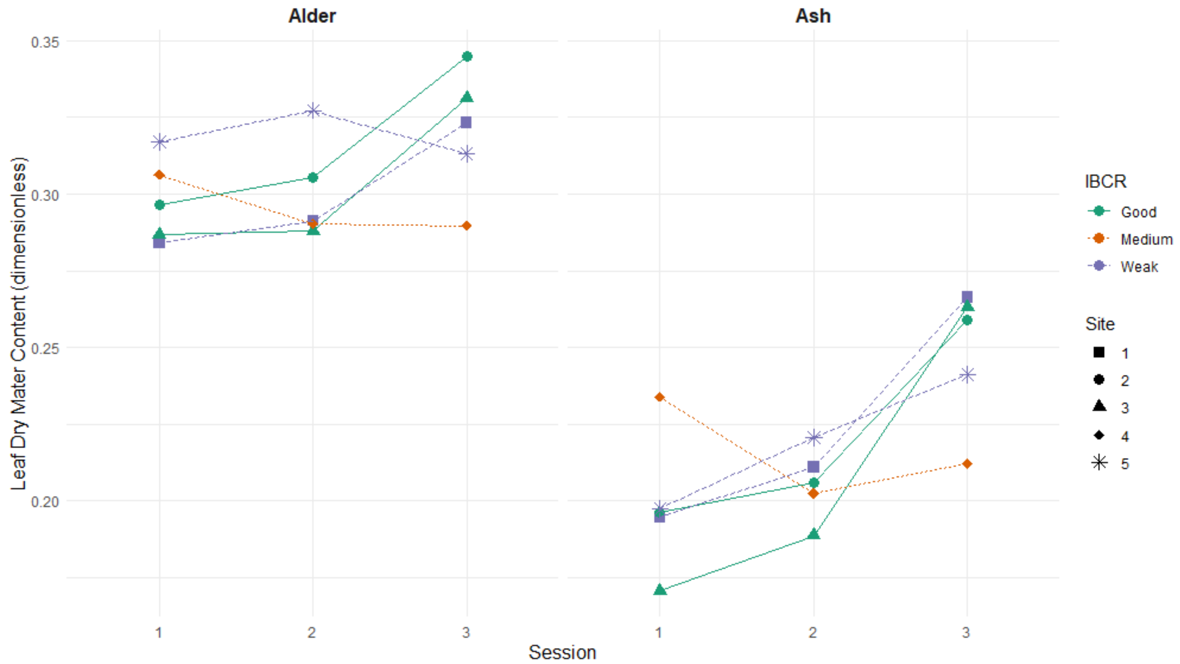

Figure 8: Plot of LDMC per species and session for the IBCR classes

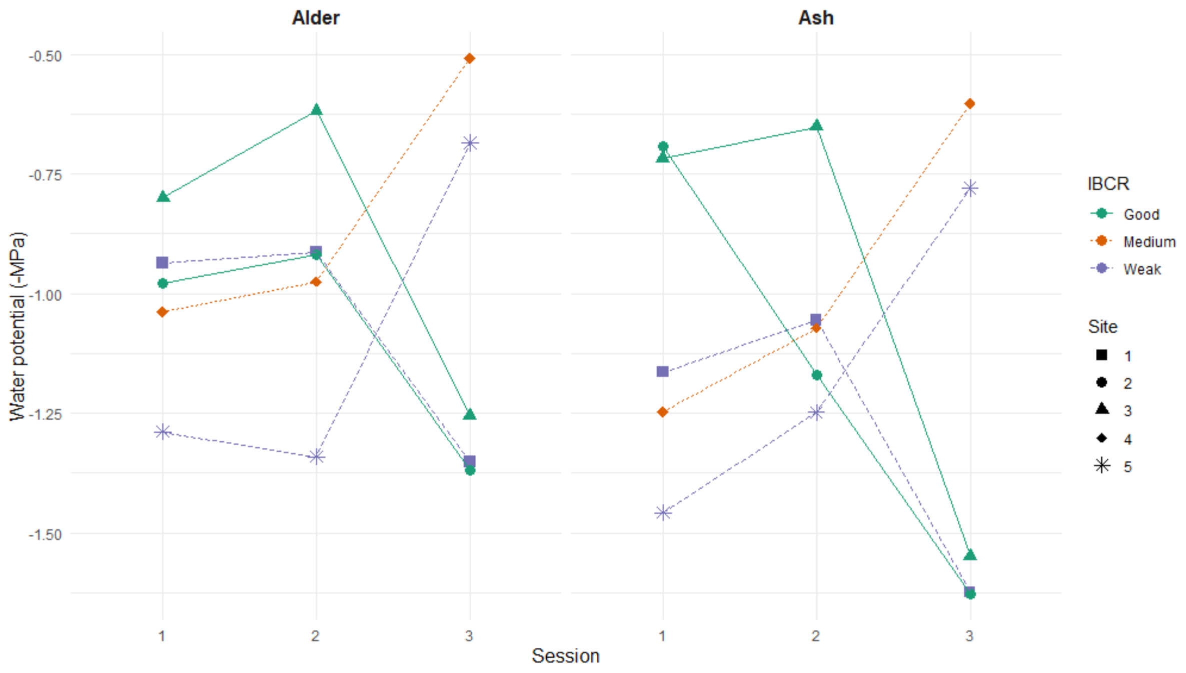

Figure 9: *Plot of LWP per species and session for the IBCR classes*

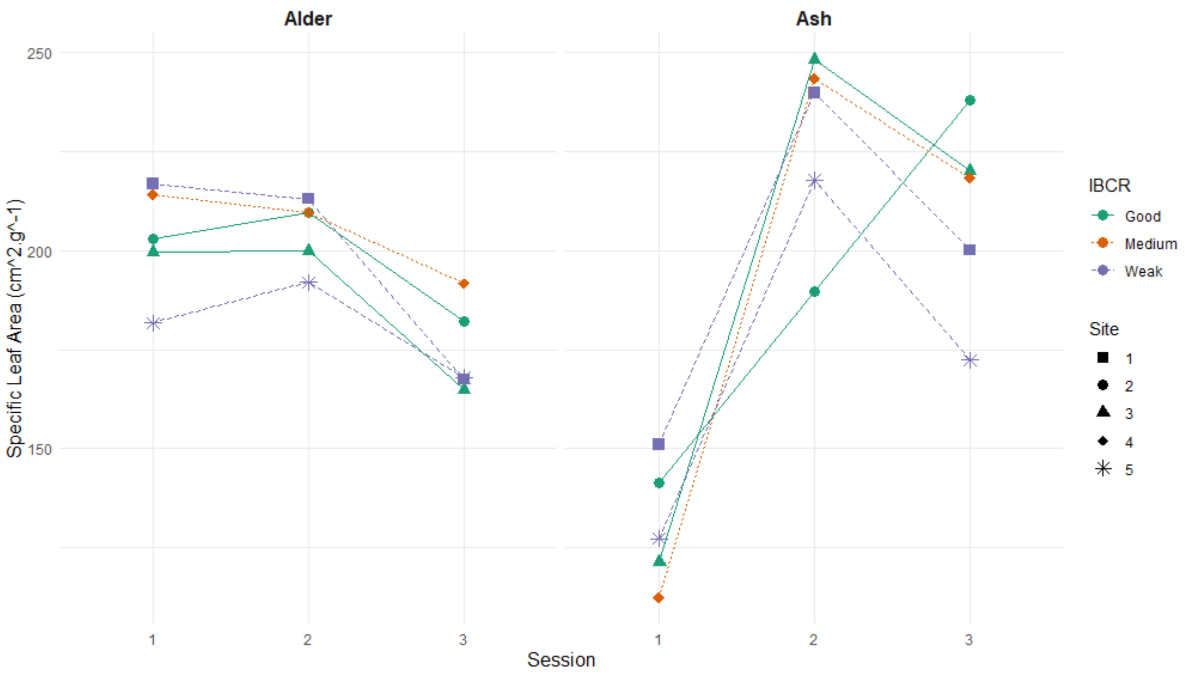

Figure 10: *Plot of SLA per species and session for the IBCR classes*

RipaScan subgroup (Fig. 11) values were not significantly associated with ecophysiological traits. However, mean site-level values revealed significant differences in LWP and SLA for Alders (Fig. 13 and 14) between “high” and “low” RipaScan classes ($p = 0.0018$ and $p = 0.0432$; $df = 47$).

