CHAPTER 3

Managing Upper Lake Constance Fishery in a Multi-Sector Policy Landscape: Beneficiary and Victim of a Century of Anthropogenic Trophic Change

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Abstract Upper Lake Constance (ULC) is a large pre-alpine lake situated between Austria, Germany and Switzerland (9°18'E, 47°39'N). Along with the smaller, conjoined expanse of Lower Lake Constance, it forms the third largest lake in Europe. Its waters underwent pronounced eutrophication during the 20th century. Commercial fisheries benefitted strongly from the increased productivity during an initial mesotrophic phase, but these advantages were effectively neutralized when eutrophication became severe. By the turn of the 21st century, internationally coordinated measures to reduce nutrient input to the lake had returned ULC to its historic reference state as an oligotrophic ecosystem. However, the remarkable success of the nutrient management program has been to the detriment of commercial fishers. Yields of most commercially important fish species have decreased, along with lake productivity. As a consequence, the high market demand for local fish products is nowadays met mainly by imports, the ecological footprint of which offsets the local benefits of environmental restoration. Responsibility for fisheries and environmental aspects of ULC managing is shared by the national and federal state administrations and in all cases, tourism, drinking water and environmental interests now take priority over fisheries. As a result, the number of fishers operating viably on Germany's largest inland water body continues to decline and the long-term viability of commercial capture operations is in doubt. Aquaculture of locally desired fish species may become an important factor in the future of the Lake Constance fisheries.

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1. Lake Constance's Fish Community

Lake Constance has a total surface area of 536 km^2 and is divided into a large (472 km^2), deep (z_{max} = 254 m, z_{mean} = 101 m) Upper Lake (Photo 3.1) and a small (63 km^2), shallow (z_{mean} = 16 m) Lower Lake (Figure 3.1). This paper deals solely with the better documented warm-monomictic pre-alpine expanse of Upper Lake Constance (ULC) which has supported a regionally important fishery for many centuries.

Figure 3.1. Location of Lake Constance in Europe and between Germany, Switzerland and Austria.

Photo 3.1. Scenery of Upper Lake Constance.

More than 30 species of fish currently occur in ULC (Rösch 2014). The pelagic fish fauna is dominated by whitefish *Coregonus spp.* Four species of this highly important commercial genus were originally found in the lake: the pelagic spawning Blaufelchen (*Coregonus wartmanni* [Bloch 1784]), the nearshore spawning Gangfisch (*Coregonus macrophthalmus* [Nüsslin 1882]), the larger Sandfelchen (*Coregonus arenicolus* [Kottelat 1997]), and a deep-water dwarf species known as Kilch (*Coregonus gutturosus* [Gmelin 1818]). The latter disappeared from ULC between 1970 and 1980 as a result of oxygen depletion of the hypolimnion (Eckmann and Roesch 1998). Beside whitefish, ULC also supports good numbers of Eurasian perch (*Perca fluviatilis*), several cyprinids including bream (*Abramis brama*) and roach (*Rutilus rutilus*), and a number of predatory species, in particular pike (*Esox lucius*), Arctic char (*Salvelinus umbla*) and lake-dwelling brown trout (*Salmo trutta*). Since 2013, the non-endemic three-spined stickleback (*Gasterosteus aculeatus*), a small fish species of no commercial importance, has been building huge stocks. Sticklebacks now dominate the pelagic zone of the lake, competing with *Coregonus* spp. for daphnia and in all likelihood preying on eggs and larvae of these and other commercially significant species.

2. The ULC Fishery

The various whitefish species present in ULC have been the mainstay of local fisheries for a century (Photo 3.2), with the Eurasian perch becoming the second most important catch since the 1950s. Other species of commercial interest are pike, eel (*Anguilla anguilla*), Arctic char, lake-dwelling brown trout and pikeperch (*Sander lucioperca*).

Independent regulation of local fisheries around Lake Constance began as early as 1350, in an effort to manage competition (Zeheter 2015). However, those early efforts proved inadequate as they did not cover the whole lake. Finally in 1893, after calls for wider regulation from local fishers' organizations and lengthy negotiations, the federal German states of Baden, Bavaria and Württemberg joined Switzerland and Austria in signing the Bregenz Agreement, which remains the legal framework for the regulation of ULC fisheries to the present day (IBKF 1893). As a condominium, the lake has no borders, and its entire area (except those less than 25 m deep) is open to all fishers regardless of nationality. Commercial fishing licenses are granted by Austria, Switzerland and the German federal States of Bavaria and Baden-Württemberg, and the number issued has been controlled since 1914.

