How to strengthen Interdisciplinarity in Ecohydraulics?

Outcomes from ISE 2018

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Abstract

Interdisciplinary approaches are needed to tackle complex environmental issues as freshwater ecosystems face unprecedented pressures globally. The emerging Ecohydraulics field of research should take steps towards developing true interdisciplinarity and embrace the transformation required as the world keeps changing in front of our eyes. This paper aims to contribute to the discussion on interdisciplinarity in Ecohydraulics and to shape its growth. This contribution builds upon previous research that identified the challenges and opportunities for early career researchers (ECRs) in Ecohydraulics and takes a step further on identifying key actions, actors, and implementation strategies that can strengthen interdisciplinarity. Based on an online questionnaire and a workshop involving over 150 early and established careers, we present a list of 20 prioritised actions that will help engage the research community towards specific goals and will result in increased interdisciplinary outcomes. While ECRs have taken the lead on creating this roadmap, its implementation should be a joint responsibility of both ECRs, established career scientists, groups, and institutions within Ecohydraulics. The list of identified actions and assigned responsibility should, therefore, be considered a conversation starter among the Ecohydraulics community on how to strengthen interdisciplinarity. This means that a continued revision of the here stated approaches will be required to in the future, as the field of research and its community progresses. With this contribution, we resume a critical reflection on where the Ecohydraulics field of research and community stands today and where efforts need to be invested in the long-term to consolidate its inherent interdisciplinarity.

58 1 Introduction

59 Interdisciplinary approaches in science are essential to understanding the complex challenges brought
60 by current global environmental changes. This is why interdisciplinary research has been well
61 recognised by funding and government agencies for decades (e.g. Engineering Committee on Science,
62 2004; European Research Advisory Board, 2008). However, fostering effective interdisciplinarity faces
63 many barriers, starting with a lack of common understanding of the factors that make
64 interdisciplinarity work (Huutoniemi et al., 2010; Kumar et al., 2019; Schummer, 2004) which hinders
65 its implementation. Despite having a central role in science policy debates and funding schemes,
66 interdisciplinary research still appears to be poorly rewarded in terms of recognition and career-
67 building (Bina, 2017). For individuals from different disciplines to work together and maximise the
68 benefits for the scientific community, these barriers first have to be resolved (Freeth and Caniglia,
69 2020; Hicks et al., 2010). In this context, research teams in the scientific community need to
70 continuously improve their interdisciplinary toolkit, drawing on hands-on experiences (e.g. learn to
71 collaborate while collaborating, Freeth and Caniglia, 2020), and investing in identifying inclusive,
72 bottom-up or peer-driven strategies for effective interdisciplinarity.

73 As an interdisciplinary field of research, Ecohydraulics faces the same pressures and challenges of
74 interdisciplinarity. Indeed, anthropogenic pressures threatening freshwater ecosystems worldwide
75 (Döll and Zhang, 2010; Vörösmarty et al., 2010), and the increasing awareness of their importance for
76 global conservation efforts (Geist, 2011; Reid et al., 2019; Strayer and Dudgeon, 2010) have led to an
77 emergence of integrative fields of research such as Ecohydraulics. Ecohydraulics combines core
78 disciplines of hydrology, fluvial geomorphology, engineering, and ecology (Maddock et al., 2013a) to
79 understand physical and ecological processes in rivers at a range of scales (Gosselin et al., 2019;
80 Pasternack, 2019). While disciplines within Ecohydraulics interact at different multi-, inter- and
81 transdisciplinary levels (see Casas-Mulet et al., 2016), here we adopt the more inclusive definition of
82 interdisciplinarity by Hicks et al. (2010): ‘the production of research which crosses disciplinary
83 boundaries’, and is considered to cover all three levels of disciplinary interaction. As such,
84 interdisciplinarity in Ecohydraulics is what gives it the potential to play a crucial role in the future
85 management of freshwater ecosystems (Maddock et al., 2013c, 2013b; Nestler et al., 2016; Rice et al.,
86 2010).

