Fish death in mountain lakes in southwestern Norway during late 1800s and early 1900s – a review of historical data

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Sammendrag

Fiskedød i fjellsjøer i Sørvest-Norge på slutten av 1800-tallet og begynnelsen av 1900-tallet – en gjennomgang av historiske data.
Mye av de historiske dataene om fisk og fiskebestander i fjellsjøer i Sørvest-Norge er i dag lite tilgjengelige. Her har vi skaffet til veie en rekke av disse gamle datakildene, og har hentet ut data om fisk og fiskebestander. Disse gamle dataene viser at aurebestandene i Sørvest-Norge ble sterkt redusert eller døde ut, tilsynelatende i de to periodene 1860-1890 og 1910-1930. Våre funn støtter hypotesen om at "sjøsaltepisoder", kombinert med begynnende forsuring, kan ha vært medvirkende årsak til fiskedøden, i hvert fall i den siste perioden.

Abstract

Most of the historical data regarding fish and fish populations in mountain lakes in southwestern Norway is currently not very available. In this study we have succeeded in aquiring a number of such old data sources, and we have extracted relevant information on fish and fish populations. These old data reveal that trout populations in mountain areas in southwestern Norway became severely diminished, or even extinct, apparently during the two periods 1860-1890 and 1910-1930. Our results support the most recent hypothesis, that a combination of "sea salt episodes" and emerging acidification may have contributed to the fish death in the latter of these two periods.

Introduction

Due to the geography, comprising numerous migration barriers, most of the trout (*Salmo trutta* L.) in the inland and mountain areas in Norway have at some point of time been stocked (Huitfeldt-Kaas 1924, Sømme 1941). At Hardangervidda mountain plateau (1000-1300 m a.s.l.), trout bones dating back to the Stone Age have been found (Indrelid 1994), and a discription of *Eilifr Elgr* stocking fish (trout) in Lake Raudsjøen in Gausdal is found on a rune stone from 1050-1100. Huitfeldt-Kaas (1924) linked the comprehensive stocking of trout to settling, and a subsequent need of a reliable source of food. From the high mountain summer farms ("støler") in southwestern Norway, trout fishing was an important and necessary part of the exploitation of the mountain resources (Pedersen and Solli 1978). In this area, the stocking have also been linked to medieval mountain paths (L'Abée-Lund 1985). Thus, possessing detailed information about trout and trout lakes was a matter of survival in these barren mountain areas in ancient times. This fact is important to bear in mind, especially when evaluating the credibility of the oldest information.

During the acidification research in the 1970s, the two most frequently cited "classical" papers, describing fish death in rivers and lakes in southern Norway during early 1900s, were Dahl (1921) and Huitfeldt-Kaas (1922). However, documentation of historical data/observations are not limited to these two papers, but are available from other sources too, ranging from newspaper articles to articles of scientific character. Another "classical" work, is the doctoral thesis by Huitfeldt-Kaas (1927), providing historical information from many lakes. Some information, dated back to mid 1800s, were gathered in early 1900s as information from "old people", critically evaluated and recorded by Knut Dahl and Hartvig Huitfeldt-Kaas.

In 1855 the institution "*Fiskeri-inspektøren*" was established ("*Inspector of the fisheries*"). The purpose was "*... on the request from the Interior Ministry to site visit rivers and lakes, and promote stockings of freshwater fish, and to survey and evaluate the status of important fisheries ...*". The annual reports from "*Fiskeri-inspektøren*" are official documents, and provide important historical information about fish and fish populations. Moreover, letters from "*Fiskeri-inspektøren*" and his assistants to landowners, scientists (etc.) also provide important information about this topic.

Unfortunately, for a broader foreign public, all of these old documents were written in Norwegian, and many of them are not very easily available today. We therefore present a comprehensive "Appendix" (electronic version only) including a relatively detailed description of specific lakes, extracted from these old data sources. This makes important historical data available for further scientific use. Moreover, this is to our knowledge the first time these historical fish data have been subjected to a common compilation.

Fish Data

We have detected 28 lakes, from which historical data on fish status exist, table 1. The individual lakes are thoroughly described in the Appendix, where also the references to the original data sources are listed. The lakes were distributed throughout southwestern Norway, figure 1, located from 240 to 1034 m a.s.l. Despite the use of highly variable data sources, originating from a time when the general scientific level and publication did not meet todays standards, the observations were remarkable consistent. The trout populations seemed to decline or expire during two periods, roughly during 1860-1890 and 1910-1930. No differences in neither lake area nor altitude between these two groups of lakes were found ($p>0.05$).

1860-1890 (n=10): From lakes in this group, no surveys have been performed. However, due to regular exploitation of the fish resources in many of these lakes, the loss of the fish populations is easily detected (Appendix). From several of these lakes comprehensive efforts to reestablish the population(s) have also been described (Appendix).

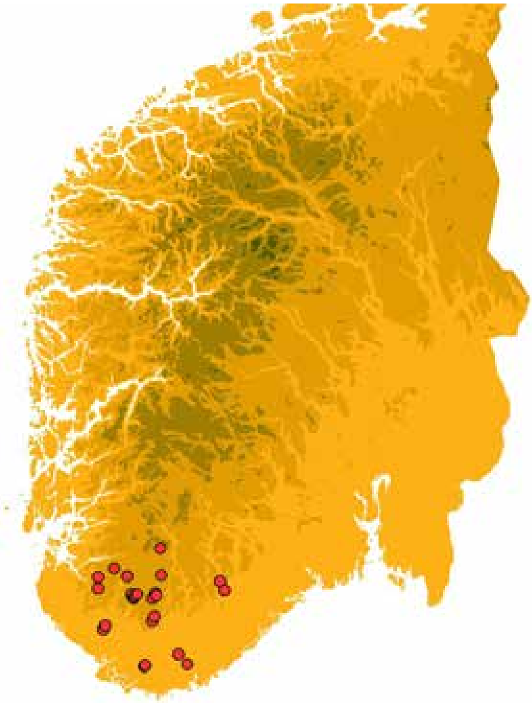

Figure 1. Location of the 28 lakes with available historical fish data.