Since 1893, ULC has been managed by a political decision-making board that meets at least once a year. The board, known as the IBKF (Internationale Bevollmächtigtenkonferenz für die Bodenseefischerei, or International Conference of Plenipotentiaries for Fishery in Lake Constance, www.ibkf.org) is advised by a group of local fisheries experts. This expert group meets at least twice a year in order to consider the latest monitoring data and the wishes of fishers and anglers (numbering around 13000) and to propose adjustments to harvest regulations such as minimum-landing sizes, closed seasons, mesh sizes and other effort controls. Its recommendations for changes to fishing rules are passed to the political board (IBKF). Most monitoring data are generated by fisheries administrators or local research stations in each country. The yields of all professional fishers have been recorded regularly since 1910, and records of all fishing licenses issued have been kept regularly since 1982. Single data for issued licenses before 1982 exist for the years 1914, 1931 and 1934, missing data were interpolated for the period 1934-1982.

Photo 3.2. Fishermen from Upper Lake Constance at work.

3. Dynamics of Anthropogenic Trophic Change

The waters of ULC underwent pronounced eutrophication during the 20th century owing to nutrient input in the form of municipal waste and agricultural run-off. Concentrations of phosphorous (P) measured during winter mixing (February–March (P_{mix}) increased from 7 $\mu g \cdot L^{-1}$ in 1951 (oligotrophic conditions) to >80 $\mu g \cdot L^{-1}$ around 1980 (eutrophic conditions) (Stich & Brinker 2010, IGKB 2014). These changes had profound effects on the lake's ecology. In particular, the increased nutrient load promoted algal growth, which in turn influenced characteristics including subsurface light penetration and the structure and function of lake food webs (Gaedke 1998). Due to strong bottom-up effects in the food web (Downing et al. 1990, Thomas and Eckmann 2007) eutrophication led initially to a sharp rise in fish production in the lake. However, negative consequences of the anthropogenic nutrient loading soon became obvious, in particular algal blooms and loss of water clarity (Zintz et al. 2010). In 1951, on the advice of the International Union of Lake Constance Fishers (Internationaler Bodensee Fischereiverband, IBF), the IBKF founded a working group on waste water management (IBKF 1951). However, this group had neither a mandate nor the political influence to initiate internationally coordinated measures to reduce nutrient loading. On the recommendations of the IBKF, the tri-national Water Quality Protection Commission of Lake Constance (Internationale Gewässerschutzkomission für den Bodensee, IGKB) was founded in 1959. This commission of environmental administrators initiated several coordinated measures including sewage collection, installation of sewage treatment plants in the catchment area and the incorporation of P precipitation into routine sewage treatment processes. To date, the total costs for these measures amount to about 5.4 billion US dollars (igkb.org). Parallel measures to reduce phosphate levels in detergents were initiated in all three nations and as a result, P inputs to ULC were drastically reduced, and the lake was restored to an oligotrophic state by the beginning of the 21st century.

The uses of ULC and its surroundings have changed in other ways over the last 100 years. Local tourism and leisure industries have burgeoned and the region currently registers more than 18 million guest nights per year (www.statistik-bodensee.org/index.php /tourismus.html). Ferry traffic has also increased, with more than 10 million person crossings recorded in 2000 (Zintz et al. 2010). ULC is also famous for recreational sailing and serves as a resource for an increasing range of other outdoor pursuits. The number of registered pleasure boats on the lake increased from around 39000 in 1980 to nearly 57000 in 2000 (Zintz et al. 2010). Docks, moorings, buoys for boats and swimming beaches impact significantly on the productive shallow water zone, and in 2000, 45% of the entire 273 km shoreline of Lake Constance was considered strongly modified, for example by straightening, embankment or construction (IGKB 2009, Zintz et al. 2010). Meanwhile, ULC water has become an ever more important resource, with more than 4 million people currently relying on it for drinking water (Zintz et al. 2010).

4. Ecological Consequences of Anthropogenically Modified Nutrient Dynamics

The trophic condition of lake water influences fish growth through bottom-up control of secondary production (Downing et al. 1990, Müller et al. 2007). Crustacean zooplankton is the main food source of pelagic fish in ULC. During the peak eutrophication of the 1960s and 1970s, their average annual density over the entire water column increased from 4×10^5 individuals$\cdot$m^{-2} to over 10^6 individuals$\cdot$m^{-2} (IGKB 2004). By the turn of the 21st century, following the implementation of nutrient input controls, these values had returned to pre-eutrophication levels (IGKB 2004, Stich and Brinker 2010, Thomas and Eckmann 2007). Whitefish living in ULC during the 1970s grew nearly 10 cm longer in their second year of life compared with those in the 1950s and 1990s when P-levels were lower (Thomas and Eckmann 2007). Although enhanced growth rates might be expected to increase fish production and yield, the high P levels also brought negative effects for the variability of standing stock and age structure. For example, from the late 1960s to early 1990s, whitefish biomass showed strong inter-annual variation, with the lowest value documented in 1967 (below 30 metric tons [mt]) (Thomas and Eckmann 2007). During that time, fish grew very rapidly and entered the fishery at a young age. The majority of stock was made up of fish less than three years old, and an increasing fraction of commercial yields consisted of age-1 fish that had not yet reproduced. By contrast, during a phase of increasing P-concentration in the 1950s, and again from the late 1980s to 2005 when P levels were declining, standing stocks of whitefish typically included five or six age classes, and standing stock biomass was relatively high and stable (Thomas and Eckmann 2007). In more recent years, with P-levels comparable to those of the 1940s and 1950s, whitefish growth rates have decreased dramatically (IBKF 2015).

