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Stories from the front lines

Learning, thinking, sharing, and working across boundaries in fisheries science

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Abstract

Fisheries science and practice are challenging and require learning, thinking, and sharing across boundaries. The idea of boundary crossing can be described as some form of multiple disciplinarity (e.g. interdisciplinarity, transdisciplinarity), yet that inherently implies that the boundaries crossed are purely disciplinary in nature. After working across various other boundaries (i.e. realms, regions, disciplines, sectors, domains, and knowledge systems) for most of our educational journeys and professional careers, we reflect on our lived experiences with a focus on identifying the benefits and challenges of engaging in different types of boundary crossing. We submit that our personal and professional lives have been enriched by stepping outside of our immediate comfort zones and expertise (i.e. fish ecology) and engaging in active listening and learning with colleagues in other disciplines (i.e. various social sciences) and with stakeholders and policymakers. We have learned much from working across boundaries and encourage others, especially early career professionals, to do the same. What may superficially appear to be a bridge too far may in fact provide novel ways of thinking about a given issue or topic that generates actionable science for sustainable fisheries management and conservation. Many of the projects that we consider to be our greatest successes represent ones that involved boundary crossing, examples of which we provide in this essay. There is a need to prepare the next generation of problem solvers for engaging in boundary crossing and celebrating examples of where such efforts have led to meaningful advances in fisheries science and practice. Ensuring that institutional and cultural barriers that may constrain boundary crossing are addressed while also supporting those doing such work will be key to address the many fisheries and aquatic science challenges of today and tomorrow in both marine and freshwater systems.

Context

Fisheries science and practice are challenging and are a space where wicked problems prevail (Hare 2020, Lönngren and Van Poeck 2021). Given the magnitude and complexity of those challenges, issues, and problems, we submit that there is a need for learning, thinking, sharing, and working across various boundaries. Boundaries are pervasive in society (e.g. socio-economic class, political, cultural, scientific disciplines, etc.) and they all influence fisheries science and management practice. These boundaries can become even more explicit and hardened because of increasing academic and managerial specialization (Akkerman and Bakker 2011). Boundary crossing is usually defined as the transitions and interactions of a person across different "sites" (Suchman 1994), which is often a cognitive process (Engeström et al. 1995). Sometimes the idea of boundary crossing is thought of as a form of multiple disciplinarity (e.g. interdisciplinarity, transdisciplinarity), yet that inherently implies that the boundaries crossed are purely disciplinary in nature. Certainly, disciplinary boundaries are real and pervasive and can be difficult to cross (Kates et al. 2001, Cooke et al. 2020), but there are many other boundaries that can be overcome and create immense opportunities for learning. Examples of boundaries relevant to fisheries science and practice include realms (e.g. freshwater vs. marine), geopolitical boundaries (transboundary), fisheries sectors, fundamental-applied domains, knowledge systems, and the science–society interface.

After working across various boundaries for most of our educational journeys and professional careers, here we reflect on our lived experiences with a focus on identifying the benefits and challenges of engaging in boundary crossing. We submit that our personal and professional lives have been enriched by stepping outside of our immediate comfort zones and expertise and engaging in active listening and learning. Using examples populated by our own experiences we summarize the boundaries we have crossed, how we have done so, and the benefits that have been realized personally and practically in management and conservation. We conclude by exploring the challenges that we faced when crossing boundaries and what can be done to overcome them through the use of two case studies.

When writing a reflective essay such as this one, it is useful to consider the positionality of those sharing their perspectives and lived experiences. In our case, we do so as established Caucasian male scholars working in G7 countries (Cooke in Canada, Arlinghaus in Germany) in the northern hemisphere. We have secured positions at respected institutions and have enjoyed strong research support in terms of funding. All of the above matters because that has enabled us to cross boundaries with relatively few repercussions that others may face

Figure 1 Arlinghaus (left) and Cooke (right) have been collaborating for two decades and enjoy professional collaborations filled with mischief, creativity, and fishing. Taking time to work and play together is fundamental to being able to do the kind of work described here.

given their positionality. Nonetheless, we have been chastised for the extent of boundary crossing we do. Yet, we have also been celebrated with awards and accolades specific to boundary crossing, emphasizing the tensions in this space. Therefore, there may be lessons for others, particularly trainees and early career professionals that can be shared when considering the barriers we have encountered and often overcome. We acknowledge that there are many boundaries and hurdles (e.g. gender, power dynamics, socio-economic, racial, etc.; see Johri et al. 2021, Shellock et al. 2022) that others might already have to be pushing themselves to secure a seat at the academic table in the first place, and that the process of crossing the realms/sectors/disciplines that are the focus on this paper may require them to keep pushing these additional boundaries, making such efforts even more challenging.

