Recent improvement of fish populations in the Jarfjord Mountains in northern Norway due to reduced surface water acidification

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1. Introduction

During the 1900s, large areas of southern Norway were affected by sulphur deposition due to emissions from several European countries, causing widespread acidification of lakes and rivers (Overrein et al. 1980). This causes serious damage to the aquatic biota in Norwegian watersheds, and about 9.600 fish populations in lakes were lost (Hesthagen et al. 1999). In northern Norway, acidification was less severe, restricted to a relatively small area in the Jarfjord Mountains near the Russian border in eastern Finnmark. This was due to emissions of SO_2 from the smelters in Nikel and Zapoljarnij on the Kola Peninsula located about 10 and 30 km, respectively, from the Norwegian border (Traaen 1985, Sivertsen et al. 1993, 1994).

During the period between 1980 and 2005 the content of sulphate in precipitation at various Norwegian sites decreased by between 64 and 77 % (Aas et al. 2006). In Finnmark county, the proportion of sulphur dry deposition relative to total deposition was much higher than elsewhere in Norway, in 2005 estimated at 53 % in winter and 50 % in summer. This is due to high air concentrations and low precipitation in Finnmark, compared to southern Norway. The reduction in atmospheric deposition of sulphur have caused a substantial recovery of acidified lakes and rivers throughout Norway including Finnmark county, with increasing pH, increasing acid neutralising capacity (ANC), and lower concentrations of labile aluminium (Skjelkvåle et al. 1998, 2001a, 2001b, 2005).

It has previously been shown that brown trout started to recover in less acidified areas in southwestern and western Norway during the 1990s (Hesthagen et al. 2001). The present study examined the recovery of fish populations in four lakes in the Jarfjord Mountains during the period between 2000 and 2005. During the period 1987 – 93, relative abundance and age-frequency distribution were obtained for 19 populations of Arctic charr (*Salvelinus alpinus*) and 21 populations of brown trout (*Salmo trutta*) from the same area (Hesthagen et al. 1992, 1998) (Fig. 1). Both pH and ANC explained a significant fraction of the variability in gill nets catches (CPUE) of both species in these lakes, indicating effects of acidification. However, total fish damage was small, only affecting a total of 10 - 15 of the 40 populations.

2. Study area

The Jarfjord Mountains are located in the northeastern region of Sør-Varanger municipality, between the fjord Jarfjorden and the river Grense Jakobselv. A few peaks in this area reach an elevation of 450 m, but most areas are located below 300 m. The marine limit is at an altitude between 85 and 90 m (Tanner 1915). Treeless heath is the most common vegetation type at higher altitudes, while birch (*Betula pubescens*) and various types of brush (*Salix,* etc.) dominate in the lower regions (Bruteig 1984). The bedrock in most areas mainly consists of slowly weathering rocks (Bugge 1978). However, The quaternary geology is characterized by large deposits below the marine line (Sollid et al. 1973, Marthinussen 1974), indicating that several areas have relatively good resistance to acidic inputs. At higher altitudes in the Jarfjord Mountains, the soil layer is generally thin.

The climate in Sør-Varanger is continental, with low levels of precipitation and cold winters (Winther Hansen 1960). There are distinct differences in climate between coastal and interior areas, as warm air penetrates from the North Atlantic and cold air from the Arctic. Coastal areas receive