The disappearance of the dwarf *Kilch* whitefish species from ULC during the eutrophic phase (Eckmann and Roesch, 1998) is attributed to sediment surface conditions detrimental to egg survival. Hypoxic conditions resulting from algae bloom caused by high P loads almost lead to the extinction of Arctic char in the 1970s. Lake-dwelling brown trout also suffered, as a result of losses of stream habitats suitable for spawning (Hartmann 1984; Ruhlé et al. 2005). Populations of both species have stabilized through improved natural recruitment since measures were taken to control eutrophication. Whitefish, Arctic char and trout are also subject to stock enhancement by stocking, which has been carried out in ULC for more than 120 years (Rösch 1993). Stocking effort increased steadily in the late 20th century, from approx. 27 million larvae in 1963 to 441 million in 2002 (Thomas 2009). Despite this effort, yields of whitefish continue to fluctuate widely and the decline in catch since 2010 has not been mitigated, lending support to models that question the value of fry stockings in naturally reproducing stocks (Lorenzen 2005).

Eurasian perch, the second-most important fishery target in ULC, also reacted to changes in food availability. Prior to eutrophication, adult perch were mainly predatory, but they switched almost completely to zooplankton (mainly daphnia) between the 1960s and late 1990s, and built to very high levels of abundance when P-levels exceeded 10 – 15 $\mu g{\cdot}P\ L^{-1}$. When P-levels subsequently dipped below this threshold, adult perch became predatory once more and standing stock size decreased substantially (Eckmann et al. 2006).

The anthropogenic modification of the ULC shoreline has been problematic for species that rely heavily on intact and macrophyte-rich littoral zones, including perch and cyprinids, which have lost significant areas of their spawning and nursery grounds (Deufel et al. 1986; IGKB 2009). Efforts to restore some littoral areas began in the 1990s (Zintz et al. 2010), and subsequent evaluations have shown increased numbers of young fish in these restored zones compared to degraded areas (www.firebo.eu).

5. Consequences of Nutrient Dynamics for Commercial Fisheries

Changing P-level is the most significant factor impacting on ULC fisheries. From the perspective of commercial fisheries, P driven developments over the past 105 years can be grouped into five phases: I) 1910 to 1955, II) 1956 to 1969, III) 1970 to 1989, IV) 1990 to 2005, V) 2005 to the present day (Figure 3.2).

Phase I (1910-1955): ULC was oligotrophic (P_{mix} = < 10 $\mu g\ L^{-1}$) and fishery yields were low, but relatively stable ($mean_{1910\text{-}1955}$ ± SD [standard deviation] = 423 ± 134 mt, CV [coefficient of variation] = 31 %; Figure 3.2). By mass, nearly 70% of fish landed were whitefish ($mean_{1910\text{-}1955}$ ± SD = 289 ± 100 mt, CV = 34 %), but the proportion of perch increased from 5% in 1910 to 15% in 1955 ($mean_{1910\text{-}1955}$ ± SD= 47 ± 35 mt, CV = 74 %). During this phase, annual catch per license was comparably low (mean ± SD = 2.4 ± 0.6 mt, CV = 25 %; Figure 3.3). At the end of the 19th century, about 400 professional fishers operated on ULC (IBKF 1895). The number of licenses was capped for the first time in 1914, at 435 (IBKF 1914), but the high impact of fishing and the low production potential of the lake meant that not all the available licenses were issued. In 1931, 273 fishermen were licensed to fish in ULC (IBKF 1934) and in 1934 the maximum number of available licenses was revised significantly downwards to 218 (IBKF 1934). While fishers were restricted by regulations controlling effort, their operations were expected to be profitable because the cap on licenses ended the race-for-fish and aimed to secure a small, but stable yield for each licensee.