According to Huitfeldt-Kaas (1922) the trout population in Lake Sandvatn was close to extinction as early as in the 1870s (photo: Anne E. Carlsen/Fylkesmannen i Rogaland).

1910-1930 (n=18): From about 1/3 of the lakes in this group, fish status, as for the 1860-1890 group, is based on information associated with exploitation. Data from fish surveys is available for the remaining 2/3 of the lakes. The majority of these lakes did apparently not experience a total extinction, but rather severe declines.

During this period, loss of trout populations has been described from lakes all over southwestern Norway (Dahl 1921). However, an unfortunate lack of lake specific data exclude most of them from our overview. Thus, an apparent lack of extinct lakes in the 1910-1930 group is possibly caused by the composition of the available data set, table 1.

Water chemistry data

Wright (1977) gathered historical pH-measurements from a number of locations in southern Norway. The historical data reported here, is not included in Wright (1977) and comprises solely dilute, unbuffered mountain lakes (pH<5.5), primarily located in the western parts of southern Norway, table 2. Fortunately, the methods used in these pH-determinations were described and thus traceable.

The oldest pH-measurements were performed using different indicators. A correctly performed determination may have an accuracy of ±0.1-0.2 pH (Felton 1921, Bartram and Ballance 1996). The limitation of this method is that the relevant indicators themselves are weak acids and may alter the pH of the samples. Dannevig (1945) was aware of this limitation, and emphasized the use of as little indicator as possible. Dannevig (1934, 1945) used indicators after "Clark and Lubs", but later changed to the use of a pH-meter. He reported excellent agreement between these two methods. Bakke (1934, 1938), used a "Hellige Comparator" equipped with color disc for "Merck" universal indicator, and Mansfield & Clark Color Chart for bromthymol blue and methyl red. These are indicators suitable for

Period	Lake	Municipality	County	Altitude m a.s.l.	Area km²	Population change
1860-1890	Sandvatn	Gjesdal	Rogaland	910	2.0	decline
“	Røynelandsvatn	Vennesla	Vest-Agder	365	0.37	extinction
“	Lolandsvatn	Vennesla	Vest-Agder	240	0.19	extinction
“	Viggjamstadvatn	Lindesnes	Vest-Agder	287	0.13	extinction
“	Sandvatn	Lindesnes	Vest-Agder	290	0.11	extinction
“	S. Krokevatn	Åseral	Vest-Agder	835	0.43	extinction
“	Kolsvatn	Valle	Aust-Agder	1034	2.7	extinction
“	Kolsheivatn	Bygland	Aust-Agder	930	1.6	extinction
“	Steinsvatn	Åmli	Aust-Agder	566	2.1	extinction
“	Måvatn	Åmli	Aust-Agder	549	3.4	extinction
1910-1930	Stølstjørn	Lund	Rogaland	423	0.04	extinction
“	Steinsvatn	Lund	Rogaland	542	0.24	extinction
“	Myrvatn	Gjesdal	Rogaland	(600)	(3)	decline
“	Månavatn	Gjesdal	Rogaland	334	0.19	decline
“	Beinesvatn	Sirdal	Vest-Agder	588	0.49	decline
“	Trestøltjørn	Kvinesdal	Vest-Agder	591	0.07	decline
“	Steinulvstøltjørn	Kvinesdal	Vest-Agder	622	0.03	decline
“	Salmelona	Kvinesdal	Vest-Agder	493	0.15	decline
“	Nesjen	Kvinesdal	Vest-Agder	677	(0.2)	decline
“	Meljevatn	Kvinesdal	Vest-Agder	688	0.17	expiring
“	Vindhommene	Åseral	Vest-Agder	787	0.07	decline
“	Sandvatn	Åseral	Vest-Agder	606	2.0	decline
“	N. Krokevatn	Åseral	Vest-Agder	(700)	(0.05)	decline
“	Nåvatn	Åseral	Vest-Agder	606	3.2	expiring
“	L. Kvernevatn	Åseral	Vest-Agder	747	0.08	decline
“	Hyttetjørn	Åseral	Vest-Agder	775	0.003	decline
“	Grønlitjørn	Åseral	Vest-Agder	748	0.03	decline
“	Fisketjørn	Åseral	Vest-Agder	747	0.01	decline

Table 1. Historical fish data from 28 lakes in southwestern Norway. (Data in brackets indicates estimated pre-regulation values.)

measuring pH in the ranges of 6.0-7.6 and 4.4-6.2, respectively. It should be noted that Clark and Lubs (1917), in some situations, reported a slight overestimation of pH when using methyl red.

The old data showed surprisingly low and uniform pH-values, Table 2. Data from many measurements is available from the three neighboring lakes, Lake Steinsvatn, Lake Hestvatn and Lake Stølstjørn, located in the mountains somewhat east of Moi (Lund, Rogaland County). These lakes are unbuffered, dilute mountain lakes, sampled several times during 1926-1932; showing pH=5.17±0.27 (n=10). Without being specific, Bakke (1933) also reported “general” pH-values in the range of 5-5.5 in these mountain areas, and a pH of about 6 in the main river in the valley bottom.