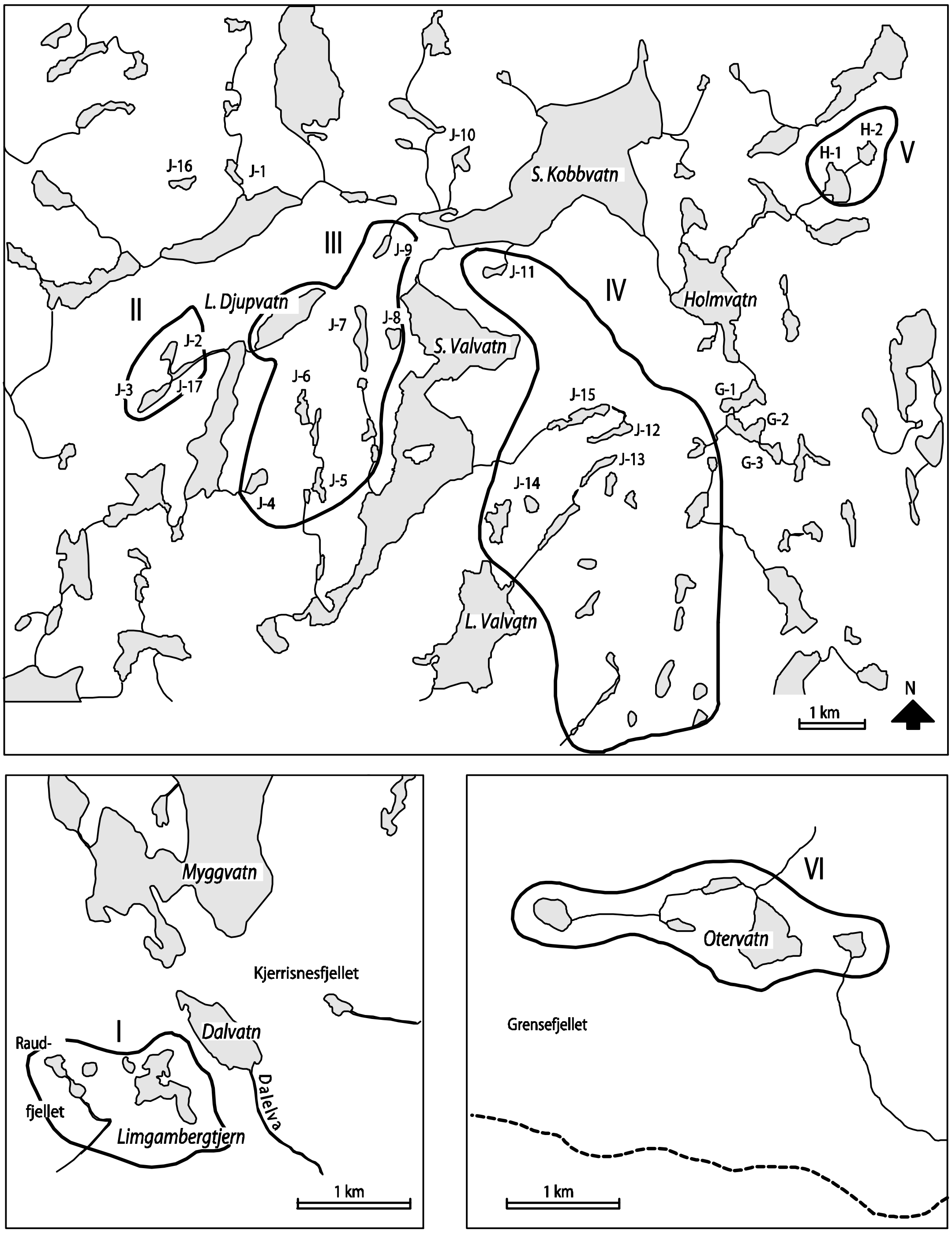

Figure 1. Areas with previous damaged fish populations in lakes in the Jarfjord Mountains (Area I - VI). From Hesthagen et al. (1998).

more precipitation than the interior, mean annual amounts to 358 and 580 mm in Lanabukt and Pasvik, respectively. Transect analyses showed that north-easterly winds are dominant during the summer, as opposed to south-westerly winds from the Nikel area during the rest of the year (Sivertsen et al. 1994).

The study was carried out in the lakes Dalvatn, Nedre Fosstjern, Store Skardvatn and Otervatn, located between 25 - 36 km from Nikel (Table 1). The lakes are at latitudes between 132 and 293 m above sea level, with lake areas between 0.1181 and 0.5980 km^2. There are four species of fish in the study lakes; brown trout, Arctic charr, three-spined stickleback (*Gasterosteus aculeatus*) and nine-spined stickleback (*Pungitius pungitius*). In Nedre Fosstjern the abundance of brown trout is expected to be low due to limited access to spawning streams.

