Council

CNL(05)34

Liming as a Mitigation Measure in Acidified Salmon Rivers in Southern Norway has been a success
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Abstract. Due to acidification, 52 Norwegian stocks of Atlantic salmon are affected. In the two southernmost counties, salmon is eradicated. Due to the high acid sensitivity, production of salmon was greatly reduced as early as 1920, several decades before acid rain was recognized as an environmental problem. International agreements on reduced atmospheric emissions will reduce acidification effects in Norway substantially during the coming 20 years. However, the extreme acid sensitivity of salmon makes the destiny of this species in Southern Norway uncertain. Liming in combination with reduced emissions will be an important contribution to protection of the Atlantic salmon species.

Liming is an effective measure to protect and restore fish populations in acidified waters. Liming of acidified salmon rivers has become important in Norway the last 10 years, and in 2005, 22 rivers were limed in Norway at a cost of NOK45 million (approximately £4 million). Mean densities of salmon fry have increased from 10 to 60 fish per 100 m^2 from 1991 to 2002. The catches of salmon in the limed rivers now constitute close to 10% of the total catch of wild salmon in Norwegian salmon rivers. The catch has increased from 5 tonnes prior to liming in the early 1980s and up to 40 tonnes the recent years. Estimates of future river catches by rod indicate an increase of 75 to 100 tons a year in around 2015 as a result of liming.

1. Introduction

The causes of acidification of surface water in Scandinavia were clarified during the 1960s and 1970s, almost one century after the first negative effect on fish populations. The first indications of acidification affecting fish are from episodic killings of Atlantic salmon (*Salmo salar*) in some southern rivers in Norway around 1910. Official Norwegian salmon catch statistics shows a large decline in catches around 1900. In the two southern counties, Aust-Agder and Vest-Agder, catches declined about 80% from 1885 to 1920. Sporadic catches of salmon were reported up to the late 1960´s, but the natural salmon stocks in this region were virtually extinct around 1960 (Fig. 1). There have been occasional catches of salmon also during the last twenty years, but we have no indications of reproduction of salmon. In southern Norway, 52 Atlantic salmon stocks are affected by acidification. In 1995, 18 Norwegian salmon stocks were extinct due to acidification, 11 in Agder counties and 7 in the western counties Rogaland and Hordaland. The physiology, life-cycle and attractiveness of Atlantic salmon as a sports fish make this species vulnerable to several other threats: overexploitation, river regulations and escaped farmed salmon. Due to a low degree of urbanisation, Norway has many intact salmon stocks in the middle and northern part.

In 1983 the Norwegian government initiated a liming programme. The funding increased year by year, until 1996, and since then yearly budgets have been around 100 million NOK. Several salmon rivers have been limed since the middle of the 1990s. In 2005, 22 Atlantic salmon rivers are being limed in Norway at a cost of NOK45 million (approximately £4 million) (fig.2).

The purpose of this paper is to give an overview of the status of Atlantic salmon in Norway with an emphasis on acidification, and from a management point of view. It also presents the future expectations of liming of acidified salmon rivers and the planned reductions of emissions in Europe.

2. Effects of acidification on Atlantic salmon

During the 1800s salmon was an important resource in southern Norway, as food and for export, and wealthy people from Europe arrived during summer for salmon fishing, bringing resources to many local communities. According to official salmon catch statistics, more than 70 tons were caught in 1885 in the 7 southernmost rivers. In Mandal River, official catches were 36 tons in 1885, among the 5 best in Norway.

There are no measurements of water chemistry from that period, and the exact relationship between water quality and the development of salmon populations cannot be ascertained. Mylona (1993) has estimated of sulphur dioxide in Europe from 1880 (fig. 1).

