



Fischnetz: Assessing outcomes and impacts of a project at the interface of science and public policy



Patricia Burkhardt-Holm^{a,*}, Alexander J.B. Zehnder^b

^a Man-Society-Environment (Program MGU), Department of Environmental Sciences, University of Basel, Vesalgasse 1, 4051 Basel, Switzerland

^b School of Biological Sciences and Sustainable Earth Office, Nanyang Technological University (NTU), 60 Nanyang Drive, Singapore 637551, Republic of Singapore

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ABSTRACT

Long-term reviews are necessary to appreciate the full outcomes and impacts of the scientific, societal and policy perspectives of transdisciplinary projects. Here, thirteen years after its completion, we assess the significance of a five-year (1999–2004) Swiss research project. The *Fischnetz* project aimed to identify the causes of fish catch decline and propose remedial measures. Engineers and scientists from different disciplines collaborated with practitioners and policy makers to approach this real-world problem and develop and implement policy interventions. *Fischnetz* proved to be an exemplarily successful case of how transgressive and socially robust research can be conducted and result in high-quality scientific outputs and policy impacts. As a result of *Fischnetz*, the Swiss Federal Water Protection Act was fully revised, two by-laws were changed, and several parliamentary interventions were launched. *Fischnetz* produced 68 scientific ISI-papers with higher than average citations. In this report, the project setup and its overall outcomes were analysed via a Mode-2 knowledge production approach.

1. Introduction

The project *Netzwerk Fischrückgang Schweiz* (project on fish catch decline in Switzerland), abbreviated '*Fischnetz*', was conducted between 1999 and 2004. Considerable decreases in inland fish catches of up to 60% since the 1980s were recorded by anglers. These declines appeared geographically widespread and affected various species, including brown trout (*Fischnetz*, 2004a). Impairments to the health of the wild brown trout population were also detected, most evidently downstream of sewage treatment plants (Burkhardt-Holm et al., 2008). A nationwide effort was initiated to elucidate the reasons for these phenomena, identify the key causative factors and develop remedial measures. The aim of *Fischnetz* was to tackle this challenge and the project demanded an inter- and transdisciplinary research approach. The specific objectives were: (I) collection, synthesis and evaluation of data on fish catch, fish health and population abundance for the last 20 years; (II) identification of the most important factors responsible for catch decline and impaired health status, and initiation of new research activities to fill the identified knowledge gaps; and (III) proposal of remedial measures.

Reporting and evaluation of the success of transdisciplinary research projects in a systematic, structured manner has been repeatedly emphasized (e.g. Buxton, 2011; Schmid et al., 2016; Krainer and

Winiwarter, 2016), and aligns with the current trend that public research investment ought to derive benefits for society (European Commission, 2010). Long-term review is crucial to evaluate the impact of transdisciplinary projects. The optimal time for review is a function of the research results, intended impacts, field of practice where impacts will occur, and tangibility of the outcomes (Kaufmann-Hayoz et al., 2016). In particular, societal impacts are not imminent and take time to become apparent (Bornmann, 2013). Two to 17 years after the end of a project have been reported as good time-points for evaluation (e.g. Molas-Gallart et al., 2000; Buxton, 2011; Balvanera et al., 2017). Impacts may not yet be clear after a short time, yet waiting too long may blur causality and attribution (Bornmann, 2013). The results of *Fischnetz* were thought to have immediate and long-term policy relevance. As a consequence, thirteen years after the end of the project seemed an appropriate time to obtain a full picture of the outputs, impacts and outcomes, without interfering with causality.

Several approaches have been developed to conduct and evaluate projects in which scientists, policy-makers and other actors cooperate directly, and where a plurality of knowledge sources is combined to address real-world issues. One discipline alone is usually insufficient to find solutions to the complex problems in our modern world. Increasingly, academia alone cannot provide answers. Inputs from a combination of disciplines and societal stakeholders are necessary for

* Corresponding author.

E-mail address: patricia.holm@unibas.ch (P. Burkhardt-Holm).

joint problem solving. While traditional knowledge production (Mode-1 knowledge production) occurs within a disciplinary, primarily cognitive context, Mode-2 knowledge production emerges in broader, transdisciplinary contexts (Gibbons and Nowotny, 2001; Gibbons et al., 1994). The various ‘new knowledge production approaches’ include ‘joint knowledge production’ (e.g. Hegger and Dieperink, 2014), ‘knowledge co-production’ (Armitage et al., 2011) and ‘socio-ecological research’ (Lang et al., 2012), among other concepts. For this evaluation, we decided to follow the Mode-2 knowledge production concept, which provides a blueprint for the set-up of research programs that promise societal, economic and policy impacts as ultimate goals, with high levels of uncertainty and complex causal paths between inputs and impacts. The transdisciplinary *Fischnetz* project was characterized by a combination of scientific and societal aspects, which falls under the remit of Mode-2 knowledge production.