87 A crucial achievement in promoting interdisciplinarity has undoubtedly been the foundation of the
88 Journal of Ecohydraulics (TJoE, Kemp and Katopodis, 2016), which highlights Ecohydraulics research,
89 as well as providing a platform for the integration of non-engineering disciplines (e.g. Hannah et al.,

2007; Lancaster, 2018). Despite the advances, Ecohydraulics has not yet reached the necessary level of integration for true interdisciplinarity. A study on the last twenty years of Ecohydraulics conference proceedings suggests a potential stagnation phase in interdisciplinary research (Casas-Mulet et al., 2016). The study found only a small detectable increase in interdisciplinarity activity between neighbouring research areas (e.g. physical habitat and flow responses), and no growth among more distant topics (e.g. hydraulic modelling and biotic responses, or social aspects) during the investigated period. In contrast, the need to solve water management problems has engaged Ecohydraulics research with end-users from its inception and has been a key driver promoting the development of Ecohydraulics as a distinct field of applied research (Nestler et al., 2008).

There is a need for a wider acceptance of Ecohydraulics as a whole discipline with both a basic science foundation (Nestler et al., 2016; Pasternack, 2019) and a critical impact on society that emerges when addressing research questions beyond traditional subject boundaries and scales. Stronger interdisciplinary collaboration and cooperation among researchers, end-users, and managers are considered necessary to achieve this goal (Dollar et al., 2007; Rice et al., 2010). A bi-directional stimulation is needed. On the one hand, a relevant challenge appears to be the implementation of interdisciplinary research into actions on the ground (Casas-Mulet et al., 2016), both at the scientific and societal levels. On the other hand, practitioners can play a central role in steering Ecohydraulics fundamental research and should challenge scientists to improve and further basic science (Palmer et al., 2010).

In order to contribute to society on local and global scales, Ecohydraulics needs to support the new generations of freshwater scientists (Wilkes et al., 2016). Early career researchers (ECRs) face additional challenges as they need to build their careers in a way that crosses traditional disciplinary boundaries, integrating physical, ecological, and social values in Ecohydraulics. To date, the efforts of the Early Career on Ecohydraulics Network (ECoENet) have been to promote inclusivity and open-mindedness among emerging researchers and encourage their participation in the scientific community. However, more work is needed to engage emerging researchers in the consolidation process of interdisciplinarity in Ecohydraulics.

By taking both an ECR and established academic perspective, this paper aims to contribute to the discussion on interdisciplinarity in Ecohydraulics and to shape its growth both among the community and the field of research. This contribution builds upon previous research that collected the challenges and opportunities for ECRs in Ecohydraulics (Wilkes et al., 2016). From this, we identified key actions, actors, implementation strategies and approaches that can strengthen interdisciplinarity in

Ecohydraulics. Based on an online questionnaire, our investigation first re-examined and updated Wilkes et al. (2016) findings. We then held a follow-up workshop involving ECRs and established careers in Ecohydraulics at a pre-conference event for the 12th International Symposium on Ecohydraulics (ISE) in Tokyo, 2018. This paper resumes a critical reflection on where the Ecohydraulics community stands today and where efforts need to be invested in the long-term to consolidate its inherent interdisciplinarity.

2 Pre-workshop questionnaire

2.1 Questions and targeted respondents

To assess the current status of the challenges, opportunities, and future directions in Ecohydraulics identified during the first Early Career on Ecohydraulics Network (ECoENet) workshop in 2016 (Wilkes et al., 2016), we created an anonymous online questionnaire that revisited them. The questionnaire was composed of 14 questions divided into four sections: (i) respondents' professional experience, (ii) challenges and opportunities, (iii) future directions, and (iv) respondents' personal background. Four multiple-choice questions focused on the professional experience of the respondents, including defining their career stage, background training, and identifying macro-topics of their core research. Five questions addressed the set of challenges and opportunities in Ecohydraulics by evaluating the respondent's level of agreement or disagreement with specific questions. One question addressed the future directions in Ecohydraulics by asking respondents to identify potential actions that could help advance the discipline. The last four questions helped portray the personal background of the respondents: current geographical location, gender, age, and whether the respondents had children (see full questionnaire in Appendix 1).

