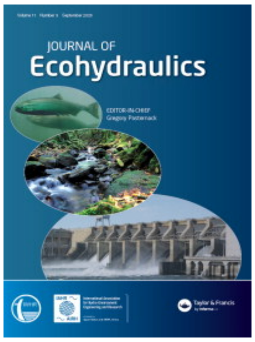

Journal of Ecohydraulics

ISSN: 2470-5357 (Print) 2470-5365 (Online) Journal homepage: www.tandfonline.com/journals/tjoe20

Charting the evolution of ecohydraulics: a community perspective on skills, technology, training needs and challenges

Mónica Basilio Hazas, Joël Wittmann, Davide Vanzo, Jan De Keyser, Melina Sattelmeier, Hannah Schwedhelm, Kevin Merl, Francesca Padoan, Ana Adeva-Bustos, Davide Vettori, Mathias Chabal, Sahra N. Sabil, Daniele Tonina & Daniel S. Hayes

To cite this article: Mónica Basilio Hazas, Joël Wittmann, Davide Vanzo, Jan De Keyser, Melina Sattelmeier, Hannah Schwedhelm, Kevin Merl, Francesca Padoan, Ana Adeva-Bustos, Davide Vettori, Mathias Chabal, Sahra N. Sabil, Daniele Tonina & Daniel S. Hayes (06 Sep 2026): Charting the evolution of ecohydraulics: a community perspective on skills, technology, training needs and challenges, Journal of Ecohydraulics, DOI: 10.1080/24705357.2026.2718924

To link to this article: https://doi.org/10.1080/24705357.2026.2718924

JOURNAL OF ECOHYDRAULICS
https://doi.org/10.1080/24705357.2026.2718924

OPEN ACCESS Check for updates

Charting the evolution of ecohydraulics: a community perspective on skills, technology, training needs and challenges

Mónica Basilio Hazas[a], Joël Wittmann[b], Davide Vanzo[c], Jan De Keyser[d], Melina Sattelmeier[e], Hannah Schwedhelm[f], Kevin Merl[g], Francesca Padoan[h], Ana Adeva-Bustos[i], Davide Vettori[j], Mathias Chabal[k], Sahra N. Sabil[i], Daniele Tonina[l] and Daniel S. Hayes[g,m]

[a]GeoZentrum Nordbayern, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen, Germany; [b]Institute of Environmental Engineering, Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, Zurich, Switzerland; [c]Institute for Water and Environment, Karlsruhe Institute of Technology, Karlsruhe, Germany; [d]Department of Landscape, Water and Infrastructure, Institute of Hydraulic Engineering and River Research, BOKU University, Vienna, Austria; [e]Department of Engineering Sciences and Mathematics, Division of Fluid and Experimental Mechanics, Luleå University of Technology, Luleå, Sweden; [f]Chair of Hydraulic Engineering, TUM School of Engineering and Design, Technical University of Munich, Munich, Germany; [g]Department of Ecosystem Management, Climate and Biodiversity, Institute of Hydrobiology and Aquatic Ecosystem Management, BOKU University, Vienna, Austria; [h]Platform of Hydraulic Constructions (PL-LCH), ENAC - IIC, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland; [i]SINTEF Energy Research, Trondheim, Norway; [j]James Watt School of Engineering, University of Glasgow, Glasgow, UK; [k]Centre Eau Terre Environnement, Institut national de la recherche scientifique, Québec, Canada; [l]Department of Civil and Environmental Engineering, Center for Ecohydraulics Research, University of Idaho, Boise, ID, USA; [m]LimnoSolve, Team for Applied Limnology, Vienna, Austria

ABSTRACT

Ecohydraulics requires the integration of diverse skill sets to understand the complex interactions among hydraulic, biological, and ecological processes in aquatic environments, particularly under the influence of natural and anthropogenic change. This article presents findings from a community survey conducted at the 15th International Symposium on Ecohydraulics and Fish Passage (ISE-FP 2024) and compares them to those of a similar survey conducted at ISE 2018, with a particular focus on early-career researchers. We examine demographic trends, perceived challenges within the field, self-assessed competencies across general, technical, and emerging skills and identify training needs, seminar interests, and emerging technologies considered relevant to ecohydraulics. While demographic patterns and disciplinary challenges remain broadly consistent with previous findings, South American and African participation increased. Both early- and senior-career participants report confidence in traditional skills, such as literature review, fieldwork, and numerical modeling, but lower confidence in emerging technologies, including machine learning, uncrewed aerial vehicles, and artificial intelligence. Participants highlight the need for improved training in these technologies, interdisciplinary collaboration, and soft skills. These findings underscore the evolving needs of the ecohydraulics community and the importance of adapting education and professional development opportunities to support innovation, inclusivity, and cross-disciplinary engagement.

ARTICLE HISTORY
Received 5 June 2025
Revised 17 April 2026
Accepted 28 May 2026

KEYWORDS
Capacity building; professional development; early career researchers; interdisciplinarity; research community; education and training; ecohydrology

1. Introduction

Ecohydraulic studies first appeared in the peer-reviewed literature in the late twentieth century (Figure 1a), as researchers began to face challenges and limitations in traditional hydraulic river engineering approaches for evaluating the biological and ecological impacts of altered flow regimes on freshwater ecosystems (Wilkes et al. 2016). Initially, ecohydraulics was considered a subdiscipline of ecohydrology (Wood et al. 2008). Eventually, specific definitions emerged, highlighting that the difference lies, among others, in spatial scale and timelines. Ecohydrology deals with hydrology-biota interactions at larger scales, often addressing population or community-level responses (Zalewski 2000), while ecohydraulics focuses on the relationship of (individual) organisms to smaller-scale "hydraulic processes resulting from moving water" (Gosselin et al. 2019). With a publication ratio of 10:1 (Figure S1), ecohydrology is generally considered more diverse than ecohydraulics (Gosselin et al. 2019).

CONTACT Mónica Basilio Hazas monica.basilio@fau.de GeoZentrum Nordbayern, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen, Germany; Daniel S. Hayes daniel.hayes@boku.ac.at BOKU University, Department of Ecosystem Management, Climate and Biodiversity, Institute of Hydrobiology and Aquatic Ecosystem Management, Vienna, Austria.

Supplemental data for this article can be accessed online at https://doi.org/10.1080/24705357.2026.2718924.

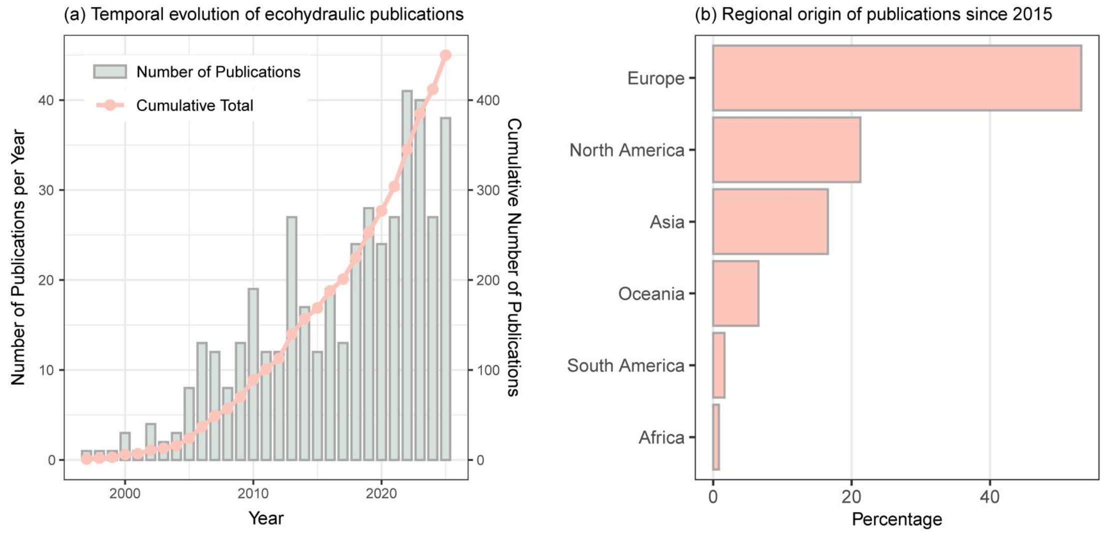

Figure 1. (a) Number of ecohydraulic publications per year (left axis) and cumulative number of the same publications (right axis), and (b) regional origin of the same publications since 2015. SCOPUS search conducted on 4 February 2026 with TITLE-ABS-KEY containing "ecohydraulics" or "eco-hydraulics", and including publications up to the end of 2025. Regional origin is taken directly from the SCOPUS statistics. We note that this search is not exhaustive, as publications addressing ecohydraulic topics may not explicitly contain the term "ecohydraulics" in the search criteria (e.g. Yang et al. 2024; Zhou et al. 2024).

The recognition of bridging engineering and ecology to answer applied questions, particularly related to river hydraulic infrastructures such as dams, gave wind to the new discipline of ecohydraulics (Pinheiro et al. 1996). The Instream Flow Incremental Methodology (IFIM) was one of the first approaches to explicitly link hydraulics to habitat quality by using quantitative hydraulic parameters (e.g. water depth, flow velocity) to predict ecological response to flow alterations, thereby supporting river management decisions (Bovee 1982; Bovee et al. 1998). The first decades focused on the development of more integrative approaches and tools to evaluate how hydraulic parameters influence the distribution, behavior, and health of aquatic species (Maddock et al. 2013; Lancaster 2018; Boavida et al. 2020) including riparian and floodplain processes. This entailed also actions aimed at defining and developing integrated methods and models to assess the interactions between aquatic organisms and their habitat (Maddock 1999; Harby 2004). Together with a growing body of literature (Figure 1a), the ecohydraulics community started to articulate the distinct identity of ecohydraulics as an emerging discipline, including dedicated conferences (e.g. the biennial International Symposium of Ecohydraulics) and journals (e.g. Kemp and Katopodis 2016), and its potential to bridge the traditional divide between engineering and natural sciences (Nestler et al. 2016). As such, ecohydraulics is inherently interdisciplinary, defined as the integration of knowledge, methods, and theories from different disciplines into new perspectives, methods, and theories (Salmela et al. 2026), as it embraces interactions and the dynamic interplay among hydrodynamic, biological, and ecological processes in aquatic environments. The regional origin of recent publications (Figure 1b) shows that ecohydraulics researchers are mostly based in Europe (53%), followed by North America (21%) and Asia (17%). Regarding Asia, China leads the publications on ecohydraulics.

