Success factors for inter- and transdisciplinary research.
Lessons from a decade of studies on invasive aquatic species.

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All authors conceptualized the aims and drafted the text, performed review and editing, LB and PBH collected the input-output data, IAK curated the data, AN and IAK prepared the figures, PBH & IAK coordinated the writing and submission, PBH oversaw project administration and funding acquisition.

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Keywords

non-native species, environmental management, research management, interdisciplinary, aquatic ecology, implementation

Abstract

Ecological research towards environmental management occupies a unique and challenging realm, as it resides at the crossroads of societal needs and the realities of academic research. In this realm, research projects face fundamental challenges in meeting calls for stakeholder involvement and local applicability whilst supporting academic careers through the accumulation of academic deliverables.

Here, we address such fundamental questions using a 12-year, inter- and transdisciplinary research project on the management of an invasive fish species in central Europe as a case study. After demonstrating the scope and outputs of the project, we distill the factors promoting the success of the project across the political, administrative, societal, institutional, team, and personal level.

We believe our findings are broadly applicable for a variety of long-term inter- and transdisciplinary projects in the realm of environmental management. We are confident that our retrospective on the project's challenges can help policy makers as well as research funders to develop more effective funding policies and to reassess existing evaluation criteria of similar projects.

Introduction

Research activities that gather data for environmental management strategies occupy a unique and challenging realm. The expectations of researchers, funders, and stakeholders with regards to research objectives, scientific rigor, and communication are often distinct (Lawrence et al. 2022). Society and policy usually call for swift progress and prefer unequivocal, locally obtained results, which misaligns with the more measured pace of scientific investigations, their inherent goal of producing academic deliverables for scientific careers and funding agencies, their reliance on larger-scale observations, and their intention to advance scientific knowledge. Thus, taking the time to engage with a diversity of perspectives and disciplinary schools of thought is essential in the production of practical knowledge that is applicable to environmental management.

The field of invasion biology is a particularly rich source of research projects that also aim to inform environmental management. Within this domain, the co-production of knowledge and the integration of natural and social science disciplines represent the state of the art. Invasion biology is a domain in which socio-ecological knowledge generation systems are particularly frequent, because invasive species serve as nucleation points for novel interactions between nature and society (Kemp et al. 2017). Procedural insights obtained from invasion biology projects may therefore offer valuable lessons for funding agencies that are active in this area and may provide conservation managers with a deeper understanding of the temporal and group dynamics and requirements of applied research projects. Invasion biology projects may also serve as compelling examples on how to stimulate discussions and foster comprehension among the environmental leaders, funders, and researchers of tomorrow.

Here, we examine an exemplary case of a problem-driven, multi-year, inter- and transdisciplinary research initiative. Our project exemplifies how science, practice, and policy can harmoniously converge to achieve a shared goal while accounting for particulate needs, and how its learnings can extend beyond a monodisciplinary project's success. The account thus encompasses a detailed description of the context, a description of the input in terms of human and financial resources (**Fig. 1**), a comprehensive overview of the outcomes across three sectors (**Fig. 2**), a description of the contribution of stakeholders to key results (**Fig. 3**) and most crucially, a set internal and external success factors for id/td projects, from political system to personal values of team members, retrospectively distilled from the project (**Table 1**). Our main objective is to assist scientists planning socio-ecological systems research by sharing factors that foster project success. In addition, the account can be used as a teaching example for lecturers and students in the field of environmental management.

The specific project under consideration unfolded in Switzerland over the span of a decade, from 2012 to 2022, and focused on invasive fish. The inter- and transdisciplinary initiative "Non-native goby species in Switzerland – Measures to control and minimize their impact" aimed to address the challenges posed by invasive gobies entering the country's water bodies. The project was sparked by the detection of invasive gobies in the Rhine in Basel in 2011 during routine governmental monitoring of juvenile fish along the riverbanks. The observation was brought to the attention of the research group Man-Society-Environment (MGU), which was well known at the time for its transdisciplinary projects on declining fish catches in Switzerland (Burkhardt-Holm und Zehnder 2018; Burkhardt-Holm et al. 2005). Subsequent discussions between management, administration and the research group revealed a shared concern regarding the upstream spread of these fish beyond the detection

site. Consequently, local researchers, regional stakeholders and federal administration launched a collaborative initiative to elucidate the ecological context of the invasion and to develop measures to stop further dispersal.

The primary objectives of the joint project were as follows:

- **Find the source**: identify origin and introduction pathways of Ponto-Caspian gobies to Basel.
- **Monitor the population**: follow local population dynamics and the expansion of geographical distribution.
- **Understand dispersal**: uncover natural and anthropogenic factors facilitating dispersal beyond the introduction site
- **Assess impact**: evaluate the impact of the invasion on the native fauna
- **Devise prevention strategies**: suggest effective measures to prevent dispersal and mitigate impact.
- **Communicate and educate**: inform, raise awareness, and educate relevant target groups about the risk of human-assisted dispersal.

Below, we first present a concise overview of the project context across three interconnected levels: science, society, and policy. We then review key scientific project outcomes to illustrate how an applied environmental management project can yield both foundational scientific contributions (i.e. academic deliverables that advance careers) and contribute to the development of mitigation measures. Finally, we retrospectively distill success factors across different organizational and motivational levels (from political to personal).

Project context

The project team was characterized by diversity in terms of career-stage, disciplinary background, and affiliations. In total, 16 academics were involved in the project across 12 years, including 1 PI, 2 senior researchers, 5 postdoctoral fellows, 4 PhD students, and 4 master students, with an average of 3.7 full time equivalents across the entire project duration (**Fig. 1)**. 10 of these team members were female, and 7 males. The team additionally featured - across the entire duration, in changing composition - 24 student assistants, 2 animal care takers, 5 administrative / IT assistants, and 2 lab technicians. The disciplinary diversity is reflected in the output (see below): first and last authors of 30 peer-reviewed papers majored in aquatic ecology, limnology, genetics, molecular biology, and sustainable development, respectively. Co-authors often included students with an interdisciplinary master's degree (Sustainable development, co-taught by the faculties of social sciences, economic sciences and natural sciences and administrated by the MGU). External co-authors had affiliations in 8 different countries. An axis of diversity not represented in the team was ethnicity and the global south.

The national policy and legislation landscape on invasive species was dynamic during initial project years. In 1992, 20 years before the project started, Switzerland had signed the Convention on Biological Diversity (CBD) (United Nations 1992). In 2008, 4 years before the project started, the national fisheries ordinance was amended to mandate the prevention of the spread of and, if possible, eradication of alien fish and crustaceans, with federal administration in charge of coordination (SR 923.01, 2021) (Schweizerischer Bundesrat 24.11.1993). In 2012, when the project started, a national "biodiversity strategy" was adopted, stating the intention of Switzerland to conserve and promote biodiversity and ecosystem services for the economy and society (Bundesamt für Umwelt

BAFU 2012). In 2016, four years into the project, a national "strategy on invasive alien species" further specified national regulations and international obligations regarding invasive alien species and identified necessary measures (Bundesamt für Umwelt BAFU 2016). This context specifically drew the attention of stakeholders to the ecological significance of invasive organisms, they were prompted to act by the adoption of the respective policies and legislations and saw windows of opportunity for action at the political level.

