Responses of brown trout *(Salmo trutta)* in lakes with different acid neutralizing capacity (ANC)

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INTRODUCTION

Acid neutralizing capacity (ANC) is usually included as a potential predictive variable in models that evaluate the effects of acidification on fish populations. ANC has also been used to estimate the tolerance limits of nature to acidification, and for setting goals for future deposition rates in order to avoid future damage and assure recovery of fish populations. The lower threshold for ANC in Norwegian lakes to avoid damaged stocks [ANC_{CRIT}] has been set at 20 μeq L^{-1}.

The relationship between ANC and biological response is indirect, because changes in ANC also involve changes in parameters such as pH and labile aluminium (LAl). Any specific ANC value may represent a wide range of pH and LAl levels.It has also been suggested that organic acids that appear permanently in the form of anions in the pH range of natural water should be grouped together with inorganic strong acid anions. This variable is denoted ANC_{OAA}.

In this study, we relate the relative abundance of brown trout on the basis of gill net catches in 42 lakes using both the traditional ANC and ANC_{OAA}. Brown trout was the only species of fish in the study lakes.

METHODS

Brown trout stocks were assessed by benthic gill-nets, and the catches is expressed as numbers of individuals 100 m^{-2} of net area [CPUE]. We used both total numbers [CPUE-T] and those of age 2+ fish [CPUE-2], which represent the recruitment strength.

We correlated CPUE both with ANC based on water chemistry from the same autumn as the test-fishing was performed (WQ_{1YR}) and with a mean value for a period of five years prior to and including the year of test-fishing (WQ_{5YR}). CPUE-2 was correlated with water quality measurements two years previously. Water samples were obtained in the autumn.

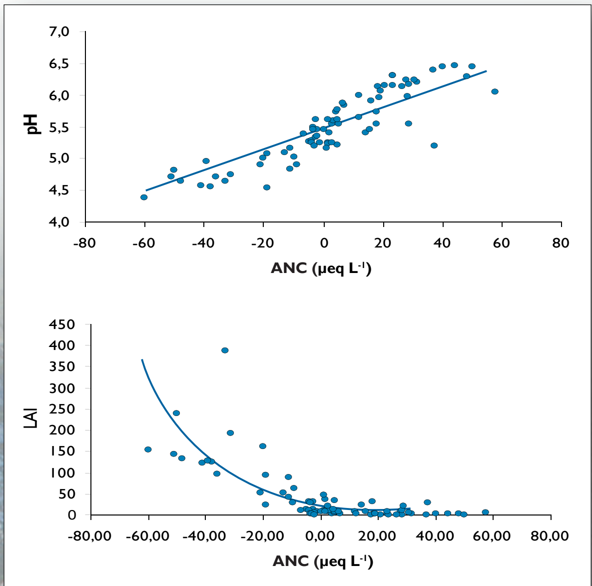

Figure 1. Relationships between ANC and pH, and ANC and Al-L in the study lakes (n=42).

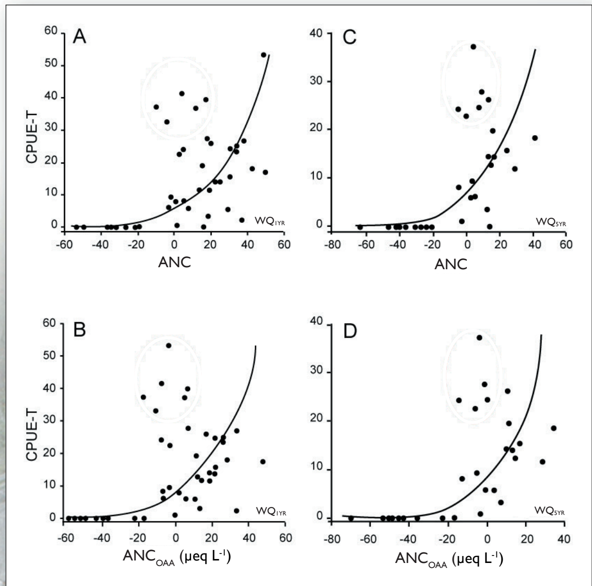

Figure 2. Relationship between brown trout catches (CPUE-T) and ANC/ANC_{OAA}. The water quality is based on both a single sample taken in the year of test-fishing (WQ_{1YR})and a mean value for five years (five samples) before to test-fishing (WQ_{5YR}).

