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Recovery of acid-sensitive species of Ephemeroptera, Plecoptera and Trichoptera in River Audna after liming

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River Audna has been continuously limed on a full scale basis since 1985. Monitoring of benthic invertebrates of the river showed that the fauna was dominated by acid-tolerant species before liming and during the first year after the start of the treatment. Moderately acid-sensitive species, like *Diura nanseni*, *Isoperla grammatica* and *Hydropsyche siltalai* were found only in small numbers in a few localities in this period. In autumn 1987, the fist appearance of the highly acid-sensitive mayfly *Baetis rhodani* was recorded at two stations in the main river. During the following years, this species colonized other localities and several other sensitive invertebrates, such as *Heptagenia sulphurea*, *Caenis horaria*, *Hydropsyche pellucidula* and *Lepidostoma hirtum* were also recorded. The change in faunal composition was highly significant compared to unlimed reference stations.

INTRODUCTION

Acidification of streams and lakes has been considered a serious problem in southern Norway for a long time. Atlantic salmon (*Salmo salar* L.) was first reported affected by acid water 80 years ago (Huitfeldt-Kaas, 1922; Sunde, 1926; Dahl, 1927; Jensen & Snekvik, 1972). During the last three decades, the detrimental effects of the acidification have been severe, reducing the brown trout (*Salmo trutta* L.) populations in southernmost Norway by 50% and wiping out all anadromous salmon populations in the same area (Leivestad *et al.*, 1976; Sevaldrud *et al.*, 1980).

Acidification also has marked effects upon benthic invertebrate communities (Sutcliffe & Carrick, 1973; Matthias, 1983; Øtto & Svensson, 1983; Økland & Økland, 1986; Meriläinen, 1988). Many species are highly sensitive, and faunal reduction due to acidic water usually commences before populations of Atlantic salmon and brown trout are affected (Raddum & Fjellheim, 1984). Freshwater surveys in southernmost Norway have verified that the invertebrate communities over large areas have been damaged (Hobæk & Raddum, 1980, Raddum *et al.*, 1986, 1988).

Since reversing acidification by reducing emissions of pollutants to the atmosphere is a difficult and slow process, liming is the only short-term way to save and restore damaged freshwater ecosystems. The effects of liming on water quality and biota were studied during the Norwegian Liming Project (1979—1985; cf. Baalsrud, 1985). This project provided a basis for later liming programmes, including those on salmon rivers.

Until 1990, the River Audna was the only Norwegian salmon river limed on a full scale basis. A benthic invertebrate survey before the liming of this river showed a highly damaged ecosystem, nearly totally devoid of acid-sensitive invertebrates. The primary goal of the liming programme was to restore the populations of Atlantic salmon and anadromous brown trout. However, as these are an important part of the ecosystem, benthic invertebrates have been monitored biannually. The purpose of this paper is to give data on the changes in the benthic community following liming.

STUDY AREA

The River Audna (Fig. 1) is situated in the southernmost part of Norway and runs into the sea about 50 km west of Kristiansand. The river has a catchment area of 466 km^2 and was formerly an excellent river for salmon sport fishing. Since around 1920, a steady decline in catches was observed and the salmon stock virtually disappeared around 1970 (Blakar *et al.*, 1989). Parallel to the decline of the salmon, the population of