The funding portfolio of the project was highly diverse. In total, the project used 4.4 Mio CHF, of which 3.9 Mio went into salaries, 0.3 into consumables, and 0.2 into infrastructure and devices (**Fig. 1B**). Funds were contributed by 5 different local administrations (0.36 Mio CHF), federal administration (0.4 Mio CHF), a collaborating university unit (0.2 Mio CHF), competitive research grants (0.33 Mio CHF), funding invested from a previous foundation contribution (0.39 Mio CHF), and the unit's own annual funds (2.74 Mio CHF). In addition, the project benefited from the use of the university infrastructure (offices, laboratories, seminar rooms, fish husbandry, storage) not further monetized here.

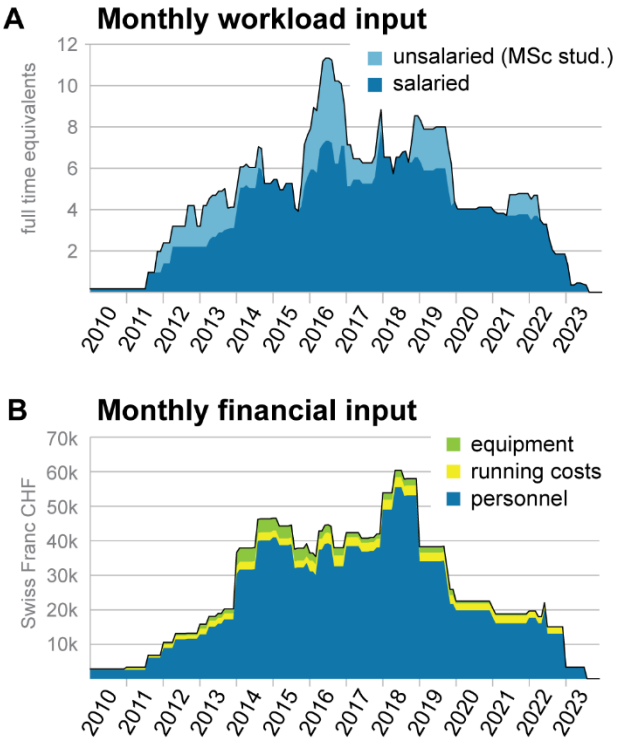

Fig. 1: Project resources. A *Workload input per month. The project was carried out with 2-6 full time equivalents of paid personnel. They were supported by 1-3 MSc students collecting data for their theses.* ***B*** *Financial input per month. During the core phase, the project required 40-50k in Swiss Francs, which mostly covered salaries.*

Stakeholders were equal partners in project design and research prioritization. A broad diversity of stakeholders (practitioners such as anglers, water sports enthusiasts, boat owners, but also commercial shipping firms, consulting firms, conservation organizations and authorities responsible for management of water courses and fisheries) were systematically identified based on published literature and personal experience and were involved as project partners on an equal footing. The intense interaction relied on methods from the social sciences, such as Futures Wheels, questionnaires, in-presence workshops, expert interviews, transdisciplinary dialogues and scenario-driven discussions. On the one hand, stakeholders contributed to data collection: For example, a network of cantonal authorities and fisher's association was informally activated to report catch numbers of invasive gobies from the very beginning. On the other hand, stakeholder input was instrumental to identify, prioritize and structure

research targets from the start. Already two months after the first report on goby occurrence, the project strategy was co-developed with fisheries association and cantonal authorities during a kick-off meeting, where participants identified the species' negative effects on native species and population control as research areas of interest (see (N'Guyen et al. 2016) for details on the transdisciplinary workshop).

Outreach activities were actively pursued with funders, society, and media. Reporting on the project to society was considered equally important as creating research output directed at an academic audience **(Fig. 2C**). Targeted outreach activities such as annual on-site stakeholder workshops allowed for personal contact with invited media representatives, who were then proactively approached with new results and invited to join field work. Further outreach activities included presentations at local fishery societies, participation in outreach for schools and the public, visits to association headquarters, contribution to a famous Swiss children's book series (Bieri 2018)) or the attendance of trade fairs.

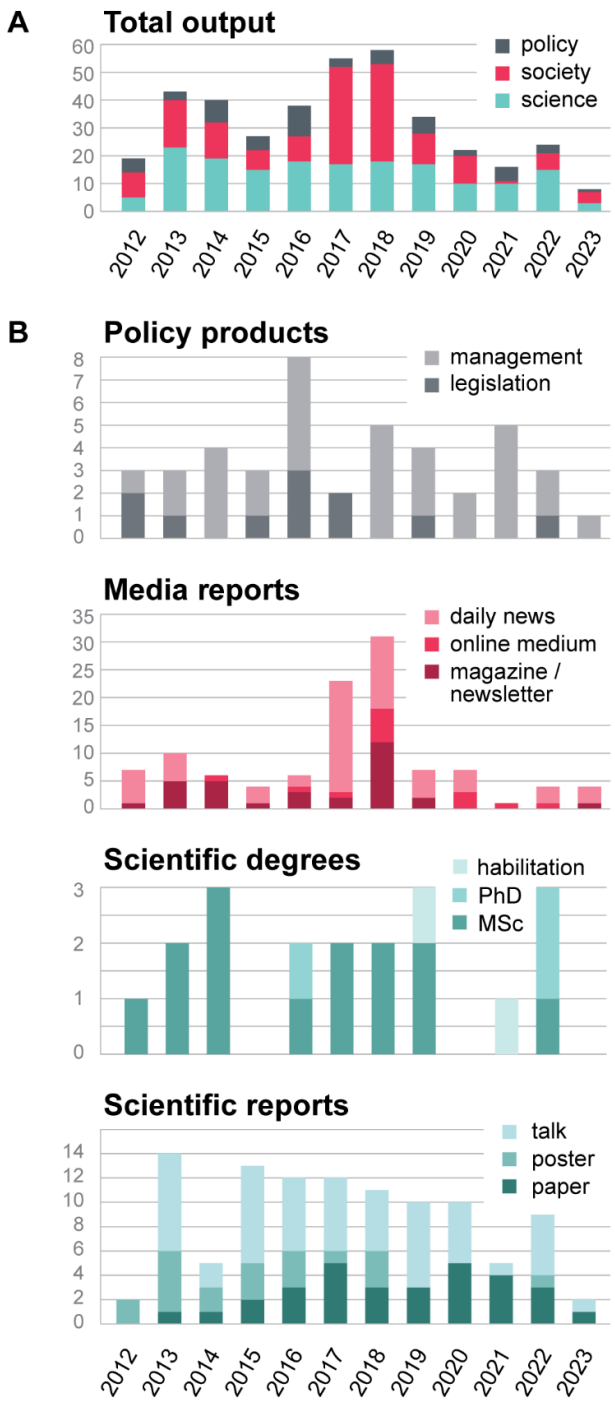

Fig. 2: Project outputs. A Total output *of the project across policy, society, and science (data from Supplemental Table 1).* ***B Policy products, Media reports, Scientific degrees, and Scientific reports.***

Scientific, career, policy and management outcomes

Overall, the **scientific output** of the project yielded 29 peer-reviewed papers, 53 conference talks, 20 posters presented at conferences, 2 habilitations, 14 master theses, and 3 PhD theses (**Fig. 1**) along 5 major research axes: method development, spread, impact, adaptation, and microplastics.