Table 1. Some physical data for lakes in the Jarfjord Mountains in eastern Finnmark

Lake	Y - coord.	X-Coord.	Altitude (m)	Size Km^2	Shore	Length (km)	Distance from Nikel (km)
Dalvatn	77345	3980	132	0.24	52	2.3	31
Nedre Fosstjern	77338	4140	186	0.11	81	2.0	36
Store Skardvatn	77250	4133	238	0.59	80	4.6	29
Otervatn	77173	4134	293	0.18	48	1.9	25

3. Methods

A baseline study of fish populations was carried out with benthic gill nets in the autumn (August to early September) in 25 lakes during the period between 1987 and 1993. The sampling was carried out by means of series of SNSF-nets which consisted of 8 gill nets (27 m long and 1.5 m deep) of mesh sizes between 10 and 45 mm (Rosseland et al. 1980). Single nets were set perpendicularly to the shore line, covering depths of mainly between 0 - 12 m. During the period between 2000 - 2005, the sampling was carried out with Nordic multi-mesh gill nets (30 m long and 1.5 m deep), with 12 different mesh sizes between 5 - 55 mm (Appelberg et al. 1995). These nets were set at fixed stations at standard depth intervals of 0 - 3, 3 - 6, 6 - 12 and 12 - 20 m. Both gill nets series catch fish with about equal efficiency (Jensen & Hesthagen 1996). For comparative reasons we included only fish that were caught at 0 - 12 m depths at mesh sizes ≥ 10 mm on Nordic multi-mesh nets. In lakes which contain a pelagic zone, i.e. with a maximum depth of at least 15 m, we also sampled fish with multi-mesh survey floating nets at depths of 0 - 6 m. This net was 54 m long and 6 m deep and consisted of the same 8 mesh sizes that were included in the SNSF-nets. We fished overnight for about 12 h periods, and the catches were expressed as numbers of fish per 100 m^2 of net area (CPUE). Fish length was measured to the nearest millimetre from the snout to the outer lobes of the tail in natural position, and the fish was aged using scales and otoliths. During the periods 1987 - 93 and 2000 - 04 the study was carried out as part of the national monitoring programme "Monitoring of long-range transboundary air pollution".

4. Results

Both lakes Dalvatn and Otervatn were subjected to acidification in the late 1980s and early 1990s (Table 2). This seems to be specially the case for Dalvatn, exhibiting low values for both pH and ANC, at 5.5 and 1.90 µeq/l, respectively. After a pronounced chemical recovery in the lake,

Table 2. pH, calsium and acid neutralizing capacity (ANC) measured in the year of fish sampling in the study lakes in the Jarfjord Mountains in Eastern Finnmark. Source: Norwegian Institute for Water Research (Skjelkvåle et al. 2005).

Locality	Year	pH	Calsium (mg/l)	ANC (µeq/l)
Dalvatn	1990	5.55	1.30	1.90
	2000	6.06	1.04	28.39
	2004	6.18	1.25	36.66
Nedre Fosstjern	1992	6.36	1.78	31.80
	2005	6.35	1.34	27.08
Store Skardvatn	1991	6.52	1.67	45.60
	2000	6.58	1.40	56.11
	2004	6.69	1.94	99.98
Otervatn	1987	6.08	1.36	32.71
	1990	5.82	1.33	9.80
	2000	6.32	1.24	49.10
	2004	6.50	1.70	98.68
	2005	6.59	1.71	74.83

pH = 6.18 and ANC = 36.66 µeq/l were measured in 2004. Otervatn had a relatively marginal water quality in 1990, with pH = 5.82 and ANC = 10 µeq/l. The chemical recovery has also been significant for this lake, reaching pH = 6.50 and ANC > 75 µeq/l in 2004/05. Nedre Fosstjern and Store Skardvatn have been less affected by acidification, as their minimum values for pH and ANC have been > 6.3 and 30 µeq/l, respectively.

The brown trout population in Otervatn was strongly reduced 15 - 20 years ago, with catches (CPUE) of 3.4 and 3.7 fish in 1987 and 1990, respectively (Figure 2).

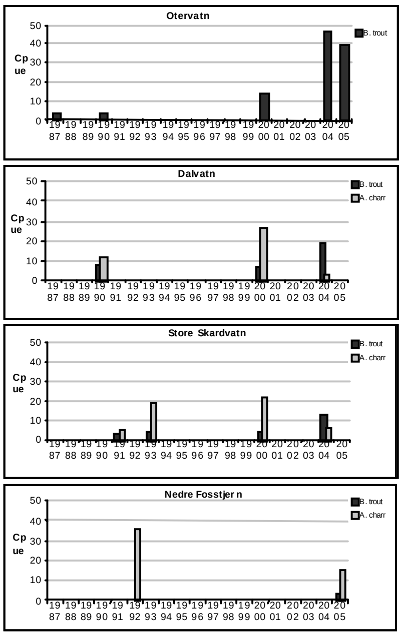

Figure 2. Catches (CPUE) of brown trout and Arctic charr in the epibenthic zone of sampled lakes in the Jarfjord Mountains in different years during the period between 1987 - 2005