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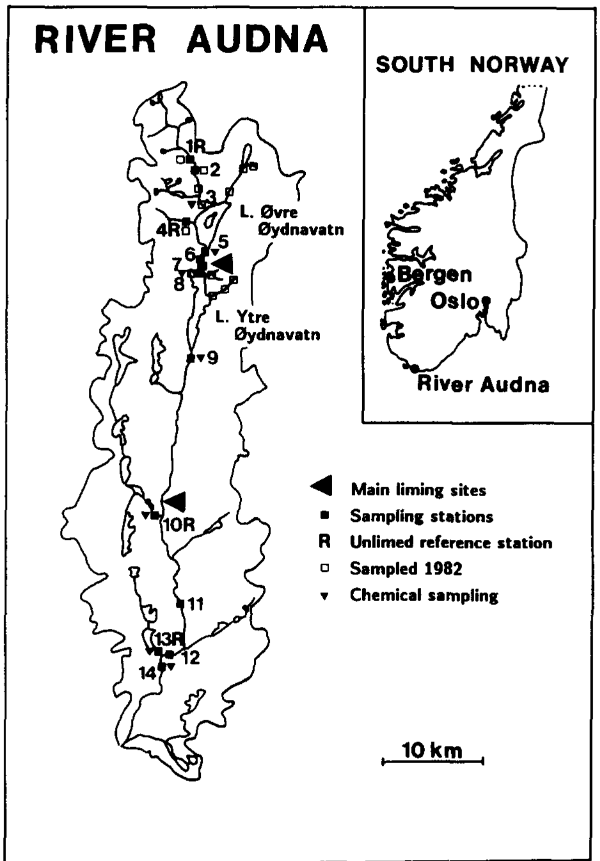

Fig. 1. Map of the River Audna showing the main liming sites and the sampling stations.

anadromous brown trout was greatly reduced. The River Audna also hosts non-migratory brown trout, eel (*Anguilla anguilla* L.), char (*Salvelinus alpinus* L.) and perch (*Perca fluviatilis* L.). The two latter species are now endangered in the watershed. Anadromous salmon and trout can migrate 50 km from the sea, and large stretches of the river would provide excellent spawning and nursery areas, if the water quality was acceptable.

Before liming, the main river was characterized by a slight decline in pH towards the sea, mainly due to acidic tributaries from the western part of the watershed (pH $\simeq$ 4·7). Generally, the pH was reduced to 5·0 near the outlet to the sea (Hindar *et al.*, (1987).

There are cultivated fields on both sides of the main river. Small streams and ditches in these areas can have higher pH values and act as refuges for fish and invertebrates.

During 1978–1984, experimental tests with different sources of lime and dosage equipment were conducted in some of the tributaries of the River Audna. The liming of the main river took place in October 1985. Lake Ytre Øydnavatn (Fig. 1) was treated with 890 tonnes of powdered limestone. In addition, two automatic dosage pumps were installed in the main river. A total of 3000–4000 tonnes year^{-1} of limestone powder has been used, equivalent to a treatment of 8–11 tonnes day^{-1} (Blakar *et al.*, 1989). The liming resulted in a considerable improvement in water quality. Table 1 presents chemical data from some selected sites in the river system. After liming yearly, average pH in the main river downstream of the dosage pumps has varied between 7·15 and 6·08. Calcium concentrations

Table 1. Chemical characteristics of River Audna given as mean yearly values. Data from Hindar (unpubl.) and Norwegian Institute for Nature Research (unpubl.) Sampling stations are indicated in Fig. 1