Beyond our positionality, it is important to note that we consider ourselves to be highly collaborative and, most importantly, passionate fisheries scientists. With that comes the motivation to lead, get things done, and leave a legacy in the practical world (of fisheries management or conservation) that may also promote creative ways of combining knowledge across boundaries. Even our relationship story was one where a mutual mentor (Ian Cowx, University of Hull, UK) connected us, saying—"You two have similar characteristics—you should connect." We did so during our Ph.D. phases >20 years ago and have maintained a productive relationship ever since, exchanging emails and information several times per week, regularly meeting in 2- to 3-year intervals either in Canada or Germany (Fig. 1) or more regularly at conferences, and continuously having joint projects (as well as many other activities that do not involve each other). We routinely engage in spirited debates and certainly have our areas of disagreement—but i.e. overshadowed by our mutual respect. Our story is shared by others in fisheries science where two colleagues have regularly interacted and collaborated over many years (e.g. Ray Hilborn and Ana Parma; Daniel Pauly and Rashid Sumaila; Gretta Pecl and Beth Fulton, etc.). In many ways, our relationship (as well as that with other mentors, like-minded colleagues, and mentees) is what spurred us to cross even more boundaries over the years, many of which were fuelled by one of us being inspired by the methods and approaches used by the other. The uniting feature has always been a desire to advance applied fisheries science and to be relevant to society. That is, the context through which we share our experiences below, which are by design subjective, but may have lessons for others and thus inspire or enable them to cross boundaries.

Boundary crossing examples

Crossing realms—freshwater and marine systems

Realms (e.g. freshwater vs. marine) are common ways to broadly categorize different aquatic systems based on factors such as salinity, tidal influences, scale, and so on, yet there are many fundamental similarities (e.g. think about the foundations of limnology and oceanography and the inherent similarities of how aquatic systems function; Downing 2014). Nonetheless, that delineation has become so entrenched and pervasive that there are bespoke journals, conferences, academic departments, degrees, and so on that are either entirely freshwater or entirely marine in focus. We have had the fortune of working in both realms as well as transitional spaces such as estuaries throughout much of our careers and have argued before that there is much merit in sharing ideas and experiences between these realms (Cooke et al. 2014). The majority of the work we have done in marine systems is focused on coastal (Adams et al. 2019) and lagoon (Arlinghaus et al. 2023) environments that are highly productive and where fish are strongly associated with physical habitat such as

mangroves, submerged aquatic plants/algae, and patch reefs. These coastal waters resemble the littoral region of freshwater systems and shallow lakes, systems that were key to our university training as freshwater fish biologists in many ways, and thus we are able to bring those experiences and understanding into our work in both realms. There are also areas where we have been able to draw upon experiences in one of the realms and bring those concepts into the other. For example, protected area science is advanced in the marine realm and comparatively less developed in freshwater systems. Through analysis and reflection on protected area science and management in the marine realm, it was possible to identify lessons relevant to freshwater protected areas (Loury et al. 2018) and to engage in critical assessments in area-based freshwater management (Nikolaus et al. 2022). Another topic has been fisheries-induced evolution, which has been known in marine systems for decades (early review, Heino and Godø 2002), including long-term experimental harvesting experiments with marine fish models (Conover and Baumann 2009). Only in recent years has this concept been considered and identified in freshwater systems, drawing inspiration from marine work (e.g. Philipp et al. 2015, Klefoth et al. 2017) and involving laboratory harvest selection experiments with freshwater fish (Uusi-Heikkilä et al. 2015). Constraining one's thinking and learning to a singular realm most certainly results in a major loss of inspiration and knowledge, and there is a tremendous opportunity to learn from the methods and approaches in one realm (say marine fisheries) and apply and merge them with issues in another (freshwater fisheries).

Crossing sectors—commercial and recreational fisheries

Superficially, the recreational and commercial fishing sectors could not be more different. For example, contrast a child sitting on a dock trying to catch sunfish on a baited hook with an industrial trawler and associated on-board processing plant operating offshore in the ocean. Yet, there are also many similarities (reviewed in Cooke and Cowx 2006) and we have both benefited from working across these two sectors. For example, reflex impairment indicators that were first applied in bycatch studies to commercial fisheries (Davis 2007) have since been validated and embraced in our work on catch-and-release in recreational fisheries (e.g. Brownscombe et al. 2015, Bower et al. 2022) to the point that these tools are now shared with anglers so they can assess fish condition and revise their behavior in real time. In another example, facilitated recovery methods for exhausted fish were first developed in the marine realm (e.g. Farrell et al. 2001) and we have now adapted and tested them in a recreational context (Brownscombe et al. 2013, 2017). More conceptually, our thinking about effort controls as potential tools for recreational fisheries (Arlinghaus et al. 2019) has been informed by the long-standing use of such methods (e.g. limited entry, input controls; Anderson et al. 2019) in the commercial realm. Although we do not do as much work in the commercial sector as we do in the recreational sector, we have worked to identify fish welfare practices that are germane to both sectors while ensuring that such efforts are evidence-based (Browman et al. 2019), and work has been completed in co-exploited situations where commercial and recreational fisheries interact and are sometimes in conflict (Arlinghaus et al. 2023). Also, methods pioneered for commercial fisheries, such as length-based assessment methods to assess fish stock status, were applied to more recreationally exploited situations (Fitzgerald et al. 2023). It would be very easy to simply rely on sector-specific research (and references), yet that would have hampered our progress in understanding how to better manage both sectors and to address common issues such as release of captured fish or the status of fish stocks exploited by anglers or fishers.

