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PRACTITIONER'S PERSPECTIVE

Fish and chips: Conservation of freshwater fish populations through an integrative multi-stakeholder approach

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Abstract

1. Rivers and their fish populations are under threat, prompting diverse conservation efforts. Effective freshwater conservation requires collaborative projects involving multiple stakeholders, including scientists, practitioners, and government agencies. Knowledge produced in these projects can be used to guide the application of evidence-based conservation actions.
2. We present a unique large-scale and long-term river and fish monitoring project at the alpine River Inn (Bavaria, Germany), where stakeholders from the private sector closely collaborate with science and governmental institutions.
3. After a first phase of implementing and assessing habitat restoration, we recently employed passive integrated transponder (PIT) technology to tag and track several 10,000 fish from diverse species. A comprehensive monitoring infrastructure comprising 34 permanent and several temporary monitoring sites across 150 river kilometres now enables the detection of fish movement patterns across main parts of the River Inn catchment. This infrastructure also includes a citizen science initiative where anglers report captured fish in scanning stations.
4. Stakeholder communication is institutionalized through the establishment of a project advisory board and an annual conference in which the major findings of the previous year are discussed and the future science and management agenda is set. Knowledge transfer also occurs through the translation of scientific findings into easy-to-follow guidelines, as well as through lectures and workshops.
5. *Synthesis and applications*. This practitioner perspective offers a template case study for integrative river restoration and fish conservation campaigns. The successful application of information into conservation actions is based on active engagement of practitioners and easy-to-follow guidelines. The approach presented herein relies on the principles of knowledge co-production and adaptive management, and is illustrated with examples that are transferable to other aquatic ecosystems.

KEYWORDS
fish conservation, fish migration, knowledge co-production, monitoring, stakeholder engagement

1 | BACKGROUND

The global biodiversity crisis is particularly evident in the impending mass extinction of freshwater fish (Su et al., 2021), which have declined by an average of 84% since 1970 (Almond et al., 2020). Although freshwater fish populations are threatened by multiple stressors, this trend can be largely attributed to anthropogenic alteration of rivers (Aarts et al., 2004; Bunn & Arthington, 2002). While the construction of instream barriers such as dams and weirs for water storage and hydropower has disrupted longitudinal connectivity and altered habitat conditions in upstream and downstream reaches (Mueller et al., 2011), the straightening of river courses and stabilization of riverbanks has resulted in the disruption of lateral connectivity between rivers and their floodplains (Tockner & Stanford, 2002). This dramatic change in river morphology is closely linked to a loss in the quantity, quality and connectivity of key aquatic habitats, and thus places enormous pressure on riverine fish populations.

To restore healthy rivers and to support freshwater fish populations, substantial conservation efforts are being undertaken, driven by international targets such as the EU Water Framework Directive (WFD), the EU Habitats Directive, the US Endangered Species Act, the US Clean Water Act, or the Australian Water Amendment ('Restoring Our Rivers') Act 2023. Efforts to conserve freshwaters are primarily aimed at restoring stream habitat quality and connectivity, but also at supporting declining fish populations through sustainable fisheries management, including supportive breeding and stocking initiatives. Although policies targeting freshwater conservation are mainly set at the national scale, the implementation of conservation measures often relies on the actions of individual practitioners at the local level. This can include legal obligations and ecological commitment of hydropower plant operators or personal motivation of angling clubs (Baker & Eckerberg, 2013; Kondolf & Yang, 2008).

However, the challenge of restoring healthy rivers and freshwater fish populations sustainably cannot be met by a single actor. It requires multiple stakeholders, such as scientists, practitioners, government agencies as well as NGOs and the wider public to engage in integrative and collaborative projects to generate the knowledge needed to support decision-making ('knowledge co-production'; Harris & Lyon, 2014), which can then be applied in evidence-based conservation actions. The principle of knowledge co-production in collaborative projects can be divided into the stages of co-design, co-development and co-delivery (Co-3D; Fleming et al., 2023), with partners usually contributing differently to each stage. Furthermore, it is highly recommended to apply a long-term adaptive monitoring approach of conservation actions to ensure their effectiveness and to mitigate the risk of unintended or adverse effects (Pander & Geist, 2013). This practice, although rarely applied, is crucial for achieving conservation goals (Westgate et al., 2013).