The evolution of ecohydraulics has been marked by an increasing emphasis on interdisciplinary collaboration and integration of advanced tools and techniques (Harby 2004). While early ecohydraulic studies focused primarily on fish habitats (e.g. Bovee 1982; Bovee et al. 1998; Katopodis 2012), particularly in the context of environmental flows (Tharme 2003; Acreman et al. 2014), the scope of the discipline has since expanded to encompass a broader set of interactions among hydrodynamics, morphodynamics and biota (Rice et al. 2010; Casas-Mulet et al. 2016). More recently, ecohydraulics has increasingly addressed pressing challenges such as freshwater habitat degradation and climate change impacts (Boavida et al. 2020; Du et al. 2025), calling for holistic, evidence-based approaches to mitigation and restoration, besides interdisciplinary research and management efforts to address these global issues (Cooke et al. 2026). Despite its inherent interdisciplinary vocation, the community is aware that significant knowledge gaps and fragmented collaboration across disciplines constrain its ability to address complex ecological challenges effectively (Woo 2010; Boys et al. 2016; Wilkes et al. 2016; Gosselin et al. 2019).

The demographic composition of the ecohydraulics community plays a critical role in shaping its interdisciplinary potential and capacity for innovation. The community encompasses researchers from diverse disciplines, including hydraulic engineering, aquatic ecology, and environmental science. However, working in such diverse groups poses additional challenges to be solved through collaboration (Specht and Crowston 2022). In particular, Early Career Researchers (ECRs) are recognized as pivotal in bridging knowledge gaps and advancing interdisciplinary progress through collaborative research (Specht and Crowston 2022; Casas-Mulet et al. 2023). Following the European Commission recommendations (Council of the European Union 2023), ECRs are typically characterized not by age, but by research experience and career stage (Boeren et al. 2015; Signoret et al. 2019; Christian et al. 2021; Amaral et al. 2024; Brütt et al. 2024), exemplified by the use of "early-career" rather than "young." This includes individuals in R1—First Stage Researcher (up to doctoral researchers) and R2—Recognized Researcher (postdoctoral, not fully independent) profiles and junior faculty.

Despite their potential to drive interdisciplinary research, many ECRs face institutional barriers that hinder their effective engagement (Wierenga et al. 2025). Notably, education and training initiatives often remain underprioritized (Wilkes et al. 2016), leaving many ECRs underprepared to effectively apply scientific tools and methods in ecohydraulics and engage in multidisciplinary collaboration (Casas-Mulet et al. 2023). These barriers mirror those reported in other interdisciplinary fields and include limited access to resources, a lack of interdisciplinary mentorship, unclear career pathways, restricted professional networks and slow acceptance within the broader scientific community (Vladova et al. 2025; Salmela et al. 2026). Many ECRs face pressures to prioritize research over teaching, contend with questionable research practices, and endure strains on their health and personal lives (Mula et al. 2022).

This contribution has three objectives: first, to assess the current disciplinary landscape and demographics of the ecohydraulics community and compare it with the findings of the work of Casas-Mulet et al. (2023); second, to identify the most pressing challenges in ecohydraulics based on the benchmark provided by Wilkes et al. (2016)—the consolidation of ecohydraulics as a discipline with its own fundamental concepts, tools, collective vision and paradigms, bridging natural and social sciences and a strong formation of ECRs at an international scale; and third, to discuss how ECRs evaluate their preparedness across a broad range of general, technical and emerging-technology skills relevant to ecohydraulic research and application. Here, we consider emerging technologies as those with recent applications in the field of ecohydraulics, even if they may be well-established in other fields. To this end, we conducted an online survey to map challenges and opportunities in ecohydraulics (Wilkes et al. 2016) and assess the skills of ECRs with regard to a range of scientific tools and methods. We identify and group those skills and emergent technologies and discuss their relevance in guiding the future directions of the ecohydraulics discipline.

2. Methods

We developed an anonymous online survey (Google Forms) as part of the early-career pre-conference workshop of the 15th International Symposium on Ecohydraulics and Fish Passage (ISE-FP 2024) held in Québec City, Canada, from 5 to 9 May 2024. The survey was based on prior Early Career on Ecohydraulics Network (ECoENet) workshops from 2016 (Wilkes et al. 2016) and 2018 (Casas-Mulet et al. 2023), allowing us to identify trends through repeated questions. The survey consisted of 42 questions divided into four sections.

The first section was about educational background and professional development, with seven questions covering continent of work, career stage, age, gender, academic and professional training, and research macrotopics (Casas-Mulet et al. 2023). The second section addressed challenges in ecohydraulics, asking respondents to rate their agreement on five major challenges defined by Wilkes et al. (2016), using a six-tier scale ("strongly agree" to "strongly disagree"). The third section assessed self-rated skills also on a six-tier scale (from "excellent" to "no experience"). The skills were identified by the authorship team and grouped into two general areas: general skills (15 questions ranging from field surveys to experimental work, spatial analysis, computer programming, project management, and science communication) and emerging technologies (nine questions). The final section included four open-ended questions to understand and identify additional challenges, emerging technologies, and required skills needed to excel in ecohydraulics, particularly those not covered by Wilkes et al. (2016) or in previous workshops, as well as preferred seminar topics.

The online survey was distributed during the ISE-FP 2024 conference. However, to reach a larger and global participation, the call to complete the survey was distributed widely by means of circulating emails, newsletters, professional societies, and social media (X and LinkedIn). The global distribution was largely based on the contacts of ECoENet and the mailing lists of the ISE-FP 2024 organizers and the International Association for Hydro-Environment Engineering and Research (IAHR). The online survey ran from April to October 2024.

We analyzed the multiple-choice and six-tier scale rating questions quantitatively and expressed them in percentage of participants. First, we compared the demographics of the current study with respect to the previous one (Casas-Mulet et al. 2023). For further analysis, we divided the participants into two career stages: early-career researchers (ECRs) and senior researchers, using age group as a proxy for career stage (Table S1). Skills were classified into three categories: 'general skills', 'technical skills', and 'emerging skills'. Responses were then analyzed by skill group, rating level and by career stage.

We analyzed the open-ended question about skills needed in ecohydraulics by disaggregating complex answers into individual entries. For instance, if a person replied, "Researchers need skills for geographical information systems (GIS), as well as for using uncrewed aerial vehicles (UAV)", the answer would be divided into "GIS" and "UAV". All responses were categorized into specific topics, which were then grouped. Lastly, we counted how many individual entries belonged to each topic. The frequency of individual entries per topic was used as a proxy for their perceived relevance. We followed a similar procedure for emerging technologies, the challenges, and the seminars.

3. Results

3.1. Survey demographics

The number of respondents to the survey in 2024 was comparable to that of 2018 (105 and 103 respondents, respectively). In 2024, most of the participants were between 26 and 45 years old (72%), compared with 63% in 2018 (Casas-Mulet et al. 2023). ECRs ($n = 47$) accounted for 46% of the participants, while 55% were senior scientists ($n = 58$) (Table S1). Only 21% of the participants identified as female. Eleven females were ECRs (23% of total ECRs) and eleven senior scientists (19% of total senior scientists); no female respondent was >55 years old, a notable decrease from 39% female participation in 2018. This underrepresentation was consistent across all subjects, with Earth Science having the highest female percentage (33%) and Engineering the lowest (16%).

As in 2018, most participants continue to be employed in Europe (~60% in both years). However, the 2024 survey shows a clear increase in participants from South America and Africa (Figure 2a). The location of employment generally mirrors the pattern observed in the geographic distribution of ecohydraulics publications authors (Figure 1b).

While the disciplinary background distribution remains broadly consistent (Engineering > Biological Sciences > Interdisciplinary > Earth Sciences), there is a notable increase in participants with engineering backgrounds in 2024 (Figure 2b). Additionally, participation from private-sector professionals, permanent researchers, and graduate students increased. In both surveys, PhD candidates and temporary researchers represent the most dominant career position (Figure 2c).

The distribution of the most dominant research macrotopics is similar across both surveys. Although, in 2024, a higher proportion of participants reported working in hydrology and hydraulic modeling (Figure 2d). Among those studying biota, most focus on fish, with fewer participants studying invertebrates and aquatic, riparian, and floodplain vegetation. Ecohydraulics social aspects remain underrepresented, with fewer than 5% of participants identifying this as a research focus.

Additionally, we compared the demographic distribution of macrotopics by career stage and gender for the year 2024, to see if there was any particular silo within the community. In general, we found very similar trends for both career stages. The same applies for gender balance across the different macrotopics, except for invertebrate, vegetation, and estuarine responses (Figure S2).

3.2. Major challenges in ecohydraulics

The major challenges identified by the ecohydraulics community remained largely consistent with those reported by Wilkes et al. (2016) (Figure 3). Participants continued to express strong agreement with the same five core issues: (1) understanding biophysical relationships, (2) fostering interdisciplinary integration and cooperation, (3) ensuring transferability across temporal and spatial scales, (4) strengthening links to management, and (5) enhancing public and political engagement.

Additionally, 12% of the participants identified additional challenges. One of these challenges addressed the working conditions, in particular, the capacity of planning and achieving stable career paths for ECRs. Other concerns included the impacts of climate change, the integration of advanced technologies, the role of policies and regulations, and the availability and accessibility of high-quality data.