Here, we initially describe the definition and inclusive development of the scientific program, the process of integrating all relevant societal stakeholders as partners and funders, and review the organization and anchoring of the project in relevant stakeholder circles. Secondly, we compile and assess the scholarly and societal outcomes the project had and continues to have on science, policy and society. Thirdly, we explore the policy impact, or in other words, what really changed as a result of this research within the context of a broad discussion of the different relevant societal participants.

2. Background of the *Fischnetz* project

This project must be understood in its political and historical context. Catch declines and impairments to fish health were observed in many other countries towards the end of the last century (Coxw, 2015). Fish are generally viewed as an indicator of water quality, and a decline in fish numbers triggers emotional doubts regarding water quality. Moreover, the book “*Our Stolen Future*” (Colburn et al., 1996), along with media reports about the presence of chemicals with endocrine-disrupting activities in rivers and lakes, fuelled doubts on water safety and created strong public pressure for action.

The level of public interest in this project was high, since approximately 240,000 individuals, equivalent to 6% of the Swiss population between 15 and 74-years-old, practice angling at least once a year (Burkhardt-Holm, 2008a). Catch decreases have consequences on angler satisfaction, as well as the sale of angling licenses that contribute to cantonal incomes. Between 1980 and 2000, the sale of angling permits for running water systems decreased by 23 percent and combined permits (rivers and lakes), by 46 percent (Fischnetz, 2004a). Public and financial pressure were strong drivers for inclusive development of a research program based on twelve hypotheses. The partners, federal and cantonal authorities, anglers and scientists agreed to the program in the autumn of 1998 (Supporting information, Fig. S1).

Fischnetz was organized with a steering committee (board) and project management (executive). Two of the six steering committee members were members of the cantonal governing council responsible for finance, one of whom chaired all cantonal finance councillors in Switzerland. The other four members were the director of the Swiss Federal Office for the Environment (FOEN); a representative of the Swiss Association of Chemical Industries (SGCI); the president of the Swiss Fisheries Association (SFV), an NGO; and as chair of the steering committee, the director of the EAWAG, the Swiss Research Institute for Aquatic Science and Technology (a co-author of this paper). The steering committee set the priorities, monitored advancement and success, and was responsible for implementing the relevant policy measures.

The *Fischnetz* steering committee was instrumental in obtaining financial support from all 26 cantons and the principality of Liechtenstein. For the first time in Swiss scientific history, all cantonal political entities and the principality of Liechtenstein contributed cash funds to a scientific project. Right at the start, the SGCI committed the

necessary financial means to investigate the role of chemicals in fish health impairment. The FOEN and EAWAG acted as leading institutions and ensured project realization and management, and contributed financing. The SFV supported with anglers volunteering for field work. The contributions of these partners represented the core financing of *Fischnetz*, totalling 4.8 million Swiss Francs for the five-year period (Supporting information, Fig. S2A). Subsequently, additional topic-specific support was provided by the Swiss National Science Foundation (SNSF) for a program on endocrine disruption, by universities for their own collaborating groups, and from a variety of other funds. External third-party funding contributed considerably to *Fischnetz*; 47 of the 77 sub-projects were externally financed (Supporting information, Fig. S2B).

The project management comprised twelve individuals with expertise in different disciplines, i.e. fisheries science, environmental chemistry, ecotoxicology, physiology, fish disease, population biology, limnology, hydrology and climate change. These individuals also represented the various stakeholders, federal and cantonal authorities, chemical industry, Swiss fisheries associations and scientific communities (the head of the project management team is the lead author of this paper). The team’s priority tasks were to identify knowledge gaps, coordinate the different sub-projects, reduce overlaps, profit from synergies arising to achieve project objectives, and synthesize and communicate results.

From the outset, other projects already running in Switzerland were invited to join as sub-projects, provided they were contributing to at least one of the objectives of *Fischnetz*. Further prerequisites were to allow access to raw data and willingness to participate in productive scientific discussions and actively collaborate with *Fischnetz*. Prior to initiation of the project, the relevant literature was analysed, the results of former and recently completed projects in Switzerland and adjoining regions were evaluated, and national and international scientists were invited for expert hearings (Fischnetz, 2004b). With this information at hand, sub-projects for further research were defined and prioritized (Burkhardt-Holm, 2008a). Most sub-projects were field studies, monitoring projects and synthesis work. To a large extent, the synthesis work was financed by the core *Fischnetz* funding (Supporting information, Fig. S2B). More than 400 people were directly involved in *Fischnetz* (Fischnetz, 2004b).