Station	Year	Number of samples	pH	Ca^{++} mg litre^{-1}	Al_0 µg litre^{-1}	Al_i µg litre^{-1}
3	1985	6	4·97	1·11	148	102
	1986	3	5·04	0·98	135	110
	1987	5	5·13	1·28	104	96
	1988	10	5·02	0·97	115	108
	1989	6	4·97	1·35	88	125
	1990	3	4·69	0·86	—	—
5	1985	6	5·14	1·31	158	105
	1986	64	5·32	1·21	147	76
	1987	36	5·21	1·17	99	108
	1988	40	5·36	1·46	126	85
	1989	41	5·09	1·36	67	120
	1990	13	4·89	1·15	—	—
8	1985	1	7·48	4·35	260	70
	1986	64	7·15	3·74	218	62
	1987	36	7·09	3·74	165	40
	1988	35	6·77	3·54	153	42
	1989	37	6·99	3·98	126	32
	1990	14	6·23	2·78	—	—
9	1985*	4	5·14	1·28	120	85
	1985	2	6·56	3·10	213	40
	1986	66	6·54	3·08	194	30
	1987	35	6·58	3·01	155	19
	1988	33	6·38	2·77	146	34
	1989	37	6·49	3·04	127	20
	1990	16	6·15	2·54	—	—
10	1985	6	4·66	0·83	110	153
	1986	6	4·66	0·76	107	142
	1987	6	4·81	0·85	92	154
	1988	9	4·88	0·94	88	127
	1989	7	4·66	1·12	53	171
	1990	3	4·60	0·89	—	—
13	1985	6	4·76	1·19	107	180
	1986	6	4·77	1·11	109	175
	1987	6	4·81	1·11	110	153
	1988	9	4·99	1·26	88	152
	1989	7	4·72	1·69	44	216
	1990	3	4·79	1·40	—	—
14	1985*	4	5·03	1·57	170	85
	1985	3	6·34	2·77	138	13
	1986	29	6·26	2·70	201	43
	1987	36	6·44	2·96	165	40
	1988	35	6·35	2·89	142	45
	1989	40	6·37	3·18	119	20
	1990	14	6·08	2·55	—	—

Al_0 = non-labile aluminium; Al_i = labile aluminium.
* Before liming.

increased three to four times, while labile aluminium was generally reduced to values <50 μg litre^{-1}. The untreated references stations remained chronically acid.

METHODS

Benthic samples were collected in spring and autumn from a selected number of stations, starting in 1985 before liming. Four of these localities, stations 1, 4, 10 and 13, were untreated and therefore chosen as reference sites. Since a lime slurry dosage pump was placed between stations 1 and 2 during the fist part of the liming project, and additionally, some other tributaries to Lake Øvre Øydnavatn were limed, stations 2, 5 and 6 were not included among the reference stations. Sampling was carried out according to the method of Frost *et al.* (1971), using a collecting net of 250 μm. The samples were preserved in ethanol and later sorted and identified in the laboratory. Results from surveys in 1982 (localities marked on Fig. 1) and 1983 (stations 1, 2 and 3), before liming the main river, are presented. The acidification index was calculated according to Raddum *et al.* (1988) and Fjellheim & Raddum (1990).

RESULTS

A total of 7 species of Ephemeroptera, 16 species of Plecoptera and 25 taxa of Trichoptera were recorded during the sampling period (Table 2). According to Fjellheim & Raddum (1990), 11 of these are sensitive to acid water. Chi-square tests, comparing the total number of sensitive species to the total number of non-sensitive species in the samples from the reference stations and the limed localities, showed no significant differences during 1985 and 1986 (Fig. 2). In the last 4 years of the investigations, differences between limed and reference stations were highly significant (P < 0·001 each year).

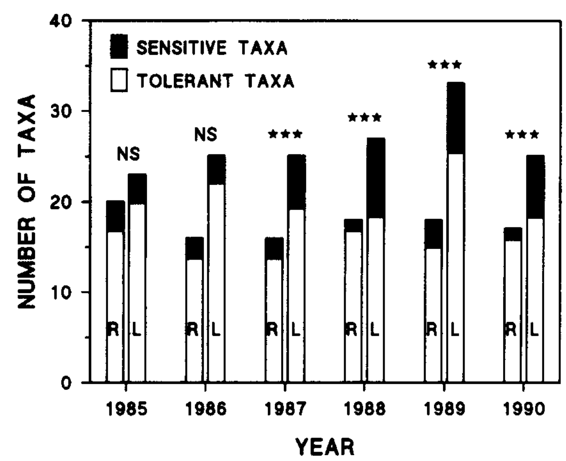

Fig. 2. Total number of taxa of Ephemeroptera, Plecoptera and Trichoptera recorded in the reference stations (R) and limed stations (L) during 1985–1990. NS = no significant difference. *** Significant difference (P < 0·001).