In spite of some improvement, their abundance in 2000 was still relatively low with CPUE = 13.3 fish. However, in recent years CPUE has increased substantially, to 46.3 and 38.9 in 2004 and 2005, respectively. Brown trout populations in the lakes Dalvatn and Store Skardvatn also exhibited much larger catches in 2004 than in the period between 1990 and 2000. In Nedre Fosstjern, brown trout was not caught during the test-fishing in 1992, and their abundance in 2005 was also very low.

In contrast to this, the abundance of Arctic charr have been reduced in the lakes Dalvatn and Store Skardvatn in recent years, being much lower in 2004 than in 2000. The population of Arctic charr in Lake Nedre Fosstjern has also experienced a reduced abundance in recent years in spite of low abundance of brown trout.

In sympatric populations, brown trout was generally restricted to the shallow areas of the epibenthic zone, at depths between 0 - 6 m (Figure 3). Arctic charr, on the other hand, occupied all depths zones between 0 - 20 m of the epibenthic area. In 2004, Arctic charr was caught in deeper areas in both lakes Dalvatn and Store Skardvatn compared with that in 2000. In Lake Nedre Fosstjern, which has a small population of brown trout, Arctic charr was most abundant in shallow areas, i.e. at depths of 0 - 6 m. There was a significant negative correlation between the abundance of sympatric brown trout and Arctic charr at depths of 0 - 12 m in the epibenthic habitat ($F_{1,7} = 7.57$, $R^2 = 0.52$, $p < 0.05$; Figure 4). The data from Store Skardvatn in one year (1991) diverged highly from this, with low abundance of both species. Sympatric populations of brown trout and Arctic charr occurred in
low numbers in the pelagic zone, except for that of Arctic charr in Store Skardvatn and Dalvatn in 2000 (Figure 5).

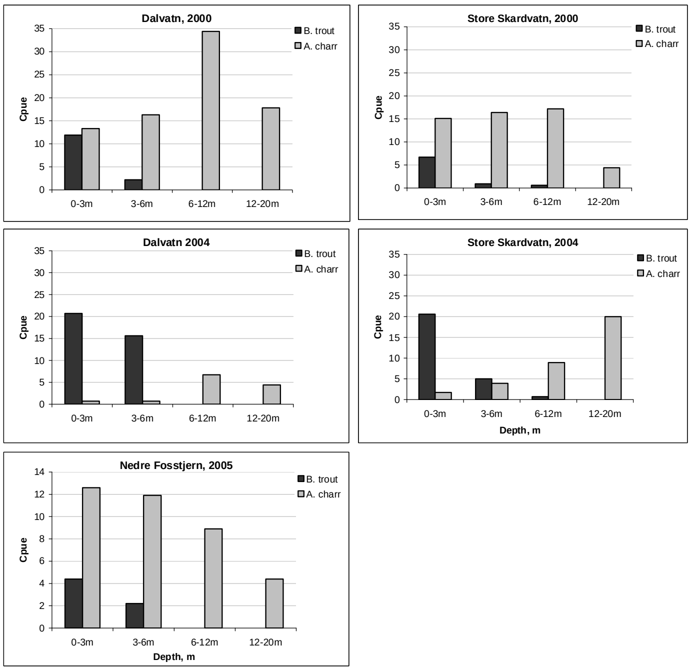

Figure 3. Catches (CPUE) of sympatric populations of brown trout and Arctic charr in different depths in the epibenthic zone of sampled lakes in the Jarfjord Mountains in 2000, 2004 and 2005.