The initially defined network of hypotheses (Supporting information, Fig. S1) proved beneficial for identifying important causes and intermediate effects. Several studies helped disprove some hypotheses (Burkhardt-Holm et al., 2005). To combine data from the numerous sub-projects creating heterogeneous knowledge and provide more general conclusions, a Bayesian probability network model and weight-of-evidence-analysis were applied (Borsuk et al., 2006; Burkhardt-Holm, 2008b). The major factors leading to catch decline were reduced fishing and a reduction in fish populations. The causes of population decline were primarily impaired health as a consequence of proliferating kidney disease (PKD), poor water quality and deteriorating habitats (Burkhardt-Holm et al., 2005). The increased incidence of PKD was the result of a changing annual temperature regime in rivers triggered by climate change (overall increase in water temperatures, primarily due to earlier spring; Hari et al., 2006). As a consequence, the ideal thermal habitat for brown trout had risen in altitude by 130 m (Hari et al., 2006). Upstream escape was difficult to impossible for fish due to insurmountable artificial obstacles mainly built for flood mitigation.

3. Methods, their application for quantifying scientific output, and societal and policy impact

3.1. Methods

3.1.1. Web search

Web searches were used to identify the products and performance of

scientific output. Publications were extracted from Web of Knowledge (<http://webofknowledge.com>) and Google Scholar (last search, 11 November 2015). Papers were grouped as Institute of Science Index (ISI)- and non-ISI papers. Search terms used to assess scientific output were *Fischnetz*, fish net, network fish decline Switzerland, fish population decline Switzerland, bio indicator fish, brown trout stock, PKD brown trout, water condition, and water quality Switzerland. Each paper was individually checked for its association with *Fischnetz* to exclude duplicates and incorrect attributions.

Web searches were used to assess societal and policy impact. The websites of political authorities, research institutes such as EAWAG (Swiss Federal Institute of Aquatic Science and Technology), NGOs, companies, and professional and recreational associations were searched for reports and oral presentations delivered to non-academic audiences, fisheries management plans, etc. Additional sources were Google Scholar and Swiss federal and cantonal authority websites. Thematically and geographically restricted journals focusing on nature, environment, angling, water management, etc. were also searched ('specialist periodicals'). The same keywords were used as for the scientific evaluation, and the equivalent terms in German, French and Italian, three of the four official languages of Switzerland (last search, 3 February 2016).

The following search terms were used to identify political interventions and conceptual adaptation/changes to planning standards and management targets: interpellations, motions and postulates, the terms *Fischnetz* and *Interpellation Fischnetz* (in German/French/Italian). They were used to search the websites of the cantons, the federal parliament (www.parlament.ch) and <http://www.basler.fischerei.ch/>, <http://www.ybbs.aesche.at/> and <http://www.derbund.ch/> for management concepts that influence current practices. Interpellation was replaced by concept when searching German, French and Italian equivalents. To obtain information on specific management advice, concept was replaced with management. Only hits that reliably demonstrated specific management advice from *Fischnetz* (source criticism) were considered (last search, 1 October, 2015).

Societal impact was also measured by searching articles in the press and electronic media. Google was searched using the keywords *Fischnetz* and fish decline Switzerland (in German/French/Italian). In addition; we analysed the *Fischnetz* final reports and CVs of project team members (*Fischnetz*, 2004b).

3.1.2. Impact factors

Journal impact factors and numbers of citations for papers were extracted from the Web of Knowledge (<http://webofknowledge.com>) to measure scientific impact.

3.1.3. Interviews

Interviews were conducted with political authorities via informal phone conversations following a guideline questionnaire on implementation of the specific management measures recommended by *Fischnetz*. The following questions were posed: Were the measures proposed by *Fischnetz* put into action? If yes, were they successful and how? Was their success measured, and if so, what were the outcomes?

3.2. Application of methods

3.2.1. Scientific output

The number of publications between 1999 and 2015 indicates scientific productivity, as a metric of the product and performance of the scientific output of *Fischnetz* (Defila and Di Giulio, 2001). ISI-publications were grouped into first- and second-round papers extracted from Web of Knowledge. First-round papers reported the results of *Fischnetz* sub-projects and were published by *Fischnetz* participants or collaborators or were initiated by the project outcomes. Most of these papers appeared during or shortly after *Fischnetz* (1999–2010). ISI-publications of *Fischnetz* follow-up projects were classified as second-round papers,

covering the publication period 2001–2014. Besides non-ISI scientific papers, all scientific reports on *Fischnetz*, oral presentations at scientific conferences or educational courses in universities and Diploma-, Master- and PhD-theses written in the context of *Fischnetz* were searched and included. The national focus of this case study made it unavoidable to include sources in German, French and Italian. We have used English sources wherever available.