3.3. Skills in ecohydraulics: self-evaluation and needs

In the next section of the survey, the participants rated their proficiency across a range of skills in different technologies relevant for ecohydraulics and identified training gaps. The responses revealed a

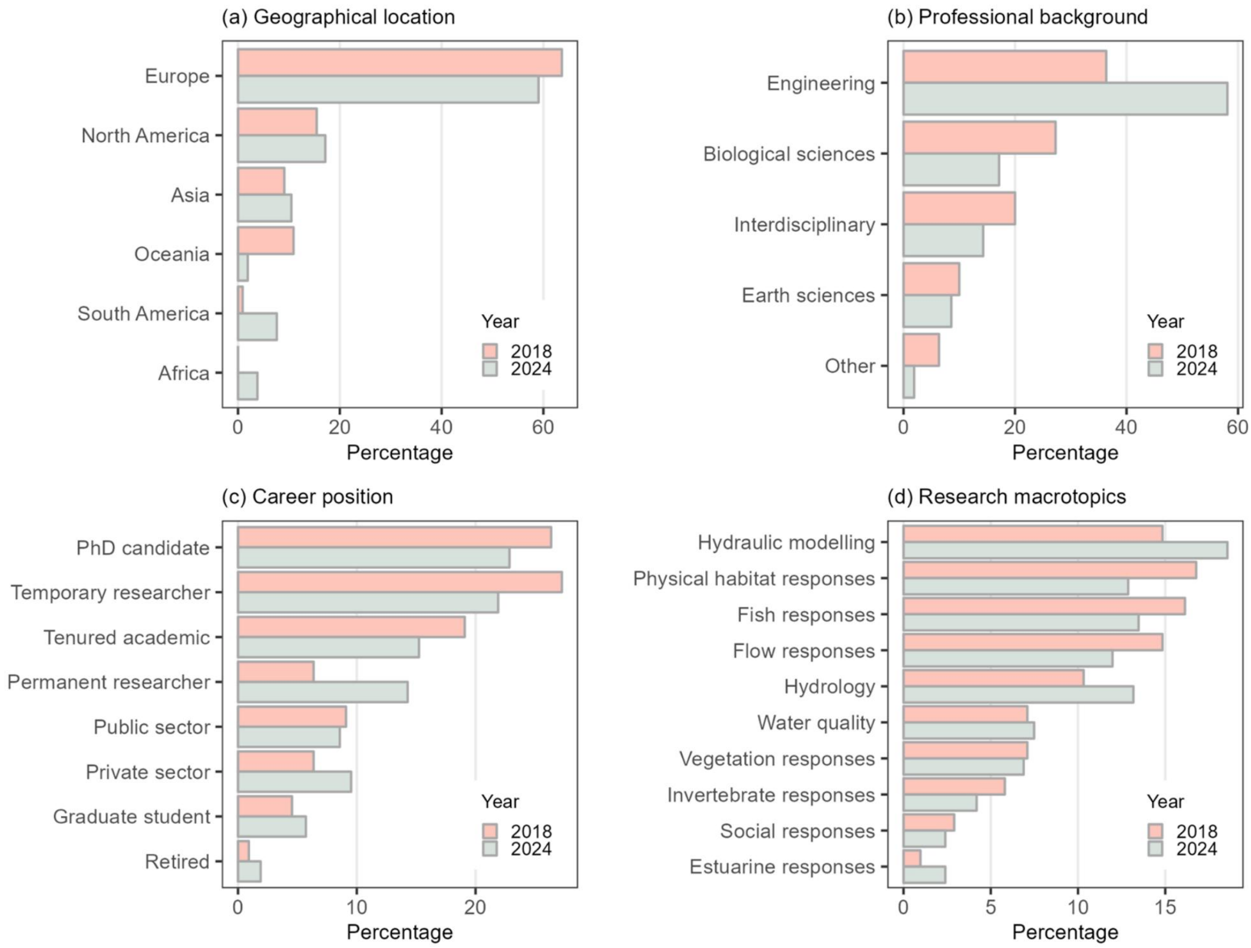

Figure 2. Comparison of demographic (a) by geographical location, (b) professional background, (c) career position, and (d) research macrotopics between the 2018 and 2024 surveys. All values are in percentages.

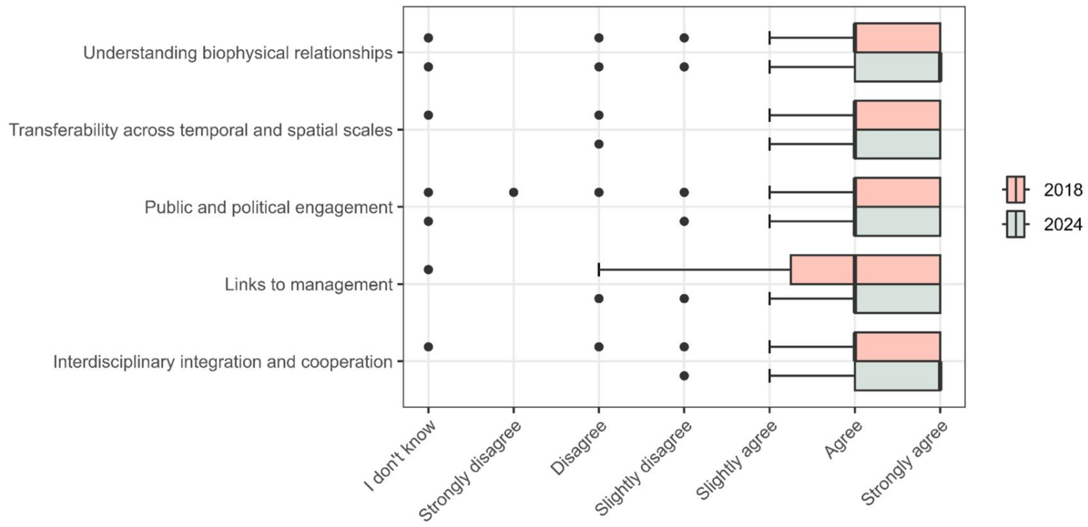

Figure 3. Agreement with major challenges in ecohydraulics as proposed by Wilkes et al. (2016).

substantial disparity between self-assessed competence in general and technical skills versus emerging technologies (Figure 4). Most participants perceived themselves as having a strong expertise in general and technical skills (Figure 4a-b). In contrast, nearly 40% of all participants indicated having no experience with emerging skills (Figure 4c), highlighting a significant training gap in areas such as machine learning and remote sensing.

No significant differences were observed in rated scientific skills between ECRs and senior researchers (Figure 5). Interestingly, ECRs tended to rate

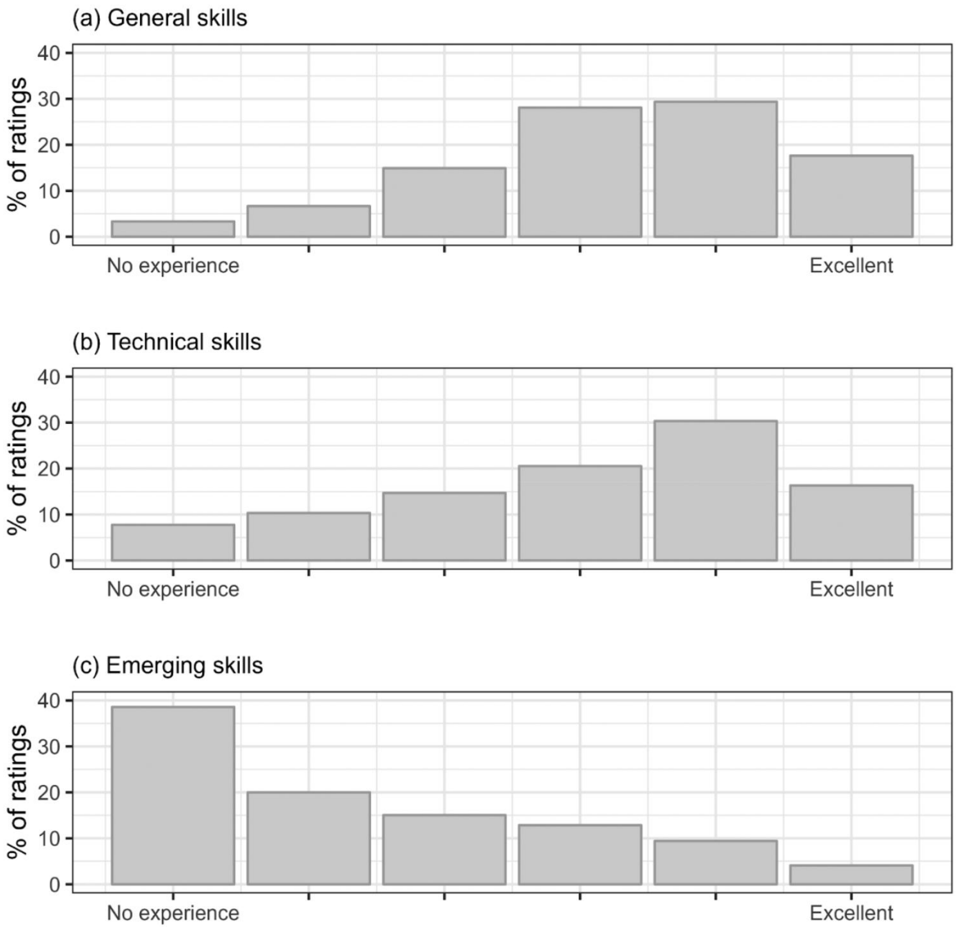

Figure 4. Distribution of aggregated ratings for (a) general, (b) technical, and (c) emerging skills.

themselves slightly higher even in areas where senior researchers would be expected to have more experience, such as in scientific writing and literature analysis (Figure 5a). While both groups rated themselves similarly in the traditional skills (Figure 5b), a wider variability emerged in responses related to emerging skills (Figure 5c). The type of emerging technology appeared to play a minor role, because overall self-assessed expertise remained low across all categories. The low experience of artificial intelligence (AI) could be due to the survey closing before the extensive increase of AI generative models in 2025.

In response to the open-ended questions, participants mentioned both previously listed skills and emerging technologies, while also introducing new ones. To ensure completeness, all responses were considered in the survey results. Based on the full set of responses ($n = 186$), we identified three overarching skill categories essential for advancing in ecohydraulics: (1) modeling, analysis, and data science, (2) personal and professional skills, and (3) data collection.

Figure 6 illustrates the relevance of specific topics, with circle sizes representing the frequency of mentions (detailed numbers are in Table S2 of the Supplementary Material). Skills related to modeling, analysis, and data science were most frequently cited (47% of all responses). Among them, computer programming and statistics were prominent, with 20 and 19 mentions, respectively. Additionally, 38 of the participants emphasized the importance of soft and personal skills, with the ability to work across disciplines being the most frequently mentioned (20 times). In contrast, only 15% of responses focused on data collection, with field work being the dominant topic (12 mentions).

Although not considered skills per se, participants also identified the importance of process understanding and expanding their knowledge in ecohydraulics-related subjects. The most frequently mentioned knowledge domains included hydraulic engineering, fluid mechanics, ecology, hydrology, and biology (Table S3).