Crossing regions and borders—transboundary research

Spatial boundaries are common in fisheries systems, and include issues such as exclusive economic zones, political borders (e.g. in multinational fisheries), multi-scalar governance challenges, and protected areas (Song et al. 2017). Most boundaries can be grouped under resources, fisheries effort, trade, and governance (Song et al. 2017). However, boundaries are often fluid or entirely social and geopolitical constructs, so they can be crossed and navigated. In various ways, our careers and research projects have been transboundary since early days. For example, our work on the migration biology of fish has involved studying animals that swim across/through both national, state/provincial, and regional boundaries and in shared marine waters or in large lakes or watersheds. This work has been enabled through international research networks where data are shared (Iverson et al. 2019, Jarić et al. 2023). For example, Arlinghaus has studied the multinational fishery of Lake Constance bordering Germany, Switzerland, and Austria (e.g. Baer et al. 2017), whereas Cooke has worked on walleye movement where fish move between US and Canadian waters (Hayden et al. 2014), and together we have collaborated on international projects focused on understanding recreational fisheries systems around the globe (Bower et al. 2020, Arlinghaus et al. 2021). Transboundary work can also be necessary in instances of multi-scalar governance where multiple jurisdictions overlap within a nation. Recent work on the Rideau Canal Waterway in eastern Ontario led by Cooke involved creating a "horrendogram" to document the overlapping responsibilities of various federal, provincial, regional, and Indigenous governments (Bergman et al. 2022), an issue i.e. shared in stocking management of inland waters in Europe (Aas et al. 2018). In watersheds, transboundary work is often a requirement (both within and among nations) to ensure systems (and fisheries) are managed in a holistic manner (Nguyen et al. 2016). Engaging in transboundary research certainly comes with challenges (e.g. different political systems, cultures, languages, capacity, etc.) but there is guidance on how to do so (see Perz et al. 2010, Hughes et al. 2016). Failure to work across regions and in associated transboundary spaces when relevant, impedes the ability of one to achieve holistic understanding and identify solutions that span the life cycle or range of a given species (Song et al. 2017).

Crossing disciplines—interdisciplinary scholarship

One of the hardest things in academia is crossing academic disciplines. Academia is organized in faculties and here in disciplines (e.g. biology) and subdisciplines (e.g. molecular ecology), and there are huge forces that attract individuals to certain home turfs and constrain efforts to cross and integrate with other disciplines. These hurdles are pervasive and involve large cognitive burden, as it is very time-consuming to become trained in the fundamentals of different disciplines (e.g.

human psychology vs. fisheries science). Yet multidisciplinary, and in some cases inter- and transdisciplinary, research is central to solving sustainability challenges (Dick et al. 2016). This is obvious in fisheries, which is a coupled social-ecological system composed of oceans, lakes, rivers, and fish stocks on one hand, and people and their organizations on the other (Arlinghaus et al. 2017a). To develop robust knowledge for sustainability, engaging in multiple disciplines and integrating across disciplines in interdisciplinarity inquiry is key (Arlinghaus et al. 2017a). While crossing subdisciplines within an umbrella discipline such as "biology" is hard enough, the true challenge is merging natural and social sciences. We both have a track record of doing ecological and human dimensions work, publishing in fisheries, conservation, but also in social science and multidisciplinary journals. Academically, we would perhaps still be considered mainly fish ecologists or fisheries scientists, but we regularly apply methods that originate from both the natural and social sciences. Clearly, much of the social side of the work emerges from collaborations with true disciplinary experts (e.g. economists, psychologists, sociologists, etc.) who serve as methodological mentors, but each of us has studied some social science aspects enough (starting in our undergraduate degrees) that we know key concepts and theories and thus can understand the language of the "alien" discipline. Arlinghaus (2004) even did his Ph.D. with empirical social sciences, which gave him some depth in selected applied subfields of social science (especially outdoor recreation and leisure studies). The motivation for crossing disciplines among the natural and the social has been (a) curiosity and (b) the desire to develop knowledge that has an impact in society and specifically fisheries management. Without understanding fish and fishers, and especially the feedback, it is impossible to derive robust management advice (Hilborn 2007). To facilitate that, it is extremely helpful to learn the language of various disciplines and then become the knowledge broker in interdisciplinary projects where one can build and glue teams and help each other's understanding (Arlinghaus et al. 2014, 2017a), although this comes at a cost. One cannot be an expert in all disciplines; collaboration with disciplinary experts remains a central endeavor, and significant time and commitment are needed to maintain networks and keep up to date. Another limitation is that sustainability scientists may exhibit "eye of Columbus" syndromes by sometimes reinventing the wheel, simply because some of the more fundamental literature of a given discipline (e.g. sociology) is simply not known to them. This phenomenon is not because one could not know but because it is very hard or impossible to become an expert with true depth of knowledge in multiple disciplines with long histories and associated depth of scholarship. What is clear is that there is much benefit derived from crossing disciplinary boundaries, especially in the context of challenging topics such as fisheries science and management (Simon and Schiemer 2015).

