Where Have All the FISH Gone?

The reasons why fish catches in Swiss rivers are declining.

PATRICIA BURKHARDT-HOLM

PATRICIA BURKHARDT-HOLM
UNIVERSITY OF BASEL (SWITZERLAND)
WALTER GIGER
HERBERT GÜTTINGER
SWISS FEDERAL INSTITUTE OF AQUATIC SCIENCE AND TECHNOLOGY (EAWAG)
UELI OCHSENBEIN
CANTONAL LABORATORY FOR SOIL AND WATER PROTECTION, BERN (SWITZERLAND)
ARMIN PETER
KARIN SCHEURER
EAWAG
HELMUT SEGNER
UNIVERSITY OF BERN (SWITZERLAND)
ERICH STAUB
SWISS AGENCY FOR THE ENVIRONMENT, FORESTS, AND LANDSCAPE (SAEFL)
MARC J.-F. SUTER
EAWAG

The decline in the inland fish catches has become a topical issue in many countries. In the U.K., the threat to inland migratory salmonid and eel stocks, as well as a significant change in species composition, is well documented. In Norway, fish suffer from severe malformations. Fewer fish are being found in Danish and French waters.

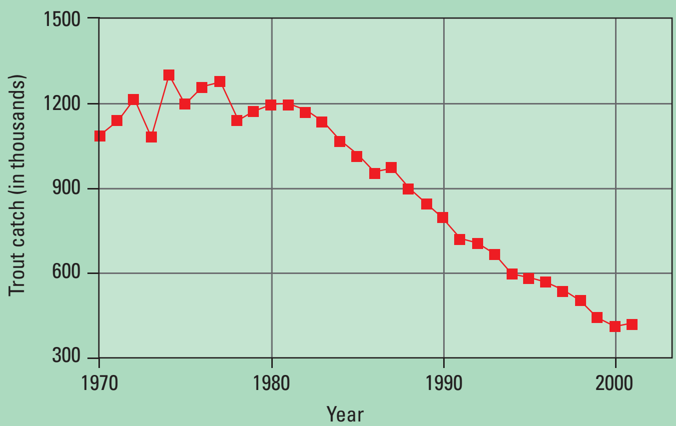
In Switzerland, the reported trout catch in streams and rivers has plummeted by 60% since the early 1980s (Figure 1). This drop has been accompanied by regional declines in fish health in Switzerland. What are the causes of this pan-European decline in fish catches, and how can it be reversed?

Switzerland is fortunate to have >240,000 recreational anglers. Proceeds from their fishing licenses benefit the maintenance of rivers and streams. But, just as importantly, these anglers keep personal catch statistics and report them to SAEFL. In this article, we will explain how those data helped Fischnetz, a nationwide study, isolate the causes of the decline.

FIGURE 1

Trout catches in Switzerland

Catches have steadily declined since the 1980s, according to anglers' personal data records.



Quietly vanishing fish stocks

In the 1970s, the apparent annual decline in fish in Switzerland was small and seemed to be within natural fluctuations, which masked the overall trend. By the 1980s, the fish catches dropped considerably. However, the decline has only begun to worry anglers recently.

The low numbers of fish elicit concern for three main reasons. First, unhealthy and reduced fish stocks indicate unsatisfactory and deteriorating ecological conditions, a situation far removed from the intact environment decreed by law (*1*). Second, with 42 of the 54 indigenous fish species in Switzerland now listed as endangered, threatened, or extinct, biodiversity is severely threatened (*2*). Moreover, fish are a bio-indicator for human health risks from toxic substances. This is especially important in Switzerland because drinking water is often produced from riverbank filtrate and, more commonly, from groundwater. Third, if fishing success is rare, then many anglers would not renew their permits, and this would result in an economic loss for the fishing administrations. Consequently, fewer funds would be available to appropriately manage the rivers.