Average citations per ISI-paper produced from *Fischnetz* were compared to the average citations in the field of environment/ecology in the Thomson Reuters Essential Science Indicator Database. For papers published between 1999 and 2004, the annual average citation per paper was based on the annual average for 1999–2009, and for papers published in 2005 or later, the average for 2005 to 2015. The overall average was calculated by multiplying the annual citation averages by the number of years between publication date and November 2015.

3.3. Scientific impact

Scientific impact was distinguished for first- and second-round papers. Scientific follow-up research programs and projects based on the results, ideas or concept of *Fischnetz*, or which dealt with open questions related to *Fischnetz*, were defined as scientific impact if their character was strictly scientific. Those mainly focusing on implementation and management advice were attributed to societal impact. Either type of output may have both societal and policy impacts.

3.4. Societal impact

According to Molas-Gallart et al. (2000), a societal impact occurs whenever research efforts identifiably influence current social, policy and management practices. For *Fischnetz*, societal impacts were essentially political interventions and conceptual adaptation/changes to planning standards and management targets. Web searches were conducted to obtain qualitative and quantitative data (see Section 3.1.1). In four catchments with catch decline and well-defined conditions, it was possible to propose specific measures (Borsuk et al., 2006). The outcomes of the corresponding implemented adapted management practices were thoroughly evaluated. We interviewed the political authorities responsible for each of the four test areas in the autumn of 2015. Though some measures were implemented by federal and cantonal authorities during *Fischnetz*, it was not an objective of *Fischnetz* to implement measures or evaluate their outcomes.

3.5. Policy impact

The term policy impact, sometimes called societal outcome, is used in this context to address the broader and long-term effects of projects on environment and society. For *Fischnetz*, policy impacts were primarily changes in law and regulations or creation of new institutions and infrastructural adaptations. Long-term effects and actual (or at least definitively planned) implementation were the guiding criteria for identification of policy impacts. Follow-up projects based on *Fischnetz* results, ideas or concepts with policy impact were considered. Google and Swiss authority, NGO and fisheries association websites were searched as described for societal impacts.

3.6. Data access

All raw data and links to scientific outputs and societal and policy impacts are compiled in Tables S1, S2, Appendix dataset 1, the datasets to Fig. 1 and datasets to Figs. S2–S4. All datasets and .pdf files of reports that are difficult to locate can be found at https://mgu.unibas.ch/en/publications/Fischnetz_2017.

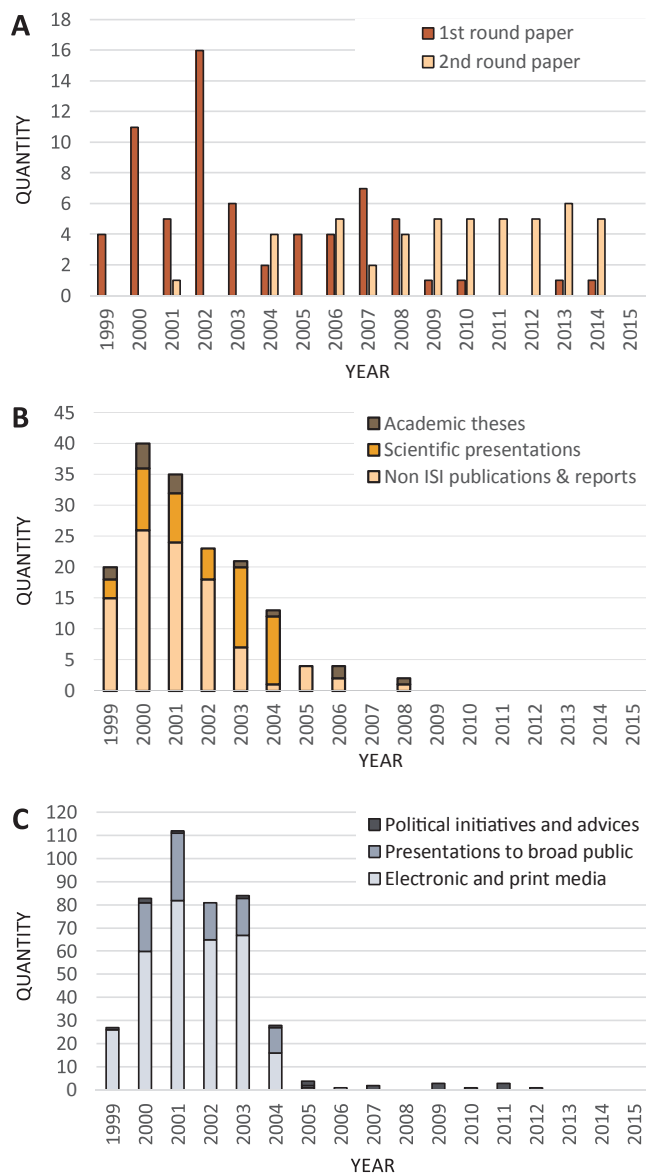


Fig. 1. Scientific output (A, B) and societal impacts (C): (A) ISI first and second round publications, (B) non-ISI publications, oral presentations at conferences or educational courses at universities, and academic theses; and (C) societal impact as measured through a number of channels, such as political initiatives, public reports, concepts and management advice, presentations to the general public, media releases (print, electronic) and journal articles delivered to stakeholders.