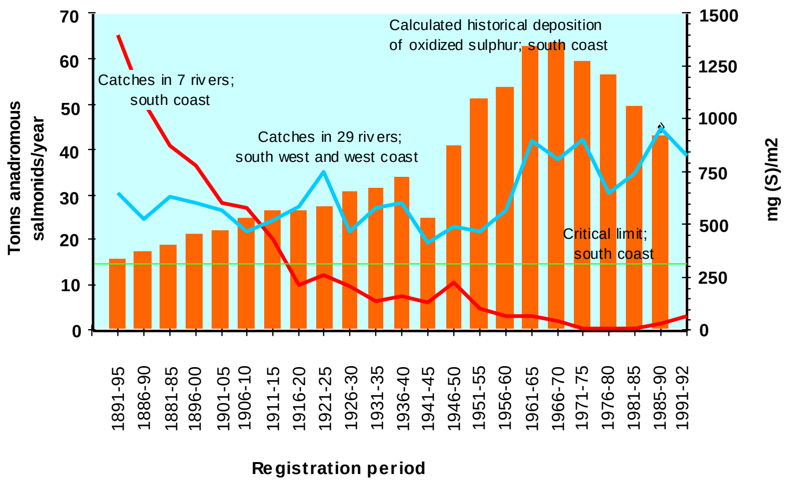

Figure 1. Deposition of sulphur and catches of salmon. Bars: Estimated historical deposition of oxidised sulphur in southern Norway. Red line: Catches of salmon in 7 rivers along the south coast. Blue line: Catches of salmon in 29 rivers on western coast. (From: Mylona 1993 and Kroglund et al. 1994.)

Sulphur deposition in southern Norway in 1890 was 400 mg S/m^2. Critical load for this area is calculated to be around 300 mg S/m^2 (Henriksen *et al.*, 1992), which indicates an exceeded critical load for acidification as early as around 1890. This may explain the declining salmon catches around 1900 and indicates that even exceeding the critical load of sulphur by a small amount may be harmful for salmon. A further increase above the critical load from 1900 and onwards was followed by a rapid decline in salmon catches up to 1920 (fig. 1) and a further decline and extinction of several salmon stocks in the next 40 years. The total annual loss of salmon production of Norwegian stocks due to acidification is estimated to range between 345 and 1,150 tons (Hesthagen & Hansen, 1991). Acidification is therefore the single factor that caused the most substantial negative effects on salmon stocks in Norway.

3. The Norwegian liming program

The national liming program is an intermittent mitigating measure against the extensive damages of freshwater ecosystems by acid rain. Operational liming followed the research program on liming run in Norway from 1979 to 1983 (Baalsrud *et al.*, 1985; Henrikson *et al.*, 1995). The two first limed salmon rivers were River Audna (1985) and Vikedal River

(1987). The salmon stock became extinct around 1970 in River Audna and was strongly reduced during the 1970´s and early 1980´s in Vikedal River (Hesthagen, 1989).

From 1994 the liming budgets reached a level that made liming of the large salmon rivers possible. A main goal is to develop an economical optimal liming program giving acceptable biological results. The main cost of most liming projects is the purchase of powdered limestone. Size of lime doses is therefore an important issue, directly related to both costs and ecological effects.

The liming strategies are under continuous development. Two main liming strategies are used for liming salmon rivers depending on the characteristics of the river and watershed (fig. 3): lime dosers for continuous liming of running water and liming directly on lake surface (Henrikson *et al*., 1995). In the lime dosers, the amount of lime discharged is usually controlled by pH and water flow to stabilise the water quality downstream (Sandøy and Romundstad, 1995). Most projects have a consumption between 500 and 3,000 tons of lime a year to produce an acceptable water quality. For all 22 salmon rivers about 40,000 tons of limestone per year would be required.

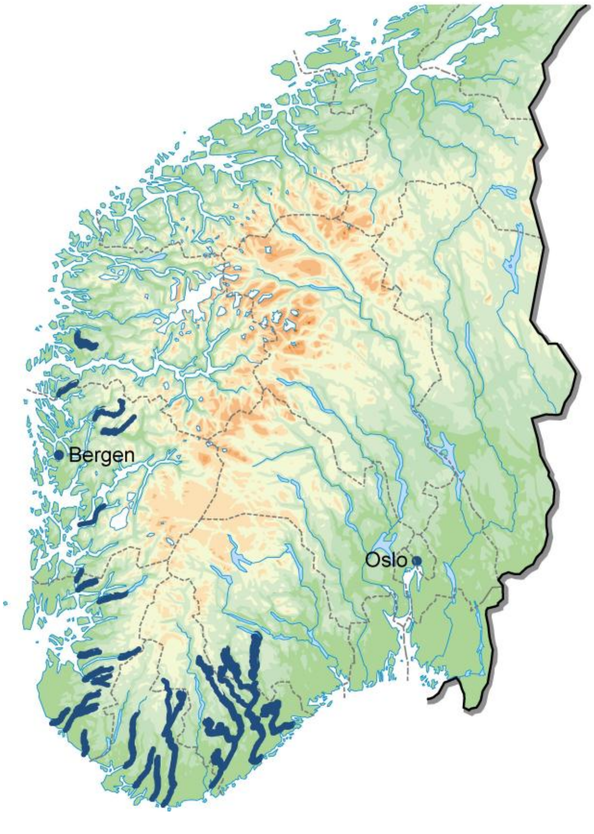

Figure 2. Limed salmon rivers in Southern Norway.