3.4. Emerging technologies

Survey participants mentioned a total of 35 different emerging technologies in ecohydraulics (14 already mentioned in the survey (Figures 5b & 5c)

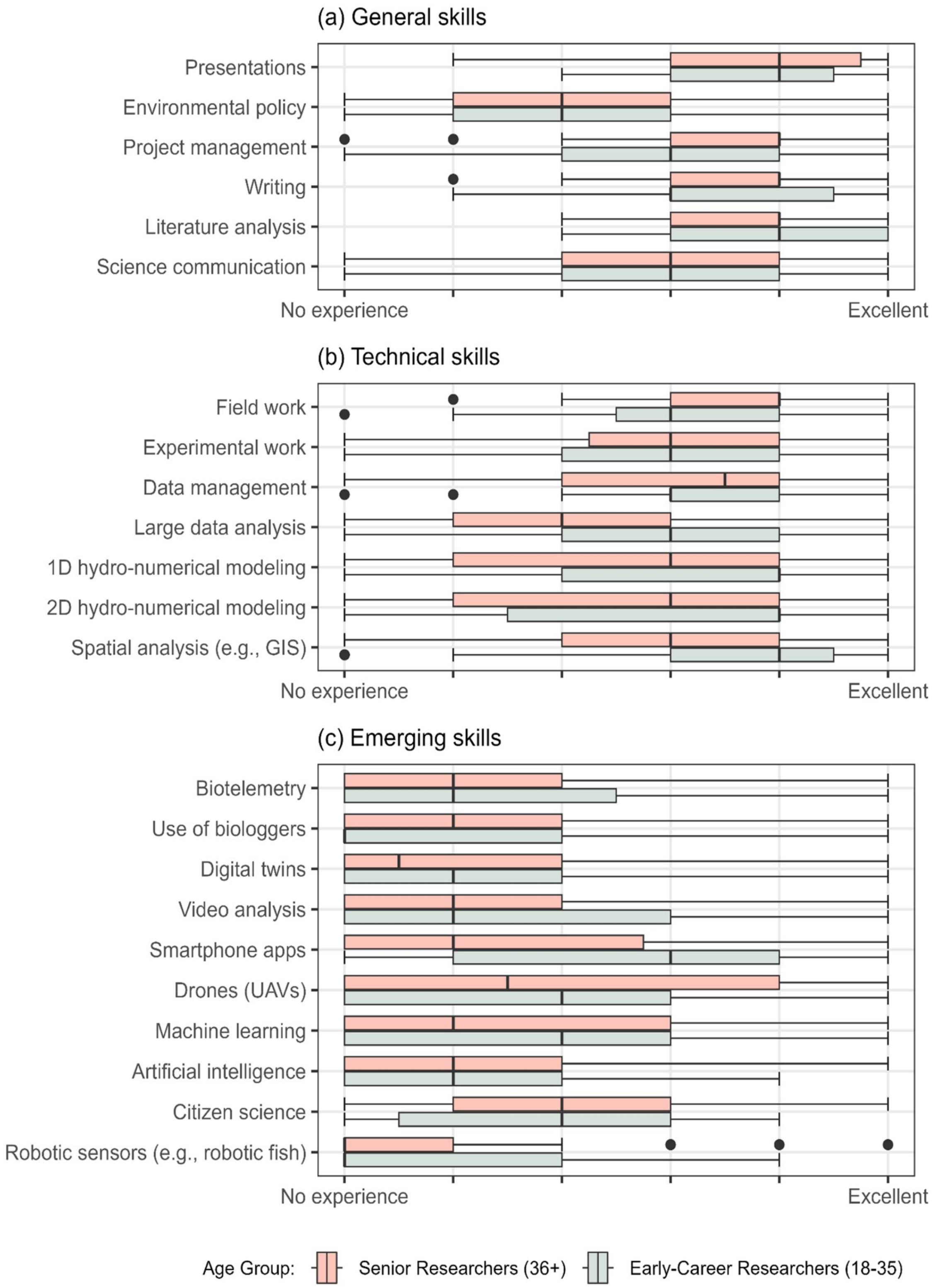

Figure 5. Ratings for different scientific skills broken down by career stage and divided in (a) general, (b) technical, and (c) emerging skills.

and 21 additional ones). We classified these technologies into three groups: (1) data collection and monitoring technologies, (2) data analysis and modeling, and (3) technological/innovative end-user applications.

Figure 7 presents a bubble chart of these emerging technologies, with bubble size indicating the frequency of mentions (details in Table S4 of the Supplementary Material). Unlike skills, most technologies (53%) were related to data collection and monitoring, with remote sensing being the most frequently mentioned (19 times), followed by biotelemetry, uncrewed aerial vehicles (UAVs; commonly known as drones), and sensors (15 mentions each).

Emerging technologies related to data analysis and modeling accounted for 40% of the responses, with artificial intelligence (AI) standing out as the most dominant tool (23 mentions). In contrast,

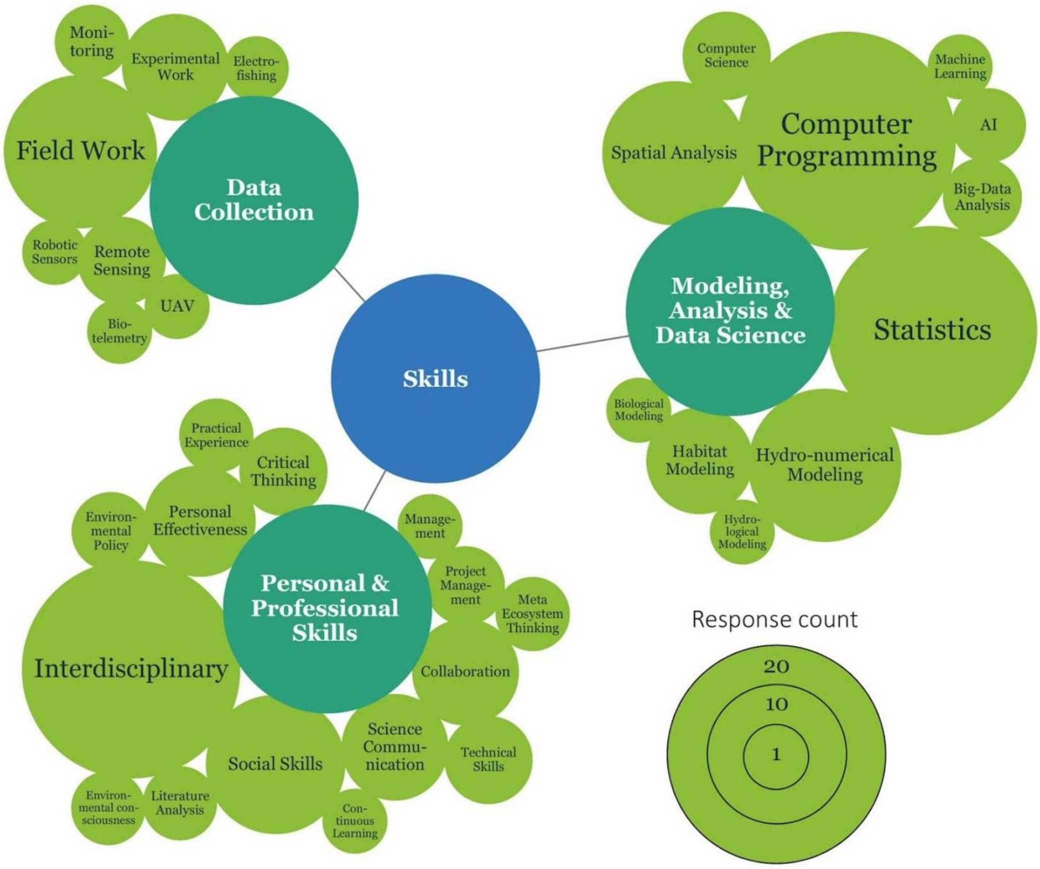

Figure 6. Bubble chart illustrating skills that researchers need to excel in the field of ecohydraulics based on survey responses ($n = 186$). Responses were grouped into three skill categories (turquoise). The circle size of the topics (light green) represents the frequency of mentions.

end-user applications received less attention, comprising only 13% of responses.

Overall, the strong emphasis on data acquisition and analysis underscores the critical role of high-quality, scalable data in advancing ecohydraulics research and practice.

3.5. Topics for seminars

A total of 65 respondents provided inputs on preferred seminar topics, mentioning one or more subjects, resulting in 78 distinct topics (Table 1). These topics were categorized into three groups: (1) data collection and field work, (2) modeling, analysis, and data science, and (3) knowledge and competencies.

Like the skill-related responses, participants primarily expressed interest in disciplinary and technical topics. Remote sensing and machine learning/artificial intelligence were frequently mentioned (8 and 7 times, respectively), followed by biophysical models and biophysical relationships (6 times each). Advanced sensors and technologies, along with field measurement techniques integrating new tools, were also commonly mentioned (5 times each).

However, the interest in seminar topics extended beyond emerging technologies. For example, respondents highlighted the importance of science communication, particularly in addressing the challenges of communicating science to policymakers as a valuable seminar topic. Suggested topics ranged from broad themes, such as biophysical modeling and the understanding of biophysical relationships, to more focused areas like climate change, wetland biodiversity, and plastic transport. A detailed list with seminar subject groups and examples is provided in Table S5 of the Supplementary Material.