4. Results

4.1. Scientific output

Fischnetz produced 68 scientific ISI-papers over 15 years (Fig. 1A) published in 32 journals (Supporting information: Dataset 1, datasets to Fig. 1). The average citation for these 68 first-round papers was 40, considerably higher than the 26 (50% percentile) expected in the field of environment/ecology. *Fischnetz* results were also presented as posters, in scientific symposia and congresses, or at academic seminars. Ninety-five written scientific contributions (non-ISI articles and scientific reports, including sub-project intermediate and final reports) were published, 15 academic theses were completed on *Fischnetz* topics, and 50 oral presentations were delivered at scientific conferences or for academic education (Fig. 1B, Supporting information, Figs. S1–S4). These contributions peaked during *Fischnetz* and rapidly dropped in the following two years, while ISI articles continued to appear for 10 years

after *Fischnetz* ended.

4.2. Scientific impact

The first-round ISI-papers were cited 2777 times (Supporting information, Fig. S3). *Fischnetz* triggered 47 s-round papers between 2001 and 2014 (Fig. 1A, Supporting information, Dataset 1), which were cited 756 times (Supporting information, Fig. S3). Fish catch decline, the potential role of loss of habitat and endocrine disruptors (two aspects considered in the *Fischnetz* hypotheses) were stated as the reasons for initiation of a research program by the Swiss National Science Foundation (SNSF) NRP50 (National Research Program) titled ‘*Endocrine Disruptors: Relevance to Humans, Animals and Ecosystems*’ in 2002 (Table S1). This program comprised 31 projects with funding of 15 million Swiss Francs. One of these projects became a sub-project of *Fischnetz* (SAFE). The other projects dealing with rivers and/or fish represented an extension of the core *Fischnetz* project. Projects dealing in-part with insufficiently-investigated hypotheses related to *Fischnetz* or follow-up research questions received additional national research funds (Table S1).

4.3. Societal impact

Fischnetz generated 316 news items in electronic and printed media: in 72 different newspapers, webpages, weekly and monthly periodicals and 21 journals addressing stakeholders more specifically, such as angling, environment and water management periodicals (Fig. 1C, Supporting information Dataset 1). A project brochure, ‘*Fischnetz-info*’, was published eleven times during the project to continuously report progress and results. Ninety-four presentations to broad public audiences were given by project team members between 2000 and 2005 (Fig. 1C). In nine of the 26 cantons, new concepts for fish and/or river management were developed and implemented. Seven political initiatives were launched at federal and cantonal levels (Table 1; Supporting information, Table S2). While media appearances are generally immediate responses, preparation and launch of management concepts and political initiatives usually occurred over the longer term (Fig. 1C).

4.4. Policy impact

Two federal by-laws and one law were adapted or revised as a result of *Fischnetz*. The list of notifiable diseases (by-law on epizootic diseases in Switzerland) (*Ordonnance on epizootic diseases, 2001*) was modified to include PKD along with rules to avoid inter-river catchment transfer of infected fish (Tables Table 1, S2). *Fischnetz* also initiated the citizen-led constitutional amendment initiative “*Living Water*” of the Swiss Fishery Association, which eventually led to total revision of the *Swiss Federal Water Protection Act* in 2011 (*Federal Act on the Protection of Waters, 2016*).

Fischnetz also triggered changes in the by-laws of the *Waters Protection Act*, which will eventually lead to technical upgrades to treat micro-pollutants at over 100 wastewater treatment plants (*Water Protection Ordinance, 2016*). The funds reserved for these investments will total approximately 1.2 billion Swiss Francs (Table 1 and Supporting information, Table S2).

Based on the relative importance of potential causal factors and for exemplary purposes, *Fischnetz* recommended precise basin-wide measures for four areas with proven fish catch declines over the last 10–15 years: the Liechtensteiner Binnenkanal (LBK), and the Emme, Venoge and Necker rivers. These rivers were chosen because they represent the main variables of Swiss rivers with respect to water flow and quality conditions, with typical pre-alpine geomorphologies. Measures in the LBK resulted in a clear improvement in fish reproduction, the outcomes were partly successful in the Emme and Venoge rivers, and for the Necker river, measures were implemented but no success evaluations have yet been conducted. The success of monitoring is the responsibility

Table 1
Main societal¹ and policy² impacts.

