Lake Säkylän Pyhäjärvi – major decline in vendace

Säkylän Pyhäjärvi (SW Finland, 60º54'-61º06'N, 22º09'-22º25'E) is a large (155 km^2) shallow lake (mean 5.5 m, max 26 m) suffering from eutrophication. It is non-stratified and has a hydraulic retention time of about 4-5 years. The catchment area is 615 km^2 (including lake surface). Two incoming rivers with high agricultural nutrient load impact account for more than 70% of the annual total phosphorus load.

The fish community consists of 18 species, dominated by perch, ruffe, roach and vendace. The lake has a vital commercial fishery, with 20 fishermen and two fishing harbours. The most important commercial catch species is vendace (*Coregonus albula*), which is the main planktivore in Pyhäjärvi (Sarvala et al., 1999). The annual harvest rate approaches the total production of vendace, which means that the fishery has for decades acted as intensive biomanipulation. In addition to this self-supporting biomanipulation, a restoration project has also subsidized the harvest of commercially unwanted fish since 1995. The fishing was especially intensive in 2002-2004 and apparently resulted in water quality improvement (Ventelä et al., 2007).

The lake is located in the boreal temperate zone (cool climate type). The winter time mean air temperature in the area is -2.1 ºC and the lake is normally ice-covered for 141 days in average. The maximum summer water temperature increased highly significantly in 1962-2010, particularly since 1989. Spring temperatures have not increased correspondingly, as seen from May temperature records that show no significant change over years. (FIGURE 1 Pj). Ice-out has shifted to an earlier date (Ventelä et al. 2011), and the duration of ice-cover is decreasing, quite dramatically so in the 2000s.

The water chemistry and hydrology of Pyhäjärvi have been monitored since the 1960s, and since 1980 monitoring became more intensive, covering even biotic components such as phyto- and zooplankton (Ventelä et al., 2007, 2011). Water samples were analysed according to international and national standards. Ice data for years 1958-2010 were recorded by local observers and Finnish Environment Institute's Oiva data service (www.ymparisto.fi/oiva); water temperature and water quality data are from Oiva data service.

Data on fish community composition were obtained from extensive test fishing with gillnets in 1984 (non-standard series) and in 2000, 2004, 2006 and 2009 (Nordic gillnets; CEN 2005), and catch samples and surveys (Sarvala et al. 1998, Ventelä et al. 2011, and unpublished). The majority of the annual fish catch is commercial and taken in winter by seining through holes in the ice. In addition, fyke nets are applied by professional fishermen in the open-water season. Recreational fishery mainly uses gillnets, fish traps, spinning, trolling and angling as well as ice fishing with rod and line. The winter seine catch of all species was monitored in 1989-2011, but samples for vendace and whitefish were collected since 1971. Sampling was done in the fishing harbour after the fishermen returned from the lake with their daily catch in special containers. At the first stage, samples of some kilograms consisting of a variable number of fish were taken from every container, sorted by species and weighed. Subsamples of each species were saved for individual measurements and age determinations; a minimum of thirty 0+ vendace individuals were measured each time. Daily seine catch records for vendace (age 0+ and older fish separately) were obtained for winters 1980–2011 from each seine crew and/or the most important wholesale fish agent. For most years, the year-class size of age 0+ vendace in the autumn could then be calculated from the decrease in the catch per unit effort during winter (Helminen *et al.* 1993). For other years, year-class size was estimated utilising the tight density-dependence of first-summer growth of vendace.

During the last hundred years, no consistent directional changes at the level of the whole fish community were observed such that could be attributed to climate change (Sarvala et al. 1998). Catches of all species fluctuated considerably in 1989-2009. In most species a linear trend was non-significant (p=0.21-0.71, explained variance 0.7-7.7%), but whitefish showed a significant declining trend with time explaining 48% of total variation (p=0.0003). Most of the variation was due to changes in fishing gear and practices, partly arising from the removal fishery exercised since 1995. Some of the catch variation may, however, derive from environmentally induced inter-annual changes in recruitment success. At least in vendace, there was a significant decline in year-class strength over the period which can be linked with climatic conditions. The signs of the trend slopes in different species were consistent with potential effects of climate warming: positive slopes in the warm-water species perch, roach and ruffe, and negative slopes in cool-water species vendace, whitefish and smelt, although whitefish decline may be more related to food web interactions (competition with vendace, egg predation by the introduced signal crayfish; Sarvala et al., 1998).