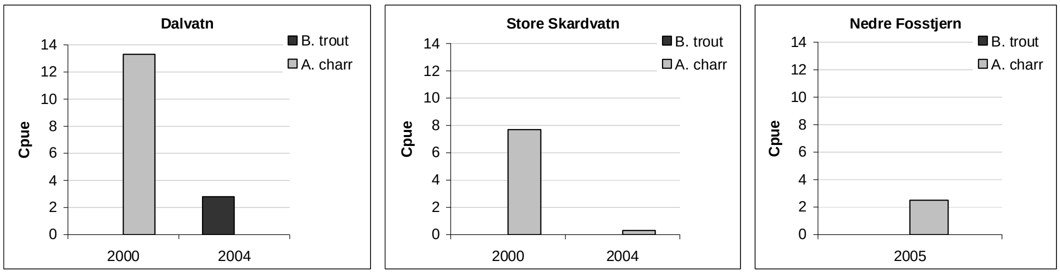

Figure 4. Relationships between the catches (CPUE) of sympatric brown trout (BT) and Arctic charr (AC) in the epibenthic zone of three sampled lakes in the Jarfjord Mountains during the study period (2000 - 2005), expressed by the equation: CPUE(AC) = 24.36 $e^{-0.106\ \mathrm{CPUE(BT)}}$.

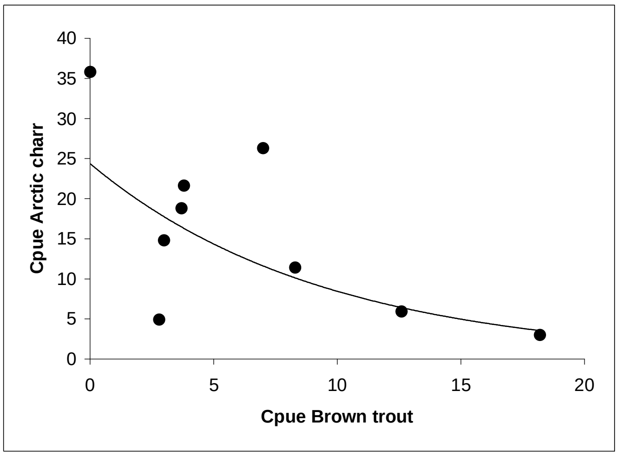

Figure 5. Catches (CPUE) of sympatric brown trout and Arctic charr in the pelagic zone of three sampled lakes in the Jarfjord Mountains in 2000, 2004 and 2005.

The age-frequency distribution of brown trout in Lake Otervatn in 1987 and 1990 was irregular, containing only a few age groups (Figure 6). From 2000 onwards, several age groups between 2 and ≥ 8 years was present. In 2004/05, age groups 3+ and 4+ were more abundant compared with previous years, indicating an improvement in recruitment rates. The age-frequency distribution of brown trout in the lakes Dalvatn and Store Skardvatn suggest that several age groups were present in recent years also in these lakes (Figure 7). The recruitment rate for brown trout in Store Skardvatn seems to have increased in recent years. For Arctic charr, younger age groups were missing in 2004 compared with 1990 and 2000. In Store Skardvatn, young age groups of Arctic charr, i.e. age 1 - 3, were less abundant in 2004 than in 2000. In Nedre Fosstjern, Arctic charr had regular age composition in both 1992 and 2005.

Simple linear regression analyses using single chemistry parameters as independent variables showed that both ANC and pH explained a significant fraction of the variability in the catches (CPUE) of brown trout in Lake Otervatn based on data from five years during the period between 1987 - 2005 (Figure 8): ANC: $F_{1,3} = 29.82$, $R^2 = 0.91$, $P < 0.05$ and pH: $F_{1,3} = 10.08$, $R^2 = 0.77$, $P = 0.05$. No attempts were made to relate the abundance of brown trout to water quality in the two other study lakes, due to too few years of sampling (n = 3) and the occurrence of Arctic charr.