Type	Subject matter	Political level	Specifics
Societal:	Parliamentary interventions	Federal	Three interpellations, two motions and one postulate
	Water management advice and concepts	Federal and canton	Four federal management advisements; eight cantonal/intercantonal management concepts and plans
	Parliamentary intervention	Canton St. Gallen	One interpellation
Policy:	Change of federal law	Federal	Full revision of the Swiss waters protection act
	Change of by-law on epizootic diseases	Federal	Addition of proliferating kidney disease (PKD) to the by-law
	Infrastructure:		
	• By-law for the subsidies supporting upgrades to wastewater treatment plants (WWTP)	Federal	Over 100 hundred WWTP will be upgraded; subsidies of over 1.2 billion Swiss Francs reserved
	• FIBER	Federal	Set up of a national advice and information office for sport fishers and fisheries associations, funded by FOEN, Eawag and SFV. Annual cost 150,000 Swiss Francs
• River restorations	Canton, varied	Restoration of impaired river systems, cost of over 130 million Swiss Francs	

¹ Other than media, reports and presentations.

² Detailed links in Supporting information, Table S2.

of cantonal and local authorities in collaboration with regional angling associations. Since success was only partly quantitatively documented and not published in the scientific literature, this information could only be obtained through informal interviews with the responsible fisheries officials.

5. Discussion

Transdisciplinarity has become a popular approach in an ever-expanding number of publications and special journal issues (Scholz and Steiner, 2015; Jahn et al., 2012; Lawrence, 2015). As theory has progressed and definitions and concepts have multiplied, new stimuli and new dimensions have emerged from introduction of the Mode-2 knowledge production concept. The essence of this approach is the production of socially-robust knowledge that transgresses disciplinary and institutional boundaries, consequently providing new or adapted insights. Since transdisciplinary research has different connotations, evaluation of such projects should be tailored to the main characteristics of the project; there is no ‘single best procedure’ (Klein, 2008). As it focusses on project attributes relevant to *Fischnetz*, we carried out this retrospective evaluation following the principles of Mode-2 knowledge production.

5.1. Problem definition

As the scientific and procedural discussions of *Fischnetz* advanced, a common language, understanding and semantics of the issues, steps to be taken and outcomes expected unfolded (Burkhardt-Holm, 2008a). Individually convincing 26 nearly-independent states (cantons) and an independent country (principality of Liechtenstein) to become fully committed took over 12 months (Fischnetz, 2004b). After the preparation period of over two-years, no stone remained unturned, and by then the goals and objectives were well-focused and defined.

5.2. Heterogeneity

Multiple stakeholders bring an essential heterogeneity of skills and expertise to the problem-solving process. The degree to which the broadest coalition can be built was identified as one of the distinguishing success factors for such networks (Hegger and Dieperink, 2014). *Fischnetz* was established on cooperation between multiple scientific disciplines and integrated the active input of practitioners from outside academia, resulting in boundary-crossing knowledge production (cf. 1.2). This strengthened the exchange and integration of different types of knowledge and enabled mutual learning (Lang et al., 2012). A collaborative community must first arrive at a shared view of the problem, then develop a common language and procedures (Defila

and Di Giulio, 2001). Furthermore, the extended discussions and joint activities created trust and confidence among participants. All stakeholders have their own goals and profit in different ways from a transdisciplinary project (Weiss et al., 2011). Researchers benefit from new scientific insight (scientific outcomes). Non-academic project members are interested in obtaining decision support, e.g. to generate new institutions (e.g. FIBER, See Tables Table 1, S2) – in short, policy impact (Walter et al., 2007). Differing interests were also evident among the non-academic sectors. For example, an NGO wished to protect birds, while a fishery association wanted to preserve fish against predatory bird attacks. *Fischnetz* provided a platform for exploring such controversial topics with boundary-crossing learning effects. Notably, these two groups joined boundary-crossing forces to study the impact of cormorants. The project outcomes indicated predatory birds were only responsible for local effects (Burkhardt-Holm et al., 2005).

The full involvement of the Finance Ministers was necessary for two reasons. First, the patents and licenses allowing holders to fish in allotted waters have been a source of income for governments and rulers since medieval times. In Switzerland, cantonal governments have the rights to dispense these patents and licenses. The funds arising from these patents and licenses are still held at the Finance Ministries of the cantons. It was in the interest of the Finance Ministries to maintain this income. Secondly, some of the ministers were sport fishers and took personal pride in being involved in *Fischnetz*.