To meet the need for rapid detection of spread and impact, novel methods were needed. In a joint effort with anglers, fishers, angler associations and cantonal authorities, a wide variety of detection approaches were applied to detect the spread into connected waterbodies. Detection methods evolved from standard bait-and-trap approaches (Kalchhauser et al. 2013) to the use of spawning traps (Adrian-Kalchhauser et al. 2018; N'Guyen et al. 2018), eDNA based assays fine-tuned to the species and habitat characteristics (Adrian-Kalchhauser und Burkhardt-Holm 2016), and ultimately, methods to detect particular predation patterns of the species (Lutz et al. 2020). Ultimately, however, the dense stakeholder network was crucial to follow the spread in real time (**Fig. 3**).

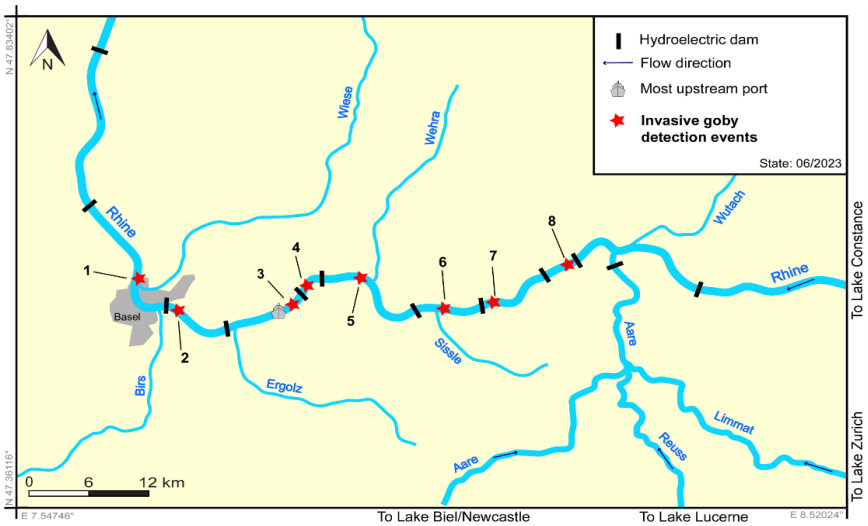

Fig. 3: Dispersal of invasive gobies along the river Rhine. *First detections upstream of the nearest hydroelectric dam (Numbered red stars) illustrate the role of the stakeholder network in monitoring the spread of invasive gobies in Switzerland.* ***1) Nov 2011*** *governmental electrofishing campaign.* ***May/Jun 2012*** *own minnow trap fishing campaign* ***2) Dec 2015*** *governmental monitoring campaign supported by local fishing communities.* ***3) Aug 2015*** *governmental monitoring campaign supported by local fishing communities.* ***4) Oct 2017*** *governmental campaign monitoring the efficiency of fish bypasses by ecobureau.* ***5) Aug 2017*** *governmental monitoring campaign supported by local fishing communities..* ***6) Sep/Nov 2018*** *snorkeler & local fisherman.* ***7) Jun 2020*** *local fishermen* ***Jun 2022*** *minnow trap campaign of cantoal authorities.* ***8) Jun 2023*** *local fishermen.*

To meet the need for evidence-based management options, impact assessments and population models were developed. Literature review efforts found that the impacts of round goby were highly dependent on the ecosystem, time scale and life stage (Hirsch et al. 2016), and thus difficult to predict. In parallel, multi-year field-data were used to parametrize modeling approaches, which underscored the immense resource requirements for post-introduction management (N'Guyen et al. 2018). Consequently, the difficult concepts of risk management,

event probabilities, and the value of precautionary management were actively communicated to stakeholders and administration, with the aim to provide recommendations, scenarios and alternatives.

To meet the need for preventative measures, dispersal-related aspects were investigated. These included active swimming, passive dispersal through boats and ships (Bussmann et al. 2021), active and passive dispersal through recreational activities, and active or passive dispersal through birds (not substantiated by the literature (Hirsch et al. 2018). Freshwater cargo ships and tankers were shown to be plausible long- and intermediate distance vectors based on population genetics (Adrian-Kalchhauser et al. 2016), egg desiccation tolerance (Hirsch et al. 2016), and use of harbour infrastructure (Bussmann und Burkhardt-Holm 2020; Bussmann et al. 2022; Adrian-Kalchhauser et al. 2017). Aspects such as personality traits (Hirsch et al. 2017) were also investigated, as was the ability of round goby to surpass in-stream barriers (Wiegleb et al. 2020; Egger et al. 2021), and the propensity for assisted dispersal by hobbyists and recreational activities (Hirsch et al. 2021). Again, the results were immediately passed on to management and administration.

The observations made during these more applied project aspects promoted basic research endeavours into adaptation and plasticity. The above results revealed and confirmed the impressive ability of invasive gobies to colonize a huge variety of anthropogenically modified habitats and thrive in novel environments. This inspired basic molecular research on short term adaptation mechanisms, resulting in the characterization of the round goby genome and mitogenome, the parental contribution in relation to temperature, and DNA methylation in relation to reproductive morphotype (Gutnik et al. 2019; Kalchhauser et al. 2013; Kalchhauser et al. 2016; Adrian-Kalchhauser und Burkhardt-Holm 2016; Adrian-Kalchhauser et al. 2017; Adrian-Kalchhauser et al. 2018; Adrian-Kalchhauser et al. 2020; Somerville et al. 2019). The surprising capacity of the species for upstream dispersal inspired basic research into hydraulic properties and the physics of swimming behaviors (Egger et al. 2021; Wiegleb et al. 2022, 2023a; Wiegleb et al. 2023b; Govindasamy et al. 2024).

Finally, inspired by the species' feeding behaviors and its ubiquitous occurrence, it was used as model for microplastic food chain studies. Specifically, we assessed the potential of invasive gobies as indicators of benthic microplastic pollution (Bosshart et al. 2020).

The project served as steppingstone for a multitude of diverse **careers**. The experience and scientific credentials gained during the research projects allowed team members to move into positions related to academic research and academic teaching, to teaching and communication positions, to applied research positions, and to positions dealing with nature-people interactions.

To promote the integration of findings into management and policy, the team actively engaged in the translation of scientific results into 31 management products, from leaflets for citizens to reports for administrative units, and 11 legislation products on the local, federal or international levels, such as parliamentary initiatives (**Fig. 1, SI**). On the political level, three interpellations, two postulates and one motion (Swiss parliamentary instruments) were submitted, requesting the protection of the native aquatic biodiversity, and investigating the threat caused by invasive gobies, respectively. These activities resulted in the adaptation of the Ordinance to the Federal Act on Fisheries, namely, the inclusion of five species of Black Sea gobies in the list of unwanted species

in the Ordinance to the Federal Act on Fisheries (*N. melanostomus, N. kessleri, N. fluviatilis, N. gymnotrachelus and Proterorhinus semilunaris*; (Schweizerischer Bundesrat 24.11.1993)). Further, the Strategy to combat invasive species was developed and implemented (Bundesamt für Umwelt BAFU 2016). Since policy relies on values, and values are developed early in life, we also took opportunities to participate in outreach to children. Of particular interest is a popular children's book series with one edition featuring gobies among other invasive species (Bieri 2018).