The online questionnaire was distributed on 27th July 2018 through several Ecohydraulics community-related email lists, soliciting participation from approximately 300 people. Respondents were given a week to return questionnaires to ensure that results were analysed before the ISE 2018 workshop in Tokyo, which was held in August 2018. A total of 103 participants responded to the questionnaire. The highest response rate came from male participants (61%), between 25 and 45 years old (63%), with a current research position in Europe (61%), either in a temporary research position or as a PhD candidate (50%). Most respondents were in engineering (39%), followed by the biological sciences

(29%, including ecology). The current area of research was a split between physical habitat, flow, fish responses, hydrology, and hydraulic modelling (67%; Figure 1).

2.2 Summary of challenges, opportunities, and future directions

Results from the questionnaire confirmed that the challenges, opportunities, and future directions in Ecohydraulics identified by Wilkes et al. (2016) are still relevant for ECRs. Insights from respondents went beyond the early career community and emphasised how interdisciplinarity in Ecohydraulics was viewed as both a challenge, opportunity and a future direction. While challenges and opportunities were well defined and further discussed by the respondents; future directions were more difficult to characterise, particularly regarding specific actions needed to strengthen interdisciplinarity within Ecohydraulics.

A preliminary analysis of the responses identified four main focus areas, which were later used to structure the discussions at the subsequent workshop. They included: Community Building (CB), Scientific Advancement (SA), Links to the Real World (LRW), and Education and Training (ET). Funding was considered an intersecting topic across the four focus areas, given that several recurrent challenges and opportunities centred around funding sources, and it was also deemed necessary to achieving future endeavours (Figure 2).

Newly identified challenges for Community Building (CB) emphasised persistent disciplinary separatism between ‘eco’ and ‘hydraulics’, the lack of a collective community vision for the future, and the absence of a common platform for networking. Respondents identified conferences as places for community growth and building a collective vision, ultimately creating an opportunity for interdisciplinary research in Ecohydraulics internationally (Figure 2).

Challenges listed for Scientific Advancement (SA) included: the lack of basic Ecohydraulics concepts and paradigms, the difficulty scaling-up integrative research for a complex global context, and the difficulties of developing interdisciplinary concepts without compromising the quality of the research. By promoting interdisciplinary collaborations, respondents agreed that knowledge in Ecohydraulics might extend beyond current ‘eco’ and ‘hydraulics’ core topics.

Harnessing technological advances and promoting scientific applications to overcome technological shortcomings were identified as both a new challenge and solution that relate to the focus area Links

to Real World (LRW). In terms of Education and Training (ET), the trade-off between single-focus specialised training vs all-in-one interdisciplinary degrees was seen as a key challenge that, in turn, can impact both professional and personal development. The participants perceived the Ecohydraulics field of research as an excellent framework to allow specialised education in a core discipline while maintaining broader connections among them (Figure 2).

3 ISE 2018 workshop

3.1 Organisation and participation

The workshop “Interdisciplinarity in Ecohydraulics: an early career perspective” was held on August 19-20, 2018, prior to the 12th International Symposium on Ecohydraulics in Tokyo in the form of a pre-conference event for ECRs and involving established academics. The workshop set out to identify key actions, actors, implementation strategies, and approaches that may help strengthen interdisciplinarity in Ecohydraulics. The challenges and opportunities summarised in the online questionnaire (Section 2.2) provided the framework for structuring the workshop.

The workshop registered 63 participants with affiliations in Asia (38%), Europe (37%), Oceania (13%), and North America (13%). Just above half of those registered were male (52%), PhD candidates or temporary researchers (51%), and with a background in engineering (58%, Figure 1).

3.2 Workshop sessions

The workshop was structured in four sessions: keynote introduction and discussion sessions during the first day and a synthesis session and prioritisation exercise on the second day. The scope, the methods, and the outcomes for each session are briefly summarised below.