4. Discussion

The results of this study highlight key trends and persistent challenges shaping the field of ecohydraulics. These include the deeply interdisciplinary nature of the discipline, the evolving role of ECRs, and the notable gaps in skills and expertise related to emerging technologies and data-driven methods, including machine learning. The findings also highlight the urgent need to strengthen training programs and professional development opportunities to support researchers in addressing the growing

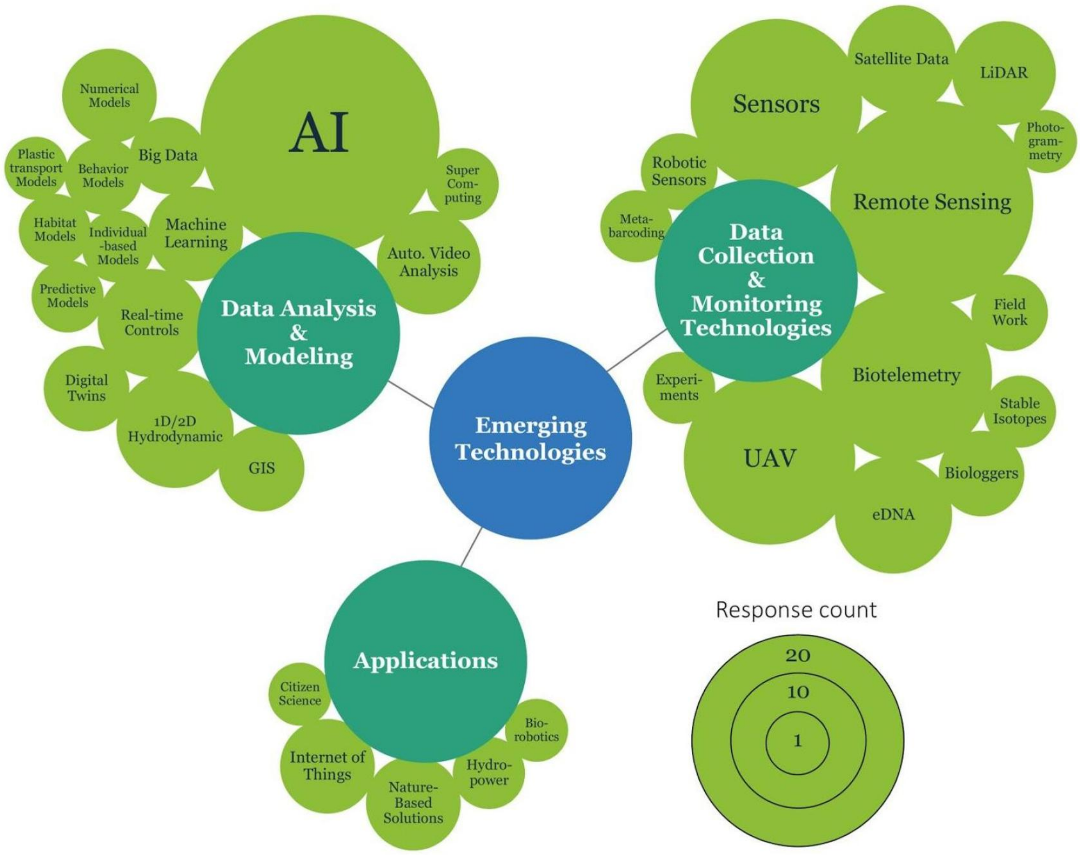

Figure 7. Bubble chart illustrating emerging technologies in ecohydraulics based on survey responses. These technologies were grouped into three categories (turquoise). The circle size of the emerging technologies (light green) represents the frequency of mentions.

Table 1. Main subject groups for proposed seminar topics.

Seminar subject groups		Frequency
Data collection and field work ($n = 21$)	Remote sensing	8
	Advanced sensors and technologies	5
	Field measurement and monitoring	5
	Others	3
Modeling, analysis, and data science ($n = 25$)	Machine learning and artificial intelligence	7
	Biophysical modeling	6
	Spatial analysis	4
	Others	8
Knowledge and competencies ($n = 32$)	Biophysical relationships	6
	Statistics	5
	Science communication	4
	Others	17
	Total	78

demands of ecohydraulic research and its real-world applications.

4.1. Demographics in ecohydraulics

The demographics of the 2024 survey respondents are similar to those of 2018 (Casas-Mulet et al. 2023), particularly with respect to geographical distribution and professional background. Engineering continues to represent the largest proportion of respondents, which underscores the need to engage with biologists, ecologists, and social scientists. Europe remains the dominant region. This trend reflects the longstanding legacy of the ecohydraulics community, rooted in the European river hydraulics tradition, which is also observed in the share of publications by region (Figure 1b). However, a noticeable increase in engagement from South America and Africa suggests a growing global participation (Figure 2a). For example, a study performed a three-dimensional analysis of two Amazon tributaries (Brazil), linking river hydraulics with bioenergetic metrics to explain species abundance and diversity (Gualtieri et al. 2020). More recently, Ngcobo et al. (2025) assessed which habitat features drive fish community patterns in the South African uMsunduze River catchment. While these are promising developments, reflecting the growing global interest in ecohydraulics, scholars in these regions may face additional challenges, including data access and scarcity, unsafe field-work conditions, insufficient funding and infrastructure, and broader economic and political instabilities (Ciocca and Delgado 2017; Kumwenda et al. 2017). Although relatively small, the increase of Asian participation in the 2024 survey is also interesting because the 2018 ecohydraulics conference was held in Tokyo. Indeed, we see a growing body of literature from China, where topics of interest include, e.g. dams and urban environments (Zhang et al. 2022; Chen et al. 2023; Wang et al. 2023; Zhou et al. 2024).

The low percentages of female participation (39% in 2018 and 21% in the current survey) align with broader gender disparities observed in engineering disciplines (Cheryan et al. 2024; Galvin et al. 2024). Regarding the significant decline in female participation, continuous monitoring of the community may help to understand whether the drop was specific to the 2024 survey, or it is a trend. Nevertheless, the importance of fostering inclusivity for gender, geographical origin and background, remains clear, and it is encouraging to see the growing representation of women within the International Association for Hydro-Environment Engineering and Research (IAHR) community (IAHR 2025).

A growing polarization in participants' professional backgrounds is evident, with an increased representation of engineering and a corresponding decline in other disciplines (Figure 2b). This trend may be linked to the IAHR's intensified focus on ecohydraulic topics (Pasternack et al. 2023), which could be attracting more professionals from engineering fields. In parallel, the increased proportion of permanent researchers and private sector respondents (Figure 2c) may indicate the aging of the early-career cohort surveyed in 2018 (Casas-Mulet et al. 2023), as many transition into more established roles in academia or industry.

Despite the different backgrounds, the primary research focus for most participants is on hydraulic modeling and physical habitat-flow interaction (Figure 2d). However, the ecohydraulics community continues to face challenges integrating social, economic, legal and humanistic aspects (Alp et al. 2023; Hayes et al. 2023). This struggle is mirrored in broader difficulties at the science-management-policy interface (Hayes 2025), reflecting existing challenges and barriers to interdisciplinary integration of social-humanistic and STEM disciplines in both education and applied projects (Milman et al. 2017; Helgeson et al. 2022). Additionally, the representation of researchers focusing on biota beyond fish remains low (Figure 2d), emphasizing the need to broaden bioecological perspectives and interdisciplinary engagement.

The period between the 2018 ISE in Tokyo, Japan, and the 2024 ISE-FP in Québec City, Canada, was also marked by the COVID-19 pandemic, which has transformed academic workflows and research practices. While the rise of remote and hybrid formats redefined how knowledge is shared and collaborations are fostered (García-Morales et al. 2021), e.g. by improving local and global accessibility, it also limited in-person networking and hands-on training. This shift is particularly relevant to the evolving demographics of the ecohydraulics community, especially the aging of ECRs. As a result, today's ECRs operate in a professional landscape different from that of 2018, navigating both new opportunities for virtual collaboration and challenges of reduced interdisciplinary in-person networking and field-based experience. As the community adjusts, these changes influence research and skill development. The growing share of permanent researchers and private sector professionals (Figure 2c) may partly reflect post-pandemic shifts in academic and professional structures. ECRs now face both expanded opportunities for collaboration and the realities of an increasingly digital research environment.

While this analysis provides valuable insights into the current state and future direction of the ecohydraulics community, it is important to acknowledge several limitations. The survey was based on voluntary participation, introducing potential selection bias, and the risk of underrepresentation of specific regions, sectors, or demographic groups. For instance, the lower response rates from specific geographic areas or occupational backgrounds may limit the generalizability of the findings. Furthermore, the open-ended responses regarding preferred seminar topics—though informative—may reflect more immediate individual interests rather than a comprehensive or balanced assessment of the community's training needs. As such, the results should be interpreted as a snapshot of current perceptions rather than a definitive agenda, offering an indicative rather than exhaustive guidance for future directions.

4.2. Emerging technologies in ecohydraulics

Ecohydraulics is undergoing a technological shift, with new tools transforming how we observe, model, and manage aquatic systems. Survey responses indicate that while technical skills remain unevenly distributed across the community, there is growing awareness of, and demand for, advanced methods—particularly those linked to data acquisition, automation, and behavioural observation. Indeed, most of the open answers relate to data acquisition, analysis and interpretation—not only in the skills and emerging technologies (Figures 6, 7), but also in the seminar demands (Table 1). In the following section, we underline a selection of emergent technologies, many of which were also identified in the open questions (Figure 7).

Historically, ecohydraulics researchers have focused on assessing the impacts of (altered) flow regimes and hydraulic conditions on aquatic organisms, especially fish (Bovee 1982; Bovee et al. 1998; Katopodis 2012). More recently, these topics have been studied through an increasing use of sensor-based fish tracking and biologging devices (Boavida et al. 2020) as well as large-scale ecohydraulic modeling (Du et al. 2025). These innovations provide critical ecological feedback while also supporting evidence-based decision-making in the management of aquatic ecosystems and hydraulic infrastructure (Brooks et al. 2017; Verhelst et al. 2022; Cooke et al. 2023).

An emerging frontier within the field is ethohydraulics, which integrates hydraulics with animal behavior to better understand how aquatic organisms interact with dynamic flow environments (Knapp et al. 2019; Lehmann et al. 2022). This subdiscipline relies heavily on advanced technologies such as biotelemetry, high-resolution video tracking, underwater robotics, and real-time monitoring systems, allowing for detailed, non-invasive observation of aquatic fauna (Cooke et al. 2012; Fuentes Pérez 2019; Haas et al. 2024; Naudascher et al. 2024). These tools not only deepen our understanding of habitat use and migration patterns but also enhance accurate validation of ecohydraulic models (Mawer et al. 2023).

In applied contexts, particularly in the hydropower sector, emerging technologies play a pivotal role in balancing energy production with ecological sustainability. Kougias et al. (2019) emphasize the shift toward digitalization, flexible turbine operation, and environmentally sustainable practices through fish-friendly infrastructure design and impact mitigation. Emerging technologies include advanced electro-mechanical components, real-time monitoring systems, and digital control platforms that facilitate more adaptive and efficient plant operations.

Across the ecohydraulics field, scientists are increasingly using UAVs, remote sensing platforms, and AI-driven models to map river morphology, monitor habitat changes, and simulate future scenarios under changes in climate or management approaches (Andualem et al. 2024; Yauchi et al. 2024), as well as for end-user applications (Sarajzadeh and Bekhoda 2021). These tools significantly enhance the spatial and temporal resolution of ecohydraulic analysis, offering scalable solutions from site-specific restoration efforts to basin-wide planning strategies (Woellner and Wagner 2019; Bätz et al. 2025).