Discussion

When comparing these old data, a clear pattern emerges. The trout populations apparently declined or expired during two separate periods; roughly between 1860-1890 and 1910-1930.

Lake (municipality)	Sampling location	Date	pH	Reference
Heievatn (Lund)	(lake)	15.10.1952	4.8	Bakke (1952)
"	(lake)	15.10.1952	4.6	Bakke (1952)
Hestvann (Lund)	(lake)	20.10.1926	5.4	Bakke (1926)
"	(lake)	24.07.1932	5.2	Jakobsen (1932)
"	tributary from Gråhei	24.07.1932	5.3	Jakobsen (1932)
"	tributary from Lake Steinvatn	24.07.1932	5.1	Jakobsen (1932)
Steinsvatn (Lund)	(lake)	20.10.1926	5.4	Bakke (1926)
"	(lake)	10.11.1926 (?)	5.2	Bakke (1933)
"	(lake)	06.09.1931	5.1	Jakobsen (1932)
"	(lake)	24.07.1932	5.1	Jakobsen (1932)
"	little pond upstream	06.09.1931	5.4	Jakobsen (1932)
Stølstjørn (Lund)	(lake)	10.11.1926	4.5	Bakke (1933)
Skutevatn (Hjelmeland)	(lake)	13.09.1938	4.8	Bakke (1939)
"	(lake)	28.06.1939	5.0	Bakke (1939)
Steinsvatn (Åmli)	(no information)	(not dated)	5.3	Dannevig (1945)
Litjern (Åmli)	(no information)	(not dated)	4.9	Dannevig (1945)
Måvasstøyltjørn (Åmli)	(no information)	(not dated)	4.9-5.3	Dannevig (1945)
Måvatn (Åmli)	(no information)	(not dated)	4.8-5.1	Dannevig (1945)
Måvassbekken (Åmli)	Harstveit	(not dated)	4.8-5.0	Dannevig (1945)
Kyrvatn (Åmli)	(no information)	(not dated)	4.8-5.3	Dannevig (1945)
Krossvatn (Åmli)	(no information)	(not dated)	4.6-5.4	Dannevig (1945)
Uvdalsvatn (Åmli)	(no information)	(not dated)	5.2	Dannevig (1945)
Røynelandsvatn (Vennesla)	(no information)	(not dated)	5.3	Torgersen (1934)

Table 2. Historical water chemistry data.

However, the data material is limited, so we cannot entirely reject the possibility of population effects between these two periods. The existence of two separate periods is also supported by Dahl (1921). When reporting the fish death in the Åseral lakes in the 1920s, he also suggested that there might have been a similar period in "ancient times". From being a highly emphasized issue in the annual reports from "*Fiskeri-inspektøren*" during 1910-1925, these matters somehow lost focus in the years following 1930.

Some of the populations, surveyed throughout the period 1910-1930, were already extinct, while the majority of them were in various stages of decline, Table 1. Severe diminished populations are easily detectable as limited catches (e.g. Lake Nåvatn and Lake Meljevatn), while emerging decline may be more difficult to determine. Trout fry is highly sensitive to adverse water quality (Malcolm et al. 2014, Enge et al. 2017). Thus, deteriorating water quality may first affect their recruitment. Hence, the first sign of a declining populations is not necessarily decreasing catches, but a gradual ageing of the populations and a subsequent accumulation of old fish, e.g. Figure A1-b and A3-b in Appendix. Moreover, an emergence of very old fish in such declining populations may also indicate increasing longevity.

The fish included in the old studies were not caught by any "standard method", but rather by any available fishing gear. This included methods ranging from gillnets to fly fishing. Thus, Dahl (1921) raised the question whether the apparent lack of young fish might be due to some methodical shortcomings. However, after a careful evaluation, including age, growth rate, size of the fish, and the applied fishing gear, Dahl (1921) concluded that the lack of young fish was not attributable to the methods used. This conclusion was also supported by the lack of small (young) fish in the brooks, i.e. at the spawning areas.

First, the observed decline of trout populations in mountain areas in southern Norway was attributed to the parasite *Glugea anomala* (Dahl 1921). This hypothesis was abandoned when it was discovered that the water in the mountain lakes was acidic, beyond the tolerance limits for early life stages of trout (Dahl 1927). Later, it has been generally accepted that acidification was the cause of the fish death in the 1920s (e.g. Rosseland 1986, Qvenild et al. 2007).

The three neighbouring lakes, Lake Steinsvatn, Lake Hestvatn and Lake Stølstjørn (Lund, Rogaland County), all experiencing fish death prior to the 1920s, showed pH=5.17±0.27 (n=10) during 1926-1932. However, this is a maximum estimate, due to i) a possible overestimation when using methyl red in the pH-determinations (Clark and Lubs 1917), and ii) sporadic small scale liming experiments in some of these lakes in 1927-1928 (Bakke 1933). This suggests that the "real" pH might have been somewhat lower. More recent data from mountain lakes in this part of Rogaland showed pH-values of slightly below 5 in the mid 1980s (Enge 2013). Thus, an apparently limited pH-decline during the 1920s to the 1980s suggests that the pH-values in lakes in this area as early as during the 1920s, may have been somehow depressed. Such low pH-values are possibly beyond what were expected considering the somewhat limited acid emissions at that time, only about 1/5 of the 1975 emmission (Mylona 1996).