Crossing knowledge systems—from western science to stakeholder knowledge and indigenous science

For centuries, so-called "western science" and research modalities have been put on a pedestal and regarded as the primary means of discovery and the basis for evidence-informed decision-making for health care, the environment, education, and so on. Yet, such a perspective fails to recognize or embrace the reality that other ways of knowing are equally valid and can complement western science. For example, there is much emphasis recently on stakeholder perspectives, running under various names such as traditional knowledge or practical knowledge. It is well known that groups such as recreational and commercial fishers have much knowledge about how their fisheries operate and what can be done to address problems. For example, our work on recreational fisheries has been informed by working closely with anglers to ensure relevancy (Cooke et al. 2017, Fujitani et al. 2017). At times, this may involve formal survey work (Dorow and Arlinghaus 2012) or could be more of a co-production approach working hand-in-hand throughout a research project (Landsman et al. 2011). There is also growing recognition of the wealth of knowledge held by indigenous rights holders. In fact, the terminology "Indigenous science" is often applied to indigenous knowledge in recognition that the knowledge acquired, refined, and shared is itself not unlike the scientific method (Gorelick 2014, Snively and Corsiglia 2016). We have been fortunate to work with indigenous scholars and community members to learn about indigenous science and how it can be respectfully bridged (or braided) with western science using frameworks such as two-eyed seeing (Reid et al. 2021). There are a growing number of examples of where bridging and braiding have been applied to aquatic science (Alexander et al. 2021), with much benefit from doing so. In the case of indigenous science, however, it is not simply about "benefit" but rather sovereign and inherent rights (see the United Nations Declaration on the Rights of Indigenous Peoples; https://www.un.org/esa/socdev/unpfii/documents/DRIPS_en.pdf). As scientists, we are lifelong learners and embrace the opportunity to learn, work, and share across knowledge systems in our quest to ensure fisheries and aquatic systems are managed in a sustainable, equitable, and responsible manner.

Crossing domains—the fundamental-applied domains

Often, research is thought of as operating in one of two major domains—fundamental or applied. Fundamental research (also known as discovery, curiosity-driven, or blue-sky research) is the pursuit of basic knowledge about how the world works—attempting to address fundamental uncertainties. In contrast, applied research is focused on addressing various societal challenges and problems (e.g. curing cancer, restoring biodiversity, building a better cell phone, etc.). In many ways, these are considered discrete domains; one can be a fundamental or applied scientist, and one can apply for fundamental or applied research funding. However, in reality, these operate more like a continuum (or spectrum) on which different projects and researchers can be positioned anywhere (Cooke 2011). Although often assumed that the domains are in competition, it is our perspective that there is much to be gained from working variously in both domains and embracing the concept that neither domain is better than the other and the only relevant issue is doing high-quality (i.e. robust and replicable) science. In many ways, research in both domains supports each other. For example, it is the accumulation of fundamental knowledge that may be necessary to address a future applied issue (Courchamp et al. 2015), whereas applied research may at times lead to discoveries that are of a fundamental nature and bring funding to the table to do so (given

that applied funding is often more plentiful). Some examples in this space include our work in movement ecology, where we have a fundamental interest in why and how fish move (Nakayama et al. 2018) and the development of ecological principles to explain such movements (Cooke et al. 2022, Verhelst et al. 2023). From an applied perspective, we have used that foundation to develop fish passage solutions (Thiem et al. 2013), evaluate stocking success (Monk et al. 2020, Radinger et al. 2023), identify fisheries exploitation risk (Arlinghaus et al. 2017b, Monk et al. 2021), and quantify habitat use to assess and inform restoration (Rous et al. 2017). Our applied research benefits from the fundamental understanding of movement processes and population dynamics, whereas our fundamental research benefits from the ability to test theory in the applied studies. Crossing the fundamental-applied boundary (or working across the continuum) has benefited our research programs and generated more holistic knowledge that can be exploited in diverse ways.