The biological effects of acid water and liming are studied by extensive monitoring and research projects (Anon. 1999). Exposure studies of salmon parr and smolt have showed different water quality requirements for the different freshwater stages (Rosseland and Staurnes, 1994). Studies indicate an increasing sensitivity towards the smolt run, usually occurring in May (Staurnes *et al*., 1993) and even moderate acidification seems to affect physiological adaptation to sea water (Staurnes *et al*., 1995; Kroglund and Staurnes, 1999). Therefore different pH targets are set for liming in different seasons. During the period 1

June to 14 February, salmon rivers should be limed to pH 6.0. A pH target of 6.2 is set for 15 February to 31 March, and pH 6.4 for 1 April to 31 May. The elevated pH levels in late winter and spring will also contribute to an increased protection of the fish against acidic episodes during snowmelt.

The rapid increases in densities of juvenile Atlantic salmon in the limed rivers are very promising. Mean densities of salmon fry have increased from 10 to 60 fish per 100 m^2 from 1991 to 2002 (Larsen and Hesthagen 2004). On the basis of the official rod catch statistics, there has been a pronounced increase in the abundance of adult salmon in the limed rivers (Larsen and Hesthagen 2004). The catch has increased from 5 tonnes prior to liming in the early 1980s and up to 40 tonnes in recent years (fig. 4). The catches of salmon in the limed rivers now constitute close to 10% of the total catch of wild salmon in Norwegian salmon rivers. Estimates of future river catches by rod indicate an increase of 75 to 100 tons a year in around 2015 as a result of liming.

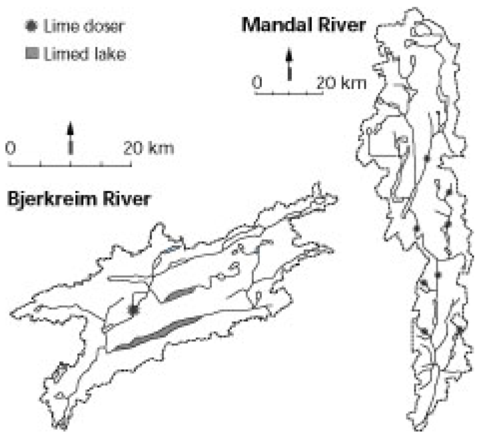

Figure 3. Liming strategies in Bjerkreim River and Mandal River.

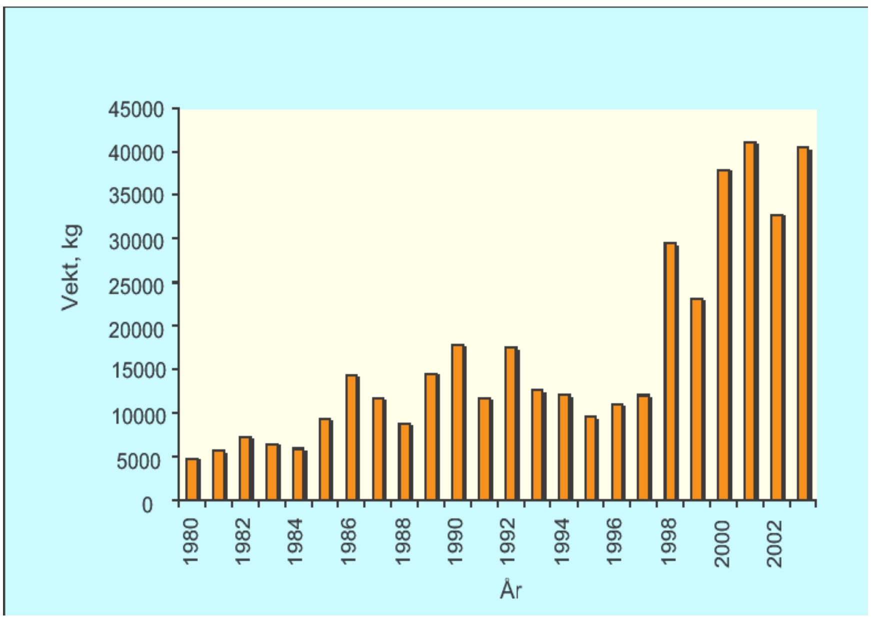

Figure 4. The official rod catch statistics show that the catch in the limed rivers has increased from 5 tonnes prior to liming in the early 1980s and up to 40 tonnes in recent years (Larsen and Hesthagen 2004).