A handful of fishermen and individual research studies alerted the authorities and the public to the first indications of fish decline in Switzerland in the 1970s. During this period, catches declined at varying rates for different waters and fish species. The best documentation is available for the most commonly caught fish species, which are nonmigratory brown trout (*Salmo trutta*) and grayling (*Thymallus thymallus*). However, data on fish caught by anglers do not necessarily reflect population size. And it is also important to note that almost every river and stream in Switzerland is stocked with varying numbers, age classes, and even different species.

How does stocking influence population density? An analysis of 24 Swiss stocking studies showed large variability. The most important factor is natural reproduction. Stocked brown trout, monitored shortly after stocking, were often more abundant than naturally reproduced (e.g., fry) trout of the same age class. However, in rivers with naturally reproduced trout, stocked young trout steadily declined, and 2 years later, they contributed only 4–20% to their respective age classes (*3*). This small number implies that stocking has a very limited effect and that managers generally overestimate the benefit of stocking streams. Furthermore, the catch data reveal a considerable geographic variation, with some rivers showing as much as 80% decline over 10 years, while a few increased 30% during the same period.

In parallel to the declining fish catch, fish health was poor in several rivers and streams. Macroscopic lesions and histopathological tissue alterations of the liver, kidneys, and gills were observed regularly. Again, the sentinel brown trout was the fish most often studied.

Pinpointing the causes

The problems observed were so widespread and their causes so obscure that the Swiss researchers and authorities initiated Fischnetz (Netzwerk Fischrückgang Schweiz; Project on declining fish catches in Switzerland) in 1998 (*4*). The cross-disciplinary project included researchers from various research institutions, cantonal and federal authorities, the chemical industry, and the fisheries associations. This nationwide research network operated for five years until the project's completion in January 2004.

The project had six main goals. First, collect and evaluate available, but scattered, data on fish catches, fish health, and population abundances from the past 20 years. Second, initiate new research activities wherever significant information gaps are identified. Third, improve coordination of the relevant diverse research activities at Swiss universities and regulatory bodies, and fourth, enhance communication among them. Fifth, identify the most important factors responsible for the present decline, and sixth, suggest measures to improve the current situation.

To structure the search for causes, the following 12 hypotheses were developed. These hypotheses include cause–effect relationships at multiple levels, with some overlap and interaction between them. The first 4 hypotheses comprise effects, and the last 8 address potential causes.

1. The declining fish catches are due to more than one factor, each possibly having a different regional significance.
2. Adult fish are failing to reproduce . . .
3. . . . or are not being replaced by younger fish.
4. The health and fitness of the fish are impaired.
5. Chemical pollution (both nutrients and micropollutants) is causing harmful effects.
6. The poor morphological quality and longitudinal connectivity of rivers (i.e., barriers dis-

rupt the rivers' continuum) affect fish survival and recruitment.

7. The relative amount of fine sediments has increased and led to sediment clogging, which reduces spawning success and disturbs the embryonic development of brown trout.

8. The amount or quality of food is insufficient.

9. Fisheries management, including stocking practices, as well as angler behavior, is causing the declines.

10. Predatory birds are removing too many fish.

11. Water temperature has changed; this harms fish, especially trout.

12. High floods in winter and the corresponding sediment transport have changed the rivers detrimentally.

Sorting through hypotheses

Results from various study types helped rule out several of the hypotheses. These studies either monitored selected parameters (e.g., occurrence of diseases and water temperature), were case studies that generated more detailed and comprehensive data for a given hypothesis in already well-characterized areas, or synthesized several projects focusing on the same questions or the same geographical region. In this way, hypotheses that are supported only by weak evidence or evidence that is geographically restricted were neglected. The basis for this procedure was the generation and application of a Bayesian network and a weight-of-evidence approach. In the end, Fischnetz researchers identified three key factors of national or regional importance: the fisheries management, the parasitic disease proliferative kidney disease (PKD), and the habitat situation (morphology and water quality).