Crossing interfaces—science and society

We have always been motivated by our science having some form of relevance in the real world. Therefore, crossing science to society, and specifically to fisheries stakeholders and managers, has been a strong target since we started our academic careers. Many scientists prefer to stay in the ivory tower. We have always attempted to communicate our science effectively to a wide range of stakeholders and actors (e.g. policymakers, fisheries managers, and very regularly also anglers, nature conservationists, and other actors). This communication is done by going beyond the standard production of a peer-reviewed paper (which we also very much enjoy) to include the development of alternative communication products, such as lay articles for angling magazines, press releases, presentations to local angling clubs, textbooks, and monographs for decision-makers at national and international levels (e.g. FAO 2012), podcasts, social media, video documentaries, comics, and many more formats. Importantly, in a portion of our work, we engage in transdisciplinary projects where the world of practice, including anglers and fishers, are engaged in co-production of knowledge through joint projects. For example, in Germany, angling clubs were involved as equal partners in multi-year projects to examine stocking (Hühn et al. 2023) and habitat enhancement (Radinger et al. 2023) or in co-developing management advice for fisheries management in coastal lagoons (Ehrlich et al. 2023). The high level of engagement with the public, not just through science communication but also through transdisciplinary cooperation, has paid large dividends to us and has been a constant motivator to see that our work is impactful and relevant beyond academic circles and can change how on-the-ground fisheries management is done. More broadly, there are many examples within fisheries where crossing the science–society interface has proved useful, e.g. for reducing scientific and institutional uncertainty in small-scale fisheries management (Sutton and Rudd 2016). Of course, working with stakeholders can only be effective if one invests the time and energy, is motivated to communicate using a common language, develops relationships (which is time-consuming), and accepts that how one thinks as a scientist is not how everybody thinks. One has to also accept and live with the fact that one's work and insights will not make everybody happy and that pushback can happen.

Reflections on boundary crossing

An obvious question to ask is why have we engaged in boundary crossing (of various forms) throughout our careers and learning journeys. First and foremost, we both really like to learn. Learning comes in many forms, and in our case, we have embraced the opportunity to learn about other disciplines and other ways of thinking and by doing that extend beyond our training and core expertise. Perhaps the fact that both of us have relatively broad training (that spans the natural and social sciences and extends beyond a fisheries context), and generally wide interest has prepared us for such work. However, it is also worth noting that boundary crossing competence can be learned/developed through bespoke training if one is interested and motivated in doing so (see Walker and Nocon 2007). Second, we are both able to identify how ideas and concepts from other contexts can be applied to a fisheries problem that we are attempting to address, and we read widely and regularly in different disciplines. With that comes the need to accept that failure may be an outcome, yet at the same time, realize that without taking the risk, the potential for transformational change is impeded. It also means keeping an open mind and looking for questions, applicable concepts, and opportunities. Fisheries problems are inherently complex, and solutions need to come from anyone and anywhere that has something to offer. We have both embraced a solutions-oriented approach to scholarship and practice as we have matured as researchers, perhaps best understood as evidence-based applied science. As is well established in the sustainability science literature, doing solutions-oriented research requires thinking and working across boundaries (McGreavy et al. 2013). Finally, we are both social creatures, are deeply passionate about fisheries, are ardent anglers (explaining our connection to aquatic systems and fish) and enjoy developing collaborative teams to undertake research. This connects back to our desire to learn and our interest in generating solutions. If one builds a diverse team (yet one with a shared goal and identity; MacPhail et al. 2009), it is almost certain that one will be pushed or pulled across boundaries (Salazar et al. 2012)—including boundaries that may not have been considered before. Indeed, research suggests that teams of diverse problem solvers often outperform teams that are populated by so-called high-ability problem solvers (e.g. world experts on a given topic; Hong and Page 2004).