Keynote introduction

Four keynote speakers were invited to offer a personal perspective of their career experiences as they relate to interdisciplinarity in Ecohydraulics and engage ECRs to provide their own insights into the field of research at the short Q&A discussion session. Different criteria were adopted in selecting the speakers: (i) ensure equal gender representation, (ii) representative career stages, and (iii) different

disciplinary backgrounds, including engineering, ecology, and social sciences. Each presenter contributed their story and experiences of interdisciplinary training and associated challenges. Overall, presentations highlighted a variety of career paths and life experiences that made each interdisciplinarity story unique. The diversity of pathways underscores the challenge and opportunity of mindfully creating interdisciplinary educational programs and cross-national engagement activities that give students practice in interdisciplinary engagement.

Discussion session

The discussion session aimed to identify and structure a series of actions, aligned with the four focus areas that emerged from the questionnaire: Community Building (CB), Scientific Advancement (SA), Links to the Real World (LRW), and Education and Training (ET) (Section 2.2). Participants were also asked to assess whether the future directions identified in the questionnaire were appropriate. Round-table discussions of seven groups were conducted in a manner consistent with the Open Space Technology principles (Owen, 2008), with keynotes acting as discussion facilitators and reporters. In particular, discussion groups were neither assigned a specific focus area nor held to a specific time schedule by the facilitators. To help focus the discussion into a series of actions, we provided a template, where groups were asked to allocate responsibility (Who are the actors?) and identify an approach (What are the implementation strategies and approaches?) to realise identified actions. Answers from each group were later discussed in a plenary session at the end of day one. A summary list of 20 actions was defined, organised by focus areas, and linked to the identified key future directions (Figure 2).

Synthesis session

The synthesis session opened day two of the workshop, and it was organised as a plenary session. Three synthesis keynote speakers with long-standing roles in the Ecohydraulics community led the opening of the meeting. The synthesis speakers had helped facilitate the previous discussion session and had been asked to synthesise the outcomes for the final prioritisation exercise.

Their summary statement emphasised the need for all career stages to engage with the broader scientific community and specific forums, as well as create opportunities to interact with fellow early

career and established scientists. The synthesis session also verified and consolidated the list of the 20 actions created the day prior and added additional viewpoints from workshop participants.

Prioritisation exercise

In the final session of the workshop, each participant was asked to vote for their top three key actions from the final consolidated list. The outcomes of the exercise illustrated that although actions focused on Community Building (CB) were prioritised, all other focus areas were deemed similarly important to help increase interdisciplinarity in Ecohydraulics (Figure 3). In terms of specific key actions, promoting one-on-one ECRs-mentor connections (CB), encouraging academic-industry internships (LRW), and the creation of an Ecohydraulics glossary of terms (SA) were the three most voted actions. They were closely followed by actions, such as workshops on disciplinary comparisons (SA), ECoENet's outreach (CB), optimal interdisciplinary training approaches (ET), and the addition of hands-on summer courses in standard University degrees (sUDs), also under the ET focus area(Figure 3).

In regard to the actors, the responsibility for implementing these actions generally lied within ECRs and, in some cases, ECoENet. However, established academics, University departments, and the Ecohydraulics Leadership Team (ELT) were also held responsible for enacting some of the key actions (Table 1). To achieve the listed actions, approaches like targeted workshops, interdisciplinary short courses, and creating new materials (e.g. newsletters, mentorship platforms, and a consolidated Ecohydraulics community mailing list etc.) were proposed.

Concerning the implementation approaches, the ECoENet platform and network were considered to be the best Community Building approach for promoting one-on-one connections between ECRs and mentors. By creating a database of both active mentors and ECRs members, mentors and mentees can be matched based on research areas of interest. Academic-industry internships were thought to be the purview of University departments and ELTs, linking fundamental research to Real World (LRW) contexts by establishing an online registry of contacts. In order to support Scientific Advancement (SA), ECoENet, ECRs, and the ELT were thought to be collectively responsible for creating an Ecohydraulics glossary and linkages among core disciplines. With respect to Education and Training (ET), developing optimal interdisciplinary training approaches and guidelines were deemed the most important, despite appearing only in the 6th position from the prioritisation exercise. Specific suggestions included: the development of interdisciplinary approaches to academic courses and

summer schools by established academics with a teaching focus, and the use and dissemination of interdisciplinary textbooks that cover varied core disciplines within Ecohydraulics (Table 1).