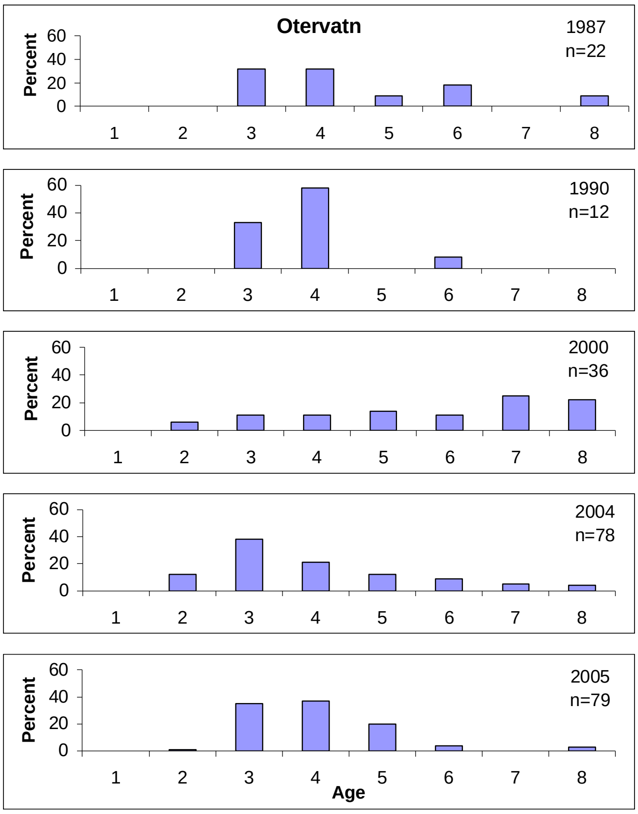

Figure 6. Age-frequency distribution of brown trout in Lake Otervatn in the Jarfjord Mountains in five different years during the period between 1987 and 2005.

5. Discussion

Several lakes in the Jarfjord Mountains suffered serious acidification due to emissions of SO_2 from the smelters in Nikel and Zapoljarnij on the Kola Peninsula in Russia (Skjelkvåle et al. 2005). This was especially the case for smaller lakes located at a relatively high altitude, with a geology which provides low resistance to acidic inputs. This corresponds with the recorded damage to fish populations caused by acidification, being most severe in these lakes (Hesthagen et al. 1998). However, lakes at a lower altitude have also been subjected to acidification, such as the lakes Dalvatn and Otervatn which are included in this study. The allopatric populations of brown trout in Lake Otervatn has recovered well during recent years, with a tenfold increase in abundance from 1987/1990 to 2004/2005 (CPUE = 39 - 46). Both pH and ANC explained a significant fraction of the variability in CPUE of brown trout in this lake. In 1990, minimum values for pH and ANC were measured at 5.82 and 9.8 µeq/l. There are reasons to assume that brown trout in Dalvatn also suffered from acidification in the past as catches in 1990 were low (CPUE = 8.0), corresponding to pH = 5.55 and ANC = 1.90 µeq/l. At present, ANC values in the lakes Dalvatn and Otervatn exceed 30 and 98 µeq/l.