Fewer angling trips? Early in the project, a fundamental fisheries management question emerged: Could the declining number of fish being caught be simply explained by fewer anglers or by their reduced efforts? To address this question, Fischnetz studied angling behavior and changes over the past 20 years as well as the corresponding catch figures (*3*). Between 1980 and 2000, the number of angling permits sold for rivers and streams decreased by 23%. A representative survey of anglers fishing in rivers and streams showed that the number of trips per permit declined from an average of 27 in 1980 to 22 in 2000. This period of declining fishing intensity corresponded with the time period when fish stocks were observed to be dropping. For example, the ratio of successful angling trips declined from 78% to 24%, while the trip duration remained the same. In addition, total annual catch per angler fell from 49 in 1980 to 25 in 2000, which is more than the drop in permits and trips per permit. On the basis of these statistics, it was concluded that a real reduction of the fish stock occurred that forced the anglers to adapt their behavior. However, changed recreational activities may also explain part of the observed catch decline.

Is a parasite making life miserable for brown trout? PKD was identified as a contributing factor to declining fish catches. The disease is caused by the

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Claude Wisson with the fisheries authority of Basel and students from the University of Basel collect fish by electrofishing to determine the success of returning this stretch of the Wiese River to its natural state.

parasite *Tetracapsuloides bryosalmonae*, which proliferates in the kidneys and other organs of fish. No treatment or cure is currently available. Up to 90% of PKD-induced mortalities in brown trout occur when water temperatures surpass 15 °C for 2 weeks or more (*5*). Young fish are especially susceptible, and as a consequence fish stocks lack offspring.

Fischnetz found PKD in river trout at 190 of 462 sites studied (*5*; Figure 2). PKD was shown to occur particularly in the waters of the Swiss lowlands, where summertime water temperatures often exceed 15 °C. Because the presence of PKD in rivers correlates with reduced fish catch (*3*), the disease seems to be a significant factor contributing to the fish decline in Swiss rivers.

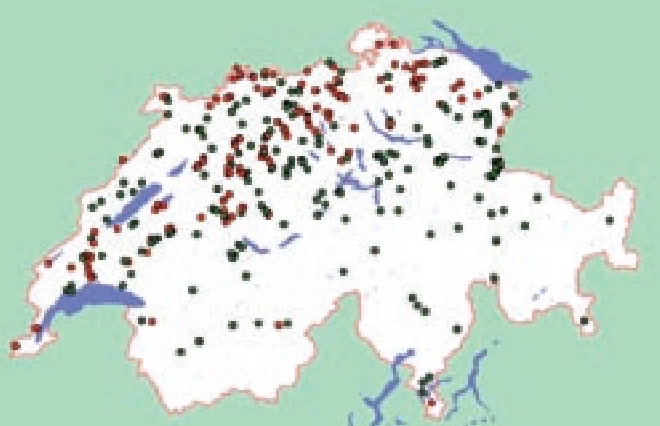
Fischnetz researchers also examined water-temperature data, finding an ~1.5 °C increase in stream and river temperatures over the past two decades, probably as a result of climate change (*3*). With this rise in temperature, the number of river stretches that reach the critical 15 °C threshold has also increased.

Stream morphology is also relevant because PKD-induced losses in one stretch of a river may be compensated for by migration from unaffected reaches—provided that migration is possible and there are no hindrances. In addition, the critical water-temperature threshold for PKD-induced mortality is usually reached in the lower parts of the rivers, while infected fish in the more upland reaches survive because of the colder water.

FIGURE 2

Proliferative kidney disease is rampant in brown trout

Of 462 river test sites, 190 had fish infected with the disease (red dots) and 272 did not (green dots). Source: www.ecogis.ch.



Poor habitat. Another important factor in the fish decline is deteriorated habitat quality, with respect to either habitat morphology or water quality.

Fish need a natural or near-natural river morphology to sustain healthy populations. This is particularly true for the stream-dwelling brown trout. Variations in depth, width, streambed roughness, substrate size and quality, and interactions with the floodplain are important elements of the river morphology. Longitudinal and lateral connectivity is vital for fish to reach the different habitats. Compare this ideal to the present situation in almost all densely populated regions in Europe, and one will find: too many artificial barriers exist, river courses have been straightened over long reaches, settlements draw ever closer to river banks, and water is diverted from natural watercourses for energy production and agriculture (Figure 3).