4 Representativeness of the study

Both the pre-workshop questionnaire and the workshop had high participation relative to the total number of attendants in the 2018 ISE symposium. This fact suggests that the issues raised in both events were likely important to ECRs and the broader Ecohydraulics community. While the crossover between questionnaire and workshop participants was low, the demographics in terms of career stage and background were aligned, which validated the use of the workshop as a continuation of the questionnaire. The low crossover was likely caused by the geographical location of ISE 2018, promoting high participation from Asia. In contrast, the questionnaire sought participants from a consolidated email list issued for ISE 2014 and ISE 2016 symposiums, with high involvement of Europe and Oceania. Although we observed a close gender balance in both exercises, the low participation of scientists with social sciences backgrounds and the lack of participation from Latin American and African countries are still unresolved issues preventing a broader representation within Ecohydraulics (Wilkes et al., 2016), and could be considered a potential limitation of this study.

5 Discussion

Following the reassessment of key challenges, opportunities, and future directions in Ecohydraulics via the online questionnaire, we identified four key focus areas (Community Building, Scientific Advancement, Links to the Real World, and Education and Training), where support is needed to strengthen interdisciplinarity within Ecohydraulics. All four focus areas and associated actions emerged in a prioritisation exercise during the ISE 2018 workshop, suggesting that efforts are required across the board to reach interdisciplinarity within Ecohydraulics. The list of prioritised actions considered various approaches to engage the community towards specific goals and should help improve long-term interdisciplinarity in Ecohydraulics. Below, we discuss the top prioritised actions in the context of each of the four focus areas (in ascending order of perceived priority).

291 Education and Training (ET)

292 Actions in Education and Training were not at the top of the priority list for the majority of participants
293 in the workshop, suggesting that despite ECRs may have felt it an important gap in Ecohydraulics (see
294 Wilkes et al., 2016), they are unempowered to drive the change. Interdisciplinary collaborations have
295 the greatest chance of success when ECRs are able to cultivate their own discipline based on academic
296 interests, but also to look beyond it. The so-called T-shaped researchers have ideally developed
297 breadth and depth during their disciplinary training (see Brown et al., 2016). However, ECRs and
298 students in Ecohydraulics are faced with a lack of interdisciplinary academic departments devoted to
299 the field of research, as well as specialised courses bridging diverse departments. Such institutional
300 barriers force students to choose among various courses offered across several disciplines and
301 departments vs mastering the fundamentals within a specific discipline. For ECRs, such barriers mean
302 that interdisciplinary career development and collaboration are not readily available. As a result,
303 students and ECRs are prevented from cultivating both breadth and depth in their chosen field of
304 research (e.g. jack of all trades, master of none).

305 Another major challenge centres around educators expected to design and deliver true
306 interdisciplinary academic courses (action ET1, priority #6). Without consolidated Ecohydraulics
307 textbooks (action ET3, priority #13), compounded by the logistical and institutional constraints of
308 having an interdisciplinary course, it is no wonder that Ecohydraulics has yet to reach the levels of a
309 recognised academic discipline. The development of truly interdisciplinary training approaches and
310 guidelines can only be achieved as a collaboration among several established academics from varied
311 backgrounds, representing the core disciplines in Ecohydraulics, and the full support of University
312 departments interested to contribute to the emerging field of research. Despite some efforts made to
313 integrate Ecohydraulics at the departmental and University level structures, academic departments
314 need to initiate interdisciplinarity through the support of specific actions.

315

316 Links to the Real World (LRW)

317 Ecohydraulics research must convert fundamental and applied research findings into practical tools
318 that can be easily used and applied by practitioners and governmental agencies. Engaging policy and
319 industry in the design of novel techniques and methods to further the Ecohydraulics toolbox should
320 meaningfully contribute to the future success of Ecohydraulics as an established interdisciplinary field
321 of research and positively impact society.

Increased engagement with industry from early ECRs via academic-industry internships (action LRW1, priority #2) has the potential to bridge Ecohydraulics research with the real-world outcomes and implementation of tools. Institutions affiliated with university departments must take the lead to foster stronger relationships with industry and governmental agencies and support ECRs' career development. This investment should positively feedback to the field of research in Ecohydraulics and society in general.

