NATURENS
TÅLEGRENSER

Miljøverndepartementet

FAGRAPPORT NR. 23

Critical Loads of Acidity to Freshwater

Fish and Invertebrates

Norsk institutt for vannforskning NIVA

Naturens Tålegrenser

Programmet Naturens Tålegrenser ble satt igang høsten 1989 i regi av Miljøverndepartementet. Programmet skal blant annet gi innspill til arbeidet med Nordisk Handlingsplan mot Luftforurensninger og til pågående aktiviteter under Konvensjonen for Langtransporterte Grensoverskidende Luftforurensninger (Genevekonvensjonen). I arbeidet under Genevekonvensjonen er det vedtatt at kritiske belastningsgrenser skal legges til grunn ved utarbeidelse av nye avtaler om utslippsbegrensning av svovel, nitrogen og hydrokarboner.

En styringsgruppe i Miljøverndepartementet har det overordnete ansvar for programmet, mens ansvaret for den faglige oppfølgingen er overlatt en arbeidsgruppe bestående av representanter fra Direktoratet for naturforvaltning (DN), Norsk polarinstitutt (NP) og Statens forurensningstilsyn (SFT).

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Styringsgruppen i Miljøverndepartementet består av representanter fra avdelingen for naturvern og kulturminner, avdelingen for vannmiljø, avdelingen for luftmiljø og industri og avdelingen for internasjonalt miljøvernsamarbeid og polarsaker.

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Abstract:

Chemical criteria have been established for estimating critical loads of acid precipitation to surface waters. Acid neutralization capacity (ANC) was used as chemical component for describing the critical limits for biological indicators. Considerable variations in critical ANC limits are recorded for different species of fish. Perch is the species that tolerates lowest ANC-values while Atlantic salmon appears to be the most sensitive of the species surveyed. Atlantic salmon and brown trout are proposed as indicator species for fish in acidic water in Norway. An ANC-concentration of 20 µeq/l is proposed as an acceptable ANC-limit for fish and invertebrates in Norwegian freshwaters exposed to acid precipitation.

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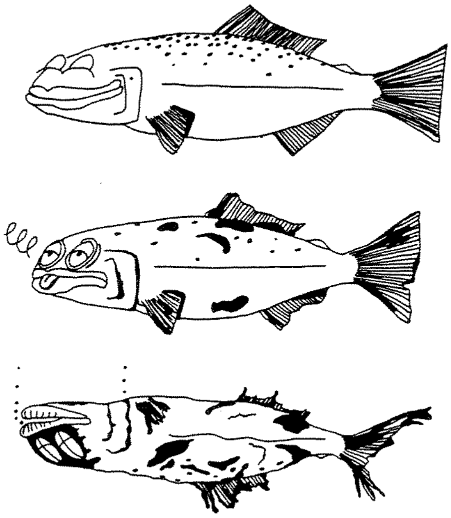
CRITICAL LOADS OF ACIDITY TO FRESHWATER - FISH AND INVERTEBRATES



Oslo, 25. April 1992

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PREFACE

The national programme "Naturens Tålegrenser" (Environmental Tolerance Levels) was initiated by the Norwegian Ministry of Environment. The programme will give inputs to the Nordic Action Plan against Air Pollution and to the ongoing activities under the Convention on Long-Range Transboundary Air Pollution (The Geneva Convention). For the work under the Geneva Convention critical loads will be used for establishing new agreements on reduced emissions of sulphur, nitrogen and hydrocarbons.

A steering group with members from the Ministry of Environment has the overall responsibility for the Norwegian programme, while the scientific responsibility is given to a working group with representatives from the Directorate of Nature Management (DN), The Norwegian Polar Research Institute (NP) and the State Pollution Control Authority (SFT).

The working group has requested the Norwegian Institute for Water Research (NIVA) and the Laboratory of Freshwater Ecology and Inland Fisheries (LFI), University of Bergen, to relate chemical criteria of surface waters to critical limits for fish and invertebrates.

NIVA is responsible for the sections on fish, and LFI, Bergen, is responsible for invertebrates. Arthur J. Bulger has carried out statistical calculations of the material on fish.

The present report is a modified English translation of the programme report: "Tålegrenser for overflatevann - evertebrater og fisk". Jennifer Follestad did the translation, and Unn Lyngstad the typing. Thanks are also due to Arne Henriksen and Richard F. Wright for critically reviewing the report.

CONTENTS page

SUMMARY

Chemical criteria have been established for estimating critical loads of acid precipitation to surface waters, based on the acid neutralization capacity (ANC) of water. ANC is defined as the difference between non-marine concentrations of base cations and strong acids anions. If long-range transported deposition of sulphur and nitrogen gives higher concentrations of the anions of strong acids (sulphate and nitrate) than concentrations of base cations, water becomes acidic.

Regression analyses for various physical-chemical parameters show almost identical high correlation coefficients for ANC, pH and labile aluminium in relation to fish data. Correlations for invertebrate fauna are best for ANC and pH. Calcium and TOC concentration appear to modify critical limits and must be taken into consideration when damage is assessed. ANC is much simpler to use than, for example, pH for making prognoses of changes in acidic inputs and their impact on aquatic organisms.

ANC measurements from approximately 1100 freshwater localities have been collocated with changes in status for fish species that live (lived) there. The status for Atlantic salmon, brown trout, Arctic char, whitefish, perch, pike, roach and minnow is grouped as (1) unchanged, (2) reduced, or (3) extinct.

Considerable variations in critical ANC concentration for different species were recorded. The species that tolerates the lowest ANC concentrations is perch, while Atlantic salmon appears to be the most sensitive of the species surveyed. Atlantic salmon and brown trout are proposed as indicator species for fish in acidic water in Norway.

The invertebrate fauna of 165 freshwater localities were compared to ANC and other chemical parameters. The invertebrates were grouped according to influence of acidic water: Little acidification damage (acidification score 1), moderately damaged (acidification score 0.5), significant damage (acidification score 0.25) and severely damaged (acidification score 0).

An ANC concentration of 20 µeq/l is proposed as an acceptable ANC limit for fish and invertebrates in freshwater rivers and lakes in Norway exposed to acid precipitation. In unimpacted areas healthy fish populations survive at ANC concentrations down to 0 µeq/l.

1. INTRODUCTION

Critical loads for atmospheric inputs of sulphur and nitrogen to an ecosystem are defined as follows (Nilsson and Grennfelt 1988):

> "The highest deposition of acidifying compounds that will not cause chemical changes leading to long term harmful effects on ecosystem structure and function."

Acidification of surface waters is due to inputs of anions of strong acids, primarily sulphate and nitrate, which are deposited in the catchment area by precipitation and dry deposition. The sulphate ion is normally a mobile anion, i.e. it moves with precipitation through the catchment area and may have an acidifying effect on surface water. Nitrate and ammonium fertilize vegetation. Therefore, nitrogen compounds that are deposited by precipitation and dry deposition will normally be taken up by trees and plants. If more nitrogen is deposited than required by vegetation, the excess will drain into watercourses mainly in the form of nitrate and will have the same acidifying impact as sulphate. Critical loads for the acidification of surface water are most thoroughly documented for sulphur deposition. Critical loads for this component were exceeded a long time ago in large areas of Norway and many other countries, resulting in acidic, barren lakes where also other parts of the food chain are affected. Today, the cause/effect relationship is well documented in the case of sulphur, and the dose/response relationship can be expressed using simple models. The documentation for nitrogen is much poorer.

Critical loads for inputs of acidic compounds (sulphate and nitrate) must be established in relation to living organisms. The critical load to surface waters can be estimated in relation to fish or invertebrates. In this report critical limits for fish and invertebrates will be estimated in relation to chemical criteria of surface waters. It has been customary to establish criteria for damage to fish in relation to several chemical components. pH, calcium, labile aluminium and humic content are most often used. For example, the lowest level for trout is a combination of pH ≈ 5.0, Ca <1.0 mg/1 and labile A1 ≈ 30 µg/1 (Rosseland and Skogheim 1986). However, it is difficult to present critical loads clearly in map form with such combinations. A more suitable method for mapping is based on the use of acid neutralization capacity (ANC).

A critical load map for water chemistry has been prepared for the whole of Norway. Each grid square of 0.5 ° in longitude x 1.0 ° in latitude has been divided into 16 subgrids. A lake has been selected in each subgrid to represent at least 25% of the area of the subgrid that is assumed to be most sensitive to acidic precipitation.

Data on water chemistry together with measurements of precipitation chemistry and runoff data provide the basis for the mapping of sulphur runoff, chemical critical loads and the exceeding of chemical critical loads for surface water in relation to the acid neutralization capacity (ANC) of the catchment areas (Henriksen et al. 1990a).

2. MATERIAL AND METHODS

This report describes critical limits for fish and invertebrates using water chemistry parameters calculated as ANC (Henriksen et al. 1990a).

This study is based on water chemistry data from 1095 lakes and the status of 1917 fish populations from the same lakes. The water chemistry of the majority of the lakes is described on the basis of a water sample collected at the outlet following the turnover of water in the autumn. Fish data are mainly obtained from interview surveys and cover the whole of Norway. A large proportion of the fish data is drawn from the 1000 Lake Survey (Henriksen et al. 1988, 1989), while data from approximately 400 localities from various other surveys are also included (Drabløs and Sevaldrud 1980, Lien et al. 1986, Sevaldrud and Hegge 1987, Lien et al. 1988, Fjeld et al. 1989, SFT 1988b, 1989b, Oppegård et al. 1990).

The invertebrate data are based on plankton collected with a scoop net, and qualitative and quantitative bottom samples from the littoral zone of lakes, from the outlet and from the outlet stream (100-200 m downstream).

Most of the data on invertebrates were collected as part of the project "Naturens Tålegrenser" (Environmental Tolerance Levels). In addition, we have used data from the above-mentioned surveys and from the Norwegian Monitoring Programme for Long-Range Transported Air Pollutants from 1987-1990 (SFT 1987a, 1988b, 1989b,1991).

Lake water chemistry is characterized by ANC. ANC for the majority of lakes is calculated as

$$\text{ANC} = \text{base cations} - \text{the anions of strong acids}$$

$$= Ca^{2+} + Mg^{2+} + Na^{+} - SO_4^{2-} - Cl^{-} - NO_3^{-}$$

For some of the lakes where the database for water chemistry is inadequate or doubtful, ANC is calculated as

$$ANC = HCO_3^- + A^- - H^+ - Al^{n+}$$

where A^- is organic anions and Al^{n+} is the sum of all the positively-charged aluminium ions. For a more detailed description of calculations of ANC, see Henriksen et al. 1990a.

