ACTA OECOLOGICA 30 (2006) 161–167

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/actoec

Original article

Fishery changes during re-oligotrophication in 11 peri-alpine Swiss and French lakes over the past 30 years

Daniel Gerdeaux [a,*], *Orlane Anneville* [a], *Daniel Hefti* [b]

[a] *Station d'Hydrobiologie Lacustre, Inra, BP 511, 74203 Thonon, France*
[b] *Environment, Forest and Landscape Federal Office, 3003 Berne, Switzerland*

ARTICLE INFO

Article history:
Received 30 May 2005
Accepted 23 February 2006
Available online 04 April 2006

Keywords:
Lakes
Re-oligotrophication
Fishery yield
Fish community
Coregonids
Percids
Cyprinids

ABSTRACT

Peri-alpine lakes in Switzerland and France exhibit a spectrum of intensities of eutrophication and re-oligotrophication over the past 30 years. Phosphorus inputs have been decreasing since the 1970s. TP has altered from 135 to 50 $\mu g\ l^{-1}$ in the more eutrophicated lakes, and 25–2 $\mu g\ l^{-1}$ in the others. Fish communities were dominated by cyprinids and perch in eutrophic lakes. During re-oligotrophication, the total yield remains nearly the same while coregonids become dominant. In oligotrophic lakes, when the TP was below 5 $\mu g\ l^{-1}$, the total yield decreased rapidly, and fish production was low.

1. Introduction

Peri-alpine deep lakes, except a few of them, underwent eutrophication during the 1950s/1960s (OFEFP: Office fédéral de l'environnement des forêts et du paysage, 1994). Since the early 1970s, the nutrient input into all these lakes has been reduced with the aim of improving their trophic status. Over the past 30 years, the eutrophicated lakes have became mesotrophic, and the mesotrophic lakes are now oligotrophic. Commercial fisheries have been exploiting fish resources for a long time in the Swiss and French lakes (Müller, 1990). Fishery statistics, published each year by the relevant Swiss and French Government departments, have been used as an index of lake eutrophication (Leopold et al., 1986). The impact of eutrophication in these peri-alpine lakes fisheries has been reported in numerous papers (Grimaldi and Nümann, 1972; Laurent, 1972; Nümann, 1972; Roth and Geiger, 1972). A summary of the changes in salmonid communities in oligotrophic lakes has described the succession of fish communities along a gradient of eutrophication (Colby et al., 1972). The sequence from salmonids to coregonids, from coregonids to percids, and finally from percids to cyprinids during the eutrophication process has been documented from the 1970s. What happens during the restoration phase? Could we observe a reverse sequence? The response of phytoplankton, zooplankton, and fish to re-oligotrophication in Danish lakes is well documented (Jeppesen et al., 2000; Jeppesen et al., 2002). These lakes are not deep, their fish communities are dominated by cyprinids and the total phosphorus range during re-oligotrophication (200–400 $\mu g\ l^{-1}$) is totally different than the one in peri-alpine lakes (2–100 $\mu g\ l^{-1}$). The changes in the fish community during the restoration of the water quality in Lake Constance is described by Eckmann and Rösch (1998). Gaedke (1998) studied the response of the pelagic food-web to re-oligotrophication of this lake. These authors concluded that the re-oligotrophication is reflected in an augmenting proportion of whitefish in commercial catches and an increasing age-at-capture. In this lake the changes in the fish community seem to be a return to the

* Corresponding author. Fax: +33 4 50 26 78 59.
E-mail address: gerdeaux@thonon.inra.fr (D. Gerdeaux).

1146-609X/$ - see front matter
doi:10.1016/j.actao.2006.02.007

state before eutrophication. In Lake Erie, where the changes of phosphorus loading were similar to those in peri-alpine lakes, the fish communities recover the richness before eutrophication (Ludsin et al., 2001). As far as we know, there is no publication regarding if the trends observed in Lake Constance and in some other lakes are the same, and if we can generalize to peri-alpine lakes. The present study examines changes in the fish yields of 11 of the larger natural lakes in Switzerland and France between 1970 and 2000.

2. Material and methods

2.1. Lake sites

The morphometric characteristics of the lakes are summarized in Table 1. For the locations of Swiss lakes, see OFEFP 1994. Lakes Annecy and Bourget are located in France, 50 and 70 km, respectively, south of Lake Geneva in the Rhône basin. The surface of these lakes exceeds 2400 ha. Their mean depths range from 30.5 to 152 m. They are at low altitudes and they are monomictic. The surface water never freezes over. The lakes have routinely been monitored by different institutions or laboratories. Total phosphorus concentrations used in this study are the concentrations over the whole water column at the end of the winter after the turnover.