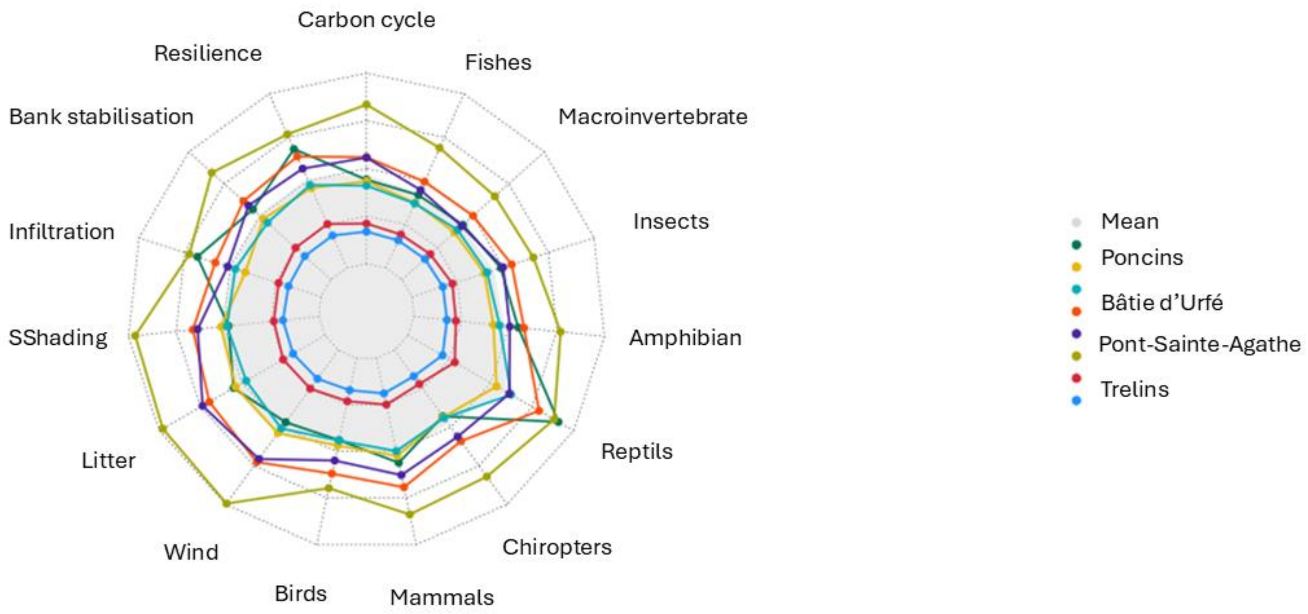

***Figure 11**: Radar graph of RipaScan results per site*

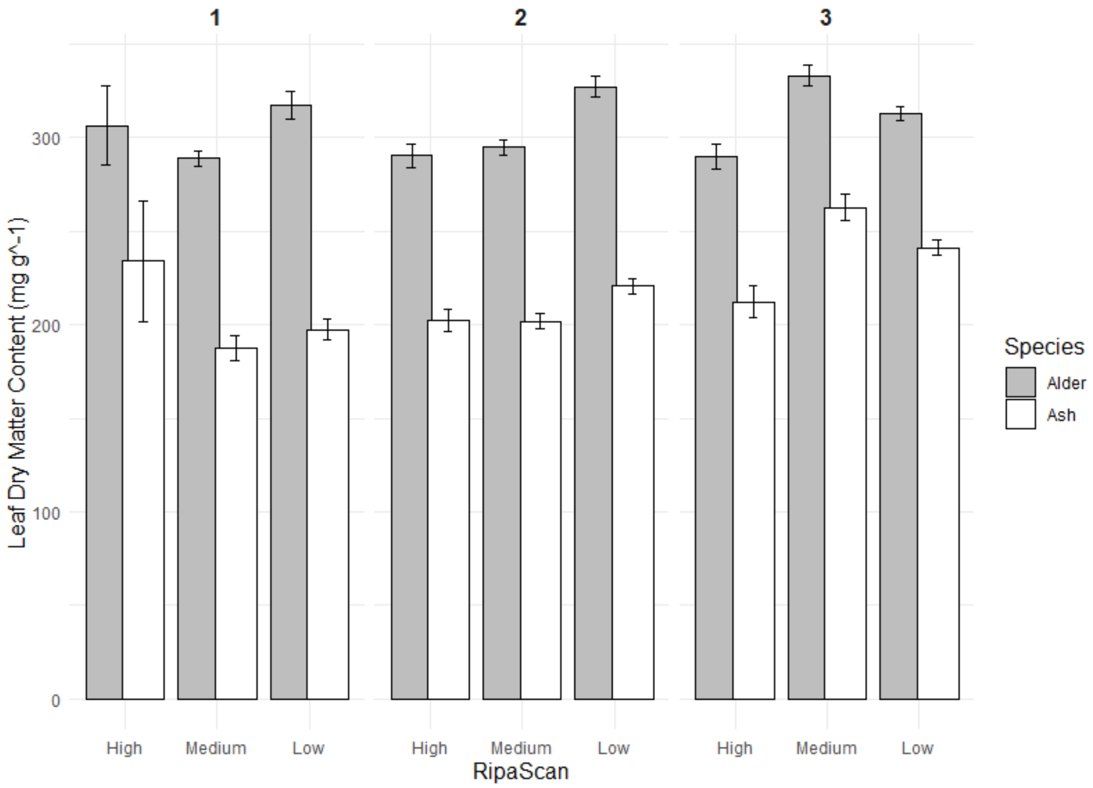

***Figure 12:** Mean LDMC per specie and session for RipaScan classes*

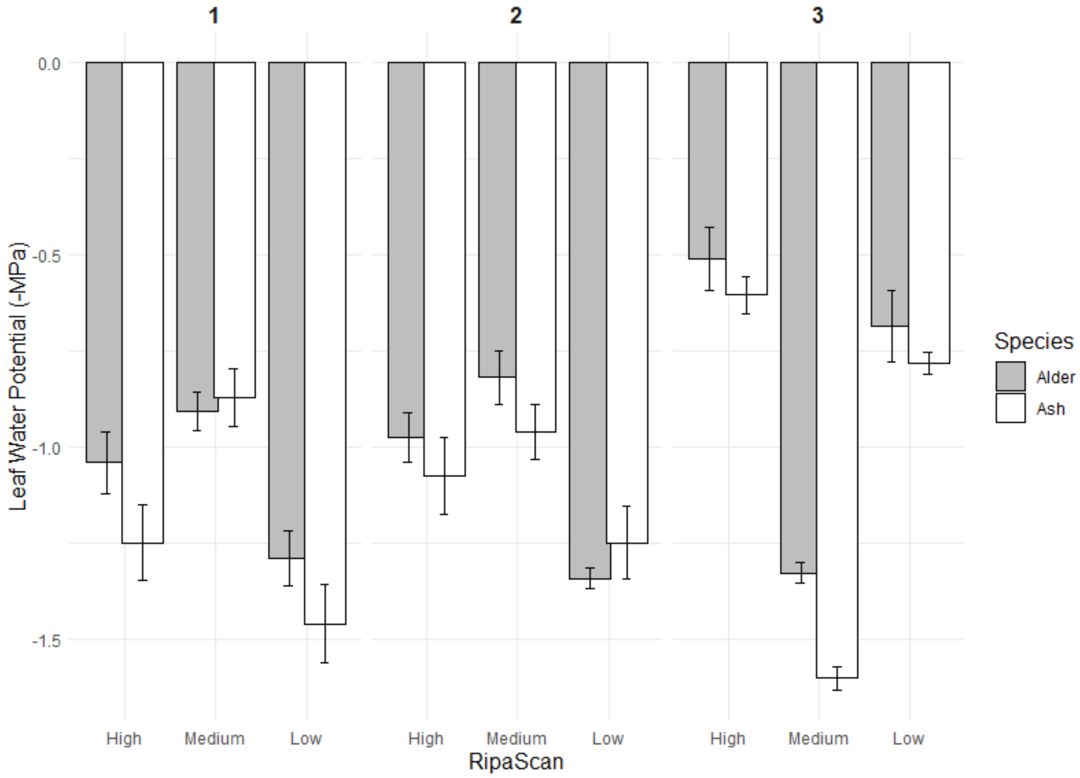

Figure 13: *Mean LWP per specie and session for RipaScan classes*

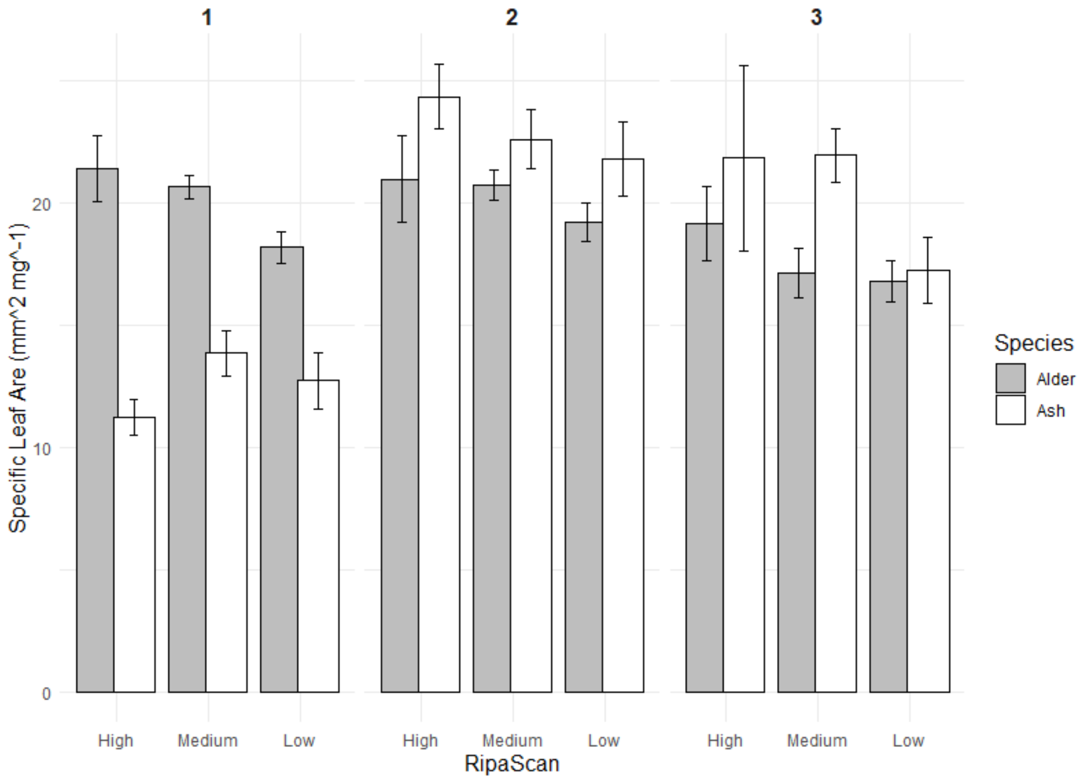

Figure 14*:Mean SLA per specie and session for RipaScan classes*

Restoration status had a significant effect on LWP (Fig. 16) in two of the three sessions. In session 1, Ashes at restored sites had higher LWP values ($p < 0.0001$; df = 48), while in session 2, this pattern was observed in Alders ($p = 0.0318$; df = 48). In contrast, session 3 showed the opposite trend in both species, with lower LWP in restored sites (Ashes: $p < 0.0001$; Alders: $p = 0.0002$; df = 48). A strong session effect was also found in restored sites, with LWP in sessions 1 and 2 being significantly lower than in session 3 for both species ($p < 0.0001$; df = 84). For Ashes, in restored sites, LWP was significantly higher in sessions 1 and 2 than in session 3 (both $p < 0.0001$; df = 84). In unrestored sites, LWP differed between sessions 1 and 3 ($p = 0.0168$; df = 84). The restoration effect varied by session, with significantly higher LWP in restored sites during session 1 ($p < 0.0001$; df = 48), and significantly lower values during session 3 ($p = 0.0001$; df = 48). In Alders, LWP on restored sites differed significantly between sessions 1 and 3 ($p = 0.0013$; df = 96), and between sessions 2 and 3 ($p < 0.0001$; df = 96), with higher values in sessions 1 and 2. A significant restoration effect was found only in session 2 (higher LWP in restored sites; $p = 0.0318$; df = 48), and the opposite in session 3 ($p = 0.0020$; df = 48).

Ashes showed significantly lower LDMC (Fig. 15) values in sessions 1 and 2 compared to session 3 (both $p < 0.0001$; df = 86), with no restoration effect detected. In Alders, LDMC also increased from sessions 1 and 2 to session 3 ($p = 0.0001$ and $p = 0.0007$; df = 98). A restoration effect was observed only in session 3, with significantly higher LDMC in restored sites ($p = 0.0214$; df = 48).

For SLA (Fig. 17) and stomatal conductance, only session effects were significant. In Ashes, SLA was significantly lower in session 1 compared to sessions 2 and 3 (both $p < 0.0001$; df = 40), while stomatal conductance differed between sessions 2 and 3 ($p = 0.0149$; df = 53). In Alders, SLA was higher in session 3 compared to sessions 1 and 2 (both $p < 0.0001$; df = 48), and stomatal conductance varied significantly between sessions 1 and 2, and between 2 and 3 (both $p < 0.0001$; df = 58)