The database for the 1000 Lake Survey (SFT 1987b, 1988a) has been reassessed and supplemented as regards fish data. Fish data in the 1000 Lake Survey are mainly based on interview surveys. Approximately fifty of the lakes have been test fished at a later date (SFT 1989b, 1991). The results that showed discrepancy with the interview survey have been adjusted. About 700 lakes out of a total of approximately 900 lakes in the 1000 Lake Survey have been used for further study. The remainder were rejected, mainly on account of inadequate information about changes in fish status or because of inexact/uncertain fish data generally. Some of the lakes rejected have recently been affected by operations that have altered the chemical conditions (regulation, liming etc.).

Furthermore, data for water chemistry and salmon status from 30 salmon rivers have been included. This information was obtained from published literature (see page 23).

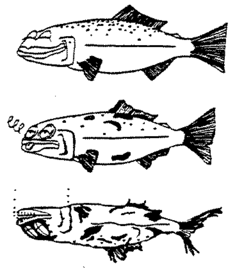
All information about fish is presented as changes in relation to previous years. This applies to general changes in fish status, and includes all fish species which are or have been present in a lake. It also applies to each individual species considered: Brown trout *Salmo trutta*, perch *Perca fluviatilis*, Arctic char *Salvelinus alpinus*, whitefish *Coregonus lavaretus*, pike *Esox lucius*, roach *Rutilus rutilus*, minnow *Phoxinus phoxinus*, and Atlantic salmon *Salmo salar.*

Changes in fish status for lakes containing one or more species are grouped as follows:

1: Undamaged.
2: Slightly damaged - still fish, but with at least one population in decline.
3: Severely damaged - still fish, but with at least one extinct population.
4: Totally damaged - barren.

For the individual fish species, changes in status are defined in three categories:

1: Undamaged.
2: Damaged - still fish, but reduced population.
3: Totally damaged - extinct population.



Damage of fish populations, means damage caused solely by acidic water. Lakes where fish species are reduced due to other possible causes (overfishing, the introduction of competing species, rotenone treatment etc.), or where the water chemistry has been altered (liming, regulations), have not been included in the further treatment of the material. This applies also to the data set from the 1000 Lake Survey (Henriksen et al.1989), from which a number of lakes where fish data are uncertain have been excluded (SFT 1989b).

3. CRITICAL LIMITS FOR INVERTEBRATES

3.1 Invertebrates and the acidification score

Our knowledge of critical limits for invertebrates with respect to acidic water is based on a growing database begun during the SNSF project in 1976. The main body of the database consists of data on water chemistry and fauna from western and southeastern Norway. Data from other parts of Norway have been added through the project "Naturens Tålegrenser" (Environmental Tolerance Levels). Critical limits for different species have been determined by laboratory experiments and observations in the field (Raddum 1979, Raddum and Fjellheim 1984 and 1987, Fjellheim and Raddum 1990). There is an ongoing process of verification and adjustment of these critical limits, for example, in connection with the Norwegian Monitoring Programme for Long-Range Transported Air Pollutants.

An acidification index (score) has been developed for the assessment of damage to invertebrates in freshwater, based on knowledge of critical limits for different species (SFT 1985, Raddum et al. 1988, Fjellheim and Raddum 1990). The acidification score is given by a figure between 0 and 1. Score 1 means that the locality contains one or more species with a low tolerance for acidic water (can tolerate a pH down to 5.5). When these species are found in a locality, this indicates that there is little acidification damage. With a score of 0.5 none of the most sensitive species are present, while the locality contains species which are moderately sensitive to acidification (can tolerate a pH down to 5.0). Such a community of fauna is termed moderately damaged. An acidification score of 0.25 indicates high damage and is given if the locality lacks all the sensitive species mentioned above, but contains species with a tolerance down to pH 4.7. Severely damaged localities contain only organisms with extremely high tolerance for acidic water (can tolerate pH < 4.7). These localities are given the score 0.

Appendix 1 presents the species and their acidification score included in the assessment of acidification damage. The list also contains a number of rare species where we know little about acidification tolerance. These species are given an acidification score of zero. Errors in the acidification score for rare species will not significantly influence the determination of the acidification value of a locality because the score is usually determined by the most common species.

There may be wide variations in the occurrence of species within the same acidification score. This is due to factors other than the acidification impact. Most important are other physical-chemical factors, eutrophic level, geographical location and biological interactions (predation, food availability, competition etc.). Several invertebrates are limited by the concentration of calcium. For instance, snails disappear when the calcium concentration is < 1 mg Ca/l even when the pH is 5.5-6.2. With increasing pH a few of these species tolerate a lower calcium content (Økland 1979, Økland and Økland 1986).

The fauna composition for 71 localities in western Norway with differing water quality is presented in Appendix 2. The fauna in localities with an acidification score of 1 varied considerably according to the calcium content. When the calcium concentration increases there is normally an increase in the total number of species of snails, mussels, leeches and mayflies (see also Økland and Økland 1986). The fauna in undamaged localities may therefore be subject to considerable variation, depending on calcium content. In a moderately acidified locality (acidification score 0.5) the number of species may also vary, though less than in undamaged localities. At the levels high-to-severe acidification (scores 0.25 and 0) the possible number of species is further restricted and there is less variation. In other words, pH becomes the chemical factor that primarily determines the composition of fauna with increasing acidification. If adequate biotope data are available, the fauna in the most acidified localities can be predicted with great certainty because the calcium content has little or no influence on fauna at an acidification score of zero.

As mentioned, pH and calcium concentrations may have a synergistic impact on critical limits for invertebrates. The content of organic material may also modify these limits (see Hobæk and Raddum 1980. Sutcliffe et al. 1986, Hämäläinen and Huttunen 1990). However, the various chemical factors that can modify critical limits are accounted for when ANC is used as a parameter. For this reason, as well as the fact that ANC is much simpler to use in prognoses of changes in acid deposition and impact on water quality, we will focus primarily on ANC and fauna composition .

3.2 Water chemistry and invertebrates

The data set for invertebrates and water quality consists of material from 71 localities situated in various watercourses in western Norway (Lien et al. 1986 and 1988, SFT 1987a) and from the 100 Lakes Project (located all over southern Norway). In the following discussion, we have treated the material as 1) the entire material (all localities grouped together, and 2) the 100 Lakes separately. In addition, data from the "Norwegian Monitoring Programme for Long-Range Transported Air Pollutants" are included.

The reason for this division is that the entire material (all localities) is dominated by clearwater streams and rivers of low ionc strength, situated in western Norway. The localities in the 100 Lakes Survey are mainly connected to lakes. The material is collected from many areas of Norway and contains a wider spectrum of water qualities. The material from the "Monitoring Programme" consists of mean values from many stations and, therefore, not suited for grouping together with the rest of the material.

The relationship between fauna composition giving acidification scores of 1, 0.5, 0.25 and 0, and water chemistry parameters is illustrated in figures 3.2-1 to 3.2-8. The standard error is given to show the range of variance in the material. The degree of overlap or lack of overlap for the standard error indicates correlation between the chemical parameter and the acidification score. Acidification score 1 is found throughout at lower ANC values in the entire material than in the 100 Lakes material (fig. 3.2-1 and 3.2-2). Correspondingly, the mean pH and calcium are somewhat higher in the entire material than in the 100 Lakes material at acidification value 1 (fig. 3.2-3 to 3.2-6). The calcium content is very similar in the 100 Lakes material regardless of the acidification scores (fig. 3.2-6). The results show that the fauna in the entire material, which is dominated by clearwater localities, are more sensitive than the fauna in the 100 Lake Survey (compare mean values for pH and ANC). This indicates that clearwater localities require more calcium to avoid damage.

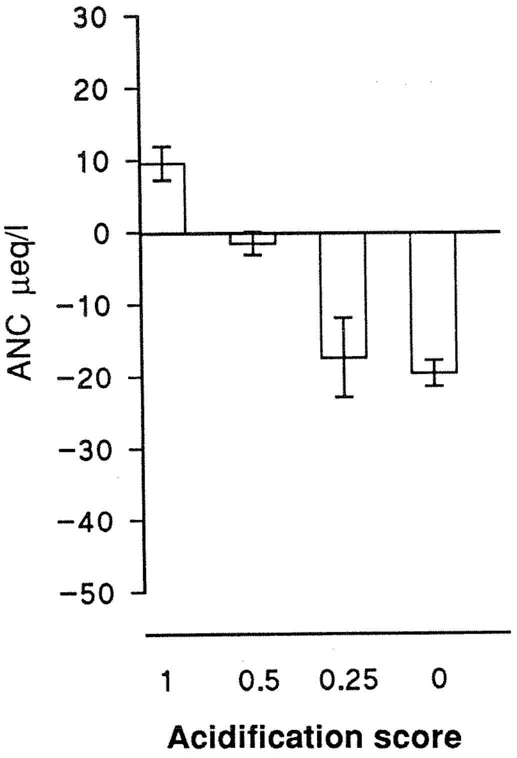


Fig. 3.2-1 Acidification score for invertebrates in relation to mean ANC concentrations for the entire material

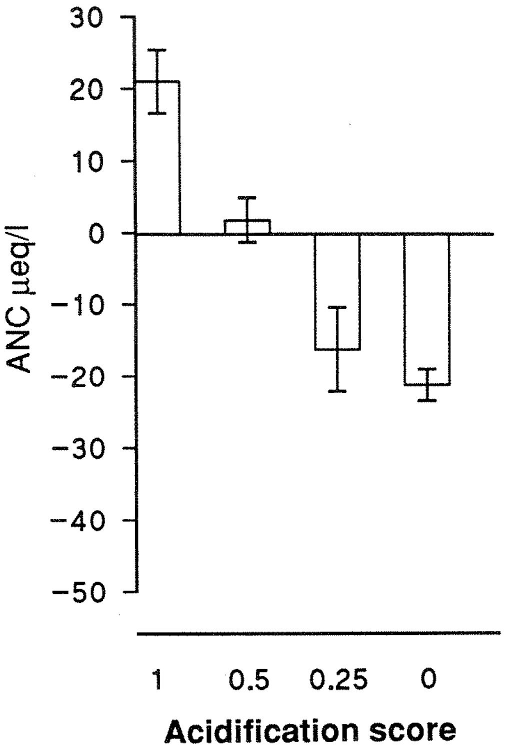


Fig. 3.2-2 Acidification score for invertebrates in relation to mean calcium content for the 100 Lakes material

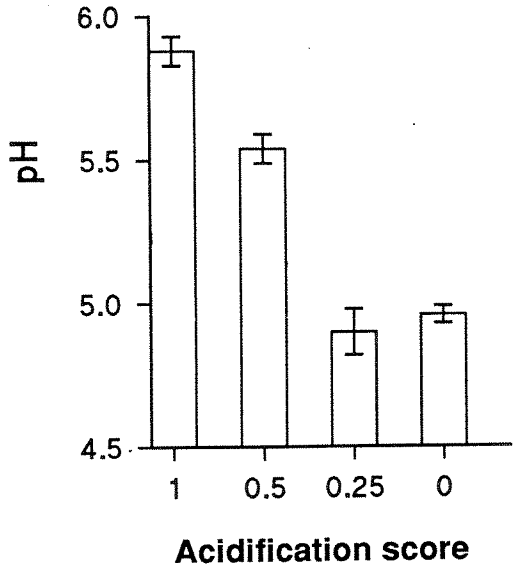


Fig. 3.2-3 Acidification score for invertebrates in relation to mean pH for the entire material.