2.2. Fish communities and fisheries

The fish communities in all these lakes are similar. The common species of high economic value are salmonids, trout, *Salmo trutta*, arctic char, *Salvelinus alpinus*, a coregonid, whitefish, *Coregonus lavaretus*, an esocid, pike, *Esox lucius*, a percid, perch, *Perca fluviatilis*, a gadid, burbot, *Lota lota*. There are also cyprinids, mainly roach, *Rutilus rutilus*. The other species of cyprinids are bleak, *Alburnus alburnus*, bream, *Abramis brama*, chub, *Leuciscus cephalus*, tench, *Tinca tinca*, rudd, *Scardinius erythrophthalmus*, and gudgeon, *Gobio gobio*. In some lakes, pike perch, *Stizostedion lucioperca*, has been introduced. Some river species are also found near the affluent of the lakes.

Fisheries traditionally use gill nets for whitefish, arctic char, trout, perch, pike perch, burbot, pike and roach, the eight most important fishery species. Yield statistics for the different species (kg ha^{-1}) are compiled annually by the cantonal fisheries agencies in Switzerland, and have also been compiled by the Agriculture Department in France since 1970. Data on fishing activity are not recorded for all these lakes. However, fishing activity is thought to be fairly constant in most lakes, since the numbers of commercial fishing permits and nets are kept constant (Gerdeaux, 1988; Müller, 1990). It has been shown that in Lake Geneva the total catch gives a good estimate of the stock abundance (Caranhac and Gerdeaux, 1998).

Stocking for salmonids and coregonids is a common practice in these lakes. Arctic char stocking is efficient and the yields of char and trout are influenced by stocking (Champigneulle and Gerdeaux, 1995), but the yield is always very low, less than 1 kg ha^{-1} and low compared with whitefish yields. Intensive whitefish stocking is only practiced in some of these lakes, such as Lake Constance and Lake Biel. Then, we did not analyze the whitefish yield of these lakes. In other lakes, the stocking density is less than 2500 larvae per hectare (Müller, 1990). It has been demonstrated that low density whitefish stocking has much less influence than other parameters (Gerdeaux, 2004).

2.3. Data analysis

We carried out analyses of the yields of the different species versus Ptot within each family: salmonids (trout and char), coregonids (whitefish), percids (perch and pike perch), and cyprinids (roach, bream, tench, ...). The box-plat charts were performed using S-PLUS 6.0 (Mathsoft).

3. Results

3.1. Changes in water quality

Lakes Lucerne, Thun, Walenstadt, Annecy and Brienz have been protected against eutrophication from an early stage. As a consequence, their mean annual total phosphorus concentrations (TP) have never risen above 40 μg l^{-1} (Fig. 1a) despite increasing land use. In these lakes, TP started to decrease at the beginning of the 1980s, except in Lake Annecy.

Table 1 – Morphometric characteristics of the lakes included in this study: altitude (Alt.), maximum depth (Max. depth), mean depth (Mean depth), lake area (Area), volume (Vol.), retention time (Rt), minimum and maximum total inorganic phosphorus concentrations (PO_4^- mini-PO_4^- maxi)

Lake	Alt. (m)	Depth Max (m)	Depth Mean (m)	Area (100 ha)	Vol. (km^3)	Rt (year)	PO_4^{3-} (μg P l^{-1}) mini	PO_4^{3-} (μg P l^{-1}) maxi
Annecy	447	65	41.0	27.6	1.124	3.8	4	16.4
Biel	410	74	30.5	39.3	1.240	0.2	21	135
Bourget	228	145	81.0	42.0	3.60	3.8	20	130
Brienz	564	261	173.0	29.8	5.170	2.7	4	21.9
Constance	400	254	100.0	540.1	49.000	4.3	15.9	90.5
Geneva	372	309	152.1	582	89.000	11.4	38	90
Lucerne	434	214	104.0	114.1	11.800	1.0	2.2	30
Neuchâtel	429	152	64.2	217.9	13.979	8.2	18	60
Thun	558	217	135.2	48.4	17.500	1.9	6	21
Walenstadt	600	145	103.0	24.1	2.521	1.5	2	28
Zurich	406	136	51.7	85.3	3.800	1.4	24	117