The participation of the Swiss Association of Chemical Industries (SGCI) must be viewed in the context of the then prominent public discussions on the fish health impairments reported downstream of wastewater treatment plants, which were suspected to be due to endocrine disruptors; some of these substances were revealed to be persistent organic chemicals (Burkhardt-Holm et al., 2008). In the second half of the nineties, a change in thinking occurred in the chemical industries. About the same time as the *Fischnetz* discussions started, long-range research initiatives (LRI) were initiated with the goal of increasing the understanding of the potential impact of chemicals on human health and the environment (De Boer et al., 2015). One of the authors of this article (AJBZ) acted as founding chair of Cefic’s European Scientific Advisory Panel (ESAP). The initiative of SGCI to allocate funds for two studies specifically examining the effect of chemicals on fish health before the official start of *Fischnetz* has to be viewed in the context of global initiatives by most large chemical industries to be a partner, rather than an opponent.

5.3. Transdisciplinarity

Transdisciplinarity goes beyond disciplinary and institutional boundaries. The extensive initial planning period ensured all stakeholders became integrated on an equal footing within a transparent

decision-making process, and no real fundamental disagreements on the project's objectives or processes occurred. In some instances, caution was necessary when tackling sensitive issues or to communicate results that contradicted common beliefs, such as the country-wide importance of predatory birds on fish populations in Switzerland (Fischnetz, 2004b). On occasions, scientific members of the project team were criticized for being too academic with little understanding of reality. Conversely, the researchers had to call for caution when causalities were sloppily drawn. Measures for improvement proposed by *Fischnetz* were undertaken in the four test areas; unfortunately, the subsequent scientific reporting was poor. This illustrates the limitations that are commonly encountered when generating data on societal impacts; this becomes even more difficult when quantitative data are required. Ideally, determining societal impacts should be based on a combination of quantitative and qualitative measurements. Such combined assessment is necessary for case study evaluations to provide a comprehensive picture of all types of societal impacts (Bornmann, 2013).

5.4. Societal accountability

Societal accountability has formal issues when contractual aspects and finances are involved, but beyond that comprises informal processes. Basically, this kind of accountability involves informing different societal groups and the general public about the project and what the project is doing for these groups. Information can flow in several ways. Regular, first-hand publication of the '*Fischnetz-info*' brochure promoted awareness and increased project transparency and the trust of the target audience (Defila and Di Giulio, 2001). An even broader audience was reached by scientific publications and reports, presentations to colleagues and the public, by news reports in the electronic and printed media and articles in specialist periodicals.

A considerable number of media appearances and reports were generated; however, the sheer number of these is not a crucial measure of success. Instead, the main messages must reach the right people in the right form and at the right moment, e.g. when fiscal planning is taking place or when a piece of legislation is under revision. The members of the *Fischnetz* steering board and project team acted as knowledge brokers (Meyer, 2010). Representatives of the federal administration knew when it was appropriate to lobby for legislation revisions.

5.5. Quality control

Quality control is a very tricky criterion, and is termed the Achilles heel of transdisciplinarity as it comprises both scientific and societal knowledge creation (Gibbons and Nowotny, 2001). These concepts are linked and even amplify each other, with no offset between the two. The primary efforts must come from the academic sectors, though their language is frequently difficult to understand for lay-persons. Scholars need to reduce scientific complexity and simplify their language to communicate effectively (Balvanera et al., 2017).

Difficulties in reaching high quality standards and successfully publishing the findings of inter- and transdisciplinary work in the top-rated scientific literature are among the arguments commonly provided by academics to explain their hesitation to participate in this type of work (Kraimer and Winiwarter, 2016). *Fischnetz* proves otherwise: the project had a good publication output of 68 peer-reviewed articles, which were cited considerably more often on average than expected for environment/ecology articles. Furthermore, the project management was asked to produce feature articles or (contribute to) special issues (Burkhardt-Holm et al., 2005, 2008; Burkhardt-Holm, 2002, 2007). *Fischnetz* also triggered several other research programs, such as the national research program on endocrine disruption (NRP 50). This clearly underlines the fact the topic was timely, as well as highly scientifically and societally relevant. Multi-disciplinary approaches are time-consuming and the resulting publications come later than for

mono-disciplinary research projects, but their scientific impact is generally higher (Hall et al., 2012).

Societal and policy impacts are indicative of the societal quality of the work. *Fischnetz* led to a number of interpellations, motions and postulates in the federal and cantonal parliaments, to fundamental changes in a law (federal Waters Protection Act) and two by-laws (federal by-law on epizootic diseases, federal by-law on waters protection ordinance), to long-term changes in water and river management, and a plan for a nationwide technical upgrade of over 100 wastewater treatment plants (Water Protection Ordinance, 2016).