4. Liming and re-establishing extinct salmon stocks

In 10 rivers the main goal is to re-establish a self-reproducing salmon population. The Norwegian Institute for Nature Research (NINA) has estimated that the salmon stocks in limed rivers will be fully re-established after about 15 years of liming. Two strategies of liming have been used: liming with or without a stocking program. So far both strategies seem to be successful, but we do not know the genetic effect or the long-term result of either strategy. Liming without stocking gives a surprisingly rapid re-colonisation of salmon. Sokndal River in Rogaland county was limed in 1989. The first yearlings of salmon were recorded in 1990 and from 1997 – 2003 density of yearlings has been between 40 and 130 per 100 m^2 (Anon., 2004). Catches of adult salmon in Sokndal River have in recent years been between 1.5 and 3 tons per year. The salmon spawning after liming must have been strayers from other rivers or escaped farmed salmon.

A research project started in 1996 with the aim of studying the re-colonisation process of salmon, evaluating the genetic effects of stocking strategies, comparing stocking and natural re-colonisation and studying population dynamics of re-colonising salmon. Mandal River, started in spring 2000, and Tovdal River, started in 2002, are the main study sites. An important challenge was to choose appropriate parent populations for stocking. For both historic populations' life history parameters are known, such as smolt age, age and size of spawners (Huitfeldt-Kaas, 1946). Abiotic parameters of the river, such as water flow and temperature, are believed to affect the phenotypic and genotypic characteristics of a salmon stock. Genetic mapping has shown that salmon stocks in the same region are genetically more related than geographically separated stocks. Geographic and watershed characteristics were important criteria when selecting parent stocks for re-establishing salmon in the Mandal and Tovdal Rivers. River Storelva has the only remaining natural salmon stock in the Agder region, and was chosen as parental stock for Tovdal River (fig 2). Bjerkreim River is the geographically closest remaining stock to Mandal River, and was selected for Mandal River. The life history parameters of salmon in the two rivers were also quite similar (Huitfeldt-Kaas, 1946).

5. Critical load and recovery

During the last two decades the European nations have made agreements to reduce atmospheric emissions of acidifying compounds. The latest and most extensive was signed in Gothenburg in December 1999. Based on the steady state critical load models, the agreed reductions are estimated to reduce the area where critical load is exceeded in Norway by about 80% compared with the 1985 level, some years after the reductions are fulfilled in 2010 (Wright, 2000). That means the water quality will make possible a recovery of, for example, brown trout (*Salmo trutta*) in a large number of lakes during the first half of this century.

The dose-response function, which the calculations of critical load exceedance are based on, is that of brown trout to ANC (Acid Neutralising Capacity) (Henriksen *et al*., 1995). A dose-response relationship between ANC and Atlantic salmon population status is much more difficult to establish, due to the complicated life-cycle dynamics and the several environmental threats affecting salmon. Salmon is much more sensitive to acidic water than brown trout. That means that the critical load of salmon is exceeded more than that of brown trout, and the recovery of salmon will take more time than usually presented as the general effect of the Gothenburg protocol. The present knowledge does not, however, allow us to conclude more exactly. Therefore, we cannot say when the recovery process may allow us to stop liming of the salmon rivers, or if the agreed reductions ever will give satisfactory conditions in the most acidified rivers. The moderately acidified rivers will most likely achieve non-acidified conditions within the next 10 to 20 years (Hindar *et al*., 1998; Wright, 2000).

6. Conclusion

In southern Norway, 52 Atlantic salmon stocks are affected by acidification. 18 of these stocks are extinct; salmon has been practically absent from the entire southern region of Norway for the last 30 years. The national liming program includes 22 salmon rivers, and the aim is to re-establish self-reproducing salmon populations in 10 of the most acidified rivers. The liming will bring the salmon back to the southern region of Norway after 50 years of absence, and allow yearly river catches of salmon by rod to increase by 75 -100 tons in the limed rivers. Reduced emissions will lead to reduced acidification. The future status of the salmon rivers is, however, uncertain due to the high acid sensitivity of salmon. Some of the populations will certainly recover, but we do not know if natural recovery from acidification will allow stopping the liming of all the salmon rivers the next 20 years.

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