This is also supported by more recent fish data from this mountain area. Lake Hovsvatn and Lake Rusdalsvatn, two large lakes located in the valley bottom, had dense populations in 1971 and 1974 at pH=4.9-5.0 (Berg 1972, 1975), suggesting that a pH-value distinctly below 5.0 is required to exterminate the trout populations.

Recent studies have demonstrated that occurrence of low pH is not necessarily *directly* linked to "acidification". In February 1993, a comprehensive mass death of trout was observed throughout southwestern Norway due to a "sea salt episode" (Hindar et al. 1994). A severe storm caused exceptionally high deposition of sea salt "spray", inducing ion exchange of Na^+ with toxic H^+ and Al^{n+} from the soil. Even very low levels of Al may have detrimental effects on aquatic organisms (Gensemer and Playle 1999). For salmon (*Salmo salar* L.), concentrations of inorganic cationic Al as low as 5-15 µg/l may be critical (Kroglund et al. 2007). Severe sea salt episodes occurred also in 2005 (Hindar and Enge 2006) and 2015 (Enge 2016), apparently without causing any fish death.

In November 1920, a comprehensive mass death of salmon were observed in several rivers in Ryfylke in Rogaland County, including the Frafjord river (Huitfeldt-Kaas 1922). Simultaneously, mass death of trout was registered in Lake Månavatn (334 m a.s.l.), located somewhat upstream of the salmon stretch (Huitfeldt-Kaas 1922). Later, this mass death has been attributed to acidification. However, episodes of mass deaths of fish due to acidification were normally associated with snowmelt (e.g. Leivestad and Muniz 1976). The 1920-incident occurred during late autumn. The nearest "official" weather monitoring station covering wind data from 1920 is "Skudesnes" (Norwegian Meteorological Institute), located about 70 km northwest of Frafjord. These data demonstrated an autumn with minimal rainfall, and with generally very strong winds, figure 2. Forty two percent of the daily observations of wind speed during October and November ranged between "fresh breeze" and

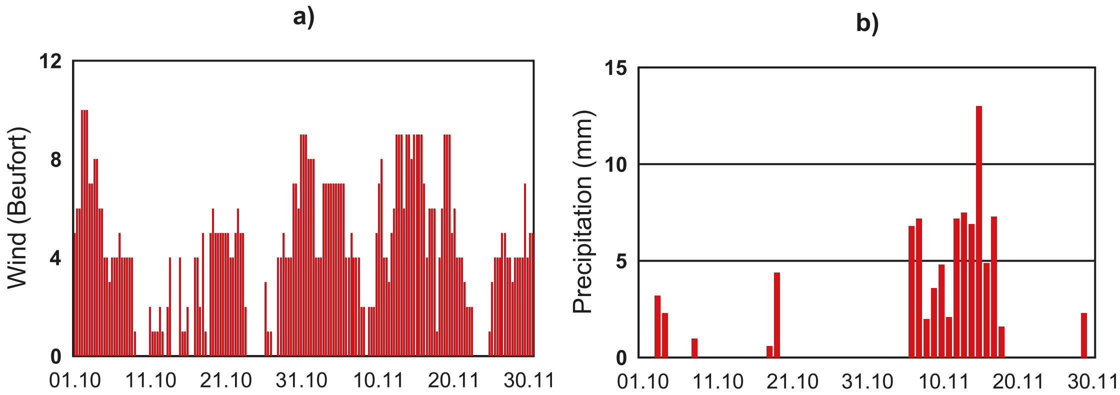

Figure 2. Meterological data from the DMNI station "Skudesnes" during October and November 1920. Wind speed (a) and daily precipitation (b). Beufort scale 10 represents "storm" (about 25 m/sec), and 5 is "fresh breeze" (about 10 m/sec).

"storm". Due to the lack of precipitation, dry depositions of sea salt may have accumulated, until being wetted by the rainfall during 6-18 November (Skudesnes: 74.9 mm). At "Lysebotn", assumed to be a more representative weather station (but lacks wind data), the precipitation during this period was 232.8 mm, where 13. of November was the first day with really "heavy" rain (41.0 mm). This coincides perfectly with the first fish death, observed the very same day.

This supports the most recent hypothesis, proposed by Hindar et al. (2004), that this episode may have been a "sea salt episode". However, it is important to notice that Na^{+} - H^{+}&Al^{n+} ion exchange primarily occurs in areas already somewhat acidified, as also emphasized by Hindar et al. (2004). In areas not acidified, Na^{+} is exchanged with cations such as Ca^{2+} and Mg^{2+} (Hindar et al. 1994).

The 1920 episode may have been very strong. Not even the severe and well documented 1993 episode, causing pH-values as low as 4.5, total monomeric Al=380 µg/l and subsequent death of trout in the neighbouring River Sira (Enge 1993), caused any death of trout in the Frafjord area.

Hindar et al. (2004) linked the occurrence of detrimental sea salt episodes in salmon rivers in western Norway to elevated values for the NAO-index (North Atlantic Oscillation Index), and the subsequent mild and stormy winters.

However, as early as the 1920s Sunde (1927) proposed possible detrimental climate effects on fish populations. He noticed that the fish death apparently coincided with a change in climate: "*... Since the turn of the century the winters have been wet and mild, the longest periode of such weather ever observed ...*" (transl. by the authors). This fits perfectly with Hindar et al. (2004), referring to the fact that the winter NAO-indexes during 1900-1925 were considerably higher than before and after this period.