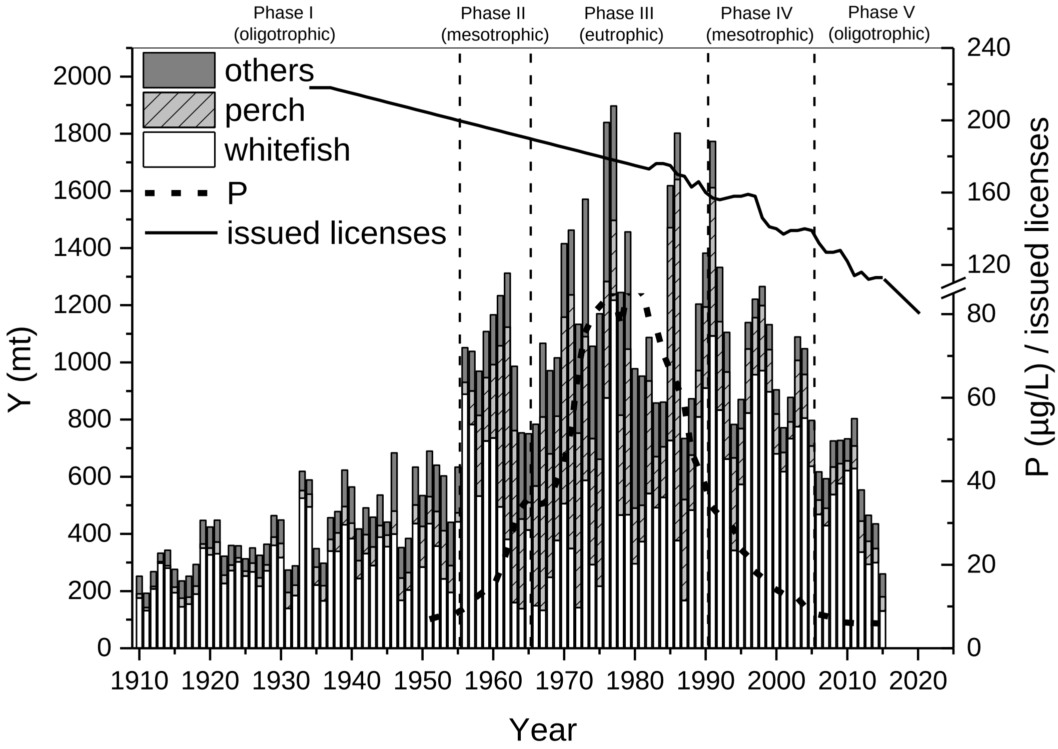

Figure 3.2. Fisheries yield in metric tons (mt) for whitefish (white columns), perch (grey, dashed columns) and other fish species (dark grey columns) between 1910 and today; the yield for 2015 is estimated. The P-level between 1951 and 2015 is the dashed black line and the number of issued fishing licenses in ULC between 1934 and 2020 is the solid line (data between 1934 -1982 and 2015-2020 were interpolated); note the discontinuity of the right y-axis. Phases group the trophic change during the last 100 years.

Phase II (1956-1965): During this mesotrophic phase P-levels rose from 10 to 35 $\mu g \cdot L^{-1}$ and yields increased accordingly. Total annual yield exceeded 1000 mt (1956) for the first time in 1956 and went on to average 1035 ± 185 mt (± SD; CV = 18 %) (Figure 3.2) between 1956 and 1965, with a maximum of 1310 mt in 1963. Compared to phase I, total whitefish yield ($mean_{1956-1965}$ ± SD = 525 ± 258 mt, CV = 49 %) and annual total catch per license ($mean_{1956-1965}$ ± SD = 5.3 ± 0.9 mt, CV = 17 %; Figure 3.3) had doubled, and yields of perch ($mean_{1956-1965}$ ± SD = 324 ± 236 mt, CV = 72 %) were six times higher than under oligotrophic conditions. Local demand for fish could be easily fulfilled and a proportion of the catch was regularly sold outside the ULC region. During this time, the possibility to earn relatively easy (and good) money in the growing industries around Lake Constance led some fishermen to give up their business, resulting in a small reduction of issued fishing licenses (Figure 3.2). The same period also saw a change in fishing techniques, from traditional ‘Klusgarn’ seine fishing to more size-selective monofilament nylon gillnets. Because whitefish growth rates at the time were high, a rapidly apparent effect of this size-selectivity was an increasing number of age-1 whitefish in the catch (Gum et al. 2014). The obvious risk of recruitment overfishing was counteracted by a moratorium on pelagic whitefish fishing for the 1964 season and then an increase in the minimum mesh size from 38 – 40 mm to 44 mm from 1965. The legal catch size for whitefish was also increased, from 30 cm to 35 cm (IBKF 1964, 1965). Due to those measures the annual whitefish catch per license decreased for two years (from $\text{mean}_{1955\text{-}1963} \pm SD = 3.2 \pm 0.9$ mt, CV = 29 % to $\text{mean}_{1964\text{-}1965} \pm SD = 0.8 \pm 0.1$ mt, CV = 9 %; Figure 3.3). Compliance with fisheries regulations had been enforced by fishery wardens since the 1950s and was probably therefore high. All in all, high yields more than compensated for stricter regulation and rendered this mesotrophic phase a “golden age” for ULC fishers.