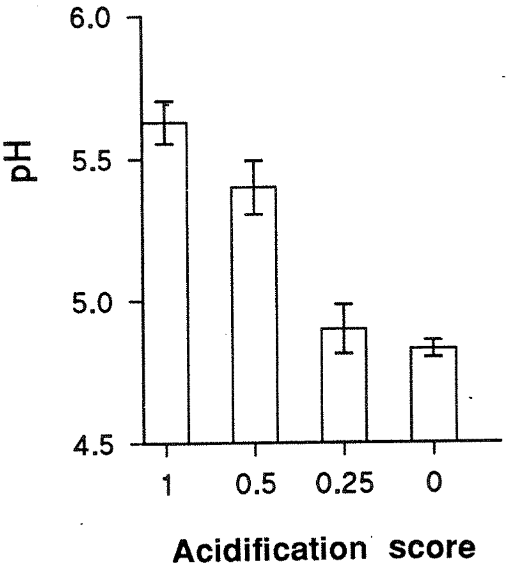


Fig. 3.2-4 Acidification score for invertebrates in relation to mean pH for the 100 Lake material.

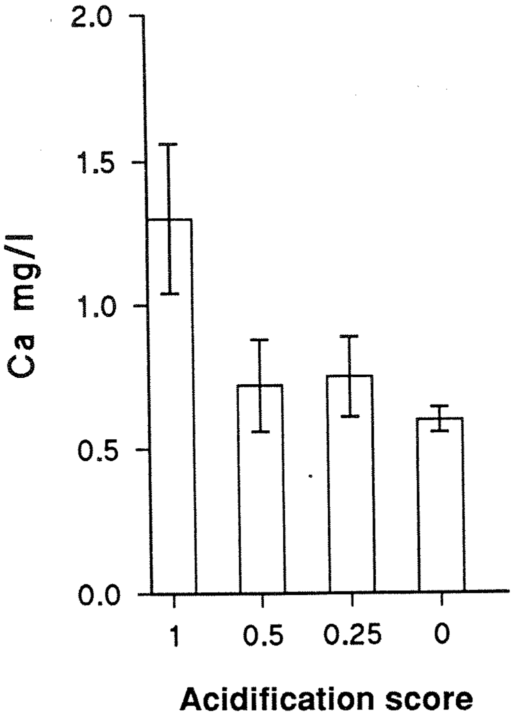


Fig. 3.2-5 Acidification score for invertebrates in relation to mean calcium content for the entire material.

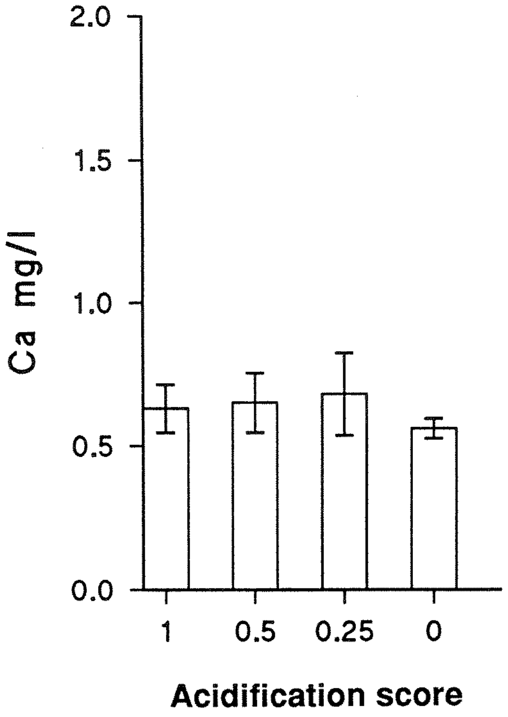


Fig. 3.2-6 Acidification score for invertebrates in relation to mean calcium content for the 100 Lakes material.

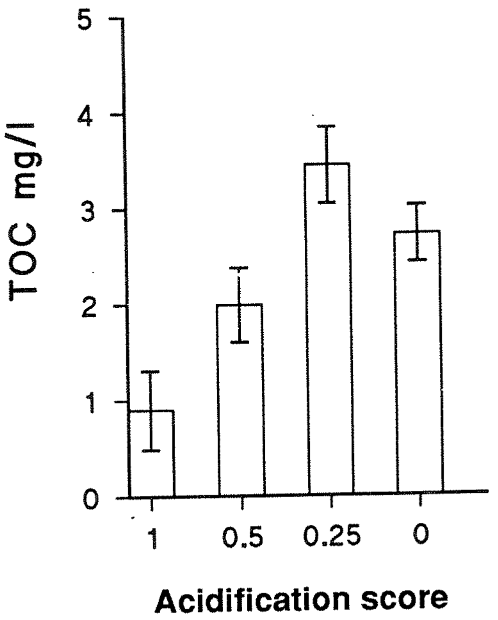


Fig. 3.2-7 Acidification score for invertebrates in relation to mean TOC (Total Organic Carbon) for the 100 Lake material.

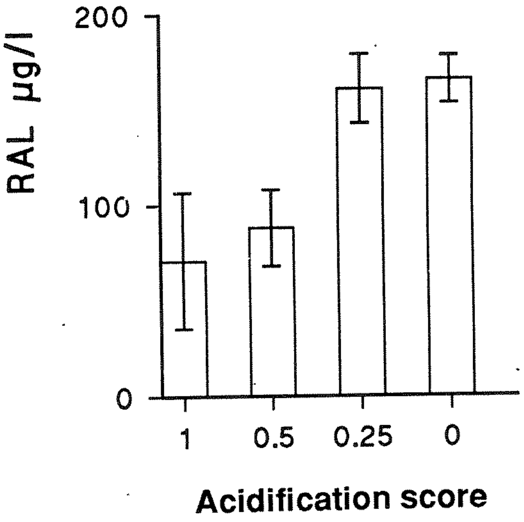


Fig. 3.2-8 Acidification score for invertebrates in relation to mean RAl (Reactive Aluminium) for the 100 Lake material.

The correlation between ANC and the acidification score is shown for mean values using data from the "Norwegian Monitoring Project for Long-Range Transported Air Pollutants" in figure 3.2-9 (NIVA 1991). A correlation coefficient of r = 0.88. was calculated. A corresponding analysis of the total material gives a poorer correlation, r = 0.63. The reason for this is that the connection between ANC and the acidification score follows a sigmoid curve and the data set in this case contains many ANC values which lie outside the area for linear correlation (ANC values > 30 and < -30 µeq/l).

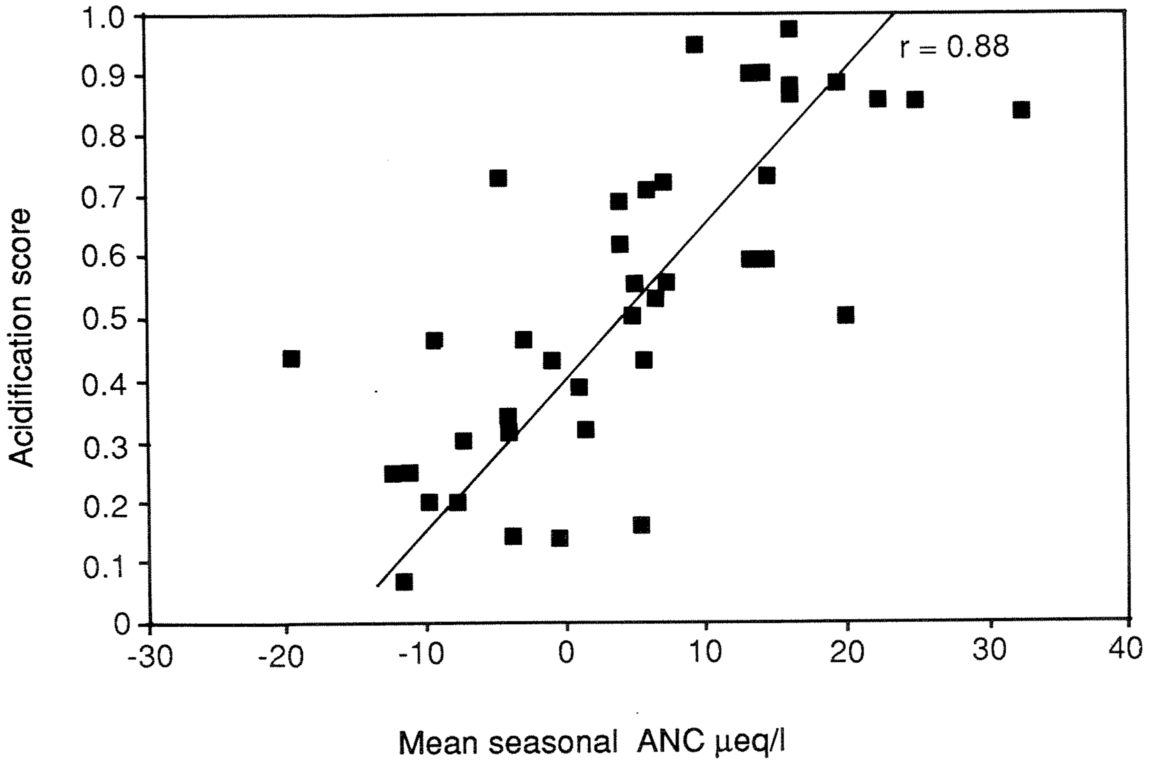


Fig.3.2-9 The correlation between the acidification score and ANC in surface water. Invertebrates and water samples collected in the same period.

3.3 Changes in the acidification score in relation to ANC

To illustrate changes in the acidification score and ANC, localities are grouped in ANC intervals of 10 µeq/l. The number of localities with different acidification scores are totalled for each of these intervals. The cumulative percentage distribution of acidification score 1, 0.5 and 0 (0.25 and 0 combined) is shown in figure 3.3-1. The figure shows that at an ANC < -30 µeq/l all the localities have a fauna composition that indicates severe acidification damage (score 0).