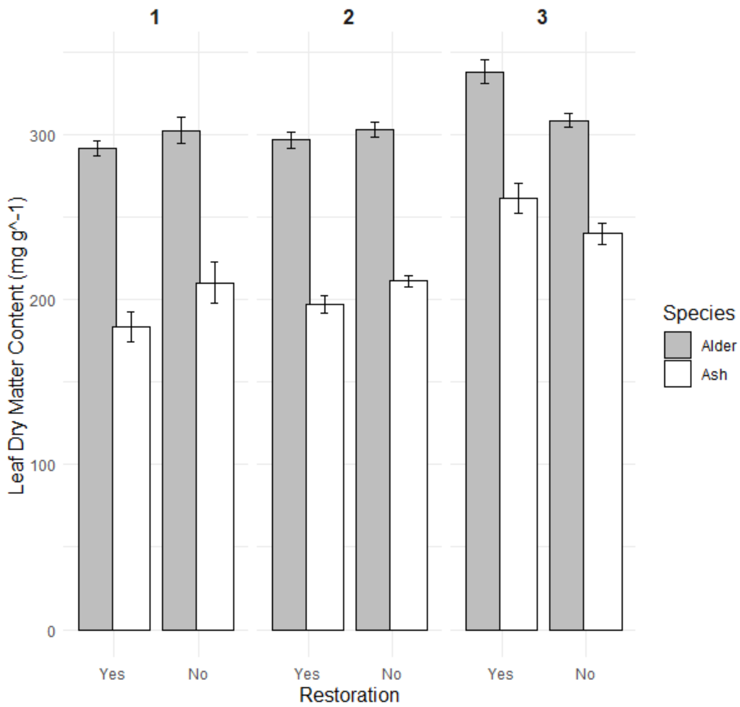

__Figure 15__: Mean LDMC per specie and session for restoration status

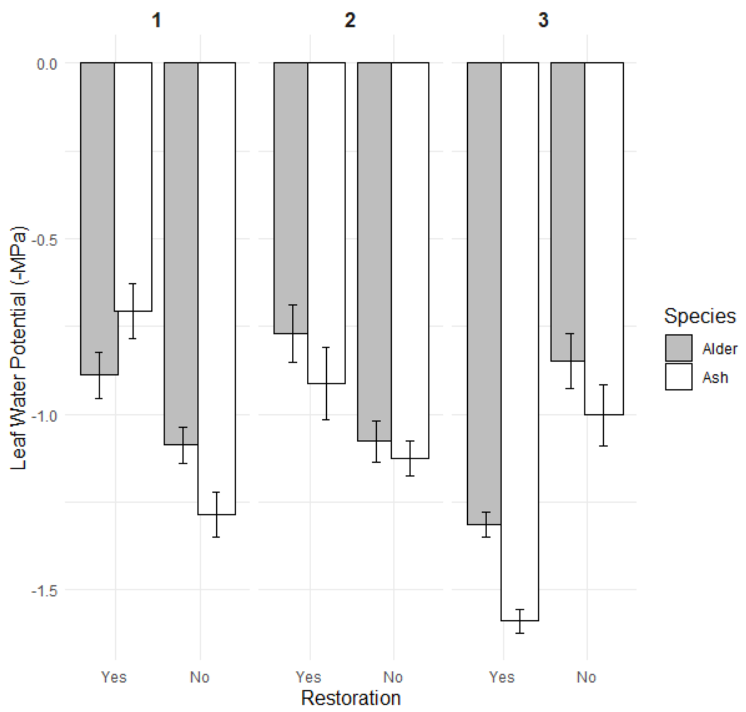

__Figure 16__: Mean LWP per specie and session for restoration status

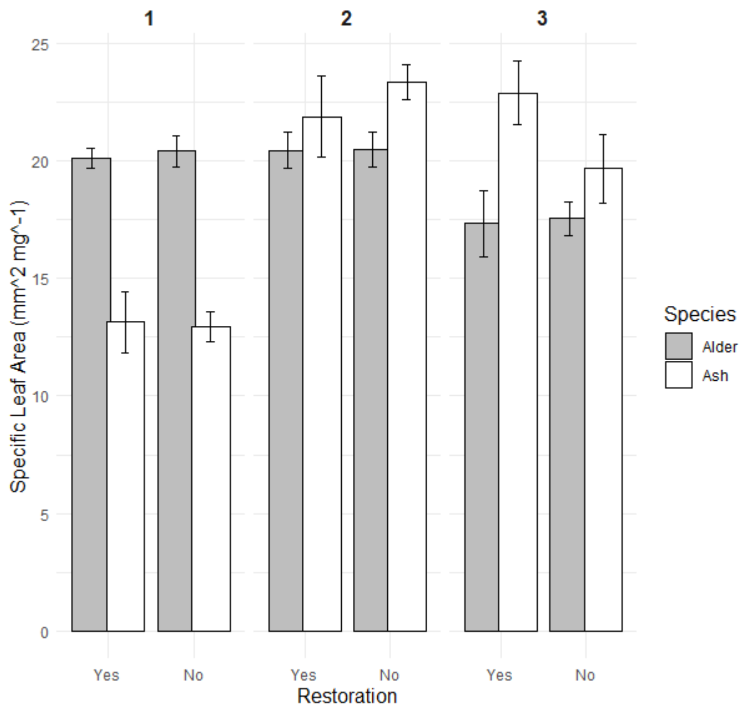

__Figure 17:__ Mean SLA per specie and session for restoration status

Finally, regarding site effects, only LWP showed significant differences: between Poncins and Pont-Sainte-Agathe for Ashes ($p = 0.0307$; $df = 45$), and between Pont-Sainte-Agathe and Trelins for Alders ($p = 0.0432$; $df = 45$). No significant site-related differences were found for SLA, LDMC, or stomatal conductance.

3.2. Hydro-meteorological results

All sampling session were following rainy day (Fig. 18) from 9 to 20mm precipitation and flow increase between 4 and 7 $m^3.s^{-1}$ on sampling date. Second session was following heat days.

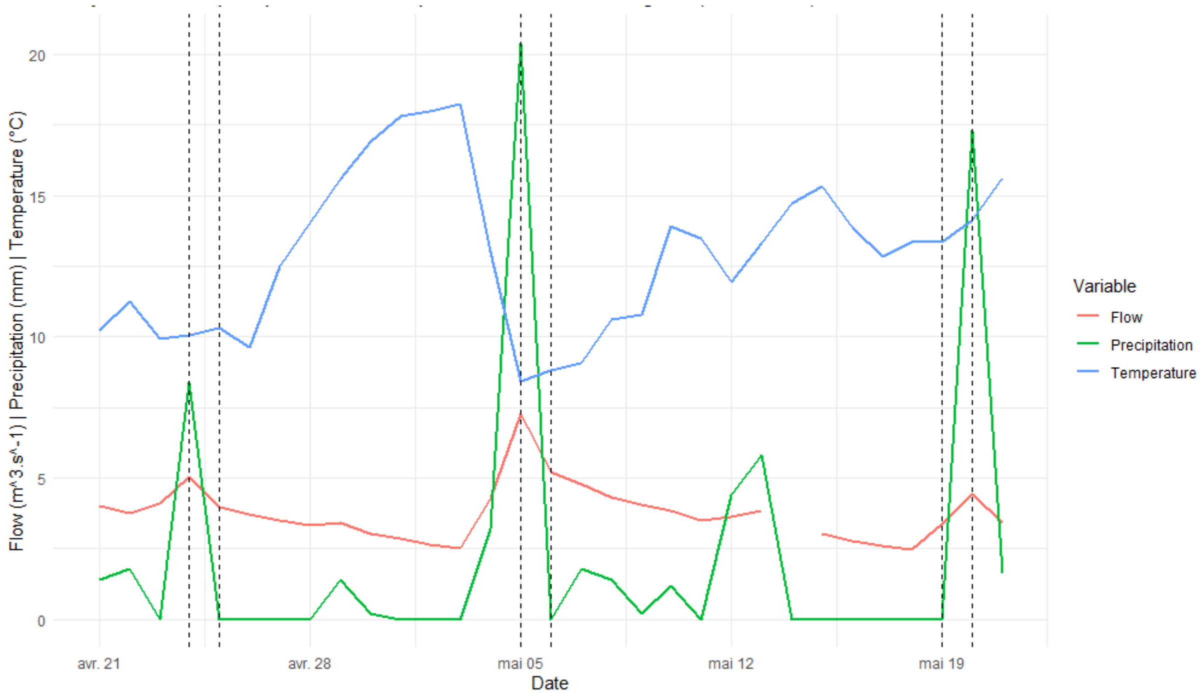

Figure 18: *Daily flow, precipitation and temperature at Boën-sur-Lignon (K075 3210)*

3.3. Sociological survey

The global analysis by theme is presented in Table 4.

Table 4: *Grid theme for sociological analysis*

Theme	Interview 1	Interview 2	Interview 3	Interview 4	Interview 5
Lack of communication	« Je ne pense pas que c'est ce qui manque parce qu'on demanderait au CNRS, je suis sûr qu'ils prendraient le temps de venir nous former. »	« On n'avait pas conscience de l'intérêt de certains habitats [before using IBCR]. »	« Et ça nécessite aussi une expertise, […] avoir des gens qui connaissent bien les arbres, etc. »; « La boîte à outils est vide. »	« Manque de connaissance sur les outils » ; « Tête dans le guidon »	« Besoin d'accompagnement sur les maladies » ; « Au niveau de la ripisylve, pas forcément. »
Variable riparian zone definition	« […] végétation qu'on retrouve en bord de cours d'eau […] multifonctionnel […]»	« […] cordon rivulaire boisé qui est complètement associé à la rivière en elle-même. » ; « […] on peut avoir une ripisylve qui fait des fois 40	« On part du pied de berge jusqu'à... […] elles sont souvent limitées dans l'espace. […] une quinzaine de mètres par rapport au pied	« Bord-cour d'eau, hélophytes » ; « puis après, […], c'est plutôt même ta forêt alluviale »	« […] on a des prairies ou des cultures à proximité, […] la ripisylve va se limiter à une rangée le long de la berge […] » ; « […] au milieu de forêts, de bois