To date, freshwater conservation efforts are rarely strategically set over a catchment scale, still lack in many cases an accompanied scientific monitoring plan and thus a knowledge-based approach. They are also often limited to single measures at the local scale, for example the restoration of particular spawning grounds or stocking measures in a very restricted regional extent (Pander & Geist, 2013). Comprehensive and integrative conservation programmes in large rivers, covering substantial parts of the catchment and a community analysis of the fish population are rare (Geist, 2011). In addition, stakeholder involvement is often insufficient, resulting in a critical gap between science and practice (Barouillet et al., 2024). This poses a significant risk of failure to achieve conservation goals such as those defined in international policies.

Here, we present a case study of a large (over 150 river kilometres) and long-term (over 10 years) fish conservation project on the alpine River Inn (Bavaria, Germany), where stakeholders from the private sector, who are mainly in charge of the implementation of conservation actions, closely collaborate with science and governmental institutions.

2 | THE RIVER INN—A LARGE AND HEAVILY MODIFIED ALPINE RIVER

The project area covers main parts of the large alpine River Inn in Germany. This river originates in Switzerland and flows through Austria and Germany, where it finally joins the Danube River at the city of Passau (Figure 1). In the project area, the mean annual discharge varies between 305 m^3/s (Oberaudorf; www.gkd.bayern.de) and 741 m^3/s at the confluence with the Danube (Passau; www.gkd.bayern.de). The River Inn used to be a highly braided river, but due to severe anthropogenic alterations, it became a straightened single channel intensively used for hydropower generation (run-of-river power plants) with heavily stabilized riprap banks for flood protection.

Since 2012, the German section of the river is subject to an extensive restoration campaign, which aims to restore the quality and connectivity of aquatic key habitats. Restoration actions are mainly conducted by the hydropower companies VERBUND Innkraftwerke GmbH and VERBUND Grenzkraftwerke GmbH. These companies operate 12 large hydropower facilities within the project area and bear responsibility for the restoration and maintenance of habitat quality and connectivity. Measures include the restoration of fish habitats, such as substrate spawning grounds (Nagel et al., 2020) and backwaters as well as the restoration of fish migration due to the installation of fishways at each hydropower plant (Loy & Reckendorfer, 2022). Depending on the characteristics of the respective site, fishways are designed in various schemes ranging from rather technical vertical slot passes to nature-like solutions with additional habitat benefits (Nagel et al., 2021; Pander et al., 2021). In addition, migration barriers are being removed in the major tributaries and spawning grounds and juvenile habitats are restored. To directly improve populations of target species, several supportive breeding and stocking initiatives, conducted by angling clubs and governmental institutions, are in place.