Thus, a possible hypothesis is that sea salt effects may not only have contributed to episodic death of salmon and trout in the rivers in the 1920s, but also to apparent low pH-values and fish death in the lakes. Sea salt mobilizes H^{+} and Al^{n+} that may have been accumulated in the soil over some period of time. Subsequently, this effect may periodically cause acidic water even at low acidification loads. Geography, the location relative to the sea, and the most frequent wind directions, makes southwestern Norway highly susceptible to sea salt deposition. The combination of sea salt effects and emerging acidification possibly explainis why lakes in southwestern Norway were the first lakes experiencing declining trout populations, even at low acidification loads.

Acknowledgements

We thank Lars Jakob Gjemlestad for making the map and Malcolm Kelland for improving the language. Moreover, we thank two anonymous reviewers for valuable comments to the manuscript.

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APPENDIX

Historical data on brown trout populations in southern Norway during late 1800s and early 1900s

An "extract" from old data sources is presented in the current appendix. The data are also put in context, by also including selected lake data. Since we mainly have referred to data/observations from the old surveys, we have also added some technical comments and graphic representations of the data. Geological data is primarily retreived from ngu.no. UTM-coordinates are given as EPSG 32632.

Lake Sandvatn (UTM: 6538373 364225), Rogaland County: The lake is located above the tree line, in possibly one of the most barren mountain areas in southern Norway (see picture in the article). The bedrock is of precambric origin and comprises gneiss and granite. Bands of amphibolite and biotittic gneisses is patchy distributed in the catchment. The bedrock is "slicked" by the glaciers during the Ice Age. Glacial deposits is virtually absent in the catchment. The specific runoff in this area is approaching 120 l/sec pr. km² (www.nve.no), equal to a precipitation of close to 4000 mm/yr.

Sporadic measurements (2002-2014) have showed pH values, conductivity and Ca in the range of 5.1-5.3, 8.1-11.8 µS/cm (H^+-adjusted, c.f. Enge and Kroglund 2011) and 0.13-0.33 mg/l, respectively (Enge, authors unpublished data). According to Huitfeldt-Kaas (1922), the trout population in Lake Sandvatn was close to extinction as early as in the 1870s. Whether the population actually became extinct the following years, is not clear.

Lake Kolsvatn (UTM: 6559749 402571), Aust-Agder County: The lake is located in "Njardarheim" in southwestern Norway, a barren mountain area located above the tree line. The bedrock in the entire watershed is granitic. A sample series from the lake (03.08.2003) showed pH-, conductivity- and Ca-values in the range of 5.5-5.6, 9.5-9.6 µS/cm and 0.33-0.39 mg/l, respectively, for samples from 0-20 m depth (Enge 2003). During mid 1800s the population declined, the size of the fish increased, and the population eventually became extinct (Sæbyggen 1890). Apparently, the population somehow reappeared, and Lake Kolsvatn was regarded as an outstanding trout lake until the 1950s, followed by a subsequent population decline (Enge 2003). Restocking or immigration is possible causes to the reappearance of the trout population.

Lake Kolsheivatn (UTM: 6535398 405364), Aust-Agder County: The lake is located above the tree line in a barren mountain area with a bedrock comprising gneisses and granite. Some biotittic granite is found in the western parts of the area. The population became extinct during the mid 1800s (Hoff 1947).

Lake Steinsvatn (UTM: 6535007 457572), Aust-Agder County: The lake is located in eastern parts of southern Norway, in a partly barren mountain area. Some forest vegetation is located along the southwestern shoreline. The bedrock is of precambric origin and comprises primarily gneiss and migmatite. Dannevig (1945) presented a pH-value of 5.3 (not dated). The lake was originally an excellent trout lake, but the population declined and became extinct during the 1880s (Dannevig 1945). Attempts of restocking were performed, the last reported in 1939 (10 000 fry). However, apparently with limited success, as only one recapture was recorded (Dannevig 1945). However, 5-6 years may be insufficient to reestablish a population.

Lake Måvatn (UTM: 6528110 462353), Aust-Agder County: The lake is very deep (Dannevig 1945), located in a partly forested area. The bedrock is of precambric origin and comprises gneiss and granite. Glacial deposits are absent in the watershed. In "ancient time" Lake Måvatn was an excellent trout lake. The trout population declined and became extinct in the 1880s (Dannevig 1945). Restockings during 1922-1939 sustained a sparse population of relatively large fish. Some reproduction (observations of fry) were recorded. Dannevig (1945) presents pH-values in the range of 4.8-5.1 in Lake Måvatn, and 4.9-5.3 in Lake Måvasstøylstjørn, in the inlet to Lake Måvatn (not dated).

Lake Sandvatn (UTM: 6455483 398477) and ***Lake Viggjamstadvatn*** (UTM: 6454473 398213), Vest-Agder County: These two lakes are located below the tree line. The bedrock comprises granittic and diorittic gneisses. The lower areas in the watershed are covered by humus, while the higher laying areas are primarily barren mountain. These two lakes were considered as outstanding trout lakes "*a generation ago*", but the populations became extinct (Sunde 1930). In Lake Sandvatn, 4000 fry were stocked in 1924 and 1500 in 1925. In the neighbouring Lake Viggjamstadvatn, 2000 fry were stocked in 1925 (Sunde 1930).

Lake Røynelandsvatn (UTM: 6467851 426710) and ***Lake Lolandsvatn*** (UTM: 6460055 435215), Vest-Agder County: Both lakes are located below the tree line and their watersheds are partly forested and humus covered. The bedrock in the Røyneland area comprises gneiss and granite, partly biotittic. The watershed is mostly covered by moraine, while the area >400 m a.s.l. appears as barren. In the Loland area the bedrock includes amphibolite and biotite gneiss. Elements of diorite gneiss is found in the eastern parts of this area. The trout populations in these two lakes became extinct during late 1800s (Sunde 1930, Torgersen 1934). pH-values of 5.3 were measured in both these lakes in the late 1920s (Torgersen 1934, Wright 1977). The restocking were apparently successful (Sunde 1930, Torgersen 1934). In Lake Røynelandsvatn, restocking was combined with some liming in three small tributaries.