Score 0.5 is found in the ANC area –30 to 30 µeq/l. Little acidification damage (score 1) is recorded down to ANC –5 µeq/l , while at ANC > 30 µeq/l all the localities show little damage. Compared to figure 3.3-1 (the whole southern Norway) the corresponding figure for western Norway alone (fig.3.3-2 from Lien et al. 1989) is similar but, the curves for western Norway span a slightly narrower range of the ANC scale than the entire material.

These figures show clearly that ANC gives a good correlation to the different acidification scores. Clearwater localities (western Norway) with an acidification score of 1 require higher calcium content. This indicates that invertebrates are more sensitive to acidification in clearwater localities. When humic-rich localities are included in the material, the sensitive invertebrates tolerate on average a somewhat lower pH. The above-mentioned factors explain why the various acidification scores are recorded over a slightly broader scale when data from the whole of southern Norway are included.

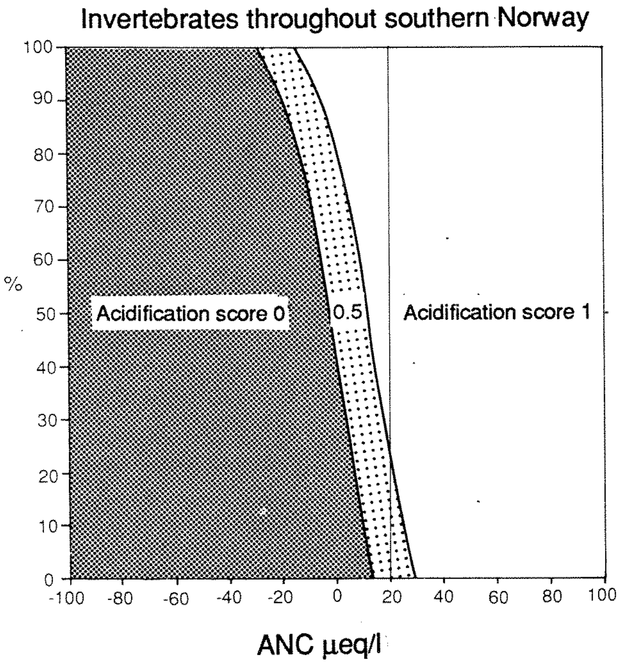


Fig. 3.3-1 Acidification score for invertebrates in relation to ANC in localities throughout southern Norway.

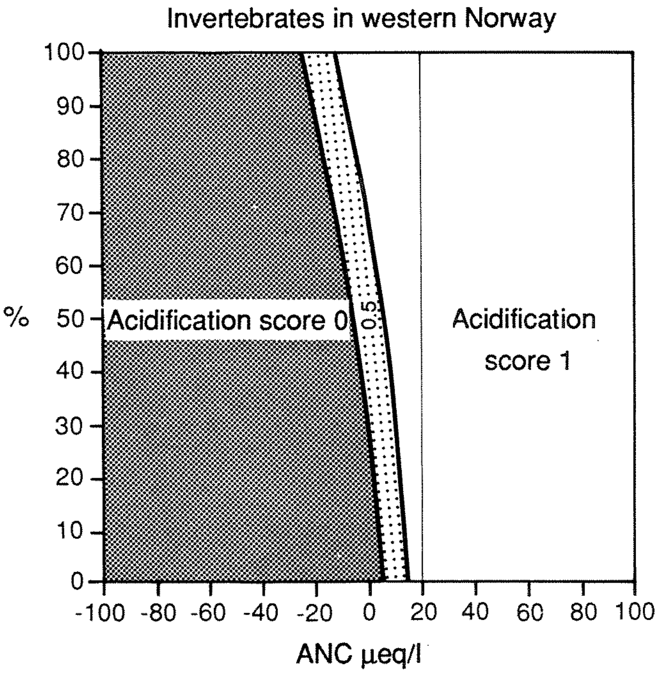


Fig. 3.3-2 Acidification score for invertebrates in relation to ANC in localities in western Norway.

4. CRITICAL LIMITS FOR FISH

4.1 Water chemistry and fish status

The relationship between changes in fish status and a number of chemical parameters from lakes where the various fish species are recorded, is shown in figure 4.1-1. The mean value plus/minus twice the standard error is indicated in the case of ANC, pH, calcium and labile aluminium for the various fish species separately, and for all fish species combined. Fish status for Atlantic salmon is only shown for ANC, and data for salmon are not included in further calculations for the group, "All species". From status 1 to 3 (4), we find a gradual reduction in mean values for ANC, pH and calcium, parallel with an increase in labile aluminium. This applies to all the fish species that are well represented in all status groups, and it applies to all the species combined.

The mean values of the various chemical parameters plus/minus twice the standard error show a range of variation of the material that can be used to compare the different chemical parameters and to indicate the chemical parameters that give the highest correlation to the fish status group. The degree of overlap (twice the standard error) of a chemical component between the different fish status groups can be assessed visually. When comparing status 1,2 and 4 for "all species" and status 1,2 and 3 for trout and perch, there is no overlap of any of the chemical parameters (fig. 4.1-1). A similar comparison of char and pike, where the database is smaller, reveals overlap for calcium and also aluminium. In the case of minnow, roach and whitefish where the database is even smaller, we find increasingly large overlaps for calcium and aluminium, then pH and finally ANC. The fact that ANC appears to differentiate best between different status groups, especially when the number of samples is smaller, makes ANC a chemical parameter that is well suited to differentiate between the effects of acidic water on fish.

4.2 Correlation between fish status and physical-chemical parameters

What physical-chemical parameters show the highest correlation with fish status? To answer this question, regression analyses of the various physical-chemical parameters were carried out on various fish status groups for trout, perch and all fish species combined. The results are shown in Table 4.2-1.

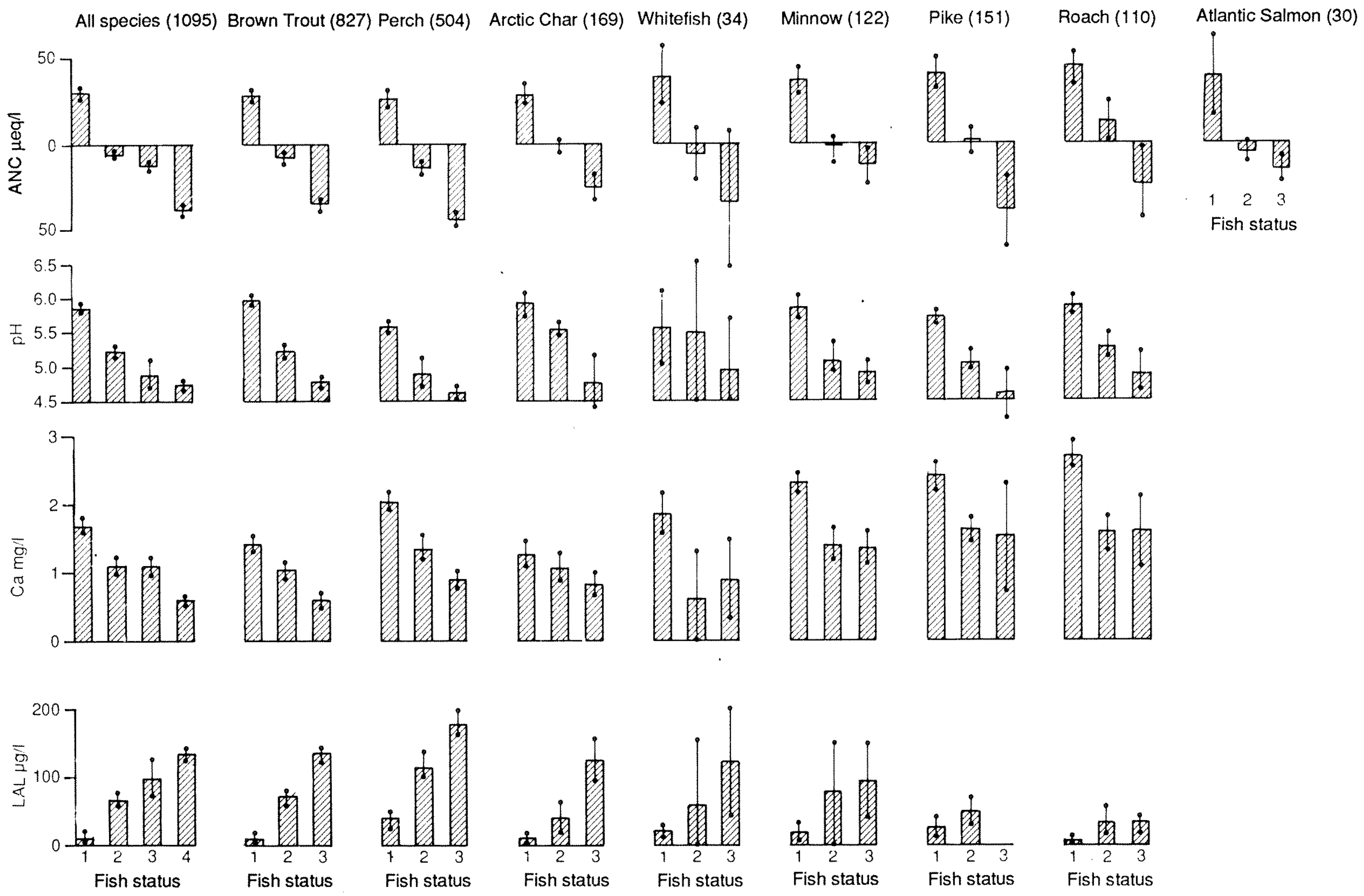


Fig. 4.1-1 Water chemistry parameters in relation to fish status for brown trout, perch, Arctic char, whitefish, minnow pike, roach, and all species combined. Acid neutralization capacity (ANC), pH, calcium and labile aluminium are shown as mean values plus/minus twice the standard error.

The status for Atlantic salmon is compared only with ANC. Fish status is: 1 = unchanged, 2 = reduced and 3 = extinct. For the group "all species" 1 = unchanged, 2 = reduced, 3 = severely reduced and 4 = extinct.