5.6. Uncertainty of causality regarding policy impacts

There is hardly any political decision that can be attributed completely to one specific transdisciplinary research project (Bornmann, 2013) due to the complexity of political decision-making processes (Walter et al., 2007). The findings from most studies percolate into people's awareness via rather diffuse and indirect channels (Weiss, 1980). Five cantons (Aargau, Bern, Graubünden, Solothurn, Zurich) revised their fish stocking regulations. Four revisions were undertaken during or shortly after *Fischnetz*; in three regulations, *Fischnetz* was explicitly mentioned; the other two incorporated elements of *Fischnetz* management advice. Nevertheless, conclusions regarding direct and unequivocal causalities are difficult to draw. Cantons may have been progressive and incorporated 'state-of-the-art' stocking recommendations independently of *Fischnetz*.

Currently, 130 million Swiss Francs are earmarked for river restoration projects by federal and cantonal authorities and communities (Supporting information, Table S2). Some river restoration projects were unequivocally attributed to *Fischnetz* (Birs vital, etc. Supporting information, Table S2). For numerous others, direct attribution to *Fischnetz* is difficult to determine. There was—and still is—real 'restoration hype'. This may be triggered through landscape planning instruments aiming to mitigate the effects of former inappropriate river management practices (Cowx, 2015). Indeed, it is possible *Fischnetz* was aided by the zeitgeist of the "restitutive compensation" movement, a modern attitude motivated by conscience about negative human impacts on nature and intentions to restore ecosystem functionality (Taylor, 1981).

5.7. Lessons learned

Systematic and conceptual-framework-based analyses, referring to scientifically sound criteria for measuring the degree of success of collaborative research practices, are only sometimes well-reported in the peer-reviewed literature (e.g. Hegger and Dieperink, 2014; Kraimer and Winiwarter, 2016, Schmid et al., 2016, Balvanera et al., 2017). For projects following Mode 2 knowledge production, both successes (Felt et al., 2016) and failures (Håkansta and Jacob, 2016) have been reported.

The time (more than two years), inclusive approach, and energy invested in setting-up *Fischnetz* proved to be crucial elements in its success. Inclusion of experts, executives and policy officials from science, government and the private sector demanded clear and stringent project management and a reporting structure that avoided uncertainties, which necessitated intense negotiations about responsibilities (Burkhardt-Holm, 2008b; Defila and Di Giulio, 2001). The management structure ensured all stakeholders had access to the same information at all times. *Fischnetz* adopted a top-down approach for financing and reporting, but fully bottom-up approach for science planning and research.

The specific political structure of Switzerland, its short lines of command and the near absence of an administrative jungle may have helped achieve successful outcomes. Having EAWAG as a leading partner was a great asset. Its financial resources (annual budget exceeding 50 million Swiss Francs) provided *Fischnetz* a high degree of

flexibility when additional funds—though small—were required at relatively short notice. This confirms other project experiences that institutional and financial support is of utmost importance (e.g. Weiss et al., 2011). The project did not have to convince science agencies of the necessity of remunerating researchers for allocating resources to manage a transdisciplinary project driven by the search for solutions to a real-world problem and expansion of effort to producing societal and policy impacts (Defila and Di Giulio, 2001).

In retrospect, we identified three aspects that were crucial to the success of this inclusive, transdisciplinary project. The first is the availability of financial means right at the beginning, or at least ensuring a process is in place that allows to the necessary funds to be obtained when they were needed; *Fischnetz* had a mixture of these. All further efforts can then be concentrated on content development. Secondly, involvement and participation of all stakeholders on an equal footing from the start. Progressive involvement is not ideal and intensive educational activities are necessary to bring “late comers” up to speed. This is particularly true for politicians with executive functions and direct access to legislation and government administrations. Though they have little time, their specific, early involvement allows them to develop ownership. Thirdly, and no less important, development of confidence-building, through continuous, transparent communication from the outset. All communication must be fully comprehensible by all stakeholders to allow them to easily relate to the main arguments and conclusions.

Assessing the successes and failures of a project after its closure is highly desirable, extremely valuable and is an act of providing responsibility to the funders, most often directly or indirectly society, i.e. tax payers. Such assessments are rarely undertaken for many reasons, e.g. momentum has moved to other topics, the key-decision makers have left the arena, other issues seem more important, funding sources have dried-up. To properly assess a project after its closure, it is essential (I) to establish systematic and complete documentation while the project is running—often different aspects than originally thought or planned gain significance at the end of project; (II) to maintain a network database to enable access to interview partners, even years after finalizing the project—nothing is more frustrating than to lose access to an initially seemingly irrelevant, but in retrospect, successful part of the research; (III) to secure financial and personnel resources after closure—funding agencies have little structural means to assure such financial support, retaining 5–10 percent of the project funding for a later assessment, particularly for larger programs, may be a solution.

Author contributions

P.B.H. and A.J.B.Z. designed, performed the research and wrote the paper.

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Conflict of interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.envsci.2018.01.010>.

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