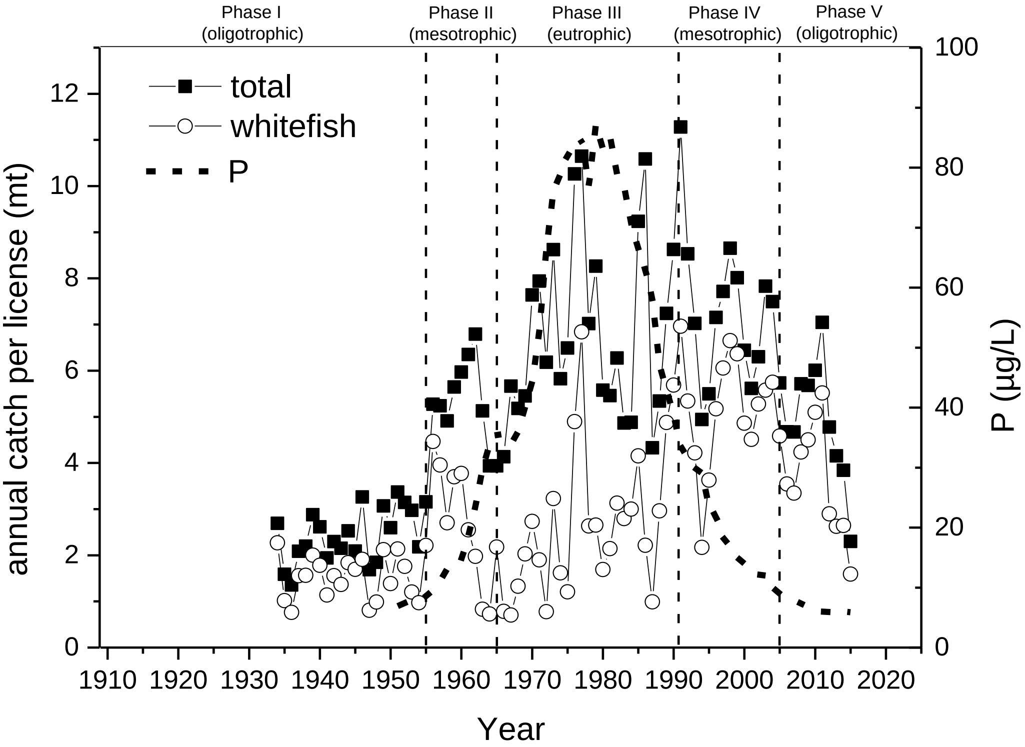

Figure 3.3. Catch per license in metric tons (mt) for total catch (grey squares) and for whitefish catch (white circles) between 1934 and today, the P-level between 1951 and 2015 is the dashed black line. Phases group the trophic change during the last 100 years.

Phase III (1966-1990): During this eutrophic phase, P-levels consistently exceeded 35 $\mu g \cdot L^{-1}$ and peaked in 1979 at 87 $\mu g \cdot L^{-1}$ (Figure 3.2). Disadvantages of excessive nutrient inputs to fisheries became apparent, with natural recruitment of all whitefish species and Arctic char suffering from low oxygen levels in the hypolimnion. Indeed, highly prized Arctic char almost disappeared from the catch (Rösch 2014). At the same time, numbers of low-priced or barely marketable cyprinid fishes such as bream and roach captured in the pelagic zone increased (Hartmann 1977; Nümann 1972). In consequence, while total annual yields remained fairly high ($\text{mean}_{1966\text{-}1990}$ ± SD = 1.215 ± 339 mt, CV = 28 %), annual whitefish catch per license ($\text{mean}_{1966\text{-}1989}$ ± SD = 2.7 ± 1.6 mt, CV = 59 %) did not increase further and was very unstable (Figure 3.3). Yields of perch were high but unstable as well ($\text{mean}_{1966\text{-}1990}$ ± SD = 448 ± 260 mt, CV= 58 %), and at beginning of the eutrophic phase poor filet quality and high parasite loads in perch were reported (IBKF 1966). The overall efficiency of gillnet fishing was reduced by blooms of algae that fouled the nets in midsummer (Thomas 2009). Towards the end of phase III, demand for fishing licenses decreased, most likely due to diminishing yields, and the number issued fell from 173 in 1982 to 160 in 1990 (Figure 3.2).