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Sampling for pesticide peaks took place along the Seebach River, which is located in a catchment that is dominated by intensive agriculture.

In Switzerland, up to 10 obstacles per kilometer of stream length prevent fish from moving up or down a river and into the tributaries (*6*). Fischnetz projects demonstrated that the trout biomass in disconnected river stretches is very low, for example, <20 kg/ha in the Rhône River compared with a 5–15× higher biomass in reaches with good connectivity. Further, the interface between water and land is very important for fish. Overhanging vegetation, such as branches and roots, provides shelter and falling insects, which represent up to one-third of the summer food for fish in small rivers. The bank zone also acts as a buffer, which protects a stretch of water from runoff and fine sediments, leaching of agricultural chemicals, and drainage from nearby roads and settlements. The fine sediments clog streambeds and render them unsuitable for gravel-spawning brown trout. These sediments also prevent oxygen-rich water from reaching the eggs and removing the metabolic products. But decreasing catches and stocks have also been observed in habitats with good morphology. So other factors must also be affecting fish.

Switzerland has 7.2 million human inhabitants, with the highest regional population density in the Swiss lowlands (100–800 inhabitants/km^2). The catchments of 30,000 km of rivers and streams are also situated in the lowlands. Pollution has been substantially reduced during the past 30 years, and

95% of the population discharges its wastewater effluents to municipal wastewater treatment plants (WWTPs). Nevertheless, surface waters still receive an excess load of nutrients as well as synthetic chemicals and their metabolites from incomplete elimination in WWTPs, atmospheric deposition, and runoff from agricultural fields and urban surfaces. Peak concentrations of chemicals such as nitrite, ammonia, pesticides, and heavy metals can be very high after heavy rainfalls. Water quality requirements for nitrite are almost never met downstream of WWTPs in the densely populated regions of Switzerland. Although the applied load of pesticides has been reduced by ~40 %, that positive result has been counteracted by the increasing potency of these chemicals. Today, we find concentrations of pesticides in agricultural regions above safe levels, especially during periods of application.

Estrogen disrupters are also chemicals of concern. These so-called environmental hormones have been found in WWTP effluents at concentrations that affect trout (*7*). Effluents throughout Switzerland contain the naturally occurring steroid hormones estrone, estradiol, and estriol; the synthetic ethinylestradiol (an active ingredient in contraceptive pills and the most potent estrogen in vivo); and, for example, the degradation products of nonylphenol polyethoxylate surfactants used in industrial cleaners. The resulting estrogenicity was calculated on the basis of the numbers of inhabitants in the catchment, the known elimination rates of estrogens in WWTPs, and the median flows in the receiving waters (Figure 4). Adverse effects on reproduction physiology of sensitive fish species downstream of WWTPs have been reported, especially during dry seasons and where effluent dilution is low (*8*).

The input dynamics and fate are only known for some of the anthropogenic chemicals that can potentially enter the aquatic environment, and their environmental risk has been assessed. Unidentified chemicals also may enter the aquatic system and are often only studied after detrimental effects in an ecosystem have been observed. Similarly, known environmental contaminants can be found to have previously unrecognized effects. For example, nonylphenol, which was regulated for toxic effects, was later found to also be estrogenic. Mixture effects further complicate the issue, because a mixture of estrogenic chemicals with the same mode of action, even when present at concentrations below minimum-effect levels, can induce effects due to concentration additivity (*9*). Fischnetz data demonstrate that some WWTPs, particularly those for which measured chemicals exceeded the environmental quality standard levels, pose a risk to fish abundance and/or health. Consequently, Fischnetz researchers suggested the implementation of regulatory measures to reduce inputs.