Table 4.2-1 The correlation coefficients calculated on linear regression between fish status groups for brown trout, perch and all fish species combined, and pH, acid neutralization capacity (ANC), labile aluminium (LAl), calcium (Ca), total organic carbon (TOC) and non-labile aluminium (IlAl).

	pH	ANC	LAL	Ca	TOC	IlAl
Brown trout	-.80	-.76	.72	-.37	-.04	.07
Perch	-.63	-.60	.69	-.37	-.36	.01
All species	-.79	-.73	.74	-.39	-.12	.01

A negative sign in front of a coefficient shows an inverse correlation. For example, - 0.80 for pH for trout indicates low pH at a high fish status (status 2 or 3, damaged or extinct). There are high correlation coefficients between all groupings of fish status and pH, ANC and LAl. In the case of trout it is highest for pH, and for perch the best correlation is with LAl, while for all species combined pH has the highest correlation. However, the differences between these three parameters are small, and in practice all three will give approximately the same result.

Moreover, there is a correlation between fish status and calcium, but this is considerably lower than for the other three chemical parameters. In addition there is a negative correlation between perch status and TOC (high TOC low fish status and vice versa). It was anticipated that high TOC values would have a positive impact on the survival of fish because TOC binds a large amount of aluminium. The fact that this only applies to perch may be due to a natural occurrence of this fish species in humic lakes with high TOC. Earlier studies have shown that TOC greater than 6 mg/l has a positive effect on the survival of perch (SFT 1988a).

A correlation analysis of the physical-chemical parameters was carried out and the results are presented in Table 4.2-2.

Table 4.2-2 The correlation coefficients between physical-chemical parameters used in the description of water quality in lakes with recorded fish status.

	pH	ANC	LAl	Ca	TOC	IlAl
pH	1					
ANC	.86	1				
LAl	-.77	-.73	1			
Ca	.48	.62	-.19	1		
TOC	.01	.31	-.07	.42	1	
IlAl	-.18	.02	.16	.33	.68	1

Table 4.2-2 shows very high correlation between pH and ANC. This means that ANC may be used instead of pH when more convenient, for example, in connection with specifications of fish status. Moreover, there are high correlations between pH and labile aluminium, and between ANC and labile aluminium. These correlations were not unexpected.

In addition there is a high correlation between TOC and non-labile aluminium. In water localities with high values of TOC most of the reactive aluminium are bound to the TOC as non-labile aluminium. At lower TOC concentrations there is less possibility of bound aluminium.

The correlation between fish status and water chemistry for this material has been statistically analyzed by Bulger et al. (In prep.).

4.3 Changes in fish status related to ANC

To illustrate the connection between changes in fish status and ANC, the lakes were grouped at ANC intervals of 10 μeq/l. Lakes within each interval were classed with regard to different status groups and different species. The percentage distribution of fish status within each ANC interval is indicated for each fish species (fig. 4.3-1A to 1H) and for all fish species combined (fig. 4.3-2).

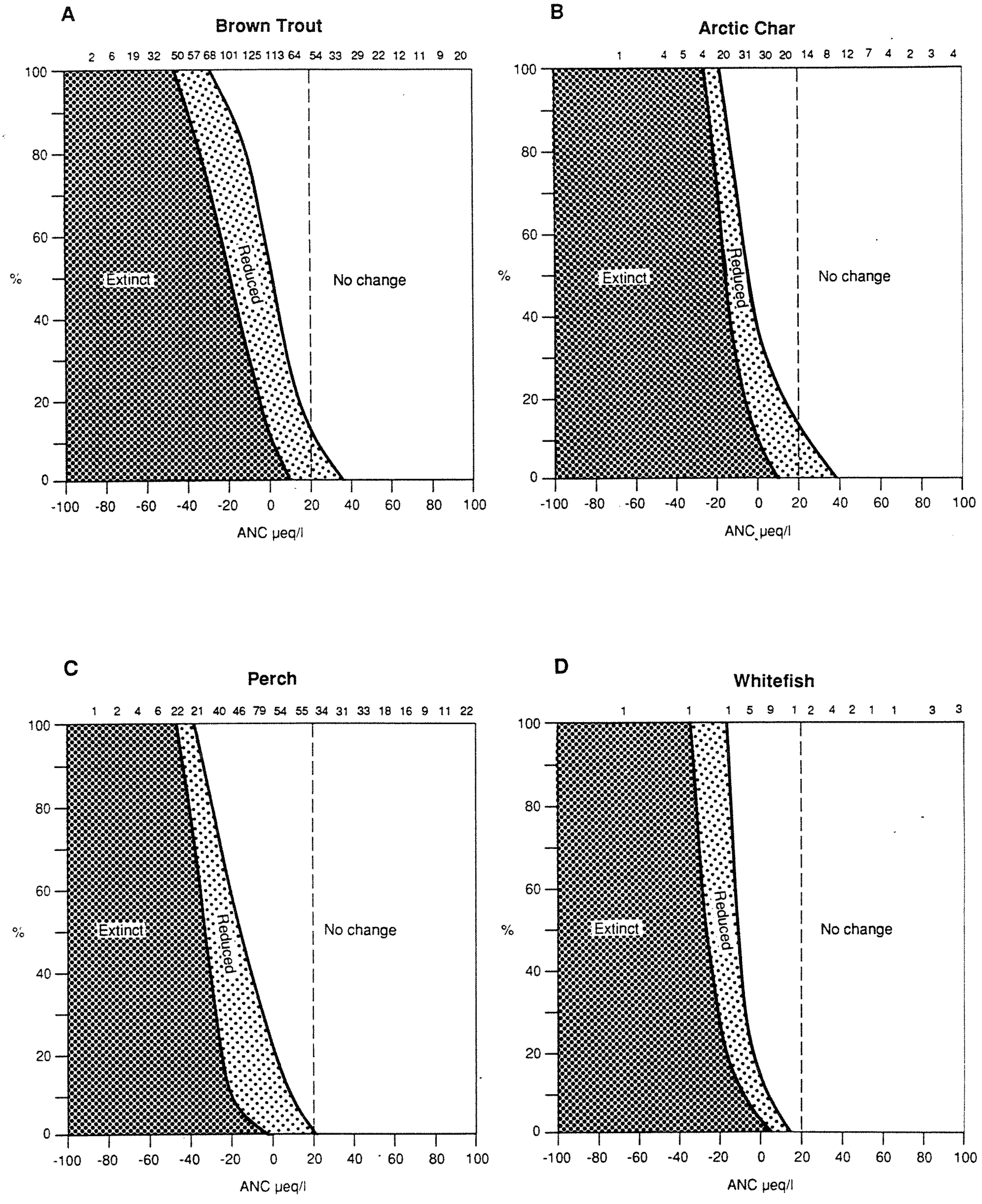


Fig. 4.3-1 Changes in fish status in relation to ANC concentrations for: A-brown trout (827 populations), B-Arctic char (169), C-perch (504), D-whitefish (34), E-pike (151), F-minnow (122), and G-roach (110).

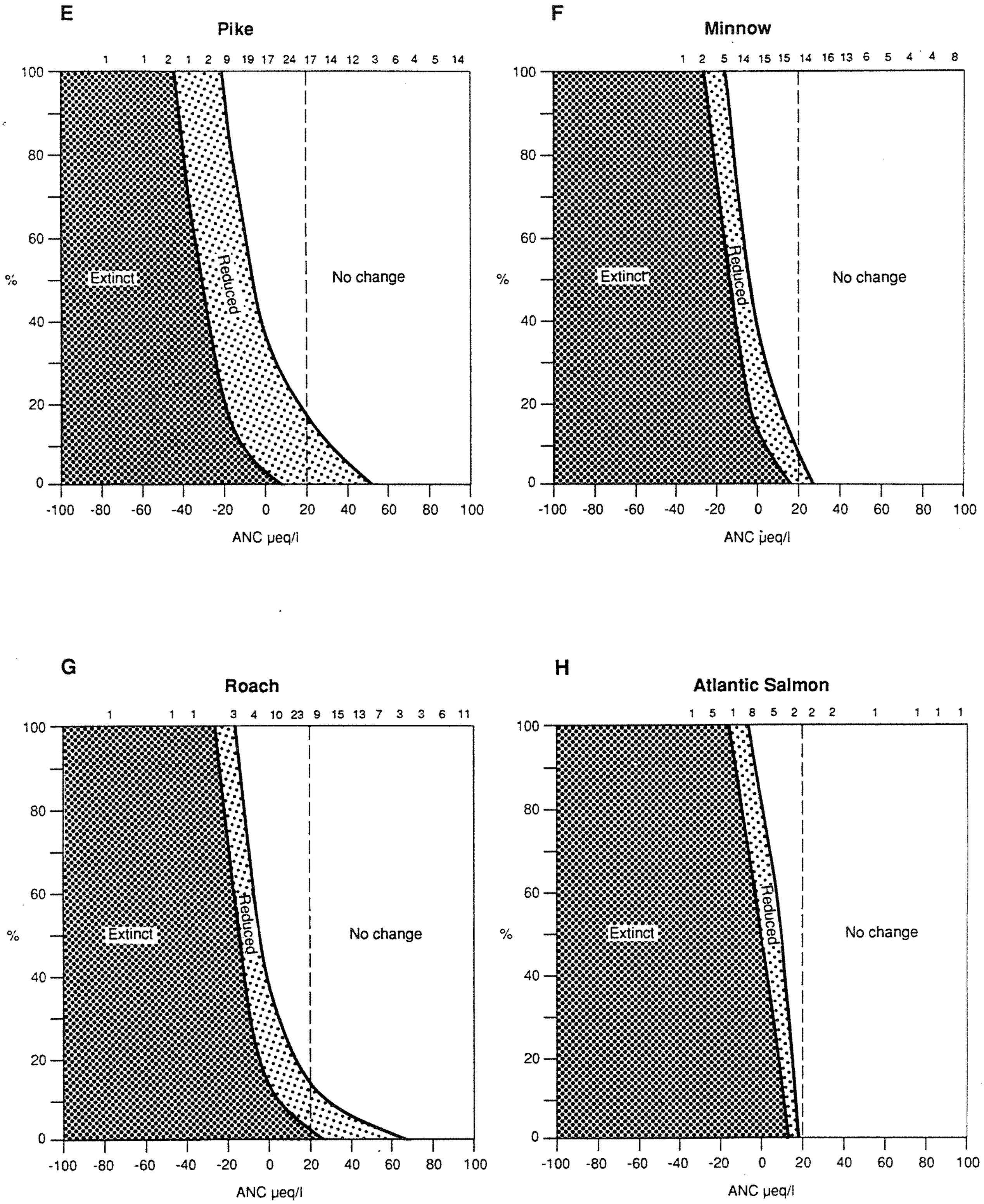


Fig. 4.3-1 H Changes in status of Atlantic salmon in relation to ANC in 30 rivers.