Success factors

The project was highly productive in terms of scientific output, career steppingstone, and applied results, and can be considered a successful example of an inter- and transdisciplinary project at the interface of science and society. Below, we attempt to deduce learnings on success factors for such projects (**Table 1**) from large-scale overarching political aspects down to the level of the individual project team member. General success factors are combined with specific examples from the project. Some additional learnings on essential factors in successful inter-and transdisciplinary research projects in applied ecology are presented below.

Time and vessels for mutual learning are essential. Projects that combine different perspectives require people who not only have highly specific skills, but also the will and expertise of sharing knowledge to impart these skills on others, and who are given the resources and time to acquire and share their skills. An interdisciplinary project needs to go beyond including scientists from the different disciplines. Time and opportunities for true knowledge transfer between the disciplines must be planned for. The ability and willingness to participate and invest in knowledge exchange should be an essential criterion for hiring decisions and deciding on collaboration initiatives.

Diversity is a two-edged sword that requires active attention. In terms of gender, the team was female-led, with a male and a female postdoc as long-term team members, and two female and one male PhD student, and several field- and lab assistants over time. Educationally**,** team members had very diverse backgrounds, and while this turned out to be essential for most of the projects, the diverging perspectives on science and the scientific method and trade also required active management. Targeted interventions of an attentive PI were essential to instill and maintain a culture of mutual appreciation. The same constellation, if managed carelessly, could have easily bred frustration and turned into a nonproductive or even problematic team culture.

ID-TD projects benefit from a certain leadership style. From the institutional perspective, any center that is supposed to work on id/td projects requires strong leadership in the sense of professional leadership capabilities and a clear leadership background. The leader needs to foster an atmosphere of trust, transparency, and mutual reliance and commitment. From the team perspective, this means that hiring processes must be a concerted team effort, and that great attention is given to the selection of fitting yet complementary candidates, with an "in dubio pro reo" mindset. Team members need to be proactive, curious, and committed to the greater cause, and the environment needs to foster intellectual freedom and maintain the playfulness of junior researchers. Our project highlights how these factors can contribute to individual research excellence and secure academic deliverables both quantitatively and qualitatively.

Stakeholder engagement is the alpha and omega. Building trust and establishing dialogue is resource-intense and emotionally taxing, as expertly laid out by other sources (N'Guyen et al. 2016; Larson und Williams) (Moon et al. 2015; Knapp et al. 2019). From the perspective of success factors identified here, is it worth the investment? This question requires a differentiated answer. Stakeholder engagement is clearly not required for excellent research in the biological sciences, nor is it an essential skill, or on its own a career advancing asset. Team members found it at times difficult to reconcile their own career aspirations with the demands of id/td research, as the latter's outcomes are not traditionally recognized as deliverables fostering an academic career. From the post-hoc perspective, however, the stakeholder-related aspects of the project-built expertise and credibility regarding interface science, and the experiences and competences acquired in the process played a role in all team members landing their current positions. It goes without saying that almost every position requires skills in interface management and all authors successfully apply skills honed during the project in their present careers.

Disagreement is a source of strength. We do not intend to convey the idea that a productive team must be perfectly aligned in their ideas and aspirations - we certainly were not always on the same page on topics such as priorities or experimental design. While we consider the diversity mentioned above as a success factor, distinct perspectives also posed challenges and did lead to intense discussions. For example, the role of aquarists was unclear for a considerable amount of time, and not everyone considered this avenue worth pursuing. Importantly, discussions were well-moderated and led to be productive, team members were free to follow their ideas even without full buy-in from all group members and were welcome to supply evidence for their hunches. In the case of aquarists, this led to the documentation of a substantial overlap between angler and aquarist groups, and a hitherto undiscovered risk or pathway for dispersal of non-native fish (Hirsch et al. 2021). A take-home therefore would be to allow and embrace true diversity in opinions, to allow room for conflict and its resolution, and to actively train the ability of a team to disagree respectfully.

Failure is a viable option. Despite the use of creative approaches, a couple of strings and ideas could not followed to their end, e.g. due to limitations with respect to available resources (e.g. systematic snorkeling for the detection of goby eggs on recreational boats, boat cleaning project, etc.), political will (e.g. managing ballast water in inland shipping), lacking consensus among relevant stakeholders (e.g. angler app for early invasion detection), changed research interests (e.g. PCR-based large-scale diet analyses) or difficulties implementing laboratory protocols (e.g. round goby population genetics). The decision to drop an approach or project, sometimes despite previous resource investments, was never held against individuals, and considered a natural part of the creative process that yields more ideas than can be realized. As a benefit, such an approach saves resources from being invested into "dead projects", and ensures they can be focused on alternative, more promising ideas.

Systemic factors have significant impact. Despite the importance of institutional settings and funding, they are often overlooked as success factors (Hoffman und Jennings 2015; Burkhardt-Holm und Zehnder 2018). Importantly, units that produce id/td content, like the host institution MGU, are often situated in-between research units, departments or faculties, and therefore face systemic challenges such as unclear supervision rights for students, or more complicated struggles for finances or affiliation than in mono-disciplinary settings. This takes resources away from the (already more time-resource intense) id/td and field-bridging work such units do. In our specific case, despite being embedded in the same department, the host institution was not authorized to offer and

supervise biology or environmental science master theses, which was a systemic disadvantage in terms of access to potentially motivated and capable students. Also, ecological and small-scale projects were continuously back-tracked at the local sequencing facility, which led to project-threatening delays in output, with one third-party funded project still not published due to the necessary shifts in project and career priorities during the waiting period. In this regard, success factors were identified by their sorely felt absence.

Efforts to reduce self-referentiality are crucial. Self-referentiality is an inherent trait of projects in ecological management. Scientifically, applied local studies and conservation projects often have poor visibility beyond the immediate study system. For example, research on invasive gobies is geographically limited to affected areas, the number of research groups in the field is low compared to, say, neuroscience or *C. elegans* research, and there are no pre-existing frameworks for (international) exchange such as e.g. global and regional Drosophila or Zebrafish meetings. Interaction with relevant peers, journals, and institutions was not a given, and required additional efforts to self-organize collaboration and exchange with other research groups (e.g. through participation in and the co-organization of mini-symposia and topic networks). It also required additional efforts to ensure relevant contributions could be communicated to an international research community at international conferences with broader scope, and to instigate international collaborations. Incidentally, the inherent self-referentiality of ecological management projects like this one underscores the importance of documented examples of process-related aspects like this paper. The post-hoc inspection of as many such projects on a meta-level hopefully will enable and support future efforts to synthesize across systems and generate broadly applicable learnings for id/td projects.

Several success factors identified relate to the team level. Since factors impacting the function and malfunction of teams have been elaborated in depth by the economic, social and psychological sciences, we will limit ourselves to the specific learnings and examples that had a major effect in our case. Firstly, the team was particularly characterized, on all hierarchical levels, by an openness towards unknown and novel approaches, and a willingness to leave personal comfort zones. Maintaining this "beginner's mind" became more challenging later in the project, when the need for productive research and data analysis to reach personal career goals became more prevalent. Secondly, a characteristic prevailing throughout the project was playfulness, which is most important because it ensures that activities are 'highly-interactive' (van Vleet und Feeney 2015). Project team members moved on into positions related to academia, academic teaching, science communication, and to the promotion of nature-people interactions. This further exemplifies how a high diversity of team members was able to return the investments made by society into the research project back to diverse parts of society.