RESULTS

Most lakes were acidic (pH 5.55±0.62), low in calcium (0.53±0.32 mg L^{-1}), low in humic content (TOC = 2.21±1.6 mg L^{-1}) and relatively high in LAl (45±79 μg L^{-1}). ANC ranged between -60 and +59 μeq L^{-1}, with a mean value of 6.94 μeq L^{-1}. ANC correlated significantly with pH and LAl (***Figure 1***). There is some obvious inter-site variability in ANC at negative values, which seems to be a function of LAl.

An exponential model gave the best statistical relationship between ANC and CPUE-T. Water chemistry based on WQ_{5YR} had a greater explanatory capacity regarding trout catches than WQ_{5YR} (***Figure 2***).There were small differences in the explanatory capacity regarding fish abundance between ANC (r^2 =0.59, P<0.0001) and ANC_{OAA} (r^2=0.62, P<0.0001). This is probably due to low TOC values. The model indicates a positive response of brown trout to ANC values of up to at least 20 μeq L^{-1}.

There was also a significant correlation between CPUE-2 and ANC based on water quality measurements two years previously, both for ANC (r^2 = 0.40, P<0.0001) and ANC_{OAA} (r^2 = 0.29, P<0.005).

CONCLUSION

The model indicates that brown trout respond positively to ANC values of up to at least 20 μeq L^{-1}. However, there are obvious difficulties in using this fixed ANC_{CRIT}:

* There was some inter-site variability in fish abundance, which probably relates to differences in LAl within the critical ANC range.

* More critical water quality occurs during certain periods of the year.

*Younger stages living in streams are more sensitive to acid water than older individuals living in lakes.

*To ensure that ANC_{CRIT} covers a range of ANC values as a function of LAl, we recommend that this value should be 30 μeq L^{-1}.

Brown trout *(Salmo trutta)* begin to recover in a formerly highly acidified lake in southernmost Norway

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Introduction

In Norway, acidified surface waters have shown substantial recovery during the last 20-30 years, with increasing pH and acid neutralizing capacity (ANC) and lower concentrations of labile Al. It has previously been shown that brown trout have started to recover in less acidified regions, i.e. in southwestern and western Norway. Heretofore there have been only scattered reports of recovery of fish populations in our most acidified areas. Here we report that brown trout are starting to recover in a formerly highly acidified unlimed lake in southernmost Norway, Lake Saudlandsvatn. Brown trout is the only species of fish in the lake, and no stocking takes place.

Water quality

The long-term monitoring record for Birkenes in the same region shows a 70% reduction in sulphur deposition in the period between 1980 and 2003 (***Figure 1***). Sulphate (SO_4) concentrations in Lake Saudlandsvatn showed a similar and parallel decrease with little or no time lag. During the 1970s and early 1980s, the lake was highly acid, with pH < 5.0. Both pH and ANC in the lake remained low until the 1990s and only then increased significantly. ANC reached positive values in 2001. The lag time between the decline in SO_4 and increase in pH and ANC was about 5-10 years.

Fish abundance in the lake vs. water quality

The population of brown trout in Lake Saudlandsvatn was sampled with benthic gill nets every second year from 1977 to 2003. In the 1970s and 1980s the lake supported a relatively dense population, followed by a gradual decline (***Figure 2***). In the late 1990s the population started to recover, and by 2003 it had reached a density higher than recorded in the late 1970s. This high catch in 2003, however, was mainly due to one strong year class (1+) which comprised 67% of the total.

CPUE correlated significantly with ANC and labile Al, but not with pH (***Figure 3***). Catches of age 1+ fish also correlated with ANC, based on water chemistry in their year of hatching (***Figure 4***). The response was highly significant when ANC rose to 20 µeq L^{-1}.

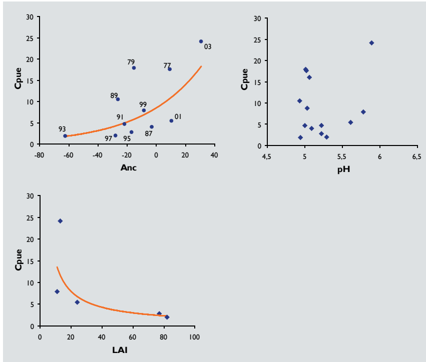

Figure 3. Catch-per-unit-effort (CPUE) of brown trout in Lake Saudlandsvatn vs. pH, ANC and labile Al. Labile Al have only been analysed after 1995.