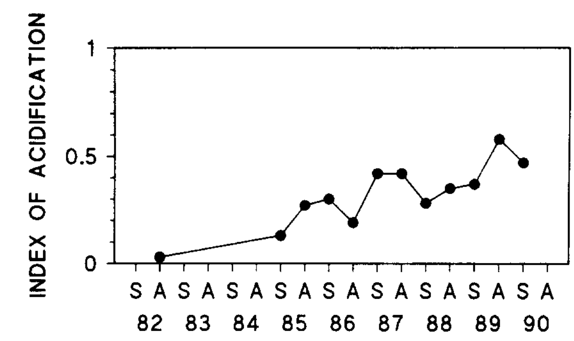

Fig. 3. Mean index of acidification for the River Audna 1982–1990. According to species composition, each locality is given a value ranging from 0 (highly acidified) to 1 (unacidified). For more details of the method see Raddum *et al.* (1988) and Fjellheim & Raddum (1990).

Before liming, only a few moderately sensitive species were recorded. The stoneflies *Isoperla grammatica* and *Diura nanseni* were most common among these, but they occurred in low densities. After liming, the total number of species increased.

The sensitive mayfly *Baetis rhodani* was first recorded at stations 11 and 12 in November 1987. Later, it increased in both distribution and density, and in the autumn of 1989 it was found at all limed localities. Several other acid-sensitive species colonized the same part of the river. Among these, the increases in numbers of the caddis flies *Hydropsyche pellucidula, H. siltalai* and *Lepidostoma hirtum* were most pronounced. A similar change in faunal composition was not observed in the reference stations.

The improved fauna is also demonstrated by increased index of acidification (Fig. 3).

DISCUSSION

Large areas of southern Norway are acidified. The biotic response to this pollution includes a reduction of fish populations (Muniz & Leivestad, 1980), a reduction in benthic invertebrate species diversity and biomass (Raddum, 1980; Raddum & Fjellheim, 1984; Økland & Økland, 1986) and in the diversity of zooplankton species (Raddum *et al.*, 1980). The only short-term, method to eliminate and reverse the acidification process is treatment with lime or other buffering agents. However, restoration of the fauna may be a slow process and liming is therefore usually accompanied by fish stocking.

The biotic response of benthic invertebrates is dependent upon both the faunal composition prior to liming and the immigration/extinction rates of species. Studies of the effects of lake liming have shown that

Table 2. Records of different taxa of Ephemeroptera, Plecoptera and Trichoptera in the reference localities (R) and limed localities (L) during 1982–1990