Overcoming challenges with crossing boundaries

The challenges to overcome when crossing existing boundaries (as outlined above and highlighted below in two detailed case studies) are multi-fold and severe. The first challenge is simply time and resources. Both are needed to cross boundaries (e.g. natural and social science)—given that doing so means having the freedom and time to explore and learn about topics that are most likely outside of one's primary expertise. The second is navigating the pushback that can arise from colleagues or perhaps pushback i.e. systemic (e.g. funding body constraints, tenure, and promotion rules). Trying to overcome the inherent challenges with crossing boundaries comes with reservations—it is not a streamlined approach and not for everybody. We have experienced this over our careers, being accused of not being pure fisheries scientists (due to the human dimensions branch of our work; see case study 1 below)

nor true fish physiologists (due to the field component of applied physiology; see case study 2 below), being merely good at selling the science (due to our focus and some awards in science communication), being freshwater people that should not work on marine fisheries, being influenced by special interest groups (e.g. anglers) or the "evil" fishing industry with associated bias, by being applied rather than fundamental in orientation, and so on. We have also witnessed substantial rejection, e.g. in hiring processes for university professorships where social-ecology or sustainability science was sought in the job application, but in reality disciplinary knowledge (e.g. in social science) was expected, or in biology/ecology lacking sufficient natural science. Thus, a true challenge of being interdisciplinary, especially if one enjoys both ecological and social science, is that one will constantly struggle to say what one "is," academically speaking; the profile is neither "fish nor meat" (Arlinghaus et al. 2014), which can and will often clash with expectations of certain academic units and institutions. One has to live with the fact that not all enjoy and respect boundary crossing, no matter the number of publications one brings to the table. In order to cross boundaries, overcoming these tensions and keeping motivation high is key, and this can yield opportunities (e.g. the development of new subfields such as conservation physiology; see case study 2) or lead to developing frontier research in recreational fisheries as complex adaptive systems (Arlinghaus et al. 2017a). Central to success is finding like-minded collaborators and being passionate and confident with their trajectory. The best collaborators for interdisciplinarity may not be the "rock stars" of a discipline, who may in fact be preoccupied with solving fundamental problems. Instead, the best boundary-crossers are those that share a passion for a given problem or want to make a difference outside their comfort zone or who like a given disciplinary method and can see it being used for problem solving in an applied field like fisheries. A final challenge is that boundaries are there for a reason; they are socially constructed. Boundaries might be resistant to change and one has to have the security to accept some boundaries are too ingrained (i.e. walls that are too high or too thick). If you hit those, move on and do not look back. One learns and growths from failures, which clearly needs a certain personality. That said, history tells us that even the most established boundaries can be crossed with sufficient time, persistence, and ingenuity.

Case Study 1. Venturing into social science research on recreational fisheries as a trained fish ecologist

One of us (Arlinghaus) was trained as a freshwater fish ecologist and fisheries scientist within an agricultural faculty in Berlin and then completed a Ph.D. in empirical social science in fisheries within the same faculty (Arlinghaus 2004). This marked the start of a 20-year-long career post-Ph.D. in applying both fisheries ecological and social scientific approaches to understand recreational fisheries, with a view towards integration in joint models of fish-angler interactions (e.g. Johnston et al. 2010, Matsumura et al. 2019) through the lens of coupled-social ecological systems (Arlinghaus et al. 2017a). Many barriers had to be overcome to set up this multi- and, in some cases, interdisciplinary work program, most importantly learning the methods to construct and design surveys or do qualitative analysis of policy documents and running participatory processes with anglers as stakeholders. To develop capacity to be relevant in the human dimensions of recreational fisheries required intensive reading in both social and ecological sciences, attending social science conferences, and developing of a network of like-minded people, usually from political ecology, institutional analysis, social psychology, leisure studies, and micro- and macroeconomics. The drawback has always been and continues to be the lack of formal training and reading of the fundamentals of social science disciplines. Several chance events helped in the transition from a trained ecologist to what one would now call a social-ecologist with a strong interest also in the human dimensions of fisheries. For example, during his M.S. studies, where recreational fisheries as a theme was not part of any lecture or course, Arlinghaus did an internship in aquaculture in Baton Rouge, LA, USA. While visiting the library, he got exposed to major textbooks available in the USA and unknown in Germany about surveys of recreational fisheries (e.g. Pollock et al. 1994). The ecology-heavy research environment at Leibniz Institute of Freshwater Ecology and Inland Fisheries in Berlin provided the second chance event—Arlinghaus lacked a mentor on his Ph.D. committee trained in social science. This meant that he had to seek out advice from people mostly in North America that were identified through the literature, such as Robert Ditton in Texas or Wolfgang Haider in Vancouver, both deceased now. Some of these people and their students became long-time collaborators. Clearly, not being trained in the theory and methods of social science meant errors in survey design and analysis were made, opportunities to use angler samples to ask more fundamental questions about human behavior were missed, and the imposter syndrome was constantly present. Cooperating intensively throughout the career with experts trained in economics, psychology, or outdoor recreation, however, helped to solve some of the challenges, but it was important to at some point accept that one is working in applied sciences of fisheries, and there is no expectation that the research makes an important conceptual advance in fundamental social science. But the struggles have remained as ecology-trained colleagues continued to express discomfort with the social science approaches, sometimes considering it "inferior" science to natural science or actively working against supporting the social scientific research "tradition" in the institute. Arlinghaus also got well-intentioned, but destructive advice after the social science Ph.D. was completed: "It is not too late to change and become a fisheries scientist." Arlinghaus did not listen and took the risk and it ultimately paid off. Today, social-ecology is an established field in conservation and environmental sciences and in fisheries. Nonetheless, the struggle with grant applications by funders of fundamental science and in hiring and promotion decisions continue. Arlinghaus' research profile does not fit pure ecology and does not fit any pure social science discipline, which is something the new generation will most likely also struggle with to some degree when embracing interdisciplinarity.