		mètres de large […] »	de berge. […] après, on est souvent dans des parcelles privées. »		[…] c'est en fonction du dénivelé de la pente de la berge. »
Unclear framework	« L'évaluation était faite à l'époque des contrats de rivière mais n'est plus systématisée »	« […] on peut avoir une forêt qui a été plantée, qui s'installe en bord de rivière. Et on se dit, où est-ce que s'arrête la ripisylve ? » ; « Tout dépend un peu des échanges qu'on peut avoir avec la rivière […] »	« L'évaluation dépend de la sensibilité de chacun"	« Besoin d'un indice généralisé » ; "10 techniciens donnent 10 projets différents"	« […] on pousserait pour avoir une ripisylve plus dense et plus large, mais bon, on n'est pas chez nous. »
Few indexes use in local context	« Non. Et celui-ci, j'ai entendu parler, mais c'est vrai que je ne m'y suis pas forcément intéressé. »	"On ne les utilise pas vraiment. » ; « On ne se sert pas vraiment de l'IBCR »	"On ne s'y penche pas trop dessus"	"Pas d'outils simples, sans faire appel à des BE (bureau d'études)"	« […] IBCR depuis 2021 […] » ; « Il n'est pas simple, mais on arrive assez facilement à l'utiliser. »
Lack of time for field	« […] c'est surtout le temps qui manque. »	« Si quelqu'un le fait à notre place, ok"	"Pas d'outils simples qui prennent peu de temps »	« Si ça prend deux jours, on ne le fera pas » ; « […] c'est un travail de terrain qui est hyper chronophage »	"Ce serait trop long" ; "il faut agir aussi"
Lack of time for survey analysis	« […] plus études de la ripisylve on a moins le temps de faire ça. »	« Déjà, nous, on court sur le temps parce qu'on a beaucoup d'objectifs. »	"Les élus ont du mal avec les études longues" ; "on finit par faire que des études"		"Si on passe trop de temps sur les inventaires, on n'agit plus" ; "la priorité est l'action"
Promote indexes application	« […] retrouver la ripisylve assez dense et fonctionnelle. »			« […] difficilement, entre guillemets, justifiable […] » ; « là, c'est plus la peine de mettre de l'argent dessus parce	« […] il faut aussi que ce soit valable et que ce soit réfléchi et que derrière il y ait un résultat. »

				qu'on n'arrivera pas à rattraper la qualité »	
Divergent scale application	« […] entre 2 et 5 kilomètres […] »	« Il faut pouvoir l'adapter à nos réalités de terrain » ; « Donc, ce jeu d'indicateur, il faut qu'il soit multi-échelle. » ; « à l'échelle d'un tronçon du kilomètre, d'une centaine de mètres, voire du kilomètre »	« Ça permettrait d'avoir une vraie cartographie à l'échelle nationale, peut-être, de l'état de la ripisylve. »	« Notre difficulté, c'est d'extrapoler la qualité de […] la ripisylve, je pense que ça me paraît compliqué. » ; « Par rapport à notre référence locale […] »	« Petite échelle, 500m c'est bien. »
Need of standardisation and simplification	« Pas besoin d'être naturaliste pour s'en servir »	« Attention à ne pas standardiser au point d'être aveugle aux particularités locales »		« Aujourd'hui, 10 techniciens donneront 10 projets différents » ; « Si c'est trop technique, les élus décrochent »	« À montrer à un élu, un graphique c'est clair »
Support prioritisation and monitoring	« Selon le diagnostic établi, ça donne des pistes d'amélioration, de restauration. »	« Ça peut aider à savoir où agir »	« Après, pour prioriser les actions, c'est important, parce que ça permet de voir justement là où on est en déficit. »	« Par exemple, on va faire de la mise en défense et ton retour, il va être finalement rapide. »	« Avant l'action on va voir sur place quelques éléments comme la densité, les envahissantes … »
Need to assess riparian vegetation status	« […] anticiper au mieux et amortir au mieux les effets du changement climatique […] »		« On peut avoir une idée de la ripisylve en regardant […] diversité des végétaux […] variété piscicole importante […] peu de phénomènes érosifs […] »	« Cours d'eau qui était permanent […] en train de passer en cours d'eau intermittent » ; « l'adaptation, avec le changement climatique aussi, le fait d'avoir une ripisylve fonctionnelle » ; « on avait de l'excès d'eau	« C'est intéressant de le faire dans le long terme, c'est aussi de voir si nos actions sont efficaces. »

				pratiquement en permanence »	
Need for restoration projects	« […] quand on fait de la plantation, c'est toujours dur de savoir quelle espèce on choisit. »	« Le seul indicateur […] c'est quand on fait le diagnostic initial […] sur la densité de la ripisylve, qui nous permet […]de prioriser […] »	« Il y avait quand même eu des recensements sur le terrain, etc. »	« […] que les services qui vont leur être rendus par cette perte de terrain sont suffisamment intéressants pour qu'ils le concèdent. »	« C'est important de voir si la plantation a tenu »
Implementation of GIS tools	« Oui, je pense que le traitement ortho ou l'analyse cartographique[..]ça permet de trier un peu et de voir les secteurs prioritaires. »	« Ce serait bien si ça se mettait directement dans QGIS » ; « Ce qui est indéniable dans ces outils-là, il faut une approche géographique et cartographique. «	« […] des solutions, entre guillemets, un petit peu plus automatique [...] » ; « ça se fait pour l'agriculture »		« Ce serait bien si ça se mettait directement dans QGIS »
Rigid regulatory framework	« Et non, après, d'autres indices, […] mais un indice, c'est bien, mais ça reste un indice où, […], on ne peut pas adapter à tous les tronçons […] »	« Il faut pouvoir l'adapter à nos réalités de terrain »		« Attention à ne pas standardiser au point d'être aveugle aux particularités locales » ; « s'il faut une certaine espèce pour avoir une bonne note… »	
Knowledge about riparian evaluation indexes	« Non. Et celui-ci, j'ai entendu parler, mais c'est vrai que je ne m'y suis pas forcément intéressé. »	« Mais stricto sensu, on n'a pas d'indicateur qu'on aurait pu mettre à l'amont avant de faire le chantier de restauration, puis à l'aval. »	« C'est important. Même si aujourd'hui, on n'a pas trop les outils pour ça. C'est un petit peu compliqué. »		« Non, l'IBCR suffit. »
Relevance for climat change	« Il y a des arbres, on se dit qu'ils sont connectés […] en fait, non. Et d'autres qu'on	« Ça serait une certaine plus-value dans l'efficience de nos actions. »		« On passe de cours d'eau permanent à d'intermittent. » ; « Beaucoup d'expositions sud,	« Donc après, si celle-là (l'aulne glutineux) venait à subir les effets du changement climatique, ça va

	peut peut-être penser déconnectés, et en fait, […] ils arrivent à aller jusqu'à la nappe. » ; « […] mais qu'on voit qu'il y a des problématiques d'arbres qui sèchent, de dépérissement, etc. »			quelles essences mettre ? » ; « De temps à autre, au niveau de la ripisylve, on croisait un érable. […] Maintenant, de l'érable, il y en a de partout. »	être problématique. » ; « Et après, les influents, on n'est pas sur des cours d'intermittent, mais on risque de le devenir. »

The semi-structured interviews conducted with five professionals from river basin and riparian management reveal strong support for developing tools aimed at evaluating riparian vegetation functionality. While all five interviewees acknowledged the potential relevance of such tools, they expressed divergent expectations depending on their professional roles. Project officers (interviewees 1 and 4) demonstrated a deeper investment in the development and refinement of such frameworks, reflecting their alignment with broader planning and policy objectives. In contrast, river managers (interviewees 2, 3, and 5) were more concerned with the feasibility and practical application of the tools, highlighting the operational constraints they face in the field. Notably, one river manager (interviewee 5) occupied an intermediate position—deeply engaged with riparian vegetation assessment but driven more by personal commitment than by institutional mandates.