	1982		1983		1985		1986		1987		1988		1989		1990	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Ephemeroptera																
Leptophlebia marginata (L.)	X	X		X	X	X		X	X	X		X		X		
L. verspertina (L.)	X		X		X	X	X	X		X	X	X	X	X	X	X
Heptagenia fuscogrisea (Retz.)				X	X	X		X								X
**H. sulphurea* (Muller)												X		X		
***Baetis rhodani* (Pictet)										X		X	X	X		X
**Siphlonurus lacustris* Eaton												X				X
***Caenis horaria* (L.)																X
Plecoptera																
Amphinemura borealis (Mort.)	X	X		X			X	X	X	X	X	X	X	X	X	X
A. sulcicollis (Stph.)	X		X	X	X	X	X	X	X	X	X		X	X	X	X
A. standfussi (Ris.)							X	X								
Nemoura cinerea (Retz.)	X	X		X	X	X		X	X	X	X	X		X	X	X
N. avicularis Mort.	X											X				
Nemurella picteti Klap.	X	X												X		
Protonemura meyeri (Pict.)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Brachyptera risi (Mort.)	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Taeniopteryx nebulosa (L.)	X	X	X	X	X	X	X	X	X	X	X	X		X		
Leuctra hippopus Kemp.	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
L. fusca (L.)	X	X			X	X	X	X		X		X	X	X	X	X
L. nigra (Oliv.)			X			X			X	X						
Siphonoperla burmeisteri (Pict.)	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
**Isoperla grammatica* (Poda)	X				X	X	X	X	X	X	X	X	X	X	X	X
**I. obscura* (Zett.)												X				
**Diura nanseni* (Kemp.)			X		X	X	X		X	X		X	X	X		
Trichoptera																
Rhyacophila nubila (Zett.)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
**Hydropsyche pellucidula* (Curtis)								X		X		X		X		X
**H. siltalai* Dohler						X				X		X		X		X
Oxyethira sp.	X			X	X	X		X		X	X	X	X	X	X	X
Polycentropus irroratus (Curtis)														X		
P. flavomaculatus (Pict.)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Plectrocnemia conspersa (Curtis)	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Neureclipsis bimaculata (L.)	X				X	X		X	X	X	X	X	X	X	X	X
Cyrnus flavidus McL	X															
C. trimaculatus (Curtis)													X	X		X
Holocentropus dubius (Rambur)																X
Agrypnia obsoleta Hagen												X				
**Lepidostoma hirtum* (Fabr.)								X		X		X		X		X
**Apatania* sp.					X									X		
Limnephilus rhombicus (L.)										X						
L. extricatus McL.						X										
Potamophylax latipennis (Curtis)							X	X					X	X	X	
Halesus sp.	X				X		X	X			X			X	X	
Stenophylax permistus McL.		X														
Molannodes tinctus (Zett.)						X		X								
Arthipsodes sp.													X	X		X
Ceraclea annulicornis (Steph.)														X		
Mystacides azurea (L.)						X		X		X	X	X		X		
Oecetis testacea (Curtis)														X		X
Triaenodes bicolor (Curtis)											X			X	X	X

* Moderately sensitive.
** Highly sensitive
(From Fjellheim & Raddum, 1990).

immigration rates of benthic invertebrates are slow, and that the most rapid response occurs through quantitative changes within the existing community (Eriksson *et al.*, 1983; Raddum *et al.*, 1986; Fjellheim & Raddum, 1988).

The immigration rate is dependent on both the distance from the nearest population and the mobility of the species. Small populations of acid-sensitive species may have been present in refuges of better water quality within the catchment. The importance of such refuges has been demonstrated previously in the partially limed River Vikedal, western Norway (Raddum & Fjellheim, 1984) and after liming Lake Søndre Boksjø on the southernmost part of the border between Norway and Sweden (Raddum *et al.*, 1984). Drift is an important mechanism of colonization in running water, and is perhaps the main reason for the more rapid response to the liming of the River Audna compared to limed lakes in the same area.

Generally the most marked succession of species occurred in the main river downstream from the lime dosage pumps. The water chemistry at stations 2, 5 and 6 was quite similar to that of the reference stations, and the benthic fauna of these sites did not change in the same way. The 1990 species list only includes the spring sample, and this explains the lower diversity recorded that year. Although species known to be acid-sensitive constituted the main part of the increase in species number, the number of other species also increased slightly. The tolerance of some of these species, like the trichopterans *Oecetis testacea* and *Ceraclea annulicornis*, are poorly known and should be examined more closely with respect to tolerance of acidic water.

Liming changes the food web and makes organic detritus more accessible to the invertebrates (Grahn *et al.*, 1974; Gahnström *et al.*,1980). However, reduced physiological stress seems to be the main reason for the recolonization of acid-sensitive species of benthic animals (Raddum & Fjellheim, 1987). Although it has been demonstrated that the sensitive mayfly *B. rhodani* may tolerate moderate acidification in calcium-rich water (Sutcliffe *et al.*, 1987) and in humic water (Otto & Svensson, 1983), this species is not found at pH levels below 5·5 in the soft water (specific conductivity <30 $\mu S\ cm^{-1}$) typical of South Norway (Raddum *et al.*, 1988). The increase in the range of *B. rhodani* in the main river downstream of Lake Ytre Øydnavatn is an important signal of improved water quality, since this species is affected before salmon and brown trout. However, both *B. rhodani* and other benthic invertebrates are known to tolerate high concentrations of aluminium better than salmonids (Allard & Moreau, 1986; Raddum & Fjellheim, 1987).