Table 1. Success factors for id/td research projects.

Project-external factors (settings the project takes place in and the research team has no control over)		
Level	**Success Factor & Description**	**Examples & Situation in the Goby Project**
Political level	**Conducive political culture**. The local and federal political environment grounds decisions in evidence and is willing to translate research results and suggestions of experts into practice.	Swiss political culture is science-oriented and values evidence and experts' inputs. Local political representatives are in close touch with public opinion and with key stakeholders. On some occasions, this facilitated action: a prototype in-stream barrier was indeed installed. On other occasions, conflicts of interest were stronger than

		evidence: measures impacting individual freedom (e.g. boat cleaning) were not widely implemented.
	Topicality and social concord: Democratic processes and legislative initiatives in the subject area have previously set societal goals and boundaries, clarified shared values, and highlighted knowledge gaps that guide future research needs.	Coinciding with the project, the National Biodiversity Strategy (2012) and the updated Fisheries Ordinance (2021) mandated action against invasive species, while the Federal Water Protection Law and Ordinance required the renovation of fish passes to ensure fish migration (SRF 2024a). Swiss politics and administration therefore had prior knowledge regarding invasive species and associated ethical and political challenges, and there was minimal dissent on the issue's importance.
Administrative level	**Approachability**. Federal and cantonal administrations are approachable, personally reachable, and actively support the bidirectional flow of information.	Administration representatives were available for personal discussions, actively invited inputs (e.g. invitations to present the state of the art in national invasive species working groups), and communicated new regulations or changes in processes. Research plans and proposals submitted to funding could be candidly discussed with administration prior to submission. Obtaining permits for sampling was straightforward.
	Decentralized Policy Responsibility: Local (approachable) administrative units hold decision-making power over funding, collaboration, and project support. Times to decision are therefore short and collaboration efficient.	In federalist Switzerland, local authorities hold significant decision-making power as well as leeway in harm-benefit analyses and can therefore come up with workable solutions quickly. For example, the protected nase must not be disturbed during spawning season. To maintain legal requirements while enabling crucial sampling, the local fishery inspectorate was personally involved in designing and executing the field sampling to ensure conservation goals and research needs were both met.
	Diverse Funding Landscape: Diverse funding opportunities are available across the axes of applied to basic research, of short-term activities to multi-year stipends, and of private to public funders.	The 10-year course of the project was supported by a colorful diversity of grants supporting both fundamental and applied research. For instance, the Swiss National Science Foundation funded work on characterizing aspects of the round goby genome, while a consortium of cantonal funds supported an applied study on the role of recreational boating in round goby translocation.
Societal level	**Consensus culture:** The societal and political culture is used to dialogue and compromise, attempts to find consensus when facing emerging challenges, and listens to scientific evidence.	In Switzerland, a deeply rooted culture of dialogue, compromise, and consensus seeking yields broadly accepted solutions, even when policies have conflicting goals. For example, the water protection law requires all waterways to be passable for all fish species by 2030, while the national strategy on invasive alien species calls for barriers to the spread of invasive species, which led to solution-oriented discussions between policymakers, administrators, and scientists to strike an acceptable balance. While a legal mandate to clean boats did not find support (due to a very high regard for personal autonomy), in a practical compromise, scientists, water sports clubs, and authorities collaborated to install a voluntary cleaning station.
	Value of study object or associated resources: Research projects targeting a subject that has high value to society (e.g. economical, recreational, symbolic) benefit from public attention and can create interest and discourse for the problems and solutions at hand.	Switzerland harbors the springs of four major European watersheds. The protection of water bodies is a national priority, both for their ecological importance and symbolic value. Significant resources are invested in aquatic conservation, such as salmon restocking programs. Public interest in water and nature-related issues is strong, which in our case lead to invited talks at stakeholder organizations, media coverage in newspapers and topical journals, and facilitated project funding.

	Established topical networks: Pre-existing stakeholder networks offer opportunities to connect science with society, and advance research by providing access to locations, resources, local knowledge, and feedback on proposed measures. However, tight-knit club-like networks can also be challenging to access for outsiders.	Switzerland features a strong culture of civic participation through associations, clubs, and collaborative structures. This led to institutionalized interest in the research project and facilitated the integration of members of the public in transdisciplinary processes (N'Guyen et al., 2016, Hirsch et al., 2020). At the same time, this created a bias towards individuals organized in such associations. Also, reaching groups who are rarely organized in formal associations, e.g. aquarists, proved challenging, and entering networks dominated by senior males was at times daunting for junior female team members.
Institutional level	**Institutional commitment and structures**: id/td projects benefit from academic evaluation systems that recognize societal impact and offer access to dedicated structures such as knowledge brokers and digital platforms. Other beneficial institutional aspects are training opportunities in communication, facilitation, and stakeholder engagement, and flexible administrative and legal frameworks that support unconventional project setups.	The institute hosting the project is also hosting an interdisciplinary master's program (Master of Sustainable Development). This facilitated the contact between natural and social scientists as well as economists and the recruitment of students from different backgrounds with an interest in projects that cross disciplinary boundaries. It also reliably receives a stable amount of personnel funds, disposable funds, and equipment funds from the department it is associated with, which facilitates initial explorations prior to funding acquisition.
Other	**The Perfect Storm of Opportunity:** The convergence of favourable conditions can create powerful momentum, and the combined effect of several success elements then exceeds what any single factor could achieve alone.	Two such dynamically interacting factors in the project were the geographical proximity between research objects, stakeholders and researchers, the strong identification with affected water bodies, and the presence of exceptionally engaged individuals in decision-making capacities.
Project-internal factors (settings and decisions the research team has control over)		
Level	**Success Factor & Description**	**Examples & Situation in the Goby Project**
Political level	**Awareness of Political Context:** Actively aligning research plans and activities with national and international strategies, policies, and regulations, and an awareness of shifting priorities, increases the likelihood that research findings will be considered by policymakers and practitioners, and translated into science-based action.	The project was designed with careful consideration of key regulations related to invasive species and water management in Switzerland (see above), ensuring that research strategies and experimental approaches were aligned with practical policy needs. From the outset, the team maintained a strong awareness of ongoing policy developments, and all members were expected to stay informed and responsive to the evolving regulatory context.
	Grooming the science-policy interface: A consistent engagement at the science-policy interface and proactive management of good connections with governmental and administrative bodies fosters mutual trust and saves time during planning and implementation of new projects.	Previous activities of the project lead at the science-policy interface allowed the project to build on existing relationships and zones of contact between science and politics. Consequently, the project started from a high level of trust and recognition by authorities, as exemplified by multiple invitations to consult on policy matters and contributions to submission of parliamentary interventions, which in turn became important drivers of the project's visibility and influence.