Phase IV (1991-2005): During this second mesotrophic phase, whitefish yield rebounded to a relatively stable level ($\text{mean}_{1991\text{-}2005}$ ± SD = 760 ± 186 mt, CV = 24 %) and sometimes exceeded local demand, as evidenced by exports to other regions of Germany. Perch yields remained at an acceptable level for 10 years ($\text{mean}_{1991\text{-}2000}$ ± SD = 259 ± 112 mt, CV = 43 %), but subsequently fell below 75 mt in 2001, 2002 and 2005, their lowest since the early 1950s (Figure 3.2). Even so, the high total annual catch per license ($\text{mean}_{1991\text{-}2005}$ ± SD = 7.2 ± 1.6 mt, CV = 22 %; Figure 3.3) and high whitefish catch per license ($\text{mean}_{1991\text{-}2005}$ ± SD = 5.1 ± 1.2 mt, CV = 24 %; Figure 3.3) marked this as a second “golden age” (*cf*. phase II) for ULC fishers.

Phase V (2006-present): From 2006 onwards, conditions in ULC returned to oligotrophy (P-level below 10 µg L^{-1}, Figure 3.2), and whitefish yields decreased to levels comparable with the 1950s ($\text{mean}_{2006\text{-}2014}$ = 465 ± 135 mt, CV = 29 %). A further decline has become apparent in the last four years. From 2012 to 2014, mean whitefish yield was only 309 mt (Figure 3.2) and the total annual catch per license fell below 4 mt (Figure 3.3). It is expected that figures for 2015 will show a further decline in yield to below 150 mt in total and less than 2 mt per license. Perch yields are also very low ($\text{mean}_{2006\text{-}2014}$ ± SD = 70 ± 24 mt, CV= 34 %). These figures threaten the economic viability of fishery operations (Straub & Meier 2010). Furthermore, increases in the yield of Arctic char since the mid-2000s have leveled off and catches are now comparable to those of lake-dwelling brown trout. Combined catches for these two species are now less than 20 mt per year. ULC fisheries can no longer meet demand for locally caught fish. In 2015, as in 1914 and 1934, a decision was made to further reduce the number of fishing licenses. From 2020 only 80 professional fishers will be permitted to fish in ULC (IBKF 2015). Compared to the number of licenses issued in 2006 (132) this will constitute a reduction of 40 % in just 15 years, despite continued high market demand. Today, it seems inevitable that the remaining professional fishers will be obliged to engage at least partly in whitefish aquaculture schemes being developed by local researchers (FFS 2015) and promoted by the agricultural administration of Baden-Württemberg, or to increase their income by purchasing and processing imported fish. The alternative is economic extinction.

6. Possibilities for Tackling the Problems in a Nutrient Mitigated System

Intensive, internationally coordinated measures have succeeded in restoring P levels in ULC to socially desired and legally required oligotrophic values and established an equilibrium in line with the contemporary environmental policies of ULC states, including the EU Water Framework Directive (Landtag von Baden-Württemberg 2013; Schweizer Nationalrat 2013; IGKB 2013). However, the current prescribed oligotrophic state of ULC is not without problems; some of these are economic: the steep decline in nutrient load since 1980 has reduced growth and standing stock biomass of whitefish and perch to levels where a local inland fishery is no longer viable (Straub and Meier 2010). There is also an ecological cost. The decision to prioritize the regional environmental ideal of P concentrations close to Ice Age levels has popular support, but it likely raises significant ecological issues elsewhere by fostering the importance of alternative protein produced (Hilborn 2013). Other yardsticks for ecological impact, such as protein-energy return on investment, greenhouse gas emissions and land area requirement (Tyedmers 2004), suggest that the capture and local marketing of wild fish from ULC is one of the most environmentally sustainable forms of animal food production available (Lynch et al. 2016). Local demand for fish is very high, given the substantial size of the local human population and the millions of tourists that visit the region each year. This demand is currently met mainly by fish imports (Dreßler 2013). In 2012 at least 50 % of all whitefish consumed at ULC originated from other countries, including Italy, Finland, Iceland and Canada (Dreßler 2013). Those imports come by plane or truck, an increasingly controversial practice in terms of ecological footprint, which lacks a certain transparency to consumers (Madin and Macreadie 2015). Diners may assume that as a regional specialty, the fish on their plate is fresh from the lake, when in fact it will often be a frozen fillet from another continent.

The decline of ULC fisheries yield is not a result of changing demand or poor fisheries management, but an exclusive consequence of the otherwise highly successful nutrient management measures deliberated and agreed at political levels beyond the core fisheries sector. These changes have impacted heavily on local fisheries and also consumers through substitution of local products by foreign fish of largely unknown origin, at substantial higher ecological cost.