To structure these findings, responses were grouped around three hypotheses corresponding to key themes: (1) the complexity of riparian assessment and the need for clearer communication; (2) the misalignment between operational and scientific approaches; and (3) the integration of functional vegetation criteria in assessment frameworks.

3.3.1. Complexity and Weak Communication

Addressing the first hypothesis, the interviews revealed that knowledge transfer and methodological clarity remain significant barriers. Only one interviewee considered that no additional scientific communication was necessary, assuming that relevant research could be accessed when needed. However, two others explicitly cited the need to deepen knowledge about riparian vegetation assessment tools, and two more highlighted the importance of understanding biotic stressors, such as disease, which they had started investigating since the implementation of tools like the IBCR.

All five respondents shared a common conceptual understanding of riparian zones as multifunctional interfaces intimately linked to the river system—from submerged roots to the top of the riverbank. However, their shared definitions quickly broke down when confronted with practical field realities. Ambiguities remain regarding the boundaries of riparian zones, particularly in alluvial floodplains where vegetation often overlaps with private agricultural lands. The variability in interpreting spatial limits—whether 10, 15, 30, or 40 meters—illustrates the operational uncertainty managers face.

Furthermore, 3 out of 5 respondents criticized the lack of a standardized monitoring framework, citing temporal inconsistencies in assessments. Two out of five pointed out the difficulty of delineating riparian zones in the field. As one participant remarked, “Ten different river managers produce ten different projects,” encapsulating the challenge of harmonizing practices even within a single region.

Interestingly, 4 out of 5 do not currently use scientifically validated assessment tools (i.e., those emerging from peer-reviewed research or coordinated scientific programs). One manager uses a locally developed tool, and only one had adopted the IBCR since its regional integration in 2021. Overall, none of the interviewees demonstrated detailed familiarity with riparian indexes, even when used in their institutions—highlighting a gap between tool availability and actual usage. Concerns were also raised about the resource demands of implementing complex indices, further discouraging systematic vegetation monitoring.

3.3.2. Misalignment Between Operational and Scientific Approaches

The second hypothesis focused on the divergence between operational and scientific uses of riparian evaluation tools. Time emerged as a critical issue: all five interviewees cited the time-intensive nature of implementing these assessments, from initial data collection to final decision-making. In addition, all five mentioned spatial scale as a persistent source of tension. While managers prefer small-scale, reach-level assessments to inform specific restoration actions, they also recognize the utility of broader-scale tools for prioritization and strategic planning—though never within the same operational framework.

Four out of five emphasized the need for simplification and standardization of assessment tools, not only to ease application but also to facilitate communication across stakeholders. Currently, riparian assessment tools are mainly used to justify or prioritize restoration actions, and rarely to monitor ecological progress over time—a gap noted by all five respondents.

Geospatial technology emerged as a promising avenue to bridge these gaps: four out of five mentioned GIS tools as essential for resolving issues of spatial scale and improving usability. These tools could also address concerns about the rigidity of index frameworks, mentioned by 3 of the 5 river managers. Participants emphasized the need for flexible tools that adapt to local conditions and decision-making contexts, rather than impose universal standards.

3.3.3. Integrating Riparian Vegetation Functionality

Finally, the third hypothesis explored whether a stronger focus on vegetation functionality could enhance assessment frameworks. Three out of five participants explicitly supported the idea that functional assessments—particularly those that reflect density and physiological health—would improve justification for resource allocation and long-term riparian management. Two others highlighted the importance of evaluating vegetation condition to guide climate change adaptation and support biodiversity. One interviewee emphasized the value of functional monitoring specifically for assessing restoration outcomes. Only one participant expressed limited interest in direct vegetation monitoring, preferring to use proxies such as species diversity or bank erosion rates.

Despite these differences, four out of five interviewees underscored the urgency of riparian monitoring in the face of climate change. Two of them reported that their territories are already shifting toward drier, more intermittent flow regimes. As species composition changes, they expressed growing interest in identifying key functional traits that can help maintain ecosystem services under future climate scenarios.

4. Discussion

4.1. Water Stress and Riparian Assessment

This study aimed to assess the capacity of riparian evaluation tools—namely IBCR and RipaScan—to reflect tree-level ecophysiological functioning, particularly under water stress. By comparing assessment indices to ecophysiological traits such as LWP, LDMC, SLA, and stomatal conductance, and by integrating morphological, topographical, meteorological, and land use data, we sought to identify which environmental factors most influence riparian vegetation condition. Despite this integrative approach, our results did not reveal clear or consistent patterns validating the predictive power of riparian indices on tree ecophysiology at local scale.

Our comparative analysis of IBCR and RipaScan showed that neither index consistently captured variations in ecophysiological status across sites and sessions. While some punctual correlations were observed—particularly for IBCR in sessions 1 and 2—the lack of statistical robustness and reproducibility across time undermines the reliability of these indices as indicators of tree functionality. For RipaScan, the observed trends in Alders' LWP and SLA between "high" and "low" categories were weakened by the fact that these classes were each represented by a single site. Consequently, the patterns observed may simply reflect site-specific differences rather than riparian status per se. The same limitation applied to other comparisons, were co-varying factors likely confounded interpretations.

For IBCR, more promising tendencies emerged, especially in earlier sessions. Sites classified as "Good" generally showed higher physiological performance, aligning with theoretical expectations. However, these correlations were neither consistent across species nor stable across sessions and disappeared entirely by session 3. This temporal inconsistency raises questions about the sensitivity of these indices to rapidly changing environmental conditions and suggests that the IBCR may not adequately reflect short-term ecophysiological dynamics, especially under variable meteorological conditions (Bhaskar and Ackerly, 2006; Martínez-Vilalta and Garcia-Forner, 2017).

Differences in index design and spatial application further complicate interpretation. The IBC is applied at a broader 500 m reach scale, likely integrating a wider range of environmental varability and vegetation characteristics. In contrast, RipaScan was applied on shorter 150 m reaches, while tree measurements spanned approximately 600 m per site. This mismatch in spatial scale may have limited RipaScan's representativeness and its ability to reflect the actual conditions experienced by the sampled trees. Such discrepancies underscore the importance of aligning the spatial scale of assessment tools with the scale of ecological measurements when evaluating riparian vegetation condition.