Lake Salmelona (UTM: 6513221 382547), Vest-Agder County: The lake is a located in River Kvina and had prior to the regulation a total catchment of close to 700 km². Thus, a variety of gneisses and granites is present in this large watershed. In the northwestern part of the area, elements of biotite gneiss and amphibolite is present. Thin moraine appear scattered in the catchment, and glacial deposits is present along River Kvina. Huitfeldt-Kaas (1927) surveyed Lake Salmelona in August 1913, and caught 35 trout which ranged in age and length of 4-12 year and 16-46 cm, respectively, figure A1. Weights were only given for 12 of the specimens (420±300 g), having a condition factor of 0.94±0.10. Applying this condition factor on the length data from the entire catch (n=35), a mean weight of 320±240 g was estimated. Thus, in 1913 Lake Salmelona had a population that comprised primarily of large, old trout, probably not reproducing The age distribution indicated that the recruitment had been variable for many years, figure A1. Lake Salmelona was testfished by Jensen (1966) in July 1965. At that time 11 trout were caught, which had lengths in the range of 15.5-26 cm and were 3-6 years old, Figure A1. The meanweight was 96±45 g. Jensen (1966) characteized the population as "large". In the 1960s, River Kvina was regulated for hydroelectric power production. Lake Salmelona is currently included in the large *Homstøl Reservoir*.

Lake Meljevatn (UTM: 6516857 380695), Vest-Agder County: This lake is located in a small

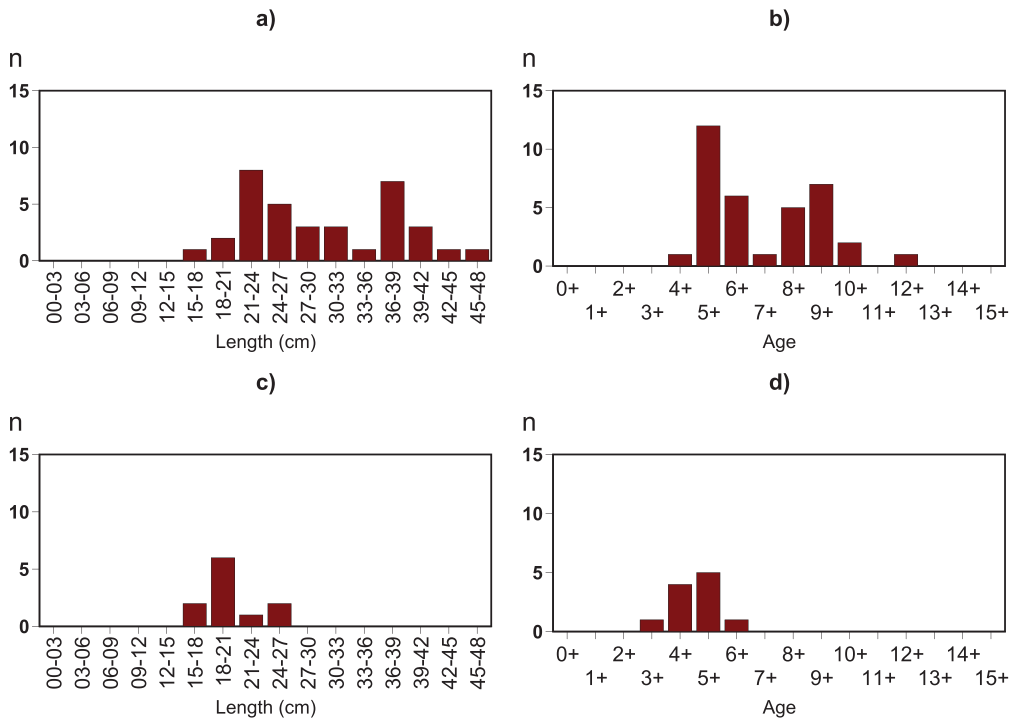

Figure A1. Data from testfishing in Lake Salmelona in 1913 (a/b) and 1965 (c/d). a/c: Length distributions, and b/d: Age distributions.

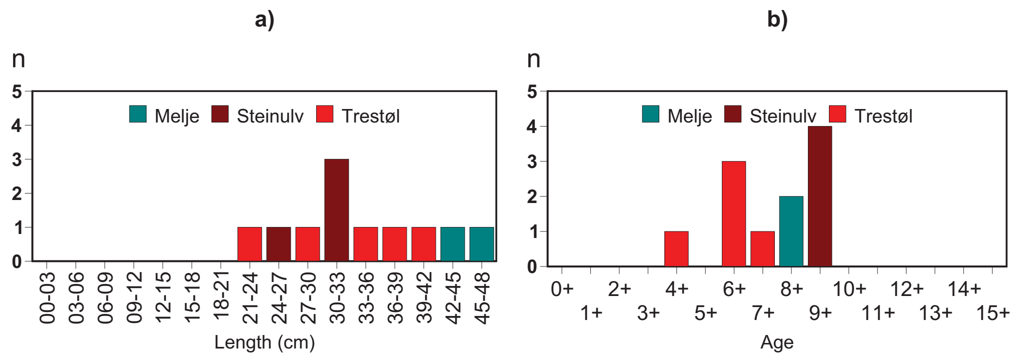

Figure A2. Data from testfishing in Lake Meljevatn (1913), Lake Steinulvstølsvatn and Lake Trestøltjørn (1910). a: Length distribution, and b: Age distribution.

tributary to Lake Salmelona. The bedrock comprises diorittic and granittic gneisses. A band of amphibolite and biotite gneiss is present north of Lake Meljevatn. The catchment is primarily barren, but thick moraine is present in the north-eastern part of the catchment. Huitfelt-Kaas (1927) surveyed Lake Meljevatn in August 1913 and concluded that the lake had a expiring trout population. Only two large trout were caught, both females having lengths of 43 and 45.5 cm and they were 8 years old, figure A2. Apparently, there had been no reproduction for many years. Both specimens had a distinct red flesh coloration.