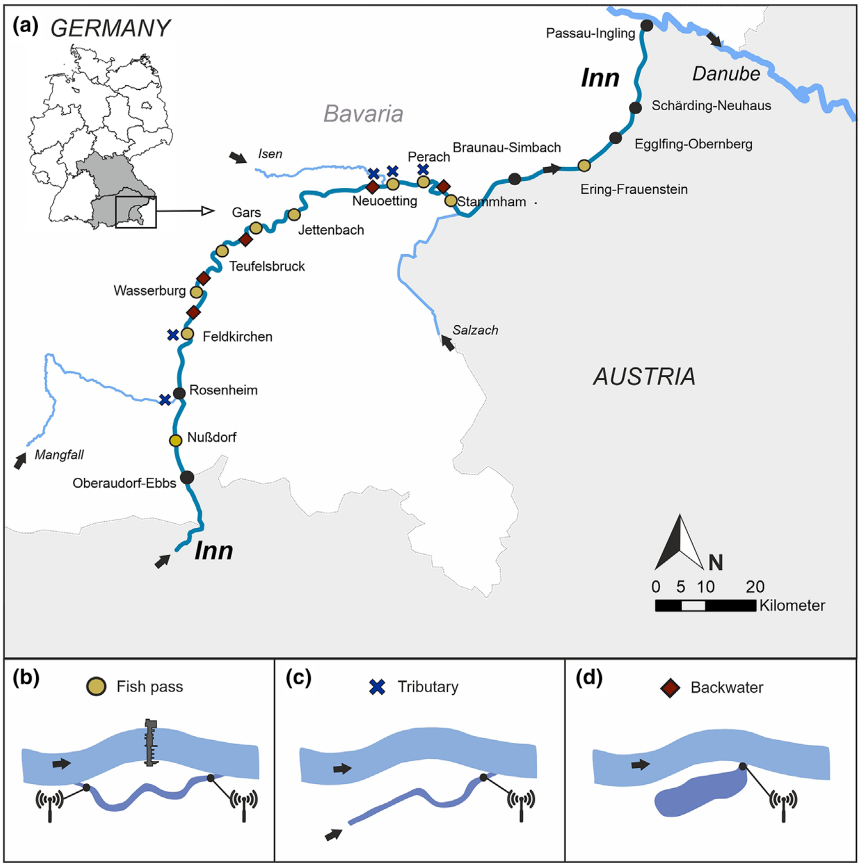

FIGURE 1 Map of the project area (a) including all stationary monitoring sites (yellow dots = fish passes, blue crosses = tributaries, red diamonds = backwaters) and PIT-antenna positioning in (b) fish passes, (c) tributaries and (d) backwaters. Each black dot represents a hydropower site that did not yet have a fish pass installed until July 30, 2024.

3 | JOINT PROJECT DESIGN AND DEVELOPMENT

3.1 | Phase I—A project evolves

Three years after the start of the restoration campaign of the River Inn in 2012, a long-term and large-scale monitoring initiative was launched (see Figure S1) with the core objective of evaluating restoration measures to ultimately meet the objectives of the WFD. To facilitate this, the hydropower operator funded a monitoring project and collaborated with the Technical University of Munich (TUM), which from then on acted as the project's scientific partner. The initial stage of the project involved the co-design of a scientific monitoring concept, in which the hydropower operator provided the restoration goals and measures to achieve them, while science developed the concept of how to assess restoration efforts. This process took about 6 months and was led by academics, with regular input from the hydropower operator and various governmental institutions such as fisheries agencies and water and environmental authorities, who were particularly involved in identifying potential restoration sites and shaping the funding scheme. In addition, input from local angler associations helped to identify target species for conservation and management, for example related to the identification of suitable spawning and nursery habitats of European grayling (*Thymallus thymallus*), a highly endangered and desired target species of conservation in the project area. However, it took another year before all the administrative work (e.g. funding contracts) was completed and the project was ready to start. Based on the developed monitoring concept, which set the goals and agenda for the time period 2015 to 2025, restoration actions were scientifically evaluated through systematic studies on the abiotic and biotic functioning of restoration measures in the River Inn catchment. This included field and laboratory investigations on methodology, autecological traits of target species (see Table S1), and habitat functionality using passive and active bioindication (for a detailed list of studies see Table S2). Despite the use of a wide range of methods, it became evident that a systematic understanding of the spatio-temporal dynamics of fish fauna in the restored and reconnected fish habitats is essential for a holistic evaluation of conservation efforts. This also referred to the assessment of supportive breeding and stocking efforts, which became an additional aspect to be integrated as a result of input from local angling associations. Therefore, in a second phase, the hydropower operator initiated a large-scale telemetric monitoring system based on passive integrated transponder (PIT) technology to prove the effectiveness of the restoration measures to the governmental authorities. Since 2022, ~10,000 fish are tagged each year.

3.2 | Phase II—A PIT-based approach

The design of this second phase from 2020 to 2022 included the installation of the monitoring infrastructure. During this period, multiple meetings and site visits were conducted by the hydropower operator, scientists, governmental authorities, and the chairs of seven angling clubs who hold the recreational fishing rights in the project area. The initial results of the first projects' years and numerous meetings provided the knowledge and built the relationships and trust needed for an active involvement of these stakeholders. Moreover, existing collaborations between TUM and key stakeholders facilitated the process of trust-building also in this initiative.

