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Management of stunted populations of Arctic char (*Salvelinus alpinus*) and brown trout (*Salmo trutta*)

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ABSTRACT

In a harvesting experiment over 6 years using gill nets of 16-26 mm bar mesh sizes, the size distribution of a resident population of Arctic char changed towards larger fish. Originally the population consisted of char maturing at a size of about 70-80 g. The fishing caused an increase in catch per unit effort of 10 times in number and 14 times in weight of char larger than 125 g individual weight. It is assumed that the general management procedure for Norwegian char-trout lakes to fish with large meshed gill nets regulated by a lower permissable limit commonly set at a 30 mm mesh size, may be one of several reasons to maintain dense stunted stocks of Arctic char. This is supported by fishing a char-trout lake for 17 years using this common procedure, which did not increase the individual size of the fish. Still both the populations of Arctic char and brown trout consists of small sized fish of about 100 and 130 g respectively. It is proposed that a proper management program for char-trout lakes should include an upper mesh size limit of 29 mm for gill nets.

1. INTRODUCTION

Many Norwegian lakes contain stunted populations of Arctic char (Salvelinus alpinus) and brown trout (Salmo trutta), as these species have a high natural recruitment capasity. The fish in such lakes are hardly harvested at all, as the fish weigh only 100 g or less. The question that arises is how one should manage such stunted populations of Arctic char in a way that increases the weight of individual fish, and thereby stimulate the fisherman to harvest the optimal yield of the fish produced. Furthermore, what kind of regulatory measures are required to maintain a desirable length - or age frequency distribution of Arctic char and brown trout populations in such lakes.

Two fishing experiments were carried out to answer these questions. In one of the two harvesting experiments that we present, the size distribution of a resident allopatric Arctic char population changed towards larger fish. This experiment lasted for 6 years, and the results from the Lake Øvre Stavåtjønn experiment have previously been published (Langeland 1986). In the other experiment carried out over 17 years, using larger mesh sized gill nets commonly used in the management of Norwegian lakes, the size distributions of sympatric populations of Arctic char and brown trout changed towards smaller fish. Using these two experiments, we compared the effect of selective gill net fishing upon the size distribution of the fish stocks.

2. THE LAKES AND FISH POPULATIONS

Lake Øvre Stavåtjønn which has a resident allopatric population of Arctic char, is located 824 m above sea level. It has an area of 4 ha and a maximum depth of 7 m. The other Lake Songsjøen, which contains sympatric populations of Arctic char and brown trout, is located 261 m above sea level, it has an area of 70 ha and a maximum depth of 32 m.

The Arctic char in Øvre Stavåtjønn segregate in habitat by age. The adults were mainly confined to benthic areas, the immature fish (1-3 years) to pelagic water, and the young of the year (YOY) were restricted to shallow stony areas in the eastern part of the lake. In Lake Songsjøen brown trout which is the more aggressive species, lives mainly in the littoral bentic areas down to a depth of about 15 m, but is also occurring in near surface water in the pelagic zone. Adult Arctic char occurred mainly in pelagic water, while the immatures were confined to deeper bentic areas at dephts of 15-20 m. The difference in spatial distribution between the allopatric Arctic char in Lake Stavåtjønn and the sympatric Arctic char in Lake Songsjøen may be caused by interspecific competition with brown trout in the latter lake (Nilsson 1965, 1967, Hindar et al. 1988).

Mark- and recapture experiments in 1985-86 indicated a population size ratio of 2:1 between brown trout and Arctic char in Lake Songsjøen. In the experiment in Lake Songsjøen only bottom-set gill nets were used, thus giving a bias towards brown trout in the dominance ratio between the species. The catches in Lake Songsjøen consisted mainly of brown trout (69-88 %).

3. METHODS

Arctic char in Lake Øvre Stavåtjønn were caught with bottom-set and floating gill nets, each with bar mesh sizes of 15.7, 19.6, 22.4 and 26.1 mm used in equal numbers and distributed randomly in the lake from 1979 to 1984. The total length was measured from the tip of the snout to the end of the tail fin while the lobes were compressed.