Lake Trestølstjørn (UTM: 6514869 383948) and ***Lake Steinulvstølvatnet*** (UTM: 6515995 384202), Vest-Agder County: These two small lakes are located in a tributary to River Kvina. Lake Steinulvstølvatnet is located somewhat upstream of Lake Trestølstjørn. The bedrock comprises diorittic and granittic gneisses. The upper part of the watershed is barren, while the rest of the area is covered by thin moraine. From Lake Steinulvstølstjørn (September 1910) data from four trout exist, all being nine years old and with lengths in the range of 27-33 cm, Figure A2. Due to high humus content, Huitfeldt-Kaas (1927) described the water color in Lake Trestølstjørn as "intense brown". Data from five trout exist; 23-43 cm, 4-7 year old, Figure A2. Thus, these two populations also represent examples of accumulation of old fish, and where younger specimens apparently were absent. The flesh coloration was light red.

Lake Nesjen (UTM: 6517518 385762), Vest-Agder County, is located in River Kvina about 5 km upstream of Lake Salmelona. In 1910-1913 the population comprised old fish exclusively (Huitfeldt-Kaas 1927). Only two of 29 (7%) trout were <6 years, figure A3. Apparently, the recruitment had ceased. Today, Lake Nesjen is included in the large *Kvifjorden Reservoir*. Jensen (1966) testfished Lake Kvifjorden in 1947, prior to the regulation. He caught 20 trout in the range of 20-38 cm (median: 25.5 cm), of which 15 (75%) were <6 years old.

In 1916, Knut Dahl was requested by "Fiskeri-inspektøren" to go to the village Ljosland in Åseral, to examine unexplainable fish death in mountain lakes (Dahl 1921). Meetings with the locals, also from neighbouring villages, revealed that the fish death was comprehensive. It should be noted that Dahl, previously to the Åseral survey, had received similar information from all over southern Norway, including Sirdal, Kvinesdal, Mandalsdalen and Setesdalen. In Åseral, Dahls primary source, Karl Ljosland, registered 24 lakes of which five never had supported trout, 8 had lost the populations, while 11 of the lakes still sustained sparse, but declining trout populations.

In 1916, Dahls (1921) surveys included seven lakes in the Åseral area. These lakes were located above the tree line in areas comprising diorittic and granittic gneisses, biotite granite and biotite gneiss. The trout population in ***Lake S. Krokevatn*** (UTM: 6514818 399921) had been extinct for many years. However, a few years later Dahl got information of young trout being observed in the lake, probably originating from a stocking of 6 000 fry in 1918 (Dahl 1922). The other six lakes, ***Lake Hyttetjern*** (UTM: 6512527 399428), ***Lake Vindhommene*** (UTM: 6513321 399719), ***Fisketjørn*** (UTM: 6517732 402903), ***Grønlitjern*** (UTM: 6517806 402353), ***Lake N. Krokevatn*** (UTM: 6519330 401402) and ***Lake L. Kvernevatn*** (UTM: 6518108 403222) sustained sparse, but declining populations of relatively old fish, figure A4. In the spawning brooks, young trout were hardly observed. Dahl (1921) concluded that recruitment failure was the direct cause to the general decline in trout populations in the

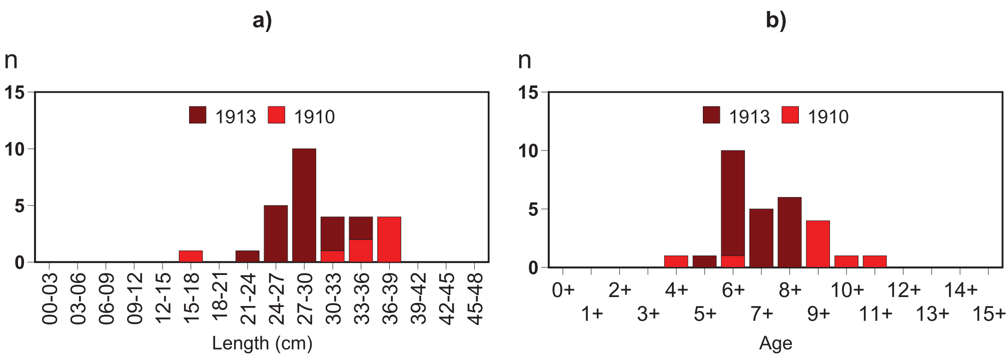

Figure A3. Data from testfishings in Lake Nesjen in 1910 & 1913. a: Length distribution, and b: Age distribution.

Åseral area. At that time Dahls theory was that the parasite *Glugea anomala* was responsible for the apparent lack of recruitment. Later, Dahl (1927) abandoned this hypothesis, suggesting that acid water was the main restricting factor.