Scientific Advancement (SA)

Despite the many important advances in Ecohydraulics applications, there has not been a parallel evolution in the research theory independent of the core disciplines. Such applications have produced largely empirical research and models, often with limited applicability beyond the conditions in which they were developed. A significant challenge is to find ways to advance Ecohydraulics theory and develop research programs to test these theories without retreating to the traditional reductionist approaches of the parent disciplines. This can be achieved by developing a collective future vision as a research community and a set of shared concepts and paradigms (Nestler et al., 2016).

The creation of an Ecohydraulics glossary of terms (action SA1, priority #3) was seen as a good starting point to ensure that all the disciplines related to Ecohydraulics have a common vocabulary and engage the diverse disciplines within Ecohydraulics in a conversation on the use of terms. This would be a first step towards consolidating shared concepts and paradigms, and undertaking integrative interdisciplinary research without compromising the advancement of each individual discipline. Another action suggested the organisation of workshops to brainstorm on Ecohydraulics fundamentals (action SA5, priority #18). The low priority given to this action perhaps reflects that the basic common language is not yet been developed, and ECRs are not ready to engage in such conversations.

While a renewed focus on advancing Ecohydraulics theory is an opportunity, the Ecohydraulics community will have to overcome significant funding challenges. Interdisciplinary research requires collaborations among research groups and across traditional disciplines. Collaborative projects require substantial resources to support long-term experimental programs that achieve significant advances because of the complex interdisciplinary nature of Ecohydraulics. Establishing such programs requires

substantial funding from different stakeholders, which is often lacking in a sector where funding agencies are looking for quick solutions to pressing local management concerns, reflecting a disconnect between Ecohydraulics research goals set out by academics and funding agencies expectations. The value of investing in long-term theoretical Ecohydraulics research in the grand scheme of improving aquatic ecosystems management needs to be better articulated to national and international funding agencies.

Community Building (CB)

The Ecohydraulics community is mostly united and engaged through the biennial ISE symposium (Casas-Mulet et al., 2016). While it initially started as an informal support group of researchers, it has now grown into a mindful, strategic organisation of substantial size, influence, and recognition. This leads to the logical question: is Ecohydraulics at the point where it merits institutional recognition? An institutionalisation of Ecohydraulics would mean the development of a shared mission for both the field of research and the community. The establishment of formal organisational structures within Ecohydraulics is critical to engaging people, allows the community to grow, and empowers community volunteers to support more specific actions. While the Ecohydraulics community can learn from written experiences of scientific institutionalisation (e.g. Gaëta et al., 2017), its implementation still poses a challenge, and its success will depend on current and future ELTs.

Engaging researchers from all career stages is crucial to building community. Scientific leaders at the peak of their careers should lead the establishment of such formal structures, as they are in the position to reflect on the overall vision of Ecohydraulics and are most likely training a critical mass of students and postdoctoral researchers on interdisciplinary research projects. The participation of ECRs in such formal structures is key. Still, their involvement must reflect their need for building their repertoire of skills with different basic and applied research challenges and establishing their careers in centres of excellence. The development of a mentorship program (action CB1, priority #1) has the potential to engage individuals at different career stages in Ecohydraulics by contributing to the field of research through collaboration mentorship, advice, and networking among peers, linking disciplines together and ultimately driving Ecohydraulics towards a more formalised field of research.

Another key action to help with CB is the creation of an inclusive Research Forum (action CB3, priority #9), including individuals from diverse geographic locations, disciplinary backgrounds and career stages. Current and developing online platforms (e.g. Ecohydraulics website, ECoENet social media

platforms) are a good start, however, the Ecohydraulics community and ELT at large should be responsible for actively engaging researchers from diverse core disciplines and nurturing a constructive dialogue among them. Inspiring students, ECRs, and established research leaders to collectively build the Ecohydraulics community, should also foster growth through learning and creative exchanges, facilitating the evolution of the discipline beyond the CB actions currently identified.