A total of 827 trout populations are recorded with regard to changes in fish status and ANC in lakes where they live (lived). 266 populations were extinct, 198 were damaged and 363 were reported to be undamaged. The distribution of trout status in relation to ANC (fig. 4.3-1A) shows that when ANC is lower than -40 µeq/l all trout populations are extinct. When ANC is higher than 30 µeq/1, there are no reports of damage to trout due to acidic water. At ANC=0, almost 10% of trout populations are extinct, 40% are reduced and approximately 50% are undamaged. At ANC=20 µeq/1, 90% are undamaged, 10% are reduced and no populations are recorded as extinct.

169 char populations are included in the survey. The material is considerably less than for trout but the changes in fish status in relation to ANC appear to lie in the same area as trout (fig. 4.3-1B).

Perch (fig. 4.3-1C) differ significantly from trout and char, and tolerate water qualities with a much lower ANC than these. Reduced populations of perch only occur after trout and char have become extinct when we descend the ANC scale (comparison of fig. 3.3-1A and B, with C). The curve for perch is based on comprehensive documentation from 504 lakes.

Whitefish (fig. 4.3-1D) appear to lie between trout and perch on the ANC scale. However, the documentation from only 34 localities is rather sparse, and the broken lines on fig. 4.3-1D could easily be displaced with an increase in numbers recorded.

The number of pike lakes, 151, seems to be reassuringly high, but the number of extinct and reduced localities is small. Consequently, there is a broken dividing line indicating uncertainty between extinct and reduced populations in figure 4.3-1E. A small number of pike populations are reported as reduced at relatively high ANC values of between 20 and 40 µeq/l. At the same time pike seem to tolerate as low ANC concentrations as perch before populations become extinct.

Roach and minnow are represented by 110 and 122 populations respectively. The number of extinct and reduced populations of roach are small, and a broken line divides these status groups in fig. 4.3-1G. A small number of roach populations are reported damaged at high ANC concentrations of up to 60 µeq/l. Otherwise the curves for roach and minnow are similar (fig. 4.3-1G and F) and lie in the same area as trout and char.

Changes in fish status for Atlantic salmon in relation to ANC in rivers are illustrated in figure 4.3-1H. Salmon appears to be the species which is most vulnerable to ANC concentrations of all the fish surveyed. Salmon are described in more detail in a later section.

Figure 4.3-2 presents changes in status for all the fish species surveyed from 1095 lakes with the exception of salmon. Altogether 1917 fish populations are included, consisting of 827 trout, 504 perch, 169 char, 151 pike, 122 minnow, 110 roach and 34 whitefish. Figure 4.3-2 is, therefore, strongly influenced by the status distribution of trout and perch. Trout and perch are among the species of fish most common in Norway. No count of all fish species in Norwegian lakes has been undertaken, but it may be assumed that the distribution of fish species in figure 4.3-2 may represent the areas of the country affected by acidification damage.

The figure shows that when ANC concentrations are lower than -40 μeq/l, very few fish populations survive. At ANC= +40 μeq/l all populations survive and very few are reduced. At ANC=0 approximately 10% of the populations are extinct and 40 % are damaged, while at ANC = +20 μeq/l no populations are extinct and only 10% are damaged.

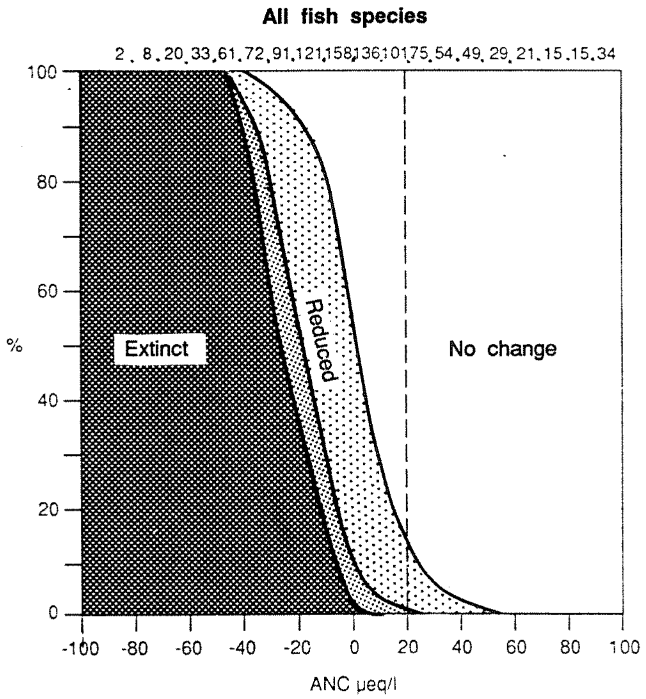


Fig. 4.3-2 Changes in fish status in relation to the ANC concentrations of lakes.

Unshaded	- unchanged populations.
Light shading	- one or more species reduced.
Medium shading	- one or more species extinct but still some fish.
Dark shading	- all fish extinct.

4.4 Critical limits for Atlantic salmon

Atlantic salmon is one of the species that are most sensitive to acidic water (Grande et al. 1978, Hindar & Lien 1988). Salmon is widespread in Norwegian river stretches near the coast and is a species of fish which attracts a great deal of attention. Therefore, salmon is an excellent biological indicator in acidic water.

Data about changes in fish status for salmon are derived from official statistics (Statistisk Sentralbyrå 1970, 1970-1988), from Hesthagen & Larsen (1987), and Sivertsen (1989). ANC values for salmon rivers are calculated as an annual mean mainly for 1987, and the chemical database is drawn from SFT (1988b) and Jonsson & Blakar (1988). For the individual rivers, salmon status and calculated ANC values are listed in Appendix 3.

Critical load maps (Henriksen et al. 1990a) were based on water samples collected after autumn turnover. The autumn sample was found to be a representative mean for lake water chemistry. ANC concentrations for salmon rivers are based on a minimum of one sample per month calculated as an annual mean. Therefore, ANC values in the two sample sets are comparable. However, the ANC values that form the basis of the critical load maps are mainly based on lakes located higher up the watercourses and not on lowland river stretches such as represented by the salmon rivers. Consequently, critical limits for salmon cannot be evaluated against national maps for chemical critical loads.

Figure 4.3-1H shows the distribution of different status groups for Atlantic salmon in relation to ANC concentrations in rivers. No population of salmon is effected when the mean ANC is above 20 µeq/l. In comparison with the status distribution for other fish species (fig. 4.3-1) the range in relation to ANC concentration is considerably less for salmon than for the other species. This is due to several factors; ANC calculations for salmon are represented by at least 12 measured values (annual mean) in contrast to ANC values for other species which are based on one single autumn sample. Fish status for salmon is assessed from official statistics and other published material and is, therefore, perhaps more reliable than fish status for other species based on the interview survey technique. The status distribution for salmon has been drawn on the basis of only 30 localities, while for most other species data are available from 100-800 localities. The range in ANC distribution might also have been greater for Atlantic salmon, if there had been more available data from salmon rivers in Norway where fish were damaged or extinct.

4.5 Uncertainties and variations in the relationship between fish status and ANC.

Critical ANC limits for each fish species are assumed to be considerably more restricted than the limits that emerge from our data for several reasons:

1 Water samples taken after the lake overturn in the autumn represent a fair annual mean of water chemistry for the locality, but do not show the low extreme values that have the greatest negative impact on fish populations.

In areas with low acidic precipitation fish populations will be little affected, even in water with a low acid neutralization capacity (0 -20 μeq/l). In similar bodies of water receiving high amounts of acidic precipitation, there may be extensive damage to fish.

Despite this, we have decided to retain the autumn sample as representative for a water locality because (a) it provides a good annual mean , (b) water chemistry mapping of the whole country is based on autumn samples, (c) it is anticipated that vulnerable areas that do not receive large amounts of acidic precipitation at present will show similar negative biological reactions to an increase in acid loads.

2. Interview surveys normally correlate well with trial fishing of a lake, but the uncertainties are greater than for trial fishing. This applies both as regards indications of time and the interviewees difficulties in confirming whether a fish population has become completely extinct (stage 3) or whether part of the population still survives somewhere in the lake.

3. Fish populations may have been affected by other impacts on a locality in addition to acidic precipitation. This applies to water regulation, water transference, liming, restocking, local sources of pollution etc. When known, such localities have been excluded from the data set, but some may remain, thus increasing the range of variance of the material.

4. Different populations of one and the same species may have varying tolerance for acidic water. An ongoing survey suggests that this may apply to brown trout (Rosseland et al. 1990). Such conditions will also increase the range of variance of ANC critical limits in the material.

The estimated ANC concentration for each lake, based on one autumn water sample, were expected to be close to annual mean value. Depending on climate and acid precipitating the

ANC value might fluctuate considerably through the year, e.g. during spring flood. Lakes with low autumn ANC concentrations between 0 and 20 µeq/l and great fluctuations through the year are vulnerable to change of fish status, e.g. from unaffected to reduced populations.

Other localities, e.g. with low acid input, are expected more stable. Many lakes were reported with no harmful effect on the fish populations although the ANC concentration of the lake water was below 20 µeq/l (figs. 4.3-1 and 4.3-2). Among these lakes we have identified localities with low ionic content and low acid deposition. With ANC concentration between 0 and 20 µeq/l and small fluctuations of acid input through the year, most fish populations are expected to survive. Even localities carried below 0 µeq/l by acid precipitation are shown to satisfy some fish species, e.g. perch (fig 4.3-1C), probably for some generations The results of this study does not predict the vitality or lifetime of a "reduced" fish population. It has been shown that many "reduced" trout populations became extinct within the short period of ten years during persistent level of acid deposition (Henriksen et al. 1989).

4.6 Variations in critical limits among different fish species

Figure 4.6-1 shows the frequency distribution of ANC values among unchanged and damaged populations of the fish species that are most fully represented in the material, as well as Atlantic salmon. Perch is the species that tolerates the lowest ANC concentration, but salmon appears to be the most sensitive.

Figure 4.6-1 also shows the frequency distribution of ANC values between reduced and extinct populations of the same species of fish. Again perch tolerate the lowest ANC concentration, while pike appear to tolerate almost as low values. Salmon are the most sensitive, followed by minnow, roach and char, while in many cases trout tolerate more than these before they die out.

An interview survey of fish will probably result in a different degree of accuracy for the different species. Edible game fish such as salmon and trout, as well as char, whitefish, perch and pike, are more popular. Therefore the information given about these fish species in an interview survey will be more accurate than, for example, about roach and minnow. This applies especially to minor changes in populations. For instance, a reduction of some cyprinid species on account of acidic water will not be so readily observed. Therefore, we may expect that the dividing line between unchanged and damaged fish may move towards the right both in the case of roach and minnow.