Beyond the indices themselves, we explored whether morphological and topographical data could provide better explanations of ecophysiological variability. Although tree height above the water table and distance to the river differed significantly among sites, these variables were not correlated with ecophysiological traits. This finding suggests that structural variables, while ecologically relevant, are not dominant drivers of functional variability in this context. Similarly, land use and land cover data did not offer consistent explanatory power—though sites with greater forest cover within 30 m and 100 m buffers tended to show higher LWP and better IBCR scores. This observation aligns with previous studies (e.g., Fernandez et al., 2014) linking riparian vegetation quality to landscape-scale metrics, such as canopy cover and buffer continuity.

Importantly, the influence of meteorological variability cannot be overstated. Measurements taken during session 3, particularly of LWP and stomatal conductance, were likely affected by recent rainfall, which temporarily elevated water availability and potentially obscured long-term stress signals. In some cases, sites previously classified as lower performing in earlier sessions reversed status, showing unexpectedly high LWP values. This inversion highlights the high sensitivity of physiological traits to short-term weather events and emphasizes the need to interpret instantaneous measurements within their full meteorological and phenological context.

This study also reaffirmed the challenge of detecting clear water stress in temperate riparian forests under moderate climatic conditions. Neither *Alnus glutinosa* nor *Fraxinus excelsior* exhibited LWP values below the typical -2 MPa stress threshold (Besnard and Carlier, 1990; Parent et al., 2010). Although *A. glutinosa* is more sensitive to drought, no major interspecific divergence was identified—likely due to the overall low water deficit during the sampling period. Additionally, phenological stages such as bud break during session 1 introduced further variability, limiting comparability among individuals. The relatively small number of SLA measurements may have also reduced our ability to detect significant patterns. However, the broader lack of clear associations between traits and riparian indices suggests that the observed stability is more likely due to ecological resilience or unmeasured environmental complexity, rather than methodological shortcomings alone.

While this study focused on water stress as a proxy for vegetation functionality, it is possible that other physiological or ecological dimensions—such as root traits, nutrient acquisition strategies, or competitive interactions or water use efficiency—may respond more sensitively to riparian degradation or restoration (Alizadeh et al., 2021; Pérez-Harguindeguy et al., 2013; Seibt et al., 2008). Additionally, stressors beyond water scarcity—such as soil compaction, pollution, or biological invasions—may exert cumulative or interactive effects not captured by water-related ecophysiological traits alone(Feld et al., 2018; Rood et al., 2003).

Given these limitations, it is worth considering the integration of additional tools such as airborne remote sensing to support field-based evaluations. While NDVI or thermal infrared imagery may not independently provide robust indicators of stress, they offer valuable contextual data for interpreting local patterns in vegetation condition and structure. Combining fine-resolution field measurements with spatial and temporal satellite or drone-based indices could greatly enhance the robustness and applicability of riparian assessment frameworks, especially for large-scale or long-term monitoring(Godfroy et al., 2022; Huylenbroeck et al., 2020; Lochin et al., 2024b).

In conclusion, while riparian assessment indices such as IBCR and RipaScan provide useful frameworks for evaluating vegetation quality, their capacity to predict tree-level ecophysiological functioning remains limited without broader contextual integration. Topography, land use, and weather conditions interact in complex ways that challenge simple, one-to-one interpretations. Future assessment efforts should seek to align spatial scales, incorporate dynamic environmental drivers, and integrate multiple indicators of vegetation function—structural, physiological, and spectral—to better inform riparian management and restoration strategies.

4.2. Needs and perceptions

This study reveals a fundamental tension between the promise of riparian assessment tools and their actual use and perception by practitioners. On one hand, there is clear support for developing scientifically grounded tools that reflect vegetation functioning and ecological health. On the other, there is a gap in communication, operational compatibility, and implementation capacity that limits their practical uptake.

First, riparian evaluation tools such as IBCR and RipaScan show limited correlation with ecophysiological indicators of water stress, as demonstrated in our ecological results. This limitation becomes even more critical when interpreted through a sociological lens. The majority of river managers are unfamiliar with these tools or lack the means to apply them effectively. Their feedback echoes the ecological findings: while these tools may align conceptually with ecological functioning, they struggle to deliver operational relevance under field conditions.

The issue of scale is particularly emblematic of this disconnect. While scientific assessments are often designed at landscape or catchment scale, river managers operate on shorter timeframes and more localized restoration targets. As each of the five interviewees suggested a different "ideal" spatial scale, it becomes clear that any index intended for real-world use must be flexible and modular—capable of scaling up or down depending on user needs. GIS-based platforms were consistently highlighted as a promising solution, offering both spatial flexibility and the capacity to integrate diverse data types. Such tools may help resolve some of the time and resource limitations cited by managers, especially if paired with user-friendly interfaces and simplified protocols.

Equally important is the need to clarify the purpose of these tools. As one interviewee put it, "What is the index for?" When assessment frameworks fail to inform management decisions, they risk becoming symbolic rather than functional. Managers feel this disconnection acutely—they are often burdened with complex administrative responsibilities and lack time for in-depth analysis. Moreover, they report difficulty justifying the use of scientific tools in contexts where financial and institutional support is insufficient or intermittent.

Yet, the urgency for such tools is growing. Climate change and river incision are visibly altering riparian systems in many regions, and managers are seeking better ways to anticipate and adapt to these changes. Functional traits, especially those related to water stress, offer a potential pathway for building more adaptive management strategies. However, these traits must be embedded in tools that are visible, accessible, and tailored to the practical needs of practitioners.

The interviews also suggest that many managers are already taking initiative—creating or adapting their own tools, participating in collaborative networks, and incorporating riparian vegetation into broader restoration planning. These grassroots efforts represent an opportunity: rather than imposing top-down frameworks, researchers should support and co-develop tools in close collaboration with field managers.

In conclusion, this study underscores the importance of translational science in riparian management. Bridging the gap between ecological insight and operational utility requires participatory tool development, flexible spatial design, and clearer articulation of tool objectives. Riparian vegetation is increasingly seen not just as a component of river systems, but as a key lever for resilience under global change. Tools that help managers act—not just assess—will be essential to meet this challenge.

5. Conclusion and perspectives

This interdisciplinary work presents an interesting framework to connect operational needs with scientific research, aiming to align and support both objectives. While current results are not yet sufficient to draw definitive conclusions, they highlight the importance of continuing this research within the broader context of developing riparian knowledge. The survey will therefore be extended with two additional sessions over the summer, and measurements of intrinsic water use efficiency will be included. Furthermore, integrating remote sensing techniques and comprehensive assessments of riparian vegetation using additional indices could strengthen and refine this approach.

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