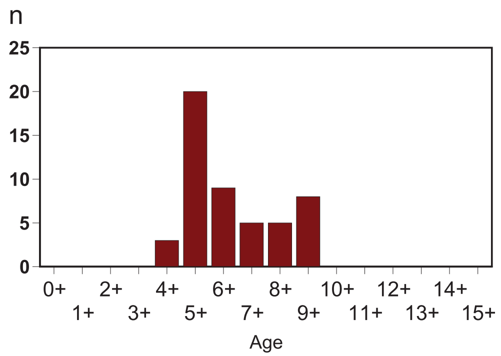

Figure A4. Age distribution of 50 trout caught in 6 lakes in Åseral in 1916.

Unspecified lakes in Åseral, Vest-Agder County: Dahl (1921) also referred to information given by "old people", indicating the trout populations in remote lakes in Åseral in "ancient times" had been extinct for decades, but that the populations somehow reappeared. *Lake S. Krokevatn* (see above) is possibly one of these earliest barren lakes. Here, the population was reestablished by means of restocking (Dahl 1922).

Lake Nåvatn (UTM: 6494889 401360) and ***Lake Sandvatn*** (UTM: 6499766 403010), Vest-Agder County: These two neighbouring lakes are located above the tree line in an area comprising gneiss and granite, the latter patchy biotittic. Due to regulations, these two lakes (and two more) is currently included in the large *Nåvatn Reservoir* (6.6 km^2, 626 m a.s.l.). In 1914 the trout population in Lake Nåvatn was close to extinction (Huitfeldt-Kaas 1927). The only specimen of trout caught was 43 cm and had a weight of 1250 g, figure A5. Lake Sandvatn sustained a sparse population of primarily old fish.

In 1920, a mass death of salmon and trout was observed in River Frafjord, River Helle and River Dirdal, Rogaland County (Huitfeldt-Kaas 1922). The autumn in 1920 was exceptionally dry. During mid November, a period of heavy rain occurred, causing a large flood. Apparently, the fish death emerged as a result of this flood. Mass death of trout were also recorded in ***Lake Månavatn*** (UTM: 6528911 350849) located somewhat upstream of the salmon rearing stretch. The fish death in Lake Månavatn seemed to be "total", and Huitfeldt-Kaas (1922) speculated if there were any "survivers" at all. Concidentally, he received information of occasional fish death (trout) in ***Lake S. Myrvatn*** (UTM: 6519301 351230) located in the neighbouring watershed Bjerkreim. Data indicating that the trout population in ***Lake Sandvatn*** (Gjesdal) (see above) was close to extinction "some 50 years ago" (e.g. in the 1870s). was also received.

Lake Beinesvatn (UTM: 6532143 375792), Vest-Agder County): As a boy, Hallvard T. Tjørhom (1912-1998, landowner, pers. comm. in 1985) stayed during the summer months at the,

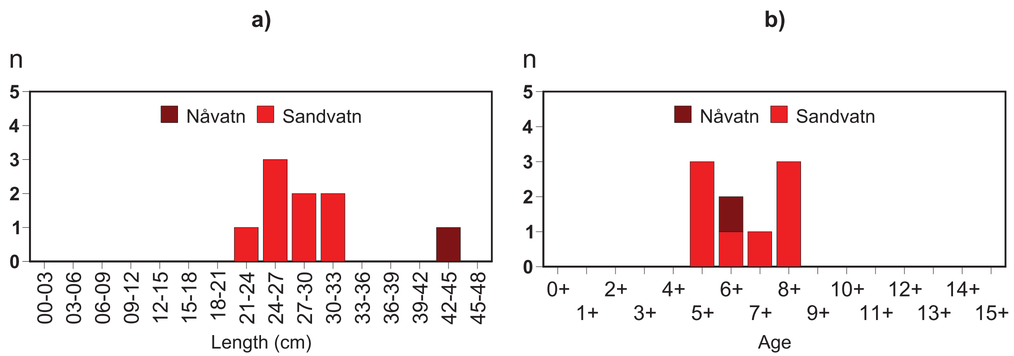

Figure A5. a: Length distribution and b: Age distribution from trout caugth in Lake Nåvatn (1914) and Lake Sandvatn (1914&1915).

previously, remote mountain farm at Lake Beinesvatn. Trout fishing was an important source of food. For a period of "many" years, during his childhood, the trout was absent, but later it reappeared. The little brook from Skardstøl has an excellent water quality (Enge, authors unpublished data). Thus, possible survival of a residual population in this brook may have been a source to the recovery of trout in that lake. Recovery due to residual populations surviving in small brooks have also been described from other lakes in this area (Enge et al. 2012).

Lake Steinsvatn (UTM: 6487942 360036) and ***Lake Stølstjørn*** (UTM: 6484033 359418), Rogaland County: The bedrock includes amphibolite and gneisses, partly biotittic or granittic. The trout were already extinct in both lakes in the 1920s (Bakke 1933). Unsuccessful stocking were repeatedly performed in both lakes. In November 1926, pH-values of 4.5 in Lake Stølstjørn and 5.2 in Lake Steinsvatn were reported (Bakke 1933). Some temporary liming experiments were performed. Lake Stølstjørn was limed with one "bag" of lime during the winter of 1927. Allegedly this raised the pH to 5.2, and fry were restocked (Bakke 1933). The following winter two more bags of lime were used. Three years later, trout were caught in the lake, originating from these stockings. Lake Steinsvatn was limed with 11 bags of lime during the winter of 1927, and fish were observed two years later. However, Lake Steinsvatn remained very acidic, at a pH-value of 5.2 despite the liming.