According to Schummer (2004), there are two components to the establishment of a field of interdisciplinary research: (i) the knowledge base (concepts and beliefs, methods, values), and (ii) the social aspects (ways in which the body of knowledge is communicated, shared and taught). It appears that the majority of actions identified in this paper are on the social aspects relevant to Ecohydraulics (Community Building, Links to the Real World, and Education and Training) vs only one on the knowledge base (Scientific Advancement). Despite a clear lack of shared concepts and paradigms in Ecohydraulics, the dominant engineering perspective provides a well-established link with research applications, providing the foundation for a consensus on the knowledge base. However, a community vision designed to bring researchers rooted in different disciplines together (Schummer, 2004) remains the key challenge. Ecohydraulics should, thus, invest most of their efforts and resources into developing the above-mentioned social aspects. The question remains whether new institutional structures within Ecohydraulics will enable more integration between the disparate disciplines, particularly those with the social sciences (Porter and Rafols, 2009), where the gap is more apparent.

6 Conclusion

This study presents a collective effort amongst established and early career scientists with different disciplinary backgrounds to identify, discuss, and prioritise specific actions to support the development of true interdisciplinarity within Ecohydraulics. A total of 20 actions involving a range of actors, implementation strategies and approaches within Ecohydraulics were identified depicting a network of players, from individuals at different career stages, to institutions, working together across all focus areas towards achieving true interdisciplinarity. Outcomes from the exercise helped evaluate the current state of the Ecohydraulics community and provided a roadmap for long-term investment of efforts and resources to consolidate interdisciplinarity. The list of prioritised actions in this paper

should, therefore, be considered as mechanisms to engage the community towards specific goals leading to increased interdisciplinarity. While ECRs have taken the lead to create this roadmap, its implementation is the joint responsibility of more established career scientists, ECRs, and institutions.

This paper is a conversation starter for all of those within the Ecohydraulics community. A continued revision of the implementation strategies and approaches to strengthen interdisciplinarity will be needed to tackle global issues in freshwater systems in the future.

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Table 1. Summary of workshop-identified actions to improve interdisciplinarity in Ecohydraulics, including the responsibility (Actor) of initiating the action and the implementation strategy and approach to undertaking the action.

Focus Area	Code	Action	Priority #	Responsibility (Actors)	Implementation strategy and approach
Community building	CB1	• Promote one-to-one connections of ECRs with mentors	1	ECoENet ELT	Create of a database of mentors and ECR members research areas to match interests Create of an Ecohydraulics community mailing list
	CB2	• Support ECoENet's outreach	5	ECRs Established academics ECoENet	Encourage ECoENet's Newsletter subscription Encourage PhD students to support the Network Creation of information packages Promote actions at conferences
	CB3	• Promote the creation of an inclusive Research Forum	9	ELT, ECRs	Join existing platforms, improve them by enabling quality control and content moderation
	CB4	• Create Regional Groups within ECoENet	10	ECoENet ECRs Established academics	Identify common research/career goals with ECRs on a continuous basis Increase trust within the Network Encourage PhD students to support the Network
	CB5	• Create multilingual materials	11	To be determined	To be determined
	CB6	• Support the establishment of JoE	15	To be determined	To be determined
Scientific advancement	SA1	• Create an Ecohydraulics glossary of terms	3	ECRs, ECoENet, ELT	List and define a database of terms led by motivated individuals, supported by ECoENet and ELT
	SA2	• Organise hands-on workshops to compare disciplinary field, lab and analysis approaches	4	Established academics, ECRs	Organise sessions embedded in student courses or multi-departmental activities
	SA3	• Organise Wiki writing sessions	8	ECRs, ECoENet	Suggest it as a Pre-ISE workshop topic, or strategic action within ECoENet
	SA4	• Encourage multidisciplinary departmental seminars	17	ECRs, Established academics	Build up multidisciplinary research from existing departmental activities, and consider include an ice-breaker
	SA5	• Organise brainstorming workshops on fundamentals	18*	Established Academics, ECRs	To be determined
Links to the real world	LRW1	• Promote academic-industry internships	2	University Departments Industry/Agencies ELT	Establish the link and the platform through the ELT
	LRW2	• Encourage research dissemination in layman's terms	12	Journal of Ecohydraulics, University Departments	Establish a layman's term abstract as a mandatory exercise when submitting a paper
	LRW3	• Organise hands-on workshops for the creation of interdisciplinary software	14	Industry University Departments?	Target workshops with Industry funding
	LRW4	• Create guidelines for positive interactions with the public	16	ELT, General public	Target workshops with ELT funds and involve the general public
	LRW5	• Organise workshops to address targeted real-world issues	18*	To be determined	To be determined
Education and training	ET1	• Define optimal interdisciplinary training approach	6	Established academics with teaching focus	Provide the definition based on evidence, expertise, and experience, in parallel with the improvement of standard University Degrees (sUDs)
	ET2	• Include hands-on summer courses in standard University Degrees (sUDs)	7	Established academics, ECRs	Organise multi-departmental short-courses targeting students from different majors (from BSc to MSc levels)
	ET3	• Produce Ecohydraulics textbooks	13	Established Academics with teaching focus	To be determined but linked to ET1.
	ET4	• Extend sUDs to add other disciplinary subjects	18*	University Departments, ECRs	Challenge Universities to include interdisciplinary subjects at the request of ECRs and prospective students