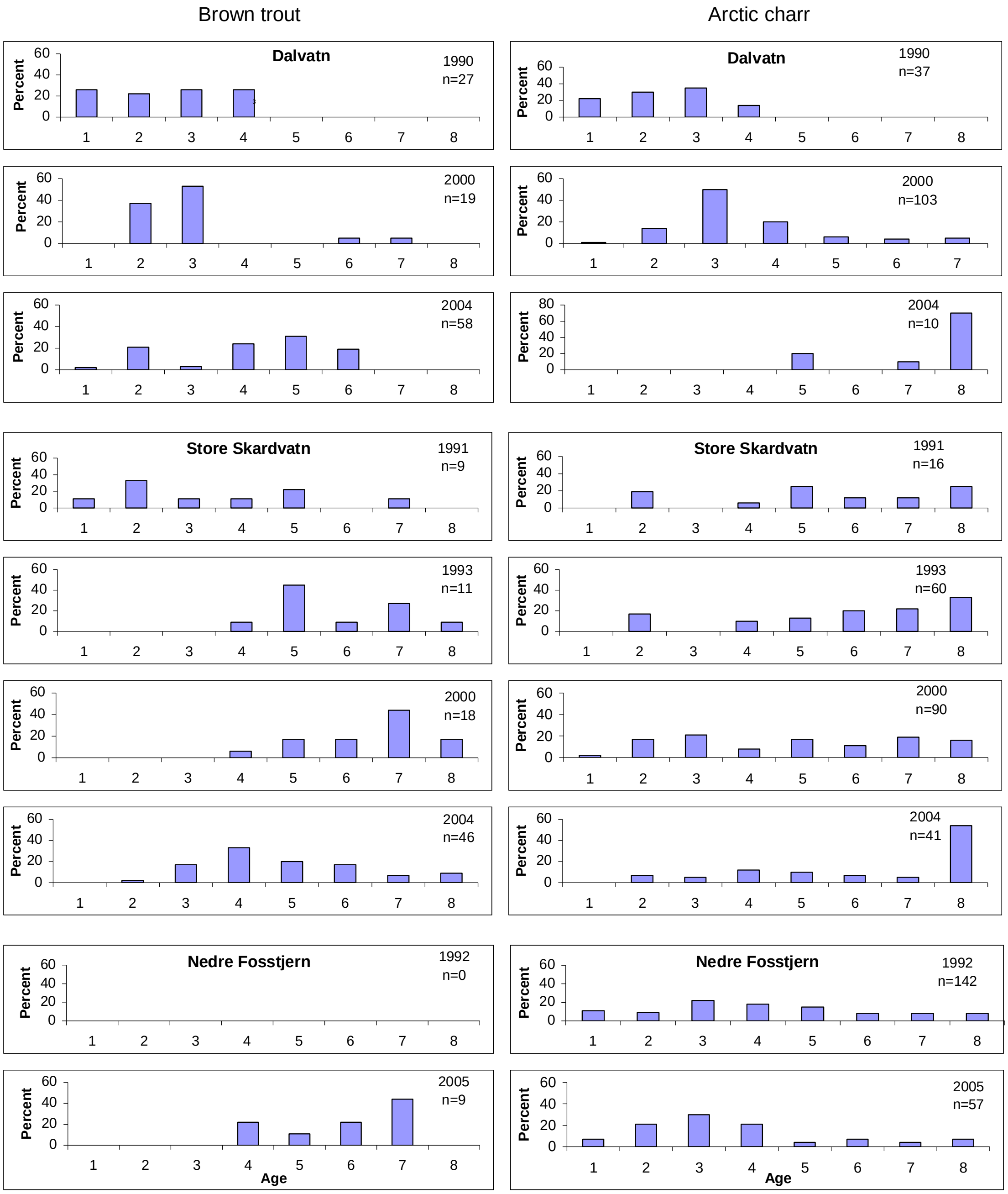

Figure 7. Age-frequency distribution of brown trout and Arctic charr in the lakes Dalvatn, Store Skardvatn and Nedre Fosstjern in the Jarfjord Mountains in different years between 1987 and 2005.

In addition to reducing the size of fish populations, acidity-induced mortality also alters the age structure (Hesthagen & Jonsson 2002). Often this is ascribed to recruitment failure, and is called ageing of the population (Rosseland et al. 1980). This seems to be evident for brown trout populations in both Otervatn and Dalvatn in the late 1980s and early 1990s, exhibiting irregular age -frequency distribution and low recruitment rate.

The abundance of Arctic charr populations has decreased during recent years in the study lakes. There was a significant negative correlation between catches of sympatric Arctic charr and brown trout in the epibenthic habitat. We suggest that this is due to interspecific competition. Brown trout is the dominant species, excluding Arctic charr from shallow littoral areas during summer (cf. Langeland et al. 1991, Saksgård & Hesthagen 2004). However, Arctic charr in Lake Nedre Fosstjern seem also to be less numerous in recent years in spite of the small sympatric population of brown trout.

In spite of a level of sulphur deposition in Sør-Varanger similar to that found in southern Norway, surprisingly few fish populations have been affected by acidification. It has been suggested that the deposition process of acidic compounds, relatively good catchment resistance to acidic inputs, and small precipitation, are important factors for the limited fish damage in this area (Hesthagen et al. 1998). Analyses of precipitation and snow pack chemistry also indicate that aerosols and particles from the smelters in Nikel are alkaline and to some extent neutralize the acid sulphur deposition (Sivertsen et al. 1994). A large fraction of the acid deposition in Finnmark reaches the ground in particulate form during the summer and autumn (Aas et al. 2006). Thus, the accumulation of acidic compounds in the snow pack is small and their subsequent release during spring snowmelt is low. This seems to be verified from continuous water quality monitoring of the acid-sensitive river Dalelva, i.e. outlet river from Lake Dalvatn (Traaen et al. 1994). During the late 1980s and early 1990s, there were only three acidic episodes with drops in pH to about 5.2 and rises in inorganic Al to 30 - 50 µg/l. This continuous monitoring shows that such extreme values are difficult to detect on the basis of only a few samples each year. Thus, there are reasons to believe that lakes such as Otervatn had a much more marginal water quality some 15 - 20 years ago than has been documented by the monitoring programmes (cf. Figure 8).