Table 4.6-1 presents all eight species surveyed. ANC concentrations where 25% and 50% respectively of the different populations are damaged are listed together with corresponding percentages for extinct populations. ANC values are read off from Figures 4.3-.1A-H and rounded off to the nearest five percent.

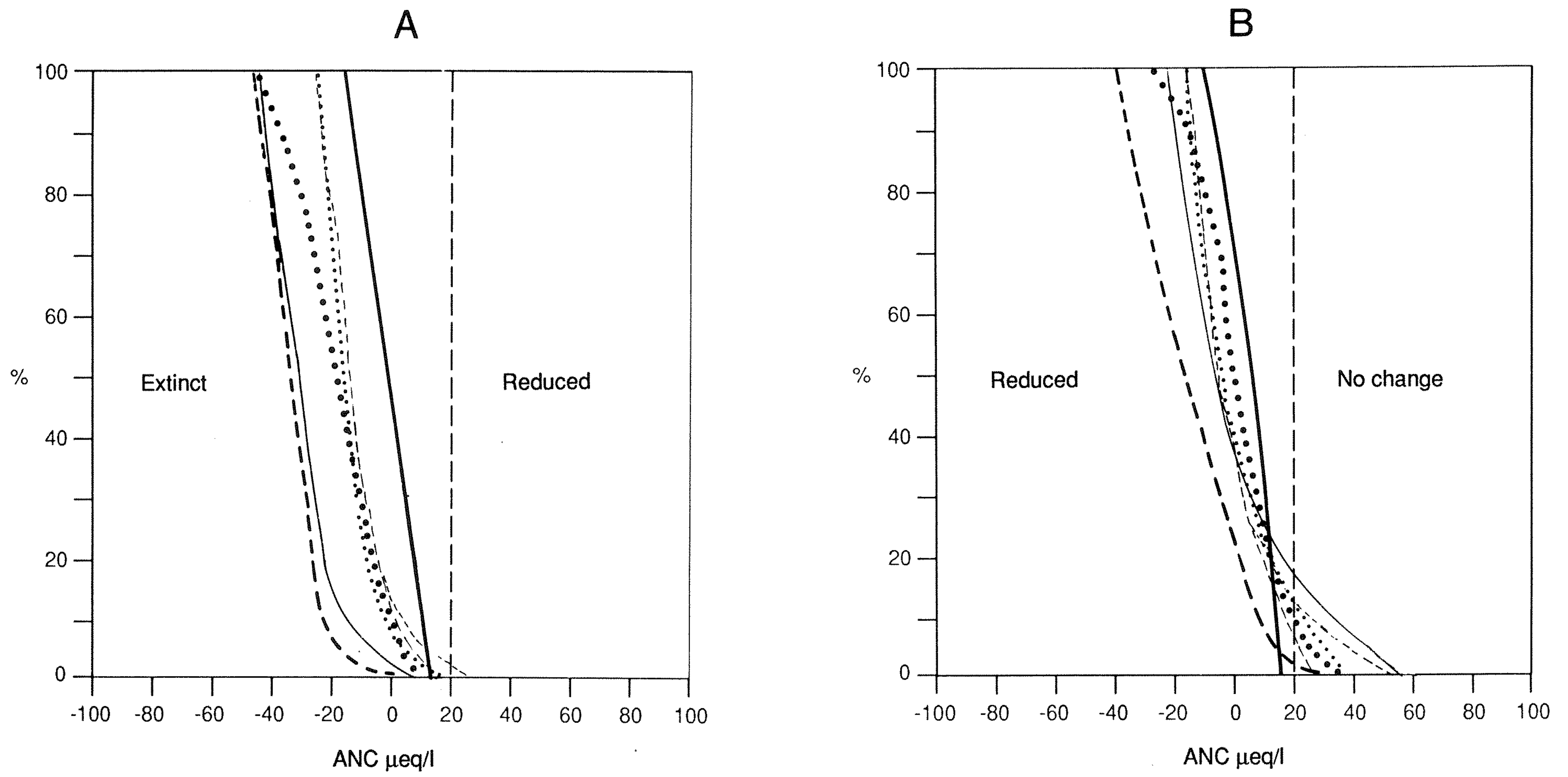


Fig. 4.6-1 Changes in fish status for different fish species in relation to ANC concentrations among A: extinct and reduced populations, and B: reduced and unchanged populations.

Table 4.6-1 ANC concentration (μeq/l) for different fish species where 25% and 50% respectively of the populations are reduced or extinct. (The figures in brackets are uncertain values.)

	% reduced		**% extinct**		**n**
	25%	**50%**	**25%**	**50%**	
Atlantic salmon	+10	+5	+5	0	30
Brown trout	+10	0	-10	-20	827
Arctic char	+10	-5	-10	-15	169
Pike	+10	-5	(-15)	(-30)	151
Minnow	+5	-5	-5	-15	122
Roach	+5	-5	-5	(-15)	110
Whitefish	(-5)	(-10)	(-15)	(-20)	34
Perch	-5	-15	-30	-35	504

Table 4.6-1 shows differences in ANC critical limits among the various fish species, and the table also provides a ranking of the species. When 25% and/or 50% of populations show signs of reductions, salmon is the least tolerant species, followed by trout, char and pike, minnow and roach, whitefish and perch. When 25% and/or 50% of the populations are extinct, the ranking of some of the species changes, but salmon is still most vulnerable while perch has the highest tolerance.

When determining critical ANC limits for fish it will be more important to assess when the damage occurred than when the populations die out. When ranking the species in Table 4.6-1 most consideration has been given to ANC concentrations when populations are reduced. ANC values for extinct populations are used for ranking purposes when ANC values for reduced populations were the same.

Critical limits for different fish species could have been calculated on the basis of laboratory studies alone. However, this would have lead to uncertainty, especially when transferring stable and controlled laboratory results to the very changeable and unstable conditions for fish populations in acidified lakes. It would also have been necessary (but very timeconsuming) to carry out part of the life history stage for all species of interest.

Critical ANC limits for the different species of fish presented in this survey might perhaps have been more accurately demarcated by supplementary laboratory studies. For instance, comparative tests of embryo development and fry survival would probably have resulted in a better distinction of the different species.

5. INDICATOR SPECIES, FISH AND INVERTEBRATES

The qualities necessary for a good indicator species are as follows:

1. Sensitive to the environmental factors we wish to measure.
2. Common over the entire survey area.
3. Good knowledge about the species generally.

5.1 Fish

Atlantic salmon was the most sensitive fish species to low ANC concentrations in this survey followed by trout, char, roach, minnow and pike. Trout, roach and char were perhaps the most sensitive of these, even if the differences varied somewhat according to the criteria used (fig. 4.61. Table 4.61). Furthermore, other studies have shown that rainbow trout (*Salmo gairdnerii*) may be more sensitive to acidic water than both trout and salmon (Grande et al. 1978, Hindar and Lien 1987).

Six of the eight species surveyed have limited distribution in Norway. This applies to roach in particular (in addition to rainbow trout), but also to pike, perch, whitefish and minnow, and to some extent salmon. Pike, perch, whitefish and minnow are not found in the most acidified areas of southern and western Norway and consequently, like roach and rainbow trout, they are not suited as indicator species for acidic water for the whole country. Both trout and char are found all over Norway, but in sensitive areas exposed to acidification trout are, or were, found in far more localities than char. Trout are also more common in running waters where char seldom occurs. Moreover, trout are to be preferred to char because our current knowledge of this species is much greater.

We are left with two possible indicator species, brown trout and Atlantic salmon. Trout are much more widespread than salmon, but salmon are more sensitive to acidic water. The reason salmon is not proposed as the (only) indicator fish for the entire country is its limited distribution. Only a small number of our freshwater inland localities contain salmon. Salmon are found all along the Norwegian coast, but they are only found in watercourses as far up as they are able to migrate due to the waterfalls. In effect, this means the lower parts of watercourses where water quality is usually best for fish as regards acidic water. Despite this, salmon have died out in many rivers in southern Norway.

Brown trout are proposed as the indicator fish for acidic water throughout Norway. In addition, Atlantic salmon are proposed as the indicator fish for those parts of the watercourses where salmon are expected to be found.

Surveys indicate that different strains of brown trout show varying tolerance to acidic water (Rosseland et al. 1990). However it is too early to determine whether restocking of the most tolerant varieties will alter Figure 4.3-1A to any extent. A number of the examined strains come from populations of wild trout included in this survey. It is reasonable to assume that different populations of Atlantic salmon also have different critical loads for acidic water.

5.2 Invertebrates

Different species of sensitive invertebrates have various responses to different water quality. In clearwater localities where the calcium content is <0.7 mg/1, many sensitive invertebrates are absent. However, a few species of snails and sensitive mayflies occur in such calcium deficient localities. The most common species with an acidification score of 1 is the mayfly *Baetis rhodani.* This species is usually the last one to disappear before acidification level 0.5 is reached. In other words, this species is the most tolerant of the sensitive species. This means that the curves dividing scores 1 and 0.5 also apply as the tolerance level for *B. rhodani.* If calcium and humic content increase, several sensitive species can survive close to the lower value. Of these the snail, *Lymnea peregra* is most abundant in our material. Most mussels and other types of snails as well as the crayfish *Gammarus lacustris* and *Lepidurus arcticus* require pH >6.0 and calcium >1 mg/1 (Økland and Økland 1986). Therefore, ANC curves for these species will lie further to the right than the curves shown in Figures 3.3-1 and 3.3-2. Consequently, in areas where these frequently occur it is possible to define the level "slightly damage" (acidification score 1) further by analyzing the most sensitive species more closely.

At acidification level 0.5 several species may determine the score. Usually the stoneflies *Diura nanseni* and *Isoperla grammatica* are the determining species in addition to species of the caddisflies *Hydropsyche spp.* and *Apatania spp.* Our data indicate that the curve separating levels 0.25 and 0.5 also applies to these species. The calcium content does not appear to affect the stoneflies. On the other hand, some of the caddisflies may be affected.

Many invertebrates have a life cycle of one year. Monitoring of invertebrates has provided several examples where critical loads for individual species have been exceeded during the spring melt, while the water quality in the autumn has improved and permitted the recolonization of sensitive species (SFT 1988b. 1989a, 1991).

6. PROPOSED CRITICAL ANC LIMITS FOR FISH AND INVERTEBRATES

The definition of critical loads, page 5 (Nilsson & Grennfelt 1988), can be used for surface water and fish and invertebrates where both sulphur and nitrogen compounds contribute inputs of acidic compounds to rivers and lakes.