Fish monitoring based on PIT technology involves the tagging of fish with small, passive transponders. These transponders require activation by a detection infrastructure, typically situated in narrow and shallow sections of aquatic habitats. The monitoring sites in the River Inn project were selected through an integrated process that considered evidence from the project's initial phase and local knowledge regarding important fish habitats, as provided by experts and angling club members. The hydropower operator financed and installed the detection infrastructure, with constant support by the scientific partner. Following a period of more than 2 years during which the infrastructure was installed, it now comprises 34 permanently installed detection sites covering a river stretch of 150 km and includes arrays in 12 fish passes, five backwaters, and five tributaries (Figure 1a). In the course of this PIT-based monitoring phase, 14 target species are tagged and monitored, which are representatives of the local fish fauna covering different ecological guilds (see Table S1). These include wild fish, which are caught, tagged, and released by university members, as well as hatchery-sourced and stocked specimens. The assessment of stocked fish (when, where, and which species in which size classes are tagged and stocked) is co-developed by academics, the fishery advisory board of Upper Bavaria, which is co-funding this part of the project, and the local angling clubs, who conduct supportive breeding and stocking efforts along the River Inn. Results are directly discussed and result in implementation of changes, for example in stocking practices.

3.3 | Phase III—Integrating citizen science

Following the reported catch of 42 tagged specimens by recreational anglers in 2023 and the increasing interest of this stakeholder group in actively contributing to the development of knowledge that is beneficial to the management of fisheries, a citizen science initiative was initiated at the beginning of 2024. Consequently, the monitoring infrastructure was recently expanded with 10 mobile fish scanning stations (Figure 2f), which are strategically positioned along a 110 km stretch between the cities of Rosenheim and Stammham (Figure 1a). These scanning stations were designed and positioned according to the preferred fishing locations in close collaboration with the local angling clubs and allow their combined membership of 5,000 people to directly scan their caught fish for a PIT tag and subsequently report their catch in an easy way. Each scanning station is equipped with a PIT scanner and devices to measure the length and weight of the fish.

All the work conducted in this project passed an ethical review and was authorized by the government authorities under licence number ROB-55.2-2532.Vet_02–21-173 (PIT-tagging, government of Upper Bavaria—field 54—consumer protection, veterinary affairs) and licence number 31-7562 (electrofishing, district office of Freising, Bavaria, Germany).

4 | MULTIPLE BENEFITS GENERATED THROUGH STAKEHOLDER INVOLVEMENT AND INTERACTION

Multiple stakeholders from the private sector, governmental institutions and science are involved in this project to co-produce and apply knowledge directly relevant for the conservation of the River Inn and its fish populations (Figure 3; Table S3). Stakeholder involvement gradually increased over the course of the project and their identification was more obvious than systematic, as they had been working together in different contexts prior to the project. Each stakeholder has a different role in the aspects of co-design, co-development, and co-delivery of knowledge, yet all of them derive benefit from the project.

4.1 | Private sector

The private sector is represented by the hydropower companies, angling clubs, NGOs and the wider public. The hydropower companies exploit hydroelectric energy from the River Inn and are responsible for the restoration and maintenance of riverine habitat quality and connectivity. They participated in the co-design of the projects' first and second phases, especially in providing ideas on restoration measures and monitoring sites. Moreover, they serve as the primary funder of the scientific monitoring (see Table S3), which provides evidence for the planning of new restoration measures to achieve the WFD objectives. The achievement of these objectives is monitored by governmental authorities. The core project benefit of the hydropower companies is advice on how to produce hydroelectric energy while supporting fish populations through an effective improvement of habitat quality and connectivity.

The angling clubs are mainly responsible for the management of fisheries, including supportive breeding and stocking initiatives for a range of species, but they also provide knowledge and workforce to small-scale habitat restoration measures. Additionally, they contribute to knowledge development through the assessment of stocking efficiency and their engagement in a citizen science initiative, which allows anglers to scan and report their catch directly at the river. Angling clubs obtain their fishing rights mainly from hydropower companies and receive advice on fisheries management from the fishery advisory boards. The main project benefit for angling clubs is information on how to ensure sustainable fisheries management, particularly for their target species.