The recolonization of sensitive invertebrates in the River Audna demonstrates how the Invertebrate Monitoring Scheme of acidification proposed by Raddum *et al.*, (1988) functions during reversed acidification. It is, however, important to stress that liming is only a method of buffering acid water and securing the existence of sensitive fish and invertebrates. It does not bring back the natural unacidified habitat and is therefore only a tool in the short-term conservation of biota in threatened localities. The main goal is to reduce emissions of atmospheric pollutants to acceptable levels.

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REFERENCES

Allard, M. & Moreau, G. (1986). Influence of acidification and aluminium on the density and biomass of lotic benthic invertebrates. *Water Air Soil Pollut.*, **30**, 673–9.

Baalsrud, K. (1985). *Liming Acidified Water. Final Report of the Norwegian Liming Project* (in Norwegian). The Norwegian Ministry of Environment, Oslo, Norway, 145 pp.

Blakar, I. A., Digernes, I. & Haraldstad, Ø. (1989). Effects of liming on water quality and fish in River Audna (in Norwegian). Directorate for Nature Management, Tronheim, Norway, Note No. 4—1989, pp. 45–49.

Dahl, K. (1927). The effects of acid water on trout fry. *Salmon Trout Mag.*, **46**, 35–43.

Eriksson, F., Hörnström, E., Mossberg, P. & Nyberg, P. (1983). Ecological effects of lime treatment of acidified lakes and rivers in Sweden. *Hydrobiologia*, **101**, 145–64.

Fjellheim, A. & Raddum, G. G. (1988). Birch leaf processing and associated macroinvertebrates in an acidified lake subjected to liming. *Hydrobiologia*, **157**, 89–94.

Fjellheim, A. & Raddum, G. G. (1990). Acid precipitation: biological monitoring of streams and lakes. *The Science of the Total Environment*, **96**, 57–66.

Frost, S., Huni, A. & Kershaw, W. E. (1971). Evaluation of a kicking technique for sampling stream bottom fauna. *Can. J. Zool.*, **49**, 167–73.

Gahnström, G., Anderson, G. & Fleischer, S. (1980). Decomposition and exchange processes in acidified lake sediment. In *Proceedings of the International Conference on the Impact of Acid Precipitation.*, ed. D. Drabløs & A. Tollan, pp. 306–7, SNSF Project, Oslo, Ås.

Grahn, O., Hultberg, H. & Landner, L. (1974). Oligotrophication—a self-accelerating process subjected to excessive supply of acid substances. *Ambio*, **3**, 93–4.

Hindar, A., Haraldstad, Ø., Kleiven, E. & Raddum, G. G. (1987). Audna, West Agder. In *The Liming Activity in Norway 1984–1986*, ed. A. Hindar, pp. 13–34 (in Norwegian). Directorate for Nature Management, Arendal, Norway.

Hobæk, A. & Raddum, G. G. (1980). *Zooplankton Communities in Acidified Regions of South Norway.* SNSF project, IR 75/180, Oslo, Ås, 132 pp.

Huitfeldt-Kaas, H. (1922). On the cause of mass kill of salmon and brown trout in Frafjordelven, Helleelven and Dirdalselven, Ryfylke autumn 1920 (in Norwegian). *Nor. Jæger Fiskerfor. Tidsskr.*, **1**, 37–44.

Jensen, K. W. & Snekvik, E. (1972). Low pH levels wipe out salmon and trout populations in southernmost Norway. *Ambio*, **1**, 223–5.

Leivestad, H., Hendrey, G., Muniz, I. P. & Snekvik, E. (1976). Effects of acid precipitation on freshwater organisms. In *Impact of Acid Precipitation on Forest and Freshwater Ecosystems in Norway*, ed. F. H. Brække, pp. 87–111. SNSF Project, FR 6/76, Oslo, Ås.