Case Study 2. The conservation physiology of fish

One of us (Cooke) has been involved in helping to define the nascent discipline of conservation physiology (Wikelski and Cooke 2006). Although in some ways this could be celebrated as a "success" in terms of bridging disciplines as described above, there were certainly many challenges and

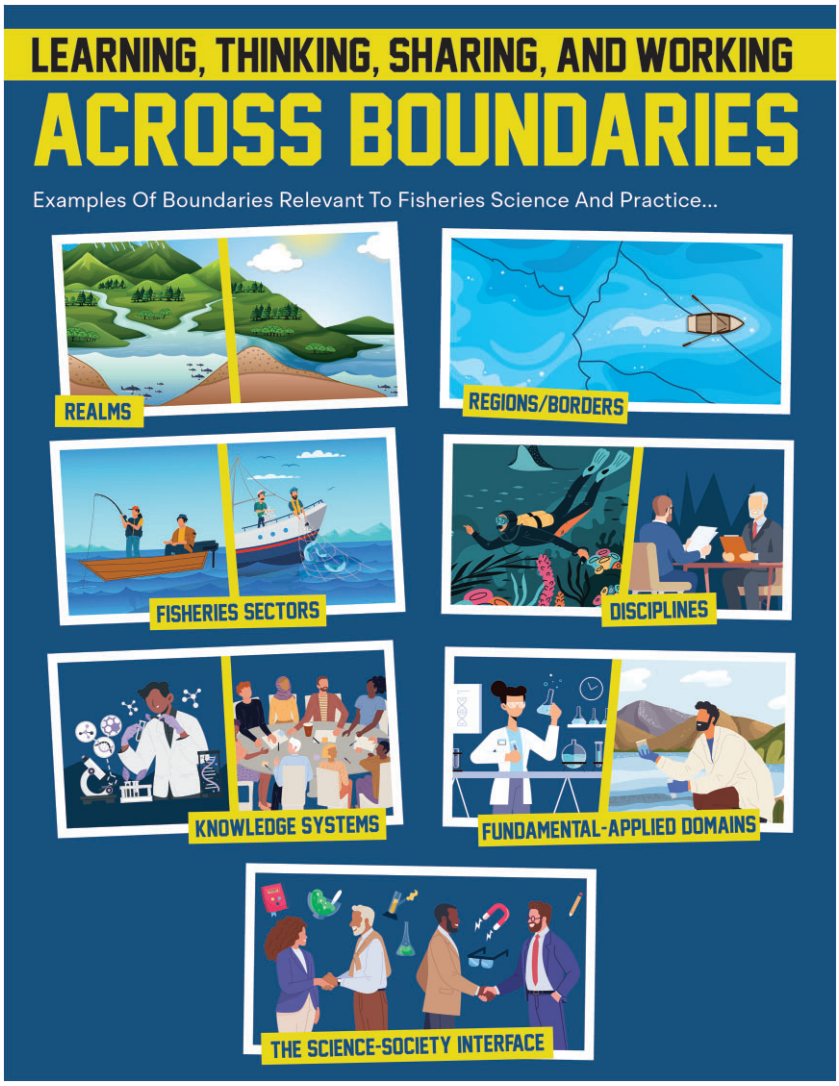

Figure 2 Conceptual diagram illustrating the boundaries that have been crossed by Cooke and Arlinghaus in the context of fisheries science and practice. Credit: Figure produced under contract by Maria at Techmint1 via Fiverr.