Figure 1. Key professional and personal aspects of the questionnaire’s respondents and workshop participants including geographical distribution (top left), background by training (top right), career stage (bottom left), and current research focus based on the macrotopics defined in Casas-Mulet et al. 2016* (bottom right, note this information was only provided by the questionnaire’s respondents). All values are in percentages.

		Challenges	Opportunities	Future directions	Actions
Funding	Community building	<ul style="list-style-type: none"> Lack of a collective future vision Lack of consolidated network platform Overcoming disciplinary separatism 	<ul style="list-style-type: none"> Creation of a true interdisciplinary international community 	<ul style="list-style-type: none"> Creation of a collective vision Inclusion of developing countries Creation of a true community 	<ul style="list-style-type: none"> Support ECoENet's outreach Support the establishment of TJoE Promote the creation of an inclusive Research Forum Create Regional Groups within ECoENet Create multilingual materials Promote one-to-one connections of ECRs with mentors
	Scientific advancement	<ul style="list-style-type: none"> Integration and transferability of concepts* Focus on specific hydro-geo-bio-chemical relationships* Establishing new concepts and paradigms Contextualisation Quality of science 	<ul style="list-style-type: none"> Development of fundamental research* Expanding knowledge beyond hydro and eco 	<ul style="list-style-type: none"> Interdisciplinary integration Promotion of interdisciplinary collaborations 	<ul style="list-style-type: none"> Create an Ecohydraulics glossary of terms Organise Wiki writing sessions Organise brainstorming workshops on fundamentals Encourage multidisciplinary departmental seminars Organise hands-on workshops to compare disciplinary field, lab and analysis approaches
	Links to the real world	<ul style="list-style-type: none"> Links to management and policy* Societal engagement and contribution* Harnessing technological advances 	<ul style="list-style-type: none"> Contribution to society* Application of science* 	<ul style="list-style-type: none"> Transdisciplinarity and governmental involvement Increase public engagement Promotion of scientific applications 	<ul style="list-style-type: none"> Promote academic-industry internships Organise workshops to address targeted real-world issues Create guidelines for positive interactions with the public Encourage research dissemination in layman's terms Organise hands-on workshops for the creation of interdisciplinary software
	Education and training	<ul style="list-style-type: none"> Specialisation vs broadening Professional and personal development 	<ul style="list-style-type: none"> Interdisciplinary education and training* Professional and personal development* Specialisation 	<ul style="list-style-type: none"> Promotion of interdisciplinary education 	<ul style="list-style-type: none"> Extend standard University Degrees (sUDs) to add other disciplinary subjects Define optimal interdisciplinary training approach Include hands-on summer courses in sUDs Produce Ecohydraulics textbooks

Figure 2. Reviewed challenges and opportunities in Ecohydraulics, and future directions linked to suggested actions. All organised by four identified priority areas “Community building”, “Scientific advancement”, “Links to the real world” and “Education and training”. Note that * indicates items identified in Wilkes et al. 2016.

Figure 3. Outcomes of the prioritisation exercise illustrating the percentage of votes received by focus areas (left) and by specific actions (right).