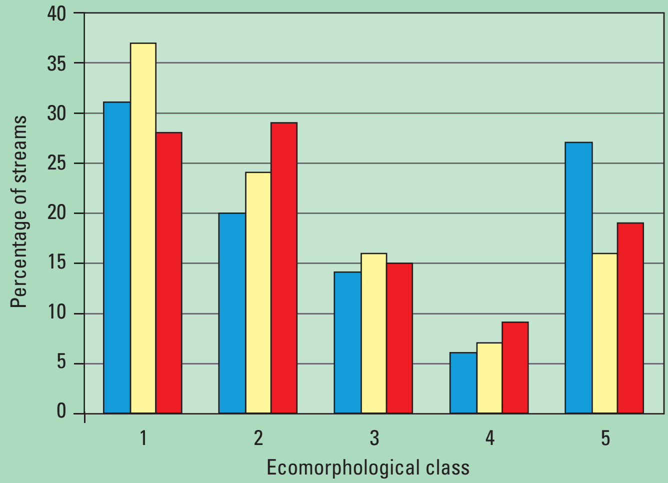
A multifactor cause

At the end of the five-year project, all the participating scientists agreed that more than one factor is likely to be involved in the case of the vanishing fish and that several of the hypotheses are interrelated: Fisheries management, PKD, and habitat quality are the key factors. These conclusions must be tempered by the knowledge that ecosystems undergo multifactor changes and that several factors may act synergistically. Furthermore, the various factors can have different degrees of importance at the national, regional, and local levels. For example, in some regions, the role of predatory birds was negligible, while elsewhere the biomass caught by cormorants (210 kg/ha) exceeded the grayling biomass removed by anglers (49 kg/ha). Clearly, changes are slow and often only noted after a certain delay—and possibly the introduction of additional stressors, such as infectious diseases, that act on the population level and aggravate the situation.

FIGURE 3

Classifying streams and rivers

Streams and rivers in three cantons (Zurich [blue], Bern [yellow], and Solothurn [red]) are classified according to the following levels of stream properties: class 1: natural/close to natural; class 2: minimally impacted; class 3: heavily impacted; class 4: unnatural/artificial; class 5: streams in culverts.



During the five-year study, Fischetz scientists took two approaches in evaluating the data. In the first approach, Fischnetz researchers developed a Bayesian probability network to summarize the qualitative and quantitative information to study the manifold interrelations among the various factors. Bayesian networks are becoming more popular for aquatic systems because they help researchers visualize causal assumptions (*10–12*). This kind of model is based on a dynamic representation of the brown trout lifecycle and was extended to include the effects of natural and anthropogenic factors. Conditional probability distributions were based on carefully elicited judgments of scientists and experts in this field. Several model scenarios were compared to assess the relative importance of the various stress factors.

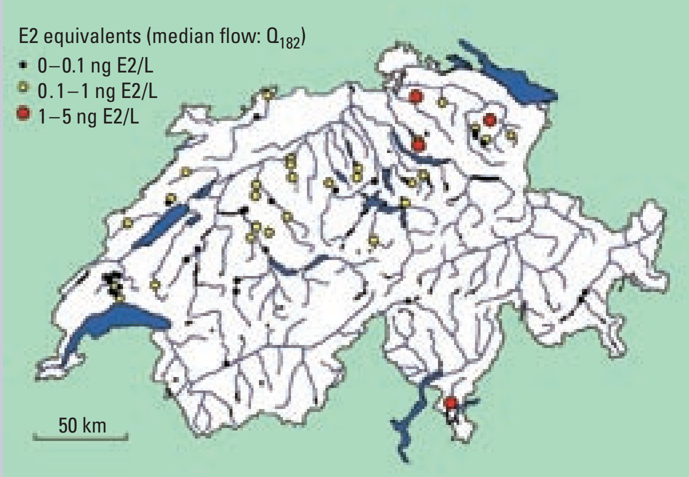
In four river basins with characteristics that represent the various conditions in the Swiss lowlands, the model identified impaired habitat as very important at all but the least-impaired sites. Sediment clogging by fine sediments and PKD are also very important at various sites. Diluted wastewater inputs are a contributing factor at 3 of the 12 sites. In some stretches, effects of stress factors are partially offset by stocking. However, stocking with fry in autumn may contribute to a density-dependent mortality. Therefore, respective numbers of fry are integrated as an input variable in the population model. Conclusively, the results of the network model calculations indicate that the relative impact of the various causal factors differs among locations, depending on the combination of factors found at a specific site (*10*).