Fish abundance in inlet and outlet stream vs. water quality

Near-failure of recruitment or low fry densities were registered in most years before 1995 (***Figure 2***). ANC correlated significantly with fry densities in both inlet and outlet streams (***Figure 5***). Recruitment failure or low fry densities was evident in several years at negative ANC values, while fry abundance increased significantly when ANC increased to 20-30 µeq L^{-1}, especially in the inlet stream.

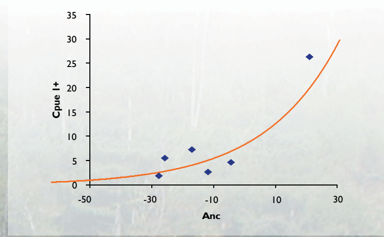

Figure 4. Catches of age 1+ brown trout (CPUE-1+) in Lake Saudlandsvatn vs. ANC.

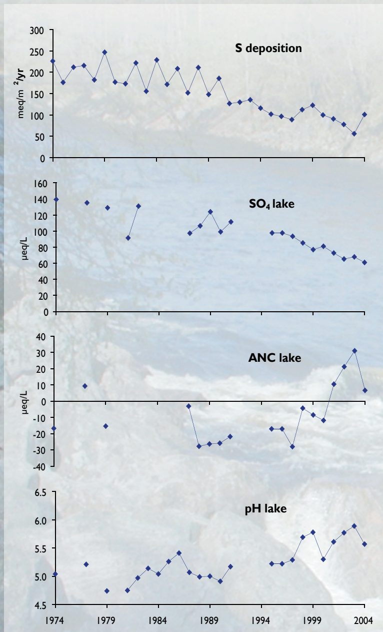

Figure 1. Sulphur deposition and SO_4, ANC and pH in lake water at Lake Saudlandsvatn sampled in the autumn between 1974 and 2004. Despotion data from NILU (www.nilu.no).

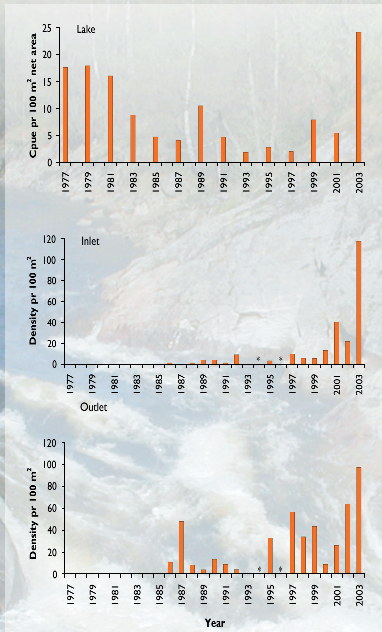

Figure 2. Catch-per-unit-effort (CPUE per 100 m²) of brown trout in Lake Saudlandsvatn (1977-2003), and densities of fry (age 0+) in inlet and outlet stream (1986-2003). In 1994 and 1996, no streams were sampled for fish (*).

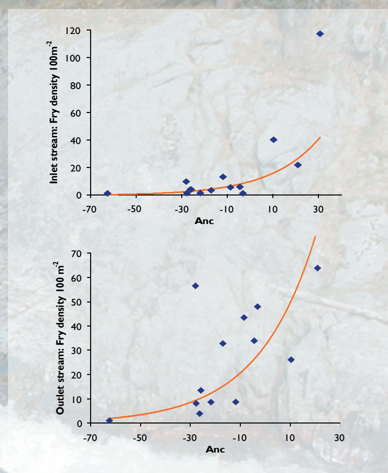

Figure 5. Densities of brown trout fry in the inlet and outlet stream of Lake Saudlandsvatn vs. ANC

Conclusion

* Both pH and ANC in the lake remained low until the 1990s, and only then increased significantly; the lag time between decline in SO_4 and increase in pH and ANC was about 5-10 years. ANC reached positive values in 2001.

*The brown trout population responded significantly when ANC reached 20-30 µeq L^{-1}.

* Catches of brown trout are now (2003) at a similar level as prior to acidification. However, this is mainly due to the large numbers of one year-class, i.e. age 1+ fish (67%). Thus, full recovery with natural representation of all yearclasses expected for this trout population, may still take many years (see: "The FIB model", Rosseland *et al.* this conference).