Several NGOs, such as the Landesbund für Vogel- und Naturschutz in Bayern (LBV; Association for Bird and Nature Protection) and the World Wildlife Foundation (WWF), are involved

FIGURE 2 Photographs of (a) the River Inn at the Feldkirchen hydropower plant, (b) bank habitat restoration at the Rosenheim hydropower plant, (c) installed antenna in pass-through-orientation in the fish pass Teufelsbruck, (d) antenna installation in pass-over-orientation in the Mangfall tributary, (e) stationary detection station with solar system to power one of the antennas in the Perach fish pass, (f) mobile scanning stations for recreational anglers at the Teufelsbruck hydropower plant.

and become regularly informed about the project's progress. One of them, the HIT Umweltstiftung (HIT Environmental Foundation), even actively contributes by co-funding parts of the project, primarily the citizen science initiative. The wider public and local citizens are involved by disseminating information about the restoration activities through media broadcasts (e.g. TV, newspapers) and information boards at most of the restoration sites explaining the idea and context of each measure.

4.2 | Governmental institutions

Governmental institutions are represented by the Bavarian Ministry of the Environment, the regional water authorities, the State Office for the Environment, the nature conservation authorities and the fisheries advisory boards of Lower and Upper Bavaria. The main responsibility of these institutions is to enforce existing policies, but also to advise the private sector on river restoration and fisheries management activities. Regional water authorities are also responsible for habitat restoration measures in their areas of responsibility, mostly in tributaries of the River Inn. Governmental authorities contributed in co-designing the projects' first and second phases and contribute to knowledge development by providing long-term fish and hydrological data. The Bavarian Ministry of the Environment and the fishery advisory board of Upper Bavaria are also co-funding the scientific monitoring (see Table S3). Governmental institutions can derive benefit from this project in two ways. Firstly, conservation measures and their monitoring provide a crucial contribution to achieve the goals of the WFD. Secondly, the fundamental ecological knowledge gained through this project can be leveraged for future decision-making processes pertaining to river restoration and fisheries management in other alpine river systems.

4.3 | Science

The main role of academia is to systematically evaluate conservation and restoration efforts and to inform and advise practitioners and government institutions as a basis for evidence-based adaptive management. This stakeholder takes the lead in the co-production of knowledge and is also responsible for ensuring compliance with animal ethics guidelines. Moreover, academia ensures knowledge delivery through lectures and seminars in a university environment, which also includes education of students from various disciplines as well as workshops for all stakeholder groups. The core benefit for science is to