Administrative Level	**Process awareness:** All project partners must be able and willing to engage in open and upfront communication about their own explicit and implicit expectations and limitations of scientific methods. For example, policymakers tend to seek quick, definitive high certainty answers that science cannot reliably provide.	Limited resources and data made a full scientific risk assessment unfeasible. The team thus developed recommendations for preventive measures coupled with scenarios related to non-implementation. During stakeholder events, participants then used Likert scales to assess the likelihood of success of proposed measures and thus prioritized actions despite uncertainties.
Societal level	**Cultural awareness:** Scientists are often immigrants to their country of residence and work. An awareness and open discussion of cultural norms, communication styles, and institutional practices improves science-society exchanges.	Cultural differences and the need for approaches that would not be everyone's primary personal choice were openly discussed and reflected. This included for example the introduction to the concept of the professional Apero as key ingredient of informal knowledge exchange and trust building.
Institutional level	**Institutional support:** units doing id/td research contribute to different reputation aspects than units performing monodisciplinary science. Continuous efforts to maintain institutional commitment are key for long-term interface projects.	The team took active steps to raise the visibility and to underline the relevance of their work within the framework of available vessels. This included active participation in department meetings, presentation of results at colloquia, engagnement as postdoc representative, or participation in lecture series and in outreach.
	Teaching feedback: Integrating id/td research projects into teaching enhances theoretical grounding through engagement with the literature, supports student recruitment, and benefits from fresh input and perspectives contributed by students.	The goby project was repeatedly used as an example in various courses about ethics, ecology, and aquatic biology. It presented a tangible case of high interest for students in the Master of Sustainable Development considering the relevance of invasive species across social, economic, and scientific dimensions.
Project level	**Shifting Priorities and Resource Flexibility:** All research projects start with a plan, but id/td projects are more likely than others to change course. The ability to accept shifted priorities and to adapt to changed resource availability is therefore key. This includes aspects of team composition (individual strengths, interests, and limitations) that may not align with initial goals, and require frequent strategic checkpoints.	Project components related to ballast water and boat cleaning turned out smaller in scope than originally planned, despite very clear relevance, partly due stakeholders' opinions and partly due to obstacles related to data collection and accessibility. Another potentially important line of inquiry related to anti-fouling agents was not pursued despite an initial planning and research stage due to a lack of resources.
	Proactive Networking: Treating networking as an integral project component and a primary task fosters mutual understanding, builds trust, and helps align goals and expectations. By embedding networking into the project's structure from the beginning, researchers can better identify synergies, anticipate challenges, and respond flexibly to emerging opportunities.	The project emphasized proactive, structured networking with stakeholders from the outset. Research priorities were defined jointlyto consider both scientific goals and practical needs. Tailored annual reports addressed stakeholders' evolving questions and priorities, annual exchange events further strengthened these relationships and offered space to share updates and actively solicit feedback and input. The resulting two-way dialogue enriched the research and its real-world application.
	Community Engagement Beyond Formal Roles: Building genuine connections with stakeholder communities leads to deeper insights, unexpected collaborations, and builds trust. Taking the time to engage informally, often	Spending time with local fishing and boating communities and seeking out informal, unplanned encounters led to several unexpected yet highly productive collaborations on boat motor use and ballast water systems, and yielded access to sampling sites, samples, and sighting reports. These commitments were not solicited by team members, but were always welcomed. Team members were always

	outside regular working hours can be resource-intensive and personally demanding but is quite essential in id/td research.	encouraged to seize interaction opportunities when they arose, with travel expenses reimbursed and time investments recognized.
Team level	**Active management of team diversity.** Diversity in disciplinary backgrounds, professional expertise, and personal perspectives is at the core of id/td research but must be actively managed. Beyond the conscious assembly of complementary skills and viewpoints, this includes deliberate efforts to create an environment where conflict is recognized, tackled, and managed so that differences can become a source of creativity rather than of misunderstanding and frustration.	Conflict was allowed, but simultaneously, team-building exercises cultivated mutual appreciation for the contrasting disciplinary backgrounds. Regular opportunities for meta-level reflection on team dynamics, e.g. distinct needs in terms of support and milestones (e.g. the differing scopes and timeframes for master and PhD theses) existed. Annual two-day retreats provided dedicated time slots to discuss contrasting perspectives and collaboration processes.
	Integrated career planning: In id/td projects, it is essential to ensure that individual career development is not compromised by the overall project strategy. To address this, an open and ongoing dialogue within the team about career goals, publication strategies, and the specific demands of ID/TD research is crucial.	A practical approach adopted by the team was inclusive co-authorship. Team members were actively invited to contribute and offered co-authorship opportunities, provided their involvement met ethical authorship standards (intellectual contribution). Invitations were tailored to individual strengths and availability, such as preparing figures, conducting literature reviews, or drafting and integrating discussion sections.
	Willingness to collaborate: A collaborative culture marked by structured resource sharing, mutual support, and the recognition of diverse perspectives as beneficial is essential. A collectively positive attitude toward internal collaboration and joint problem-solving promotes success.	Senior researchers actively onboarded new team members e.g. by establishing contacts with administrative units and stakeholder networks. The team invested in internal communication infrastructure, such as shared contact tables, an wiki for knowledge sharing, and an annual two-day retreat. Information relevant for other team members, e.g. from conferences, was actively collected and shared.
Individual level	**Curiosity, Openness, and Mental Flexibility:** A mindset that embraces curiosity, intellectual freedom, and adaptability supports id/td work. The ability to maintain a "beginner's mind", for playful exploration, and the freedom of thought to treat science as both inquiry and creative process is essential. Mental flexibility, the ability to compromise, shift perspectives, and adapt plans is equally important. The ability to spot and grasp opportunities for one own's as well as colleagues' research interests also plays a role.	Team members were free to pursue unexpected or random questions and ideas. Time and resources were made available for exploratory efforts with a "try and fail" mindset. This approach led to DIY spawning trap construction, egg desiccation experiments, edibility tests, or hydraulic experiments with preserved goby. These activities generated surprising insights or, alternatively, led to rapid changes in direction, and helped build a culture of curiosity, experimentation, and innovation. This was selective on occasion and led to the loss of team members with different approaches to research.
	Transparency and awareness about career aspirations: id/td work requires time for activities other than classical academic career-advancing measures and outputs. An awareness of own needs, expectations, id/td requirements, and a proactive navigation of the associated challenges is essential.	Regular open discussions around career development and the challenges of publishing interdisciplinary work were integrated into grant planning, project design, and publication meetings and raised both by junior researchers and the PI. This ongoing dialogue enabled the team to identify tailored solutions that balanced individual career goals with the collaborative demands of ID/TD research.

Discussion

This project reviews a range of challenges and success factors for id/td research projects in applied ecology. Although the findings were derived from a specific context, we are convinced that they are valid for comparable situations, and that the success factors are robust against major contextual variations. For example, aspects of leadership and management are largely context-independent: embracing a sense of curiosity and allowing junior researchers to try, and fail, is essential for true innovation in any field. Similarly, engaging with stakeholders on a truly equal footing as a cultural success factor has already been suggested by other and more general social-science recommendations (https://transdisciplinarity.ch/en/transdisciplinarity/research-process/supporting-concepts/).