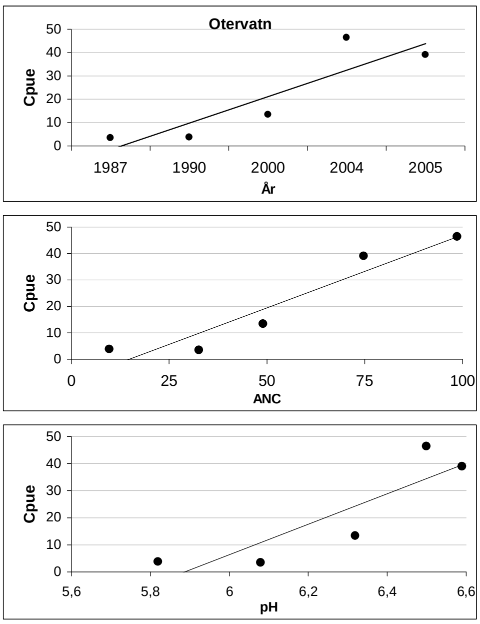

Figure 8. Relationship between ANC and pH and catches (CPUE) of brown trout in Lake Otervatn in five different years during the period between 1987 and 2005. The regression lines: CPUE = -8.14 + 0.55*ANC, CPUE = -333.38 + 56.29*pH.

Fish populations in the study lakes in the Jarfjord Mountains seem to respond to the chemical recovery following reduced deposition of sulphur in recent years. Thus, the monitoring programme should continue in order to reveal further recovery of fish in this area. However, this programme should also include studies in several other lakes, such as smaller acidic localities located at a relatively high altitude, in areas where the geology is less resistant to acidic inputs.

6. Summary

We studied the responses of populations of brown trout and Arctic charr to recent improvement in water quality in four acid-sensitive lakes in the Jarfjord Mountains in eastern Finnmark, northern Norway. These lakes are located near the Russian border, and their water quality is affected by emissions of SO_2 from the smelters in Nikel and Zapoljarnij, which are located about 25 - 36 km away from the lakes. Fish populations were sampled with benthic and pelagic gill nets in the autumn, and the catches are expressed as number of fish per 100 m^2 of net area (CPUE). The initial sampling was carried out between 1987 and 1993, while re-analyses were conducted from 2000 to 2005. Several lakes in the Jarfjord Mountains have previously been subjected to acidification. However, a significant chemical recovery have occurred during recent years, as shown by increasing pH and acid neutralising capacity (ANC). The allopatric population of brown trout in Lake Otervatn has recovered almost completely during recent years. This population was very low in abundance in 1987 and 1990 with a CPUE of about 4 fish. In 2004/05 CPUE had increased about tenfold, to 39 - 46 fish. Both pH and ANC explained a significant fraction of the variability in CPUE of brown trout in this lake. There has also been an increase in the catches of brown trout in two other lakes, which also contain Arctic charr. The age-frequency distribution of brown trout in the study lakes indicate that a higher number of age groups are present in recent years, and the recruitment rate has also increased. In contrast to this, Arctic charr populations have decreased in abundance during recent years. There was a significant negative correlation between the catches of sympatric brown trout and Arctic charr in the epibenthic habitat (depths of 0 - 12 m) of the study lakes. Thus, we suggest that the abundance of Arctic charr in these lakes is regulated by interspecific competition from brown trout.

7. Recommendations

We recommend to focus on three elements in a monitoring programme on fish related to acidification in Jarfjord Mountains in eastern Finnmark. I: This study showed that brown trout to a large extent have recovered in some acid-sensitive lakes in this area. However, in contrast to this, the abundance of Arctic charr populations have decreased during recent years. Thus, the monitoring of these populations should continue in order to reveal whether this is an effect of acidification or due to competition from brown trout. II: It has previously been shown that fish populations in several smaller lakes located at a higher altitude in this area had suffered most heavily from acid water. However, no study has been conducted to assess whether these fish populations have recovered from acidification. Thus, we suggest to include some of these localities in a monitoring programme. III: We also recommend to include a regional study of juvenile brown trout densities in tributary streams to obtain data of recruitment rate, which should be related to possible variation in water chemistry. This would reveal possible effects of acidification on the youngest and most sensitive stages.

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