Nevertheless, the integration of such technologies is not without its challenges. Many require substantial financial investments, specialized technical expertise, and interdisciplinary collaboration—barriers that persist across parts of the community (Chapter 4.1). As the field evolves towards a more data-intensive and organism-behavior-informed paradigm, widespread adoption will require stronger support systems, including access to shared datasets, open-source tools, and collaborative frameworks bridging engineers, ecologists, and data science experts. A notable initiative in this regard is the open tag protocol of the European Tracking Network, which allows for pan-European data sharing and collaboration on fish biotelemetry detection (ETN 2025). As data acquisition improves, analysis and machine learning interpretation also gain relevance, reflected in the high perception of AI and machine learning algorithms as emergent technologies (Figure 7). Moreover, with the strong increase of AI tools and large language models (LLMs), in particular between 2023 and 2025, it is possible that the community has gained experience with emerging skills associated with programming, coding and (generative) AI since the closure of the survey. Yet, the full extent of AI use remains to be assessed.

In summary, emerging technologies are not only redefining what ecohydraulics can study but also transforming how they can contribute to more adaptive, responsive, and ecologically sensitive water management. Continued progress in this domain will depend on sustained investment in the institutional, technical, and collaborative frameworks necessary to foster innovation, accessibility, and inclusivity across the ecohydraulics community.

4.3. Education and training in ecohydraulics

The value of interdisciplinary and transdisciplinary research addressing complex societal and environmental challenges is widely acknowledged (e.g. Lawrence et al. 2022). Over the past decade, this recognition has spurred a growing body of literature documenting practical experiences (e.g. Kluger and Bartzke 2020), as well as the development of frameworks for the design and management of interdisciplinary research projects (Laursen et al. 2024; Deutsch et al. 2025a, 2025b). However, significant barriers remain—particularly regarding academic recognition and career progression of ECRs engaged in interdisciplinary work (e.g. Wilkes et al. 2016; Salmela et al. 2026). Despite encouraging trends toward greater interdisciplinarity, these persistent challenges continue to affect the education, training, and professional development of ECRs, especially in inherently interdisciplinary fields such as ecohydraulics.

The advancement of ecohydraulics relies significantly on the skills and training of its researchers, particularly ECRs. The field demands a broad skill set, ranging from general competencies such as literature analysis, project and data management, and science communication to more technical proficiencies in fieldwork, hydraulic and statistical modeling, and experimental methodologies. Moreover, expertise in emerging technologies, including remote sensing, real-time monitoring, and machine learning, is becoming increasingly critical for modern data acquisition and analysis (Gosselin et al. 2019).

Yet despite this clear need, many ECRs report feeling underprepared to fully leverage these tools (Wilkes et al. 2016; Casas-Mulet et al. 2023). This gap is reflected in participants' preferences for seminar topics (Table 1), which showed the greatest interest in practical skills and emerging tools rather than theoretical foundations or general scientific competencies such as writing, presenting, or conducting literature reviews. Seminar topics related to new technologies, including advanced modeling techniques and big data analytics, were prioritized, while more "traditional" scientific skills were notably absent. Nevertheless, broader topics such as biophysical modeling and interdisciplinarity remain relevant, highlighting continued recognition of the complex nature of ecohydraulic challenges.

These preferences suggest that while the community is aware of technological innovations, they hesitate—or have limited access to resources—when it comes to developing expertise in these areas. The current focus appears to be on the acquisition and analysis of larger and more complex datasets, reinforcing the need for hands-on training with new tools and methodologies. To support this transition, education and training programs should not only emphasize technological competencies but also forge stronger connections to real-world applications through industry partnerships and stakeholder collaboration (Cooke et al. 2020; Casas-Mulet et al. 2023).

Interestingly, little difference is observed between how early- and senior-career researchers perceive their own skill levels (Figure 5), raising questions around self-assessment and confidence. ECRs may overestimate their capabilities, a notion aligned with the Dunning-Kruger effect (Kruger and Dunning 1999). The reduced opportunities for physical networking and peer comparison during the COVID-19 pandemic (Chapter 4.1) may have amplified this effect by limiting informal (in-person) feedback and benchmarking. Simultaneously, the growing accessibility of digital tools, including AI, may be lowering perceived barriers to entry, leading ECRs to feel more technically competent than previous cohorts at similar career stages. Cultural and generational dynamics may also influence how openly individuals self-assess or communicate their abilities.

Lastly, some of the perceived training gaps (being as broad and diverse, e.g. from data science and modeling to fieldwork, disciplinary knowledge and science communication) may stem from persistent challenges of being an interdisciplinary researcher or participating in interdisciplinary collaboration (Salmela et al. 2026). Addressing these issues will require more than technical upskilling; it demands a re-evaluation of how ecohydraulics education values and integrates interdisciplinary, socially relevant, and systems-oriented approaches to research and practice.

5. Outlook

Since the last major survey in 2018, the ecohydraulics community has grown in both size and visibility within the broader water and environmental sciences. Networks such as ECoENet have expanded, with increasing participation across platforms. The *Journal of Ecohydraulics* is now indexed with a growing impact factor, reflecting the scientific maturity and relevance of the field.

A key area of attention remains the integration of interdisciplinary education and training. In 2021, a joint initiative by ECoENet and the IAHR Ecohydraulics Committee mapped global educational offerings in ecohydraulics. While the findings point to a growing interest in the field, they also reveal that many programs remain specific to traditional disciplines, particularly within engineering and environmental sciences. This underscores the persistent need for more integrated, interdisciplinary curricula and training. Encouragingly, awareness of this gap is rising, and targeted initiatives—such as interdisciplinary workshops, training schools, and mentoring—are helping to bridge it.

IAHR leadership and various ecohydraulics working groups have also led to concrete initiatives benefiting ECRs. These include dedicated workshops, travel grants, and mentoring activities designed to foster inclusion, career development, and knowledge exchange (IAHR 2025). Two examples are the IAHR Young Professionals Hydro-Environment Challenge and the Young Professionals Congress (both including a challenge and session dedicated to ecohydraulics), encouraging peer-to-peer collaboration and presenting ecohydraulics studies to an international audience.

Importantly, the post-COVID return to in-person events has reaffirmed the value of face-to-face interaction. These gatherings not only facilitate the exchange of ideas but also play a critical role in building trust and collaborative relationships necessary for interdisciplinary work.

Since the closing of the 2024 survey, our society has experienced mass-accessibility to large language models (LLMs), like ChatGPT, Claude and DeepSeek, which hold tremendous potential to change our society and community. As ecohydraulics evolves toward increasingly data-intensive and interdisciplinary approaches, AI and language-based tools such as LLMs offer significant potential to support research, education, and application. These tools can assist in automating data processing, enhancing model calibration and scenario forecasting, and enabling more efficient analysis of large and complex datasets such as those derived from remote sensing, UAV imagery, or biotelemetry. Beyond technical tasks, generative AI can support researchers at any career stage in literature reviews, proposal writing, science communication, and interdisciplinary knowledge synthesis. In education and training contexts, AI-driven platforms can provide adaptive learning environments and on-demand mentoring, helping to address the widespread skills gaps identified in this study. However, realizing this potential will require careful integration into research workflows, attention to transparency and reproducibility, and continued emphasis on human oversight, collaboration, and ethical use. As the ecohydraulics community seeks to adapt to new technological frontiers, AI should be seen not as a replacement, but as a catalyst for innovation, accessibility, and inclusion.

Looking ahead, the ecohydraulics community is well-positioned to address the complex and evolving challenges facing aquatic ecosystems (Cooke et al. 2026). Continued investment in ECRs' support, emerging skills, and disciplinary integration will be essential to sustaining the field's momentum and ensuring its impact in both science and practice. In this way, ECRs are well equipped to advance ecohydraulics into the next century.

Acknowledgments

The survey and the workshop were designed and conducted by the Early Career on Ecohydraulics Network (www.ecoenet.org). Special thanks go to Mahmoud Awadallah and Véronique Simard for their contribution. The workshop also received logistical support from the ISE-FP 2024 Local Organising Committee. ECoENet and the authors would like to thank the keynote speakers of the 2024 pre-conference workshop—Carole-Anne Gillis, Raphaël Pilon, and Luiz da Silva—for providing us with perspectives from academia and industry. We are grateful to the editor and reviewers for their constructive comments, which helped to improve this manuscript. Finally, we thank all survey respondents and workshop participants for openly sharing their views on ecohydraulics and early-stage research. Open access funding provided by BOKU University.

Author contributions

CRediT: **Mónica Basilio Hazas**: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing; **Joël Wittmann**: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing; **Davide Vanzo**: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing; **Jan De Keyser**: Formal analysis, Visualization, Writing – review & editing; **Melina Sattelmeier**: Investigation, Writing – original draft, Writing – review & editing; **Hannah Schwedhelm**: Investigation, Writing – original draft, Writing – review & editing; **Kevin Merl**: Formal analysis, Investigation, Writing – original draft, Writing – review & editing; **Francesca Padoan**: Writing – original draft, Writing – review & editing; **Ana Adeva-Bustos**: Supervision, Writing – original draft, Writing – review & editing; **Davide Vettori**: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing; **Mathias Chabal**: Conceptualization, Data curation, Writing – review & editing; **Sahra N. Sabil**: Writing – original draft, Writing – review & editing; **Daniele Tonina**: Supervision, Writing – original draft, Writing – review & editing; **Daniel S. Hayes**: Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

Disclosure statement

This work was revised for grammar, phrasing, and text structure correctness with assistance from AI tools. Subsequent revisions were made by the authors to ensure that the final manuscript accurately conveys the intended message and adheres to the standards of scholarly writing. No potential conflict of interest was reported by the authors.

Funding

This research was funded in whole, or in part, by the Austrian Science Fund (FWF) (P 34061-B), the Swiss National Science Foundation (SNSF) (IC00I0-232304), the Deutsche Forschungsgemeinschaft (DFG) (CH 981/4-1 and WO 671/16-1), and the European Union's Horizon 2020 research and innovation programme under grant agreement No 101022905. KM thanks the Doctoral School 'Human River Systems in the twenty first Century (HR21)' at BOKU University for supporting his PhD.