Clearly, the success factors are not sufficient on their own to ensure project success, nor are all of them essential. The line between success factors and conditions of success (sine qua non) is blurry. For example, our project highlights how a political environment that provides trust and resources for investigation is to some extent a necessary condition for the success of any management- related research project. However, some specific aspects related to this can be actively worked for. Also, the explicit and upfront consideration of conditions in future projects may lead to conscious mitigation of weaknesses, and to the intentional capitalization on strongholds, and thus may increase overall chances of project success (though in a probabilistic rather than a predictive manner).

An overarching theme is that success factors across all levels, from the political to the team level, are facets of interactivity, applied to the intellectual pursuit of truths about the living environment and its social framings. As simple as "interactivity" as a concept may seem, the described project provides a documented example of a td/id-project that depended on and benefited from this characteristic across all scales in practice.

Conflicts of interests

The authors have no relevant financial or non-financial interests to disclose.

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Literaturverzeichnis

Adrian-Kalchhauser, I.; Hirsch, P. E.; Behrmann-Godel, J.; N'Guyen, A.; Watzlawczyk, S.; Gertzen, S. et al. (2016): The invasive bighead goby Ponticola kessleri displays large-scale genetic similarities and small-scale genetic differentiation in relation to shipping patterns. In: *Molecular ecology* 25 (9), S. 1925–1943. DOI: 10.1111/mec.13595.

Adrian-Kalchhauser, Irene; Blomberg, Anders; Larsson, Tomas; Musilova, Zuzana; Peart, Claire R.; Pippel, Martin et al. (2020): The round goby genome provides insights into mechanisms that may facilitate biological invasions. In: *BMC biology* 18 (1), S. 11. DOI: 10.1186/s12915-019-0731-8.

Adrian-Kalchhauser, Irene; Burkhardt-Holm, Patricia (2016): An eDNA Assay to Monitor a Globally Invasive Fish Species from Flowing Freshwater. In: *PloS one* 11 (1), e0147558. DOI: 10.1371/journal.pone.0147558.

Adrian-Kalchhauser, Irene; Svensson, Ola; Kutschera, Verena E.; Alm Rosenblad, Magnus; Pippel, Martin; Winkler, Sylke et al. (2017): The mitochondrial genome sequences of the round goby and the sand goby reveal patterns of recent evolution in gobiid fish. In: *BMC genomics* 18 (1), S. 177. DOI: 10.1186/s12864-017-3550-8.

Adrian-Kalchhauser, Irene; Walser, Jean-Claude; Schwaiger, Michaela; Burkhardt-Holm, Patricia (2018): RNA sequencing of early round goby embryos reveals that maternal experiences can shape the maternal RNA contribution in a wild vertebrate. In: *BMC evolutionary biology* 18 (1), S. 34. DOI: 10.1186/s12862-018-1132-2.

Bieri, Atlant (2018): Globi und die neuen Arten. Wenn Pflanzen und Tiere auf Weltreise gehen. Unter Mitarbeit von Daniel Frick. Zürich: Globi-Verlag (Globi Wissen, 11).

Bosshart, Sophie; Erni-Cassola, Gabriel; Burkhardt-Holm, Patricia (2020): Independence of microplastic ingestion from environmental load in the round goby (Neogobius melanostomus) from the Rhine river using high quality standards. In: *Environmental pollution (Barking, Essex : 1987)* 267, S. 115664. DOI: 10.1016/j.envpol.2020.115664.

Bundesamt für Umwelt BAFU (2012): Strategie Biodiversität Schweiz. BBl 2012 7239. Online verfügbar unter https://www.fedlex.admin.ch/eli/fga/2012/1071/de, zuletzt geprüft am 05.05.2025.

Bundesamt für Umwelt BAFU (2016): Strategie der Schweiz zu invasiven gebietsfremden Arten. Online verfügbar unter https://www.bafu.admin.ch/dam/bafu/de/dokumente/biodiversitaet/fachinfo-daten/strategie_der_schweizzuinvasivengebietsfremdenarten.pdf.download.pdf/strategie_der_schweizzuinvasivengebietsfremdenarten.pdf, zuletzt geprüft am 05.05.2025.

Burkhardt-Holm, Patricia; Giger, Walter; Güttinger, Herbert; Ochsenbein, Ueli; Peter, Armin; Scheurer, Karin et al. (2005): Where have all the fish gone? The reasons why fish catches in Swiss rivers are declining. In: *Environmental science & technology* 39 (21), 441A-447A. DOI: 10.1021/es053375z.

Burkhardt-Holm, Patricia; Zehnder, Alexander J.B. (2018): Fischnetz : Assessing outcomes and impacts of a project at the interface of science and public policy. In: *Environmental Science & Policy* 82, S. 52–59. DOI: 10.1016/j.envsci.2018.01.010.

Bussmann, Karen; Burkhardt-Holm, Patricia (2020): Round gobies in the third dimension – use of vertical walls as habitat enables vector contact in a bottom-dwelling invasive fish. In: *AI* 15 (4), S. 683–699. DOI: 10.3391/ai.2020.15.4.09.

Bussmann, Karen; Hirsch, Philipp; Burkhardt-Holm, Patricia (2021): Invasive goby larvae: First evidence as stowaways in small watercraft motors.

Bussmann, Karen; Hirsch, Philipp Emanuel; Lehmann, Moritz F.; Burkhardt-Holm, Patricia (2022): Differential habitat use of a notorious invasive fish, the round goby, in a translocation-relevant system. In: *Ecology and evolution* 12 (8), Artikel e9202. DOI: 10.1002/ece3.9202.

Egger, Bernd; Wiegleb, Joschka; Seidel, Frank; Burkhardt-Holm, Patricia; Emanuel Hirsch, Philipp (2021): Comparative swimming performance and behaviour of three benthic fish species: The invasive round goby (Neogobius melanostomus), the native bullhead (Cottus gobio), and the native gudgeon (Gobio gobio). In: *Ecology of Freshwater Fish* 30 (3), S. 391–405. DOI: 10.1111/eff.12592.

Govindasamy, Nandhakumar; Rauter, Georg; Seidel, Frank; Burkhardt-Holm, Patricia; Hirsch, Philipp E.; Wiegleb, Joschka (2024): Does swimming at the bottom serve as a hydraulic advantage for benthic fish Neogobius melanostomus Pallas (1814) in flowing water? In: *Biology open* 13 (11). DOI: 10.1242/bio.060533.

Gutnik, Silvia; Walser, Jean-Claude; Adrian-Kalchhauser, Irene (2019): Long-read sequencing of benthophilinae mitochondrial genomes reveals the origins of round goby mitogenome re-arrangements. In: *Mitochondrial DNA Part B* 4 (1), S. 408–412. DOI: 10.1080/23802359.2018.1547133.

Hirsch, Philipp E.; Adrian-Kalchhauser, Irene; Flämig, Sylvie; N'Guyen, Anouk; Defila, Rico; Di Giulio, Antonietta; Burkhardt-Holm, Patricia (2016): A tough egg to crack: recreational boats as vectors for invasive goby eggs and transdisciplinary management approaches. In: *Ecology and evolution* 6 (3), S. 707–715. DOI: 10.1002/ece3.1892.

Hirsch, Philipp Emanuel; N'Guyen, Anouk; Burkhardt-Holm, Patricia (2021): Hobbyists acting simultaneously as anglers and aquarists: Novel pathways for non-native fish and impacts on native fish. In: *Aquatic Conservation* 31 (6), S. 1285–1296. DOI: 10.1002/aqc.3557.