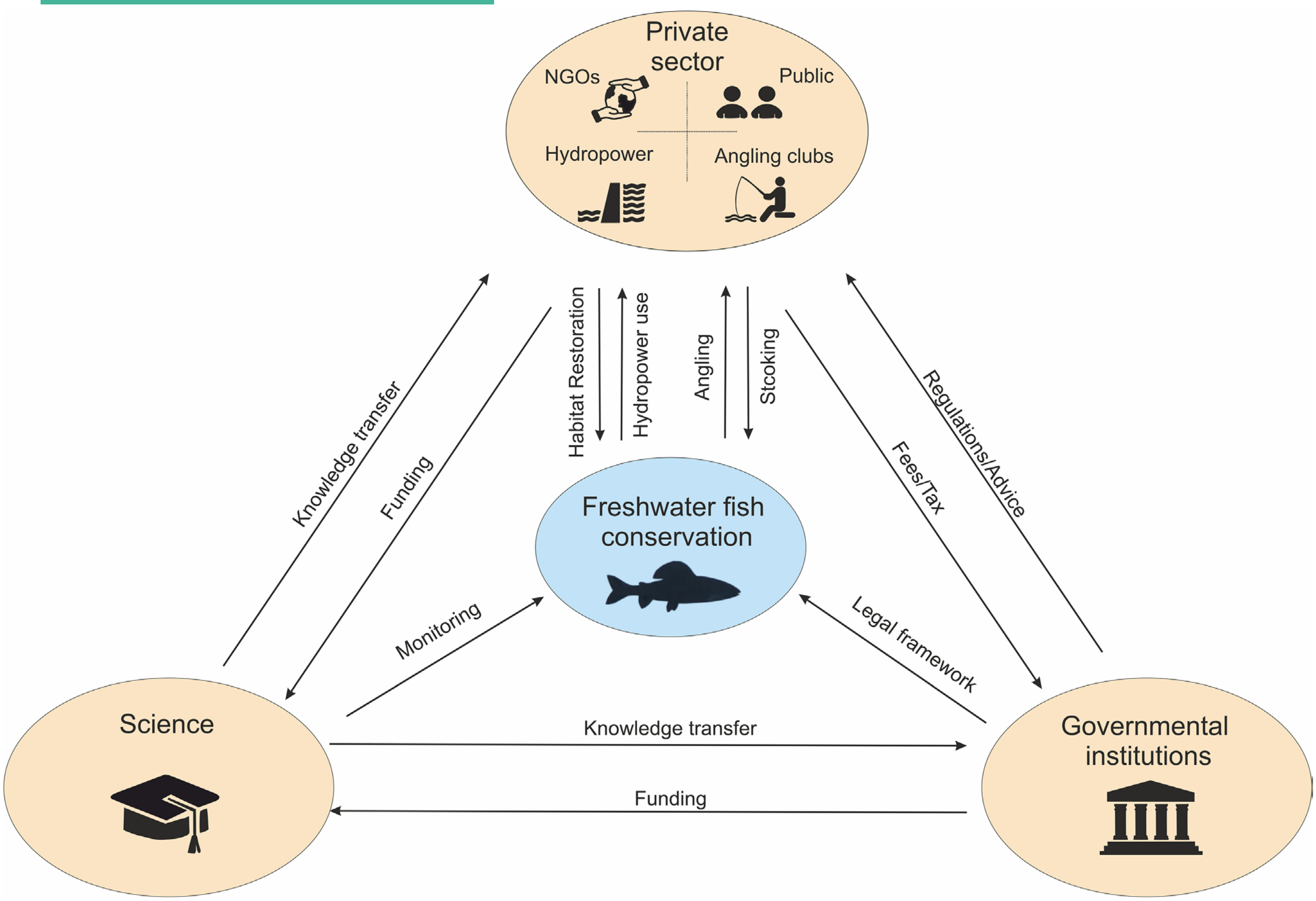

FIGURE 3 Flow chart explaining main stakeholder interactions in the fish conservation project at the River Inn catchment.

gain fundamental knowledge on fish ecology and habitat restoration efforts and to combine single case studies into a systematic and holistic understanding of fish conservation efforts in the River Inn catchment, and to publish those results in the peer-reviewed literature so that this knowledge also becomes available for related initiatives globally.

Concerning participation, an additional involvement of crucial stakeholders beyond those already considered, would be useful. This is particularly true for the landowners (agriculture, forestry) which may play an important role when it comes to provisioning of sites adjacent to the stream system critical for restoration. Moreover, communication to the wider public as well as knowledge transfer to similar settings beyond the project area would be desirable, yet has not been fully achieved.

5 | SYNTHESIS: FROM EVIDENCE TO APPLIED CONSERVATION

The conservation management in the River Inn catchment is characterized by a strategic, systematic and long-term monitoring approach, in which recent results are regularly reflected, discussed and translated into management recommendations. Therefore, it can generally be considered as an adaptive management approach, which is highly advocated for the improvement of biological systems (Westgate et al., 2013). To ensure the effectiveness of this approach, our project is accompanied by an advisory board, which contains members of each stakeholder group. Apart from irregular meetings in small groups throughout the year, the flow of information is institutionalized through an annual conference in which the major findings of the previous year are discussed and the agenda for future actions is set accordingly. These conferences are attended by 40–50 participants and are held in a university setting at TUM. In addition, monitoring results are regularly published in peer-reviewed journals and annual reports and directly translated into evidence-based conservation management recommendations. This ensures an effective and direct link between gaining and application of ecological knowledge and implementation of measures and actions, which can be illustrated by three examples.

The first example concerns the management of fishways, which are often constructed in a nature-like scheme. In the course of the project, several studies showed that diverse habitat features in this type of fishway, such as floodplain ponds and fast-flowing gravelly areas, contribute to high species richness and provide successful spawning grounds and nurseries for threatened fish species such as *T. thymallus* and *Chondrostoma nasus* (Nagel et al., 2021; Pander et al., 2021). However, these features require regular management to maintain them. Based on monitoring results, guidelines were developed, which provide a point-by-point management plan for each specific fishway including where, when and at what intervals certain measures such as gravel cleaning of spawning grounds and de-sedimentation of floodplain habitats should be implemented to maintain critical habitat features.