In the early 1900s, size distributions were skewed towards big fish, but the change towards smaller fish in the contemporary fish community was likely mostly due to intensified fishery and species introductions (whitefish, vendace) (Sarvala et al., 1998) . In addition, erratic stock fluctuations in individual species influence the size distributions. Strong year-class variations are typical for many northern fish species (e.g. Townsend 1989). For example, strong year-classes of smelt occur unpredictably at roughly decadal intervals (Sarvala, unpublished data), while strong year-classes of perch are associated with warm summers (Böhling et al. 1991, Lappalainen et al. 1996, Sarvala & Helminen 1996).

In spite of large inter-annual fluctuations, the vendace year-class strength in Pyhäjärvi showed a highly significant declining trend in 1971-2009 (with pronounced lows in 1990-1991, through 1993-1998 and again in 2003 and 2009-2010) (FIGURE 2 Pj). During the same period, there was a significant increase in the size of one-summer- and two-summer-old vendace, apparently due to a release from intraspecific competition. In the 1970s and 1980s, the vendace population oscillated around a roughly stable mean in a two-year cycle which was broken in 1987-1998. A weaker cycle was restored from 1999 until 2007 at a lower level (Helminen et al. 1997 and unpublished).

Vendace stock is affected by climate through several routes. The timing of ice break and the following temperature development are key factors affecting the year-class variation in vendace (Helminen & Sarvala 1994). Ice-out triggers the hatching of vendace larvae which are most vulnerable to predation as newly-hatched from 8 to about 15 mm total length. The longer this early larval period the higher is the larval mortality. The critical period for the survival of the larvae is 2-4 weeks after the ice break, when the temperature should be high enough to enable rapid growth (Helminen & Sarvala 1994). Larval growth rate increases with increasing temperature which also enhances spring development of zooplankton food, both factors shortening the duration of the susceptible stage. For example, in 1989 and 1990, the early ice break in Pyhäjärvi led to unusually early hatching of vendace larvae. In 1989, temperature increased quickly and larval mortality remained moderate. In 1990, in contrast, much slower warming of water after the very early ice-break caused high mortality of vendace larvae (Helminen et al. 1997). In Pyhäjärvi, with climate change, the date of ice-out has become earlier, but the spring temperature has not correspondingly increased, creating increasingly unfavourable conditions for vendace larval survival.

The abundance of predators in the lake is important for both larval spring mortality and juvenile mortality during summer, and it is affected by temperature conditions 2-3 years back in time (Helminen & Sarvala 1994): one of the most abundant predators on young vendace is perch, the year-class strength of which is positively correlated with summer temperature (Böhling et al. 1991, Sarvala & Helminen 1996). Accordingly, triggered by the more frequent warmer summers, strong perch year-classes have appeared more often in the 1990s and 2000s than in the 1970s or 1980s (Sarvala & Helminen 1996 and unpublished), and we may expect this trend to continue.

Commercial fishery in Pyhäjärvi is mainly based on winter seining through the ice, and therefore the ice-cover is of crucial importance to the fishery. Usually 70-90% of each year-class of vendace is harvested during its first winter. The remaining vendace are released from food competition and grow exceptionally fast, maintaining high population fecundity in spite of the small spawning stock. In 2007 and 2008 the winter time temperatures were high, resulting in an exceptionally short period of ice-cover. Therefore the winter fishing season was very short and most of the young vendace remained in the lake. This increased food competition between the YOY and adult fish, leading to a poorer recruitment in 2008 and 2009 than expected from the normal year-class rhythm or environmental conditions.