some of those persist today. First was some level of hesitancy that we were simply reinventing the wheel. For example, going back decades Rachel Carson espoused the importance of using physiological methods to reveal toxicology pathways underpinning raptor reproductive failure. Were we simply renaming something that already existed? We believed we were doing much more than that with a particular focus on creating a community of practice. However, that community was largely dominated by scientists. Then and now, we struggle with demonstrating the relevance of physiological research to managers and decision-makers (Cooke and O'Connor 2010). Why study mechanisms when what we really need to do is protect or restore wildlife populations? For good reason, we have argued that mechanisms enable one to focus on the pathways of effect and thus select management interventions that are working on the correct "lever" (Cooke et al. 2023). A survey of conservation physiologists revealed i.e. a common concern (Madliger et al. 2021) amplified by the fact that physiology is almost entirely absent from conservation conferences (Madliger et al. 2017) and other forums where there is potential to demonstrate or discuss the intersection between physiology and conservation and engage with managers. Establishing relationships with fisheries managers and co-developing research questions has proved somewhat effective for helping to jointly determine if and when physiology is the right tool for the job. As someone who does this work on fish, Cooke has at times struggled to find funding for conservation physiology projects. Failures in that realm have cost time and slowed down progress. Like Arlinghaus, Cooke has also struggled with imposter syndrome given that physiology is such a diverse topic that brings in immunology, endocrinology, energetics, and genomics, just to name a few. How can one possibly know or do all of that and connect those concepts with conservation? To overcome that barrier, Cooke has embraced collaboration and, in doing so, learned more about those topics from subject-matter experts. That is, an important lesson—one can't do it alone! However, Cooke also admits to having played it safe at times—perhaps not taking as many risks as one could or should have. Cooke often finds himself leaning on methods or techniques that are understood or embraced by managers rather than what might be the most scientifically defensible or novel approach. What is clear is that this journey has not been linear and nearly 20 years after publishing some of his first work in this space, challenges with this

Table 1 Summary of guidance for trainees and early career professionals for engaging in boundary crossing based on our experiences and informed by Kelly et al. (2019), Nyboer et al. (2023), and Shellock et al. (2023).

Guidance
• Read and think broadly and beyond your own discipline.
• Go to seminars/presentations/conferences that are outside of your normal learning community.
• Embrace concepts from different disciplines into your own work.
• Exercise intellectual humility recognizing it is impossible to know or do it all.
• Build/join diverse teams, take the time to listen to each other, and engage in collaborative teamwork.
• Find support from diverse mentors with experiences that extend beyond the academy.
• Maintain an open mind with a willingness to listen, learn, and adapt.
• Treat others with respect and embrace the value of diverse perspectives, knowledge systems, scholarly domains, and cultures.
• Be patient—crossing boundaries does not happen quickly. If you run into a barrier, be persistent if you think you are generally on right track.
• Celebrate successes and acknowledge those that helped.
• Be purposeful in deciding when to work across boundaries—it is not always the most appropriate approach or necessary.
• Enjoy!

More detailed treatments of that topic are available in the aforementioned references.

intersection between conservation and physiology continue. Not only does this highlight challenges with working across disciplinary boundaries but also working at the interface between science and application.

Conclusions

Based on our own experiences of >20 years of interdisciplinary fisheries research and learning, we posit that the crossing of existing boundaries can be useful, enriching, and impactful (Fig. 2). Going into new terrain is always uncertain. However, armed with passion, the right team, and sufficient funding, it can and will be productive and may yield transformational change that would otherwise not be possible. Clearly, boundary crossing comes with some costs and may be resented by some colleagues, departments, and people in civil society. There are a variety of institutional barriers in place that make such work inherently challenging but fortunately there are ways in which these can be overcome (Blythe and Cvitanovic 2020, Nyboer et al. 2023, Shellock et al. 2023). Needless to say, one has to be prepared to not always achieve what one attempts to achieve (especially on expedited timelines) and to show perseverance to continue on the path chosen. A major benefit that arises from boundary crossing is the potential for immense novelty (in terms of discovery and solutions), and it is this novelty and impact that has been the fuel for our motivation. Clearly, what has worked for us may not work for others (especially given unique challenges that may be faced by individuals that do not have the same privilege as we do), but we can state with confidence that for us the crossing of boundaries has been instrumental and has shaped our thinking and what we are as scholars, mentors, citizens, and parents. Trainees and other early career professionals undoubtedly encounter additional challenges as they navigate educational systems and employment opportunities that may not fully enable boundary crossing (see Kelly et al. 2019, Nyboer et al. 2023, and Shellock et al. 2023; for guidance for early career professionals related to boundary crossing; summarized in Table 1). We therefore recommit our efforts to be allies and champions for others wishing to engage in boundary crossing and embrace the notion that boundary crossing needs to be reframed in the context of equity, diversity, and inclusion (Bradshaw 2021). We recognize that some scholars have gone so far as to embrace the concept of "boundary breaking" rather than boundary crossing in an attempt to emphasize the gravity of the challenge yet also the magnitude of benefit that can come from doing so (Kidron and Kali 2015). At this point, it is difficult for us to ascertain if we have truly "broken" any boundaries, but we look forward to the next chapters of our careers where we will certainly continue to work across boundaries when and where it makes sense to do so and encourage and support others interested in doing the same.

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Author contributions

S.J.C. and R.A. jointly conceived the idea, wrote the paper, and edited the final manuscript.

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Data availability

This is a perspective article so there are no data to share.

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