Meanwhile, other environmental threats to the lake are increasing, particularly such as those resulting from transportation, tourism, the heavy use of productive shallow water zones and negative impacts of climate change (Straile et al. 2007; Stich and Brinker 2010; Wahl 2009). ULC is also polluted by a variety of pharmaceuticals, microplastics, and other chemicals, but these have received nothing like the attention focused on P. Furthermore, after more than 100 years of inconspicuous occurrence, the abundance of non-endemic three-spined stickleback in the pelagic zone has risen sharply in the last three years. Sticklebacks have the potential to outcompete other fish species (Bergström et al. 2015; Byström et al. 2015), and according to recent research this seems to be the case in ULC. These multiple negative influences on the fish community render achieving fish stocks and yields comparable to their previous stable values at 1950s P-levels as unrealistic. Indeed, current trends indicate a future in which much lower yields will be the norm. It remains to be seen whether the new maximum limit of 80 fishing licenses due to coming into force in 2020 will be low enough to sustain even a small number of viable commercial fisheries.

The precarious economic situation faced by the remaining professional fishers of ULC has led to calls for a moderate increase in permitted levels of P, to 10-12 µg L^{-1}. This slight elevation could be achieved by a small reduction in the quantity of precipitation agent used in sewage treatment. The fishers argue that such action would result in oligotrophic conditions only slightly above the currently prescribed reference state, and indeed similar to those that prevailed in years when ULC was celebrated for its exceptional high water quality by environmentalists, water authorities and tourism managers but when yields were also comparatively high (Figure 3.4). However, the public discourse strongly indicates that even a slight increase in P is currently unthinkable to the governments and their environmental administrations.

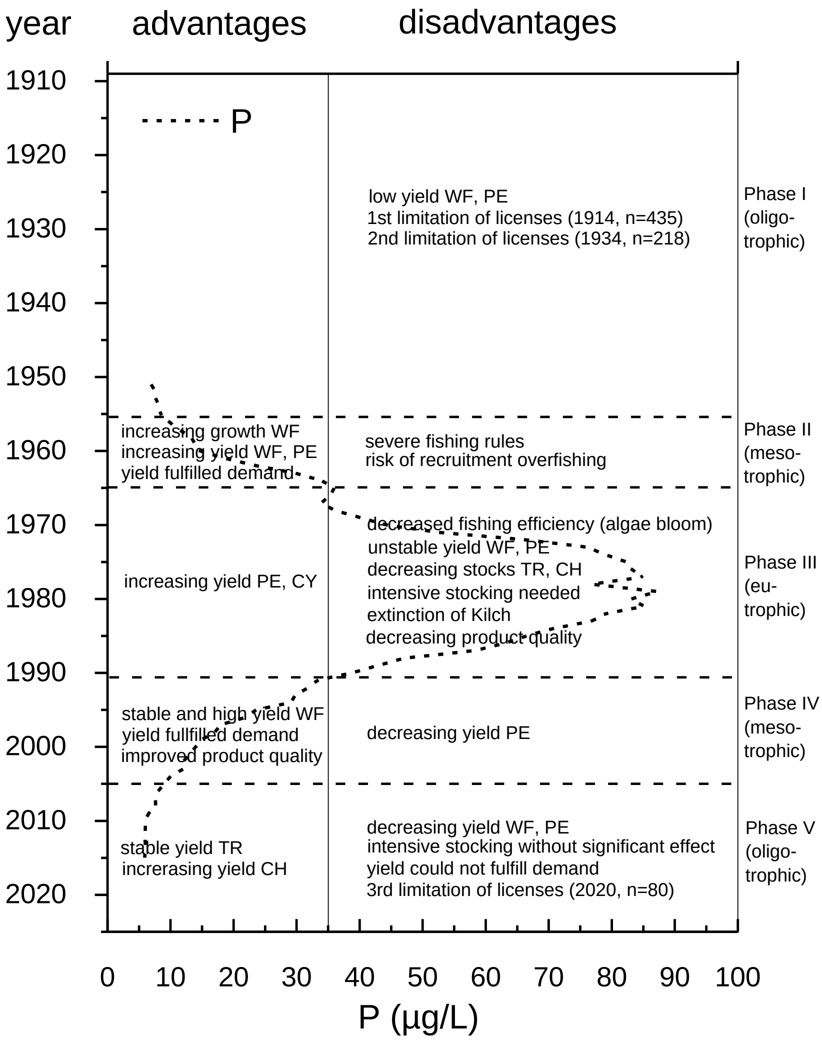

Figure 3.4. Advantages and disadvantages during eutrophication and re-oligotrophication of ULC from the view of the commercial fishers (WF = whitefish, PE = perch, TR = trout, CH = arctic char, CY = cyprinids). Phases group the eutrophication during the last 100 years.