Hirsch, Philipp Emanuel; N'Guyen, Anouk; Muller, Roxane; Adrian-Kalchhauser, Irene; Burkhardt-Holm, Patricia (2018): Colonizing Islands of water on dry land—on the passive dispersal of fish eggs by birds. In: *Fish and Fisheries* 19 (3), S. 502–510. DOI: 10.1111/faf.12270.

Hirsch, Philipp Emanuel; Thorlacius, Magnus; Brodin, Tomas; Burkhardt-Holm, Patricia (2017): An approach to incorporate individual personality in modeling fish dispersal across in-stream barriers. In: *Ecology and evolution* 7 (2), S. 720–732. DOI: 10.1002/ece3.2629.

Hoffman, Andrew J.; Jennings, P. Devereaux (2015): Institutional Theory and the Natural Environment. In: *Organization & Environment* 28 (1), S. 8–31. DOI: 10.1177/1086026615575331.

Kalchhauser, Irene; Kutschera, Verena E.; Burkhardt-Holm, Patricia (2016): The complete mitochondrial genome of the invasive Ponto-Caspian goby Ponticola kessleri obtained from high-throughput sequencing using the Ion Torrent Personal Genome Machine. In: *Mitochondrial DNA. Part A, DNA mapping, sequencing, and analysis* 27 (3), S. 1887–1889. DOI: 10.3109/19401736.2014.971272.

Kalchhauser, Irene; Mutzner, Peter; Hirsch, Philipp; Burkhardt-Holm, Patricia (2013): Arrival of round goby Neogobius melanostomus (Pallas, 1814) and bighead goby Ponticola kessleri (Günther, 1861) in the High Rhine (Switzerland). In: *BIR* 2 (1), S. 79–83. DOI: 10.3391/bir.2013.2.1.14.

Kemp, Catherine; van Riper, Carena J.; BouFajreldin, Lama; P. Stewart, William; Scheunemann, Jarrod; van den Born, Riyan J. G. (2017): Connecting human–nature relationships to environmental behaviors that minimize the spread of aquatic invasive species. In: *Biol Invasions* 19 (7), S. 2059–2074. DOI: 10.1007/s10530-017-1418-0.

Knapp, Corrine Nöel; Reid, Robin S.; Fernández-Giménez, María E.; Klein, Julia A.; Galvin, Kathleen A. (2019): Placing Transdisciplinarity in Context: A Review of Approaches to Connect Scholars, Society and Action. In: *Sustainability* 11 (18), S. 4899. DOI: 10.3390/su11184899.

Larson, S.; Williams, LJ.: Monitoring the success of stakeholder engagement: Literature review. In: People, communities and economies of the Lake Eyre Basin, S. 251–298. Online verfügbar unter https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=8933280d9d9d789c68fddae5b4600b64dee8a36c.

Lawrence, Mark G.; Williams, Stephen; Nanz, Patrizia; Renn, Ortwin (2022): Characteristics, potentials, and challenges of transdisciplinary research. In: *One Earth* 5 (1), S. 44–61. DOI: 10.1016/j.oneear.2021.12.010.

Lutz, Elisabeth; Hirsch, Philipp Emanuel; Bussmann, Karen; Wiegleb, Joschka; Jermann, Hans-Peter; Muller, Roxane et al. (2020): Predation on native fish eggs by invasive round goby revealed by species-specific gut content DNA analyses. In: *Aquatic Conservation* 30 (8), S. 1566–1577. DOI: 10.1002/aqc.3409.

Moon, Katie; Blackman, Deborah A.; Brewer, Tom D. (2015): Understanding and integrating knowledge to improve invasive species management. In: *Biol Invasions* 17 (9), S. 2675–2689. DOI: 10.1007/s10530-015-0904-5.

N'Guyen, Anouk; Hirsch, Philipp E.; Adrian-Kalchhauser, Irene; Burkhardt-Holm, Patricia (2016): Improving invasive species management by integrating priorities and contributions of scientists and decision makers. In: *Ambio* 45 (3), S. 280–289. DOI: 10.1007/s13280-015-0723-z.

N'Guyen, Anouk; Hirsch, Philipp E.; Bozzuto, Claudio; Adrian-Kalchhauser, Irene; Hôrková, Kristína; Burkhardt-Holm, Patricia (2018): A dynamical model for invasive round goby populations reveals efficient and effective management options. In: *Journal of Applied Ecology* 55 (1), S. 342–352. DOI: 10.1111/1365-2664.12934.

Schweizerischer Bundesrat (24.11.1993): Verordnung zum Bundesgesetz über die Fischerei. VBGF, vom 2021. Online verfügbar unter https://www.fedlex.admin.ch/eli/cc/1993/3384_3384_3384/de, zuletzt geprüft am 07.06.2024.

Somerville, Vincent; Schwaiger, Michaela; Hirsch, Philipp E.; Walser, Jean-Claude; Bussmann, Karen; Weyrich, Alexandra et al. (2019): DNA Methylation Patterns in the Round Goby Hypothalamus Support an On-The-Spot Decision Scenario for Territorial Behavior. In: *Genes* 10 (3). DOI: 10.3390/genes10030219.

United Nations (1992): Convention on Biological Diversity. CBD. Online verfügbar unter https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-8&chapter=27&clang=_en, zuletzt geprüft am 05.05.2025.

van Vleet, Meredith; Feeney, Brooke C. (2015): Play Behavior and Playfulness in Adulthood. In: *Social & Personality Psych* 9 (11), S. 630–643. DOI: 10.1111/spc3.12205.

Wiegleb, Joschka; Hirsch, Philipp E.; Egger, Bernd; Seidel, Frank; Burkhardt-Holm, Patricia (2020): Flow field-induced drag forces and swimming behavior of three benthic fish species. In: *Limnologica* 84, S. 125812. DOI: 10.1016/j.limno.2020.125812.

Wiegleb, Joschka; Hirsch, Philipp E.; Seidel, Frank; Rauter, Georg; Burkhardt-Holm, Patricia (2022): Flow, force, behaviour: assessment of a prototype hydraulic barrier for invasive fish. In: *Hydrobiologia* 849 (4), S. 1001–1019. DOI: 10.1007/s10750-021-04762-z.

Wiegleb, Joschka; Hirsch, Philipp E.; Seidel, Frank; Rauter, Georg; Burkhardt-Holm, Patricia (2023a): Round goby [Neogobius melanostomus (Pallas, 1814)], gudgeon (Gobio gobio L.) and bullhead (Cottus gobio L.) show distinct swimming patterns in a vertical slot fish pass. In: *Front. Environ. Sci.* 11, Artikel 1156248. DOI: 10.3389/fenvs.2023.1156248.

Wiegleb, Joschka; Hirsch, Philipp E.; Seidel, Frank; Rauter, Georg; Burkhardt-Holm, Patricia (2023b): Impact of hydraulic forces on the passage of round goby (Neogobius melanostomus), gudgeon (Gobio gobio) and bullhead (Cottus gobio) in a vertical slot fish pass. In: *Ecology of Freshwater Fish* 32 (2), S. 416–430. DOI: 10.1111/eff.12696.