Criteria have been established for the calculation of chemical critical loads for depositions of strong acids to surface waters in Norway (Henriksen et al. 1990a). Calculations have been carried out and a map showing chemical critical loads for Norway has been prepared. Critical loads was initially calculated on the basis of ANC concentrations of zero. It was assumed that surface waters ecosystems (rivers, lakes) could tolerate concentrations down to zero without harmful effects.

In Sweden the aim of liming acidified Swedish localities is to attain ANC concentrations in rivers and lakes of over 50 µeq/l.

By comparing the two ANC concentrations 0 and 50 µeq/l with empirical data of critical limits for freshwater fish and invertebrates in southern Norway (fig. 4.3-2 and fig. 3.3-1) it is clear that ANC = 0 involves significant damage. Figure 3.3-1 and Figure 4.3-1 show that invertebrates and all species of fish surveyed are damaged. At ANC = 50 there is no recorded damage to invertebrates and only slight or no decline in fish populations.

Figure 4.3-2, shows changes in the general fish status in relation to ANC. There is a limit of ANC = 20 µeq/l where no fish species are reported to be extinct because of acidification. 10% of fish populations are, however, reduced at this ANC concentration. Moreover, ANC = 20 µeq/l is also a concentration where no severe damage to invertebrate fauna has been recorded (figs. 3.3-1 and 3.3-2). Therefore, an ANC value of 20 µeq/l is also acceptable for invertebrates.

An ANC concentration of 20 µeq/l are proposed as an acceptable critical ANC limit for freshwater fish and invertebrates in Norway. Calculating and mapping critical loads to surface waters in the Nordic countries, an ANC critical limit of 20 µeq/l was selected based on the same data as this report (Henriksen et al. 1990b.).

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APPENDIX 1 The acidification score for various species of invertsbrates (Modified after Raddum and Fjellheim 1990). Rare species are designated by an asterisk.

Species/group	Acidification score
Turbellaria:	
Crenobia alpina (Dana)	0.5
Otomsostoma auditivum (Pless.)	0.5
Bivalvia:	
* *Margaritana margaritifera* L.	1
Sphaerium spp.	0.5
Pisidium spp.	0.25
Gastropoda:	
Lymnaea peregra (Muller)	1
Planorbis spp.	1
* *Gyraulus* spp.	1
Hirudinea:	
Helobdella stagnalis (L.)	0.5
* *Theromyzon tessulatum* (O.F. Muller)	1
* *Glossiphonia complanata* (L.)	1
* *Haemopis sanguisuga* (L.)	1
Crustacea:	
* *Lepidurus arcticus* Kroyer	1
* *Gammarus lacustris* Sars	1
* *Asellus aquaticus* (L.)	0.5
Daphnia magna Straus	0.5
Daphnia longispina O.F. Muller	0.5
Bosmina spp.	0
Holopedium gibberum Zaddach	0
Bytothrepes longimanus Leydig	0
Polyphemus pediculus (L.)	0
Diaphanosoma spp.	0
Cyclops spp.	0.5
Rotatoria:	
Keratella spp.	0
Keratella cochlearis (Gosse)	0
Keratella hiemalis (Carlin)	0
Kellicottia longispina (Kellicott)	0
Conochilus spp.	0
Polyarthra spp.	0
Asplanchna spp.	0
Ephemeroptera:	
Ameletus inopinatus Eaton	0.5
Siphlonurus aestivalis (Eaton)	0.5
Siphlonurus lacustris Eaton	0.5
Siphlonurus linnaeanus (Eaton)	0.5
Baetis rhodani (Pictet)	1
Baetis fuscatus (L.)	1
Baetis lapponicus (Bengts.)	1
Baetis macani Kimmins	1
Baetis muticus (L.)	1
Baetis niger (L.)	1
Baetis scambus Eaton	1
Baetis subalpinus Bengts.	1
Baetis vernus Curtis	1
Centropilum luteolum (Muller)	1
Heptagenia sulphurea (Muller)	0.5
Heptagenia fuscogrisea (Retz.)	0
* *Heptagenia dalecarlia* Bengts.	1
Leptophlebia vespertina (L.)	0
Leptophlebia marginata (L.)	0
Ephemerella aurivilli (Bengts.)	1
* *Ephemerella mucronata* (Bengts.)	0
* *Ephemerella ignita* Bengts.	0
Caenis horaria (L.)	1
Plecoptera:	
* *Arcynopteryx compacta* (McL.)	0.5
Diura nanseni (Kempny)	0.5
Diura bicaudata (L.)	0.5
Isoperla grammatica (Poda)	0.5
Isoperla obscura (Zett.)	0.5
Dinocras cephalotes (Curt.)	0.5
Siphonoperla burmeisteri (Pict.)	0
Taeniopteryx nebulosa (L.)	0
Brachyptera risi (Mort.)	0
Amphinemura standfussi (Ris)	0
Amphinemura borealis (Mort.)	0
Amphinemura sulcicollis (Stph.)	0
Nemoura cinerea (Retz.)	0
Nemoura avicularis Mort.	0
Nemurella picteti Klap.	0
Protonemura meyeri (Pict.)	0
Capnia atra Mort.	0.5
Capnia pygmaea (Zett.)	0.5
Leuctra digitata Kempny	0
Leuctra fusca (L.)	0
Leuctra hippopus Kempny	0
Leuctra nigra (Oliv.)	0
Trichoptera:	
Rhyacophila nubila (Zett.)	0
Glossosoma intermedium Klap.	1
Ithytrichia lamellaris Eaton	0.5
Oxyethira spp.	0
Philopotamus montanus (Donovan)	0.5
Tinodes waeneri (L.)	0.5
Cyrnus flavidus McL.	0
Cyrnus trimaculatus (Curtis)	0
Holocentropus dubius (Rambur)	0
Holocentropus picicornis (Steph.)	0
Neureclipsis bimaculata (L.)	0
Plectrocnemia conspersa (Curtis)	0
Polycentropus flavomaculatus (Pict.)	0
Polycentropus irroratus (Curtis)	0
Hydropsyche angustipennis (Curtis)	0.5
Hydropsyche pellucidula (Curtis)	0.5
Hydropsyche siltalai Dohler	0.5
Agrypnia obsoleta Hagen	0
Agrypnia varia (Fabr.)	0
Agrypnia pategana Curtis	0
Phryganea grandis L.	0
Micrasema gelidum McL.	0
Lepidostoma hirtum (Fabr.)	0.5
Apatania zonella (Zett.)	0.5
Apatania stigmatella (Zett.)	0.5
* *Annitella obscurata* (McL.)	0
Chaetopteryx villosa (Fabr.)	0
Limnephilus centralis Curtis	0
Limnephilus extricatus McL.	0
Limnephilus flavicornis (Fabr.)	0
Limnephilus lunatus Curtis	0
Limnephilus rhombicus (L.)	0
Limnephilus stigma Curtis	0
Limnephilus vittatus (Fabr.)	0
Nemotaulius punctatolineatus (Retz.)	0
Halesus radiatus (Curtis)	0
* *Micropterna lateralis* (Steph.)	0
Potamophylax cingulatus (Steph.)	0
Potamophylax latipennis (Curtis)	0
Stenophylax permistus McL.	0
Notidobia ciliaris (L.)	0
Sericostoma personatum (K & Sp.)	0.5
Molanna angustata Curtis	0
Molannodes tinctus (Zett.)	0
* *Adicella reducta* McL.	0
Athripsodes aterrimus (Steph.)	0
Athripsodes cinereus (Curtis)	0
Mystacides azurea (L.)	0

APPENDIX 2 **The occurrence of invertebrates at acidification score 1 at high (> 0.7 mg Ca/l) and low calcium, and acidification score 0.5 and 0 independent of calcium levels.**

Acidification score Species/Group	1 high calcium	1 low calcium	0.5 varying calcium	0 level
Margaritana margaritifera	x			
Pisidium spp	x	x	x	
Lymnaea peregra	x			
Gyraulus sp.	x			
Hellobdella stagnalis	x			
Glossiphonia complanata	x			
Baetis rhodani	x	x		
Baetis fuscatus	x			
Baetis niger	x			
Heptagenia fuscogrisea	x	x	x	x
Heptagenia sulphurea	x	x	x	
Leptophlebia sp.	x	x	x	x
Ephemerella aurivilli	x	x		
Caenis horaria	x			
Diura nanseni	x	x	x	
Taeniopteryx nebulosa	x	x	x	x
Brachyptera risi	x	x	x	x
Amphinemura sulcicollis	x	x	x	x
Amphinemura borealis	x	x	x	x
Nemoura cinerea	x	x	x	x
Protonemura meyeri	x	x	x	x
Leuctra nigra	x	x	x	x
Isoperla sp.	x	x	x	
Leuctra hippopus	x	x	x	x
Leuctra fusca	x	x	x	x
Rhyacophila nubila	x	x	x	x
Philopotamus montanus	x			
Neureclipsis bimaculata	x	x	x	x
Pletrocnemia conspersa	x	x	x	x
Polycentropus flavomaculatus	x	x	x	x
Polycentropus irroratus	x	x	x	x
Hydropsyche pellucidula	x		x	
Hydropsyche siltalai	x		x	
Lepidostoma hirtum	x			
Notidobia ciliaris	x	x	x	x
Limnephilus sp.	x	x	x	x
Oxyethira sp.	x	x	x	x
Athripsodes sp.	x	x	x	x
Hydroptila sp.	x			
Itytrichia lamellaris	x			
Apatania sp.	x	x	x	
Tinodes waeneri	x	x	x	
Glossosoma intermedium	x			

APPENDIX 3 Changes in fish status for salmon rivers as a result of acidification. ANC is given as annual mean for 1987. (Status 1 - unchanged, status 2 - reduced, status 3 - extinct.)

River	Fish status	ANC	River	Fish status	ANC
Gaula	1	5	Gjerstadelva	3	-1
Lærdalselva	1	35	Storelva	3	-5
Ørstaelva	1	53	Nidelva	3	-14
Øyensåa	1	32	Tovdalselva	3	-25
Numedalslågen	1	75	Sogndalselva	3	1
Etneelva	1	27	Mandalselva	3	-25
Driva	1	131	Lygna	3	-22
Stryneelva	1	25	Kvina	3	3
Eidselva	1	13	Sokndalselva	3	-36
Årdalselva	1	11	Hellelandselva	3	-22
Ekso	1	7	Dirdalselva	3	-8
Stjørdalselva	1	94	Frafjordelva	3	-29
			Modalselva	3	-6
Vikedalselva	2	-8			
Ogna	2	-6			
Nausta	2	5			
Rødneelva	2	-8			
Bjerkreimsåna	2	-6			

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