Because Pyhäjärvi is in summer mostly unstratified, vendace do not have any cool-water refuge in the deeper water layers. Increased summer temperatures may thus lead to increased mortality and reduced recruitment.

Warming climate has thus affected vendace recruitment in Pyhäjärvi in several ways, most of them negative, but some positive. In contrast, in the subarctic Lake Inari, which is already north of the natural distribution area of vendace, warmer summers in the 2000s have had a straightforward positive impact on vendace recruitment (Puro-Tahvanainen & Salonen, 2010).

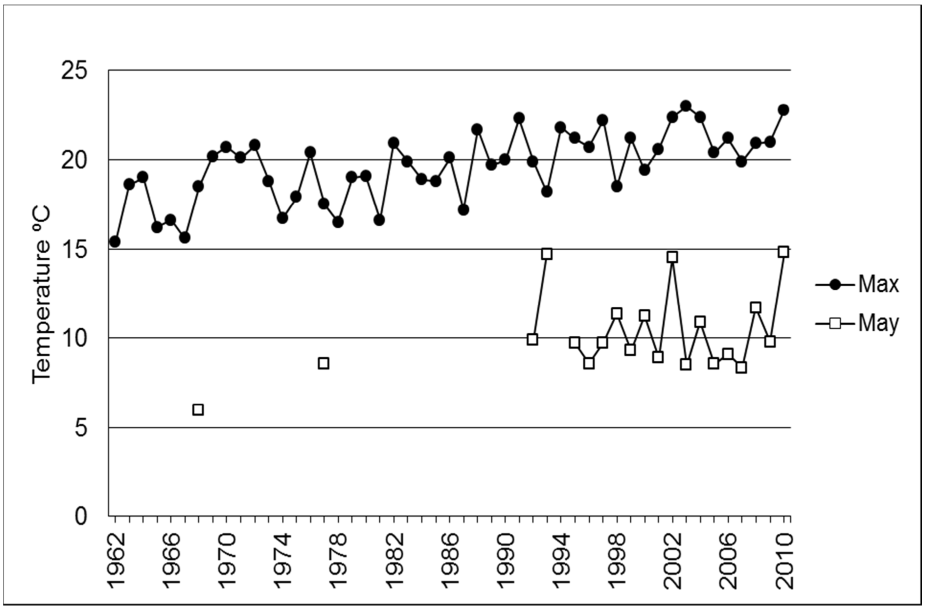


FIGURE 1 Pj

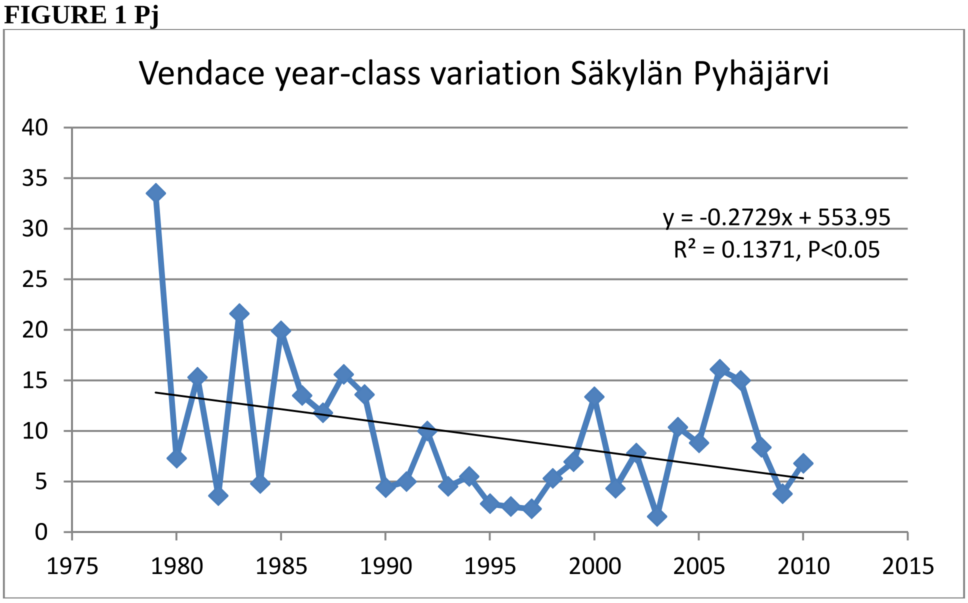


FIGURE 2 Pj

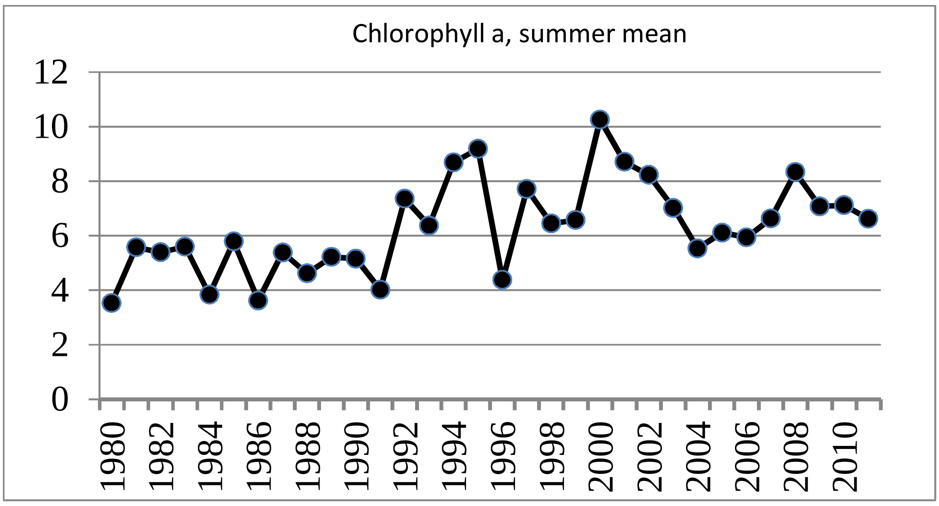
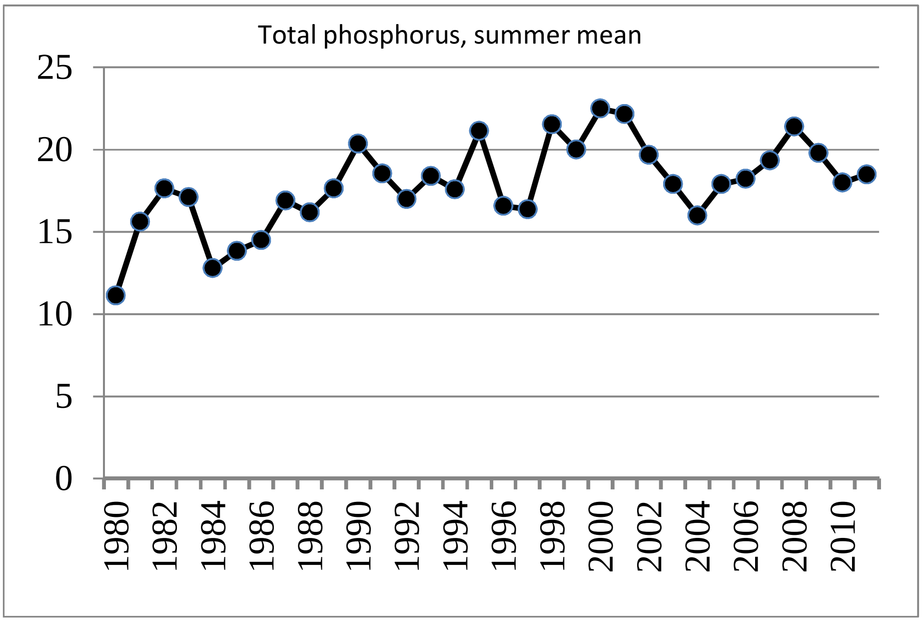


FIGURE x


Total phosphorus, summer mean
25
20
15
10
5
0
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010