The second approach was the weight-of-evidence analysis or retrospective ecological risk assessment (*13*). It aims at evaluating the available evidence as objectively as possible. Although sufficient data were only available for the most thoroughly investigated

FIGURE 4

Estrogen disrupters escape from wastewater treatment plants

The levels of estrogenicity downstream of municipal wastewater treatment plants were calculated on the basis of the number of inhabitants in the catchment, elimination rates of estrogen in WWTPs, and median flows in the receiving waters. Q_{182} is the flow rate for at least 182 days/yr; E2 is 17-β-estradiol.



parameters, the weight-of-evidence analysis makes the assessment more transparent. This transparency greatly facilitates discussion, particularly with experts outside of academia.

Potential primary causes were raised and given a weight-of-evidence test, including PKD, NH_4^+, NO_2^-, pesticides, flame retardants, estrogen equivalents, percentage wastewater, river morphology, connectivity between rivers and tributaries, fine sediments, benthic organisms, stocking, angling intensity, water temperature, and high floods in winter. This epidemiological approach is used to query the occurrence, relevance, and interrelationship of potential factors. In this project, these results have been determined for the 12 river sites that had the most data available. The most probable cause of declining fish populations was found to be PKD in some reaches, water temperature for other river stretches, and degraded habitat morphology for other locations. Several reaches were affected by multiple factors. However, this approach does not tackle the combination of factors; for example, synergistic effects could not be assessed. Another drawback of this approach is seen when knowledge is lacking, such as on the effects of chemicals.

Nevertheless, the Fischnetz researchers concluded from both integrative approaches that a single factor is not responsible for the widespread catch decline; rather, a combination of stressors contributes to the observed negative effects.

Proposed measures and future activities

Even if several long-range historical data sets are incomplete and many relationships among factors are unknown, the results of the Fischnetz project still yield concrete measures for improving the living conditions of fish. The following three measures vary in efficiency because they act on different regional levels and address different stakeholders. Any proposed measure must clearly be adapted to local conditions; because of space limitations, the focus here is on the top-priority issues: First, stocking PKD-free waters with fish from PKD-infected waters must be avoided. Second, the habitat morphology, especially the connectivity of rivers and streams, must be improved along the entire length of rivers as well as within their tributaries. Third, Swiss rivers and streams should have a water quality that neither acutely threatens the life of fish or other organisms nor induces poor health in fish and their progeny in the medium or long term, as defined in the EU Water Framework Directive. Equally important is better supervision and consistent application of Swiss water protection regulations in agricultural locations with a cultivated fraction of 10% or more, in order to reduce pollution from pesticides or other harmful substances, such as veterinary pharmaceuticals. Interventions at the source of the problem are particularly effective but sometimes difficult to conduct.

When the Fischnetz project was completed, an information center was established at one of the participating institutions to help answer anglers' questions. In a follow-up project called Fischnetz Plus, which is already under way, the authorities of the Swiss cantons are using the data from Fischnetz to improve the living conditions of fish in Swiss rivers. We hope that these efforts will eventually improve the quality of the aquatic environment and restore the fish populations in Swiss rivers.

Patricia Burkhardt-Holm is a professor at the University of Basel and heads the Man–Society–Environment Institute. Walter Giger is a department head at Eawag and a professor at the Swiss Federal Institute of Technology. Armin Peter is a stream ecologist and fish biologist at Eawag in Kastanienbaum. Herbert Güttinger is a senior scientist, Karin Scheurer is a specialist in aquatic ecology and water quality, and Marc J.-F. Suter is an analytical chemist at Eawag in Dübendorf. Ueli Ochsenbein is the water protection chemist head of the Cantonal Laboratory for Soil and Water Protection in Bern. Helmut

Segner is a specialist in fish pathology and toxicology, and a professor in and head of the Swiss Federal Centre for Fish and Wildlife Health at the University of Bern. Erich Staub is a specialist in fish biology and fisheries management at SAEFL in Bern.

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