In Lake Songsjøen the fish were caught with bottom-set gill nets, each with bar mesh sizes of 22.4, 24.1, 26.1, 28.5, 31.4. 34.9, 39.2 and 44.8 mm in numbers of 1, 9, 8, 6, 7, 7, 7, 7, respectively and distributed randomly in the littoral bentic areas.

In Lake Songsjøen the total length was measured from the tip of the snout to the end of the tail fin while naturally distended.

According to the calculations of gill net selectivity for brown trout (Jensen 1977) and Arctic char (Jensen 1986) the gill net series used was expected to catch fish from 15 to 29 cm in Øvre Stavåtjønn and 22 to 50 cm in Lake Songsjøen with a relative efficiency of more than 50 % compared to the modal fish length for best mesh size (100 %).

Condition was estimated with Fulton's coefficient of condition

$$K = 10^2 \times W/L^3,$$

W is weight (g) and L is length (cm).

4. RESULTS

The total yield of Arctic char in Lake Øvre Stavåtjønn during the period 1979-1984 decreased constantly from 18.0 kg ha^{-1} in 1979 to 3.0 kg ha^{-1} in 1984 (Table 1). The mean weight of the fish increased consistently from 67 g in 1979 to 91 g in 1983 (except for the 1982 value of 74 g, due to the relative dominance of 2-year-old fish). In 1984, the mean weight was less due to the high density of small fish.

The size distribution changed during the experiment toward larger fish size (Figure 1). The size distribution of Arctic char in Lake Øvre Stavåtjønn exhibit a three-modal pattern where the different age-groups of young fish could be identified. The ageing was verified by analysis of the otholiths. The increase in individual size is shown by the CPUE (Catch per unit effort) of Arctic char over 125 g (Table 2). The yield of such fish increased 9.6 times in number and 13.5 times in weight. Also the maximum individual weight increased as well as mean weight of fish over 125 g (Table 2).

Due to the great fishing effort in 1979-81 the biomass in Lake Øvre Stavåtjønn declined from 71 kg ha^{-1} in 1979 to 40, 24, 11-15,9 and approximately 20 kg in the years 1980-84, respectively. Other changes observed were increased growth rate and condition factor (K), e.g. 3-years-old fish increased from K=0.78 in 1979 to K=0.97 in 1984.

The yield of brown trout and Arctic char in Lake Songsjøen during the experimental period 1968-1984 varied between 1.2 and 5.2 kg ha^{-1}, mean for all years was 2.9 kg ha^{-1}, brown trout constituted 69-88 % of the catches (Table 3). The change in mean individual weight showed the same pattern for both species. An increase was recorded the first two years following the start of fishing in 1968 (Figure 2, Table 3). From 1970 to 1976 the mean weight of Arctic char declined from 128 g to 82 g. An increase up to 114 g in 1981 was proceeded by a new decrease to the lowest mean weight calculated at 80 g in 1984. The maximum mean weight recorded in the last cycle (1976-1984) was 11 % lower than maximum in the previous cycle (1968-1976). Mean weight for all 17 years was 105 g.

For brown trout the mean weight declined from 163 g in 1970 to 105 g in 1975 (Figure 2 Table 3). The next years were followed by an increase to 149 in 1982 proceeded by a new decrease to 128 g in 1984. The mean individual weight in the last cycle (1975-1984) was 8 % lower than maximum in the previous cycle (1968-1975). Mean weight for all 17 years was 130 g.

No significant correlation was found between yield and mean individual weight for neither brown trout ($r=0.43$ $p>0.05$) nor Arctic char ($r=0.25$ $p>0.05$).

The length-frequency distributions of fish in Lake Songsjøen in 1968-1969, 1974 and 1983 showed a shift towards smaller fish in later years for both species (Figure 3). Both species exhibited an unimodal pattern of distribution in all years with a more compressed bellshaped distribution of Arctic char. The modal length of Arctic char decreased from 24-25 cm in 1968-1969 to 23 cm in 1974 and 22 cm in 1983. A similar shift in modal fish length of about 2 cm was also recorded for brown trout, from 25-26 cm in 1968-1969 to 24 cm in 1983.