ORCID

Mónica Basilio Hazas http://orcid.org/0000-0002-5925-9426
Joël Wittmann http://orcid.org/0009-0007-7664-1022
Davide Vanzo http://orcid.org/0000-0002-2033-9197
Jan De Keyser http://orcid.org/0009-0005-5494-4394
Melina Sattelmeier http://orcid.org/0009-0007-0545-5177
Hannah Schwedhelm http://orcid.org/0000-0003-1272-4236
Kevin Merl http://orcid.org/0009-0004-8687-5760
Francesca Padoan http://orcid.org/0009-0005-9410-5368
Ana Adeva-Bustos http://orcid.org/0000-0001-7655-784X
Davide Vettori http://orcid.org/0000-0001-5121-4197
Mathias Chabal http://orcid.org/0009-0005-1300-8022
Sahra N. Sabil http://orcid.org/0009-0005-5068-6236
Daniele Tonina http://orcid.org/0000-0002-1866-1013
Daniel S. Hayes http://orcid.org/0000-0003-3709-8630

References

Acreman MC, Overton IC, King J, Wood PJ, Cowx IG, Dunbar MJ, Kendy E, Young WJ. 2014. The changing role of ecohydrological science in guiding environmental flows. HydrolSci J. 59(3-4):433–450. doi: 10.1080/02626667.2014.886019.

Alp M, Batalla RJ, Bejarano MD, Boavida I, Capra H, Carolli M, Casas-Mulet R, Costa MJ, Halleraker JH, Hauer C, et al. 2023. Introducing HyPeak: an international network on hydropeaking research, practice, and policy. River Res Apps. 39(3):283–291. doi: 10.1002/rra.3996.

Amaral L, Grimm J, Pradilla CA. 2024. Navigating academia's stressful waters: discussing the power of horizontal linkages for early-career researchers. Business Soc. 63(3):496–501. doi: 10.1177/00076503231182691.

Andualem TG, Peters S, Hewa GA, Myers BR, Boland J, Pezzaniti D. 2024. Channel morphological change monitoring using high-resolution LiDAR-derived DEM and multi-temporal imageries. Sci Total Environ. 921:171104. doi: 10.1016/j.scitotenv.2024.171104.

Bätz N, Judes C, Vanzo D, Lamouroux N, Capra H, Baumgartner J, Berger B, Weber C. 2025. Patch-scale habitat dynamics: three metrics to assess ecological impacts of frequent hydropeaking. J Ecohydraul. 10(1):79–106. doi: 10.1080/24705357.2024.2426790.

Boavida I, Fuentes Pérez JF, Hayes DS, Jesus J, Moreira M, Belmar O, Vila-Martínez N, Palau-Nadal A, Costa MJ. 2020. Ecohydraulics of river flow alterations and impacts on freshwater fish. Limnetica. 39(1):213–232. doi: 10.23818/limn.39.14.

Boeren E, Lokhtina-Antoniou I, Sakurai Y, Herman C, McAlpine L. 2015. Mentoring: a review of early career researcher studies. Frontline Learn Res. 3(3):68–80.

Bovee KD, Lamb BL, Bartholow JM, Stalnaker CB, Taylor J, Henriksen J. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004.

Bovee KD. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper 12. U.S.D.I. Fish and Wildlife Service, Office of Biological Services. FWS/OBS. 82/(26), 248 pp.

Boys CA, Brown RS, Deng ZD, Baumgartner LJ, Pflugrath BD, Silva LGM, Phonekhampeng O, Thorncraft G. 2016. Ecohydraulic research to protect downstream migrating fish at hydropower and other river infrastructure: solving a global problem through international collaboration. In: Proceedings of the 11th International Symposium on Ecohydraulics.

Brooks JL, Boston C, Doka S, Gorsky D, Gustavson K, Hondorp D, Isermann D, Midwood JD, Pratt TC, Rous AM, et al. 2017. Use of fish telemetry in rehabilitation planning, management, and monitoring in areas of concern in the Laurentian Great Lakes. Environ Manage. 60(6):1139–1154. doi: 10.1007/s00267-017-0937-x.

Brütt AL, Fahsold A, Köberlein-Neu J, Palm R, Pohontsch NJ, Tönnis L. 2024. Situation des wissenschaftlichen Nachwuchses in der Versorgungsforschung – eine Survey-Studie. Z Evid Fortbild Qual Gesundhwes. 187:79–87. doi: 10.1016/j.zefq.2024.05.006.

Casas-Mulet R, King E, Hoogeveen D, Duong L, Lakhanpal G, Baldwin T, Stewardson MJ, Webb JA. 2016. Two decades of ecohydraulics: trends of an emerging interdiscipline. J Ecohydraul. 1(1-2):16–30.

Casas-Mulet R, Vanzo D, Adeva-Bustos A, Macnaughton CJ, Stewardson MJ, Pasternack GB, Enders EC, Dyer F. 2023. How to strengthen interdisciplinarity in ecohydraulics? Outcomes from ISE 2018. J Ecohydraul. 8(1):1–12.

Chen Q, Li Q, Lin Y, Zhang J, Xia J, Ni J, Cooke SJ, Best J, He S, Feng T, et al. 2023. River damming impacts on fish habitat and associated conservation measures. Rev Geophys. 61(4):e2023RG000819. doi: 10.1029/2023RG000819.

Cheryan S, Lombard EJ, Hailu F, Pham LNH, Weltzien K. 2024. Global patterns of gender disparities in STEM and explanations for their persistence. Nat Rev Psychol. 4(1):6–19. doi: 10.1038/s44159-024-00380-3.

Christian K, Johnstone C, Larkins J-A, Wright W, Doran MR. 2021. A survey of early-career researchers in Australia. eLife. 10:e60613. doi: 10.7554/eLife.60613.

Ciocca DR, Delgado G. 2017. The reality of scientific research in Latin America; an insider's perspective. Cell Stress Chaperones. 22(6):847–852. doi: 10.1007/s12192-017-0815-8.

Cooke SJ, Auld HL, Birnie-Gauvin K, Elvidge CK, Piczak ML, Twardek WM, Raby GD, Brownscombe JW, Midwood JD, Lennox RJ, et al. 2023. On the relevance of animal behavior to the management and conservation of fishes and fisheries. Environ Biol Fish. 106(5):785–810. doi: 10.1007/s10641-022-01255-3.

Cooke SJ, Hinch SG, Lucas MC, Lutcavage M. 2012. Biotelemetry and biologging. In: zale AV, Parrish DL, Sutton TM, editors. Fisheries Techniques, Third Edition. Bethesda, Maryland: American Fisheries Society. p. 819–881.

Cooke SJ, Rytwinski T, Taylor JJ, Nyboer EA, Nguyen VM, Bennett JR, Young N, Aitken S, Auld G, Lane J-F, et al. 2020. On "success" in applied environmental research—What is it, how can it be achieved, and how does one know when it has been achieved? Environ Rev. 28(4):357–372. doi: 10.1139/er-2020-0045.

Cooke SJ, Silva LGM, Harby A, Bao J, Enders EC, Boavida I, Duan M, Drake J, Rennie C, Zielinski DP, et al. 2026. The role of ecohydraulics in addressing the

freshwater biodiversity crisis. Water Biol Secur. 5(2): 100475. doi: 10.1016/j.watbs.2025.100475.
Council of the European Union. 2023. Annexes to council recommendation on a European framework to attract and retain research, innovation and entrepreneurial talents in Europe. 15135/23 ADD 1(15135/23 ADD 1 - 2023/0285. (NLE)). Available from: https://data.consilium.europa.eu/doc/document/ST-15135-2023-ADD-1/en/pdf.
Deutsch L, Björnsen A, Fischer AM, Hama AM, Zimmermann NE, Zurbrügg C, Hoffmann S. 2025a. Herding cats: integrative leadership strategies in inter- and transdisciplinary research programs. Sustain Sci. 20(1):95–115. doi: 10.1007/s11625-024-01585-4.
Deutsch L, Pohl C, Bresch DN, Hoffmann S. 2025b. Creating favorable conditions for inter- and transdisciplinary integration—An analytical framework and empirical insights. Global Environ Change. 91:102963. doi: 10.1016/j.gloenvcha.2024.102963.
Du H, Ban X, Li P, Shih W, Diplas P, Wu J, Li J, Cheng P, Li P, Liu W, et al. 2025. The crucial role of ecohydraulic factors in triggering sturgeon reproduction: implications for active habitat restoration strategies in the Yangtze River. J Appl Ecol. 62(4):1052–1062. doi: 10.1111/1365-2664.70020.
ECoENet. Early Careers on Ecohydraulics Network. [Internet]. Available from www.ecoenet.org.
ETN. 2025. The European Tracking Network. [Internet]; [cited 2025 May 30]. Available from: https://www.europeantrackingnetwork.org/en.
Fuentes Pérez JF. 2019. Flow sensing with pressure sensor-based artificial lateral lines: from the laboratory to the field. Doctoral Thesis. Estonia: Tallinn University of Technology.
Galvin DJ, Anderson SC, Marolf CJ, Schneider NG, Liebl AL. 2024. Comparative analysis of gender disparity in academic positions based on U.S. region and STEM discipline. PLoS One. 19(3):e0298736. doi: 10.1371/journal.pone.0298736.
García-Morales VJ, Garrido-Moreno A, Martín-Rojas R. 2021. The transformation of higher education after the COVID disruption: emerging challenges in an online learning scenario. Front Psychol. 12:616059. doi: 10.3389/fpsyg.2021.616059.
Gosselin M-P, Ouellet V, Harby A, Nestler JM. 2019. Advancing ecohydraulics and ecohydrology by clarifying the role of their component interdisciplines. J Ecohydraul. 4(2):172–187. doi: 10.1080/24705357.2019.1658137.
Gualtieri C, Abdi R, Ianniruberto M, Filizola N, Endreny TA. 2020. A 3D analysis of spatial habitat metrics about the confluence of Negro and Solimões rivers, Brazil. Ecohydrology. 13(1):e2166. doi: 10.1002/eco.2166.
Haas C, Meyer M, Schmalz M, Tuhtan JA. 2024. Kamerabasiertes monitoring von Fischen in Deutschland und der Schweiz. Wasserwirtsch. 114(10): 19–29. doi: 10.1007/s35147-024-2401-1.
Harby A. 2004. Baptist M, Dunbar MJ, Schmutz S (Eds.) State-of-the-art data sampling, modelling analysis and applications of river habitat modelling. COST Action 626 Report, p. 313.
Hayes DS, Bruno MC, Alp M, Boavida I, Batalla RJ, Bejarano MD, Noack M, Vanzo D, Casas-Mulet R, Vericat D, et al. 2023. 100 key questions to guide hydropeaking research and policy. Renew Sustain Energy Rev. 187:113729. doi: 10.1016/j.rser.2023.113729.
Hayes DS. 2025. Schwallforschung auf unterschiedlichen Ebenen: vom Einzugsgebiet zur Kiesbank. Wasserwirtsch. 115(5):10–14. doi: 10.1007/s35147-025-2513-2.
Helgeson C, Nicholas RE, Keller K, Forest CE, Tuana N. 2022. Attention to values helps shape convergence research. Clim Change. 170, 17. doi: 10.1007/s10584-021-03274-y.
IAHR. 2025. Committee on Education and Professional Development. [Internet]. [cited 2025 May 30]. Available from: https://www.iahr.org/index/committe/19.
Katopodis C. 2012. Ecohydraulic approaches in aquatic ecosystems: integration of ecological and hydraulic aspects of fish habitat connectivity and Suitability. Ecol Eng. 48:1–7. doi: 10.1016/j.ecoleng.2012.07.007.
Kemp PS, Katopodis C. 2016. Introducing the *Journal of Ecohydraulics*: fundamental and applied research on the road to transdisciplinarity. J Ecohydraul. 1(1-2):1–4. doi: 10.1080/24705357.2016.1259139.
Kluger MO, Bartzke G. 2020. A practical guideline how to tackle interdisciplinarity—A synthesis from a post-graduate group project. Humanit Soc Sci Commun. 7, 47. doi: 10.1057/s41599-020-00540-9.
Knapp M, Montgomery J, Whittaker C, Franklin PA, Baker C, Friedrich H. 2019. Fish passage hydrodynamics: insights into overcoming migration challenges for small-bodied fish. J Ecohydraul. 4(1):43–55. doi: 10.1080/24705357.2019.1604091.
Kougias I, Aggidis G, Avellan F, Deniz S, Lundin U, Moro A, Muntean S, Novara D, Pérez-Díaz JI, Quaranta E, et al. 2019. Analysis of emerging technologies in the hydropower sector. Renew Sustain Energy Rev. 113:109257. doi: 10.1016/j.rser.2019.109257.
Kruger J, Dunning D. 1999. Unskilled and unaware of it: how difficulties in recognizing one's own incompetence lead to inflated self-assessments. J Pers Soc Psychol. 77(6):1121–1134. doi: 10.1037/0022-3514.77.6.1121.
Kumwenda S, Niang EHA, Orondo PW, William P, Oyinlola L, Bongo GN, Chiwona B. 2017. Challenges facing young African scientists in their research careers: a qualitative exploratory study. Malawi Med J. 29(1):1–4. doi: 10.4314/mmj.v29i1.1.
Lancaster J. 2018. What is the right scale? Encouraging fruitful engagement for ecology with ecohydraulics. J Ecohydraul. 3(2):63–76. doi: 10.1080/24705357.2018.1535260.
Laursen B, Vienni-Baptista B, Bammer G, Di Giulio A, Paulsen T, Robson-Williams M, Studer S. 2024. Toolkitting: an unrecognized form of expertise for overcoming fragmentation in inter- and transdisciplinarity. Humanit Soc Sci Commun. 11, 857. doi: 10.1057/s41599-024-03279-9.
Lawrence MG, Williams S, Nanz P, Renn O. 2022. Characteristics, potentials, and challenges of transdisciplinary research. One Earth. 5(1):44–61. doi: 10.1016/j.oneear.2021.12.010.
Lehmann B, Bensing K, Adam B, Schwevers U, Tuhtan JA. 2022. Ethohydraulics. Wiesbaden: springer Fachmedien Wiesbaden.
Maddock I, Harby A, Wood PJ (eds.) 2013. Ecohydraulics: an integrated approach. Chichester, UK: Wiley-Blackwell.
Maddock I. 1999. The importance of physical habitat assessment for evaluating river health. Freshw Biol. 41(2):373–391. doi: 10.1046/j.1365-2427.1999.00437.x.