A principle concern of leading authorities to insist on extremely low (Ice Age) P levels is the likely effect of ongoing climate change. With increasing temperatures and stronger stratification of the lake, the probability of holomixis at the end of winter is decreasing. Some model predictions assess that this will lead to lower oxygen levels in the hypolimnion (Landtag Baden-Württemberg 2013; Wahl 2009; Wahl & Peeters 2014). Earlier research predicts that P levels of around 10 µg L^{-1} would be sufficient to protect the lake from the stronger stratification that will develop as a result of increasing global temperature (Müller 2002), leading fishers to question the need for reductions significantly below this threshold. Indeed, the climate change argument may be moot in terms of nutrient loading. A recent report suggests that even with Ice Age P levels the lake is unlikely to escape the effects of temperature increases (IGKB 2015).

Another decisive factor behind resistance to elevated P is that under the EU Water Framework Directive, and in contrast to any other published limnological standards, ULC is regarded an alpine rather than a pre-alpine lake (Mathes et al. 2002). This designation carries an expectation of extremely low P-levels further undermining the fisher community's case for an increase.

A further new avenue under discussion is aquaculture, specifically the potential for whitefish reared in open net cages in the lake or in closed land-based farms to fulfill the demand shortfall in regionally caught whitefish. However, the high investment costs (even with subsidies) for aquaculture operations would exclude all but a minority of the current fisher community, especially given the recent economically disastrous years for the industry. The proposal may simply be too late for many. Furthermore, the majority of local fishers are culturally resistant to the idea of aquaculture. Some are operating as 13th generation family businesses and wish to continue their centuries-old way of life. They see the traditional capture fishery as much more in line with regional and personal tastes and habits and argue that they are fishers, not farmers. One solution that may overcome some of these reservations is for a core group to found a cooperative aquaculture enterprise to produce a local product (whitefish raised in ULC-water and originated from local stocks). These fresh, consumer- and environmentally friendly products could then be sold locally through the fishers' existing direct marketing avenues, while maintaining important elements of the traditional fishery.

Local whitefish aquaculture may help to address the issues of fish supply and environmental impact, but from the view of the fishers as a solution it is second-best. It is somewhat ironic given their long experience in producing a highly sought-after, sustainable product, and their central role in highlighting the damage caused by eutrophication and proposing relevant and effective actions to improve water quality, the centuries-old professional fisheries of ULC are now mere spectators and commentators on policy. The fishers continue to provide a romantic backdrop for lake tourism but have little power to influence their own future or that of the lake.

7. Synopsis

Having played a central role in lake management and decision-making in the past, in particular during the eutrophic phase, ULC fisheries now find themselves second in terms of socio-political importance compared to environmental protection, tourism, water quality and outdoor recreation. The lake condition that would constitute an optimal solution from a fisheries perspective (i.e. P at about 10-12 µg L^{-1}) is anathema to prevailing societal concerns, including those of environmental protection organizations, and contravenes current interpretation of environmental policy such as the EU Water Framework Directive. However, the recent history of the commercial fisheries in ULC highlights some common pitfalls in environmental management, and the blind spots that can afflict even the most successful schemes. One such problem is a tendency to focus disproportionately on apparently successful measures, at the expense of progress with other urgent but less easily resolved problems (Butler 2002). The reduction of P-levels in ULC was initiated without a final target (lower limit) being set, and has been delivered with enthusiasm that has limited the consideration of available scientific knowledge and societal impacts. The ideal time to mitigate an emerging crisis is before it begins to bite. Of course predicting the future is difficult as is navigating all trade-offs, but the time to try is during periods of stability, when resources of money and time resources are available. The decline in ULC fishery yields in response to sharp P reduction was in fact predictable, but a blind eye was turned. As a result, the opportunity to investigate alternatives (such as aquaculture) in a timely fashion at the end of the second mesotrophic phase, was missed by all involved parties.

A further concern stemming from the crisis facing ULC fisheries is that alterations to the local food supply will inevitably have ecological and social ramifications in other parts of the world (Hilborn 2013). Current developments are set to substitute a product of exceptionally high sustainability (wild caught local fish) (Tyedmers 2004) with imports from foreign countries, thereby unintentionally expanding the ecological footprint of food production and neglecting a consumer preference for locally produced food.

It may be too late to save the ULC fisheries as an economically viable operation, given that none of the recent proposals to improve yields (P-increase, aquacultural development) seem likely to find widespread approval in time. Thus, a key conclusion must be that the objectives of environmental management and sustainable fisheries cannot be served without early engagement of all parties along the full parameter space of key environmental variables.

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