Matthias, U. (1983). Der Einfluss der Versauerung auf die Zusammensetzung von Bergbachbiozönosen. *Arch. Hydrobiol. Suppl.*, **65**, 407—83.

Meriläinen, J. J. (1988). Meiobenthos in relation to macrobenthic communities in a low saline, partly acidified estuary, Bothnian Bay, Finland. *Ann. Zool. Fennici*, **25**, 277–92.

Muniz, I. P. & Leivestad, H. (1980). Acidification—effects on freshwater fish. In *Proceedings of the International Conference on the Impact of Acid Precipitation*, ed. D. Drabløs & A. Tollan, pp. 84–92. SNSF Project, Oslo, Ås.

Økland, J. & Økland, K. A. (1986). The effects of acid deposition on benthic animals in lakes and streams. *Experientia*, **42**, 471–86.

Otto, C. & Svensson, B. S. (1983). Properties of acid brown water streams in South Sweden. *Arch Hydrobiol.*, **99**, 15–36.

Raddum, G. G. (1980). Comparisons of benthic invertebrates in lakes with different acidity. In *Proceedings of the International Conference on the Impact of Acid Precipitation*, ed. D. Droblös & A. Tollan, pp. 330–31. SNSF Project, OSLO, Ås.

Raddum, G. G. Fjellheim, A. (1984). Acidification and early warning organisms in freshwater in western Norway. *Verh. Int. Verein. Limnol.*, **22**, 1973–1980.

Raddum, G. G. & Fjellheim, A. (1987). Effects of pH and aluminium on mortality, drift and moulting of the mayfly *Baetis rhodani*. *Ann. Soc. R. Zool. Belg.*, **177**, 77–87.

Raddum, G. G., Hobæk, A., Lømsland, E. R. & Johnsen, T. (1980). Phytoplankton and zooplankton in acidified lakes in South Norway. In *Proceedings of the International Conference on the Impact of Acid Precipitation*, ed. D. Drabløs & A. Tollan, pp. 332–3, SNSF Project, Oslo, Ås.

Raddum, G. G., Hagenlund, G. & Halvorsen, G. A. (1984). *Effects of Lime Treatment on the Benthos of Lake Søndre Boksjø*. Institute of Freshwater Research, Drottningholm, Report No. 61, pp. 167–76.

Raddum, G. G., Brettum. P., Matzow, D., Nilssen, J. P., Skov, A., Sveälv, T. & Wright, R. F. (1986). Liming the acid Lake Hovvatn, Norway: a whole-ecosystem study. *Water Air Soil Pollut.*, **31**, 721–63.

Raddum, G. G., Fjellheim, A. & Hesthagen, T. (1988). Monitoring of acidification through the use of aquatic organisms. *Verh. Int. Verein. Limnol.*, **23**, 2291–7.

Sevaldrud, I. H., Muniz, I. P. & Kalvenes, S. (1980). Loss of fish populations in southern Norway. Dynamics and magnitude of the problem. In *Proc. Int. Conf. Impact Acid Precip.*, ed. D. Drabløs & A. Tollan, pp. 350–1., SNSF Project, Oslo, Ås.

Sunde, S. E. (1926). Acid water kills salmon and trout fry (in Norwegian). *Nor. Jæger Fiskerfor. Tidsskr.*, **2**, 1–4.

Sutcliffe, D. W. & Carrick, T. R. (1973). Studies on mountain streams in the English Lake District. I: pH, calcium and the distribution of invertebrates in the river Duddon. *Freshwater Biol.*, **3**, 437–62.

Sutcliffe, D. W., Carrick, T. R., Charmier, A. C., Gledhill, T., Jones, J. G., Marker, A. F. H. & Willoughby, L. G. (1987). Acidification problems of freshwaters: trophic relationships. In *Reversibility of acidification*, ed. H. Barth, pp. 64–6. Elsevier, London.