Mawer R, Pauwels IS, Bruneel SP, Goethals PLM, Kopecki I, Elings J, Coeck J, Schneider M. 2023. Individual based models for the simulation of fish movement near barriers: current work and future directions. J Environ Manage. 335:117538. doi: 10.1016/j.jenvman.2023.117538.

Milman A, Marston JM, Godsey SE, Bolson J, Jones HP, Weiler CS. 2017. Scholarly motivations to conduct interdisciplinary climate change research. J Environ Stud Sci. 7(2):239–250. doi: 10.1007/s13412-015-0307-z.

Mula J, Rodríguez CL, Domingo Segovia J, Cruz-González C. 2022. Early career researchers' identity: a qualitative review. High Educ Q. 76(4):786–799. doi: 10.1111/hequ.12348.

Naudascher R, Boes RM, Fernandez V, Wittmann J, Holzner M, Vanzo D, Silva LGM, Stocker R. 2024. Fine-scale movement response of juvenile brown trout to hydropeaking. Sci Total Environ. 952:175679. doi: 10.1016/j.scitotenv.2024.175679.

Nestler JM, Stewardson MJ, Gilvear DJ, Webb JA, Smith DL. 2016. Ecohydraulics exemplifies the emerging "paradigm of the interdisciplines". J Ecohydraul. 1(1-2): 5–15. doi: 10.1080/24705357.2016.1229142.

Ngcobo NB, Burnett MJ, Downs CT. 2025. Influence of habitat structures on fish abundances and diversity: comparing mainstream and tributary communities in the urban uMsunduze Catchment, KwaZulu-Natal, South Africa. Urban Ecosyst. 28(2):86. doi: 10.1007/s11252-025-01688-5.

Pasternack GB, Tonina D, Casas-Mulet R, Adeva-Bustos A, Vanzo D, John A, Tinoco R. 2023. Climate change prediction and adaptation in ecohydraulics. Hydrolink, 14–8.

Pinheiro AN, Ferreira MT, Quintela AC. 1996. A Ecohidráulica e a Conciliação de Obras Hidráulicas Fluviais Com os Ecossistemas Aquáticos. 3.° Congresso da Água/VII SILUBESA. Vol. II, p. 517–526.

Rice SP, Lancaster J, Kemp P. 2010. Experimentation at the interface of fluvial geomorphology, stream ecology and hydraulic engineering and the development of an effective, interdisciplinary river science. Earth Surf Processes Landf. 35(1):64–77. doi: 10.1002/esp.1838.

Salmela M, Vienni-Baptista B, Cheas K. 2026. Towards the recognition of interdisciplinary and transdisciplinary researchers. Minerva. 64(2):367–386. doi: 10.1007/s11024-025-09578-y.

Sarajzadeh M T, Bekhoda E. 2021. Developing a hydrodynamic-based GIS toolbox for aquatic species migration. arXiv. 10.48550/arXiv.2107.13251.

Signoret C, Ng E, Da Silva S, Tack A, Voss U, Lidö HH, Patthey C, Ericsson M, Hadrévi J, Balachandran C. 2019. Well-being of early-career researchers: insights from a Swedish Survey. High Educ Policy. 32(2):273–296. doi: 10.1057/s41307-018-0080-1.

Specht A, Crowston K. 2022. Interdisciplinary collaboration from diverse science teams can produce significant outcomes. PLoS One. 17(11):e0278043. doi: 10.1371/journal.pone.0278043.

Tharme RE. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Res Apps. 19(5-6):397–441. doi: 10.1002/rra.736.

Verhelst P, Brys R, Cooke SJ, Pauwels IS, Rohtla M, Reubens J. 2022. Enhancing our understanding of fish movement ecology through interdisciplinary and cross-boundary research. Rev Fish Biol Fisheries. 33: 111–135. doi: 10.1007/s11160-022-09741-8.

Vladova G, Haase J, Friesike S. 2025. Why, with whom, and how to conduct interdisciplinary research? A review from a researcher's perspective. Sci Public Policy. 52(2):165–180. doi: 10.1093/scipol/scae070.

Wang C, Zhou X, Xu M, Zhang L, Hou X, Wang Z, Yang Y, Luo Y. 2023. Evaluating the ecological health of aquatic habitats in a megacity through a multimetric index model based on macroinvertebrates. Ecol Indic. 150:110235. doi: 10.1016/j.ecolind.2023.110235.

Wierenga M, Heucher K, Chen S, Grewatsch S, Montgomery AW. 2025. Communities for impact: empowering early-career researchers in the pursuit of impact. Strateg Organ. 23(1):19–30. doi: 10.1177/14761270241274038.

Wilkes MA, Neverman AJ, Casas-Mulet R, Adeva-Bustos A, McCluskey AH, Ouellet V, Vanzo D, Franklin PA, Silva AT. 2016. Early careers on ecohydraulics: challenges, opportunities and future directions. J Ecohydraul. 1(1-2):102–107. doi: 10.1080/24705357.2016.1249423.

Woellner R, Wagner TC. 2019. Saving species, time and money: application of unmanned aerial vehicles (UAVs) for monitoring of an endangered alpine river specialist in a small nature reserve. Biol Conserv. 233: 162–175. doi: 10.1016/j.biocon.2019.02.037.

Woo H. 2010. Trends in ecological river engineering in Korea. J Hydro-Environ Res. 4(4):269–278. doi: 10.1016/j.jher.2010.06.003.

Wood PJ, Hannah DM, Sadler JP. 2008. Ecohydrology and Hydroecology: an Introduction. Chichester, UK: Wiley. p. 1–6.

Yang S, Liang R, Wang Y, Li K. 2024. Fish habitat assessment model considering the spatial pattern and connectivity of habitat patches. Ecol Indic. 160:111840. doi: 10.1016/j.ecolind.2024.111840.

Yauchi E, Wakabayashi S, Oda R. 2024. Forecasting green tide events in a semi-closed tidal flat using artificial intelligence and environmental big data. J Ecohydraul. 9(1):34–42. doi: 10.1080/24705357.2023.2204107.

Zalewski M. 2000. Ecohydrology—the scientific background to use ecosystem properties as management tools toward sustainability of water resources. Ecol Eng. 16(1):1–8. doi: 10.1016/S0925-8574(00)00071-9.

Zhang P, Liu Q, Wang Y, Zhu DZ, Liang R, Qin L, Li R, Ji Q, Li K. 2022. River habitat assessment and restoration in high dam flood discharge systems with total dissolved gas supersaturation. Water Res. 221:118833. doi: 10.1016/j.watres.2022.118833.

Zhou X, Wang C, Kattel G, Zhang J, Xu M. 2024. Hydrodynamic and trophic variations reshape macroinvertebrate food webs in urban ecosystems. Environ Sci Ecotechnol. 22:100478. doi: 10.1016/j.ese.2024.100478.