The second example pertains to a genetic assessment of the common breeding practice in *C. nasus*, as described in local rearing guidelines and being carried out by the local angling clubs for many years. This assessment revealed that using a very limited number of adult fish has a detrimental effect on the gene pool of hatchery-sourced offspring (Stoeckle et al., 2022). As a consequence, a new standard for supportive breeding of *C. nasus* has been applied, which involves using a greater number of parental fish and conducting multiple collection events.

The third example refers to the newly installed PIT monitoring infrastructure, which very recently revealed spawning runs of *C. nasus* in the second week of March 2024 and thus more than 2 weeks earlier than ever observed in the River Inn catchment. This documented shift in the timing of *C. nasus* spawning activity, which can be very likely related to climate change induced warming of water temperatures, provides important information for the timing of supportive breeding campaigns (as conducted by angling clubs, see above), but also for the timing of spawning ground restoration (as conducted by the hydropower plant operator and water authorities), which a previous study in this project has shown can significantly improve recruitment success (Nagel et al., 2020).

6 | CONCLUSIONS AND LESSONS LEARNED

The River Inn fish conservation and habitat restoration approach presented in this perspective provides a case model of how the existing gaps between applied ecological research and the actual practice of species conservation and ecosystem restoration can be bridged, increasing chances of successful implementation.

First, a strong legislative context, such as the WFD in our case, provides the crucial framework for such integrative and large-scale conservation projects by setting clear overall goals, timelines and responsibilities. In many parts of the world, however, such policies have yet to be implemented, and existing policies need to be regularly adapted to changing realities, such as the emergence of new stressors on ecosystems.

Second, is often argued that the involvement of all relevant stakeholders in collaborative projects should ideally take place in a strategic way from the very beginning. However, as we experienced in our approach, building trust and relationships is fundamental to achieve mutual understanding as a basis for successful stakeholder involvement. Such processes are dependent on dedicated individuals in each stakeholder group, take time to develop, and are strongly driven by the initial success of projects and the recognition of benefits by the respective stakeholder groups. Consequently, stakeholder participation and their role in the different aspects of the co-production process can evolve over time if projects are designed with the possibility for an adaptive management and are funded with a long-term perspective.

Finally, we identified another key driver for participation in the establishment of a communication platform in the form of a yearly conference. This platform proved to be highly valuable as a basis for knowledge transfer, critical reflection on project design and development, as well as joint decision-making on conservation and restoration targets. It also helped to de-escalate smouldering conflicts that were present before the first project started, for example over the choice of target species for conservation measures, which for some species had conflicted between angling clubs, NGOs, and regulatory authorities.

The approach presented herein ultimately results in an improved biodiversity conservation, which can be measured in enhanced recruitment of target species and higher species richness in restored habitats (see e.g. Nagel et al., 2020, 2021; Pander et al., 2021, 2022). The integrative project design also leads to an increased acceptance of measures and successful translation of knowledge, which can also be adapted to realize tangible improvements in other aquatic ecosystems.

AUTHOR CONTRIBUTIONS

This long-term project was initiated by VERBUND Innkraftwerke GmbH (Georg Loy) and the Chair of Aquatic Systems Biology of TUM (Juergen Geist). Christoffer, Nagel, Juergen Geist, Joachim Pander, Georg Loy, Jan Droll, Barbara Grüner, and Johannes Wesemann, conceived the ideas and designed methodology for this paper. Christoffer Nagel, Juergen Geist and Joachim Pander led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

None of the authors has a conflict of interest to declare.

DATA AVAILABILITY STATEMENT

This manuscript has no data.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1. Timeline of the project development including critical events.

Table S1. List of all species tagged in this study listed in scientific and common names, their affiliation to reproduction guilds (based on the classification of Jungwirth et al., 2003), ecological flow guilds (based on the classification of Zauner & Eberstaller, 1999) and conservation status [according to Annex II or V of the Habitats Directive, Council of the European Communities (1992), Red List (RL) Bavaria and Germany (Effenberger et al. 2021)]. Categories: 1 = threatened with extinction, 2 = highly endangered, 3 = endangered. Asterisks indicate main target species for recreational anglers.

Table S2. List of all publications related to the first phase of the fish conservation project at the River Inn.

Table S3. List of key stakeholders and their role in funding and participation in the different phases of the project. Active participation = active role in co-design and/or co-development of the project phase. Passive participation = no active role in the co-design and/or co-development of the project phase, but included in the news flow.