Calculations of the condition coefficient (K) in 1968, 1974, 1981-1983 were about the same in all years; 0.86-0.89 for brown trout and 0.81-0.83 for Arctic char. This indicate that the fishing experiment did not increase the weight - length ratio of the fish.

Mark- and recapture experiments in Lake Songsjøen in the years 1968-1972 gave the following estimates for brown trout $\geq$ 23 cm: 2842, 2740, 1952, 2010 and 1431, respectively.

5. DISCUSSION

The outcomes of the two harvesting experiments were quite different with respect to the size distributions and mean individual weights of the fish populations. Fishing intensively with small meshed gill nets in Lake Øvre Stavåtjønn obviously changed the individual size towards larger fish sizes. However, the experiment in Lake Songsjøen where larger mesh sizes were used, reduced the individual sizes of both brown trout and Arctic char.

To interprete the different outcomes of the experiments four factors have to be considered; the selectivity of the gill nets, fishing mortality, habitat segregation and change in food availability.

According to the calculations of the gill net selectivity made by Jensen (1977) for brown trout and Jensen (1986) for Arctic char, the gill nets used in Lake Øvre Stavåtjønn would remove fish between 15 and 29 cm compared to 22 and 50 cm in Lake Songsjøen. This is based on a relative gill net efficiency of more than 50 % for the length groups involved. This means that fish over 29 cm in Lake Øvre Stavåtjønn had much reduced probability to be caught compared to the fish in Lake Songsjøen. This certainly caused a much higher survival of larger fish in Lake Øvre Stavåtjønn. In Lake Øvre Stavåtjønn younger age classes were exposed to higher fishing mortalities than in Lake Songsjøen.

In Lake Øvre Stavåtjønn the annual fishing mortality from 1979 to 1982 was calculated to vary between 0.15 and 0.65 based on weight. This caused a change in the population structure towards younger age and increased growth rate. In Lake Songsjøen mark- and recapture experiments have been made during most years. From 1968 to 1972 the brown trout population of fish $\geq$ 23 cm declined from 2842 to 1431 fish which gave a reduction of 50 %. Based on the removal of brown trout $\geq$ 23 cm in 1968-71 we calculated an annual fishing mortality rate of 0.50-0.60 which was about the same as the reduction of brown trout from 1968-1972. As this high fishing mortality mainly was confined to the larger fish, this has obviously reduced the probability of survival for larger fish. However, smaller fish less than 23 cm benefited by increased survival in Lake Songsjøen permitting the smaller fish to dominate during the last years of exploitation.

The cyclic pattern in mean individual weight is more difficult to explain. The time lag of 5-6 years between peak and bottom, is the same as the mean life span for both brown trout and Arctic char. The most reasonable explanation for this cyclic pattern is that the fishing caused changes in age composition. In years with high mean individual weight the catches of brown trout was dominated by higher mean age (4.35-5.25 years) than in years with low mean weight (4.02-4.12 years). Changes towards a younger age distribution due to heavy fishing was a typical result of the fishing in Lake Øvre Stavåtjønn (Langeland 1986).

In Lake Øvre Stavåtjønn all habitats were fished permitting the catches to give a representative description of the whole population of Arctic char. However, in Lake Songsjøen fishing was only carried out in the littoral bentic areas. Continued studies in 1985 and 1986 revealed that most Arctic char were caught in floating gill nets in pelagic waters during summer and fall. Also some brown trout were caught in floating gill nets. The immature fish of Arctic char were mainly caught in deeper benthic water using bottom-set gill nets and traps. This show that the catches of both Arctic char and brown trout do not give a representative description of the whole populations.

Finally, the improved growth rate of Arctic char in Lake Øvre Stavåtjønn indicated increased availability of food. This was supported by increased density and individual weight of the larger cladoceran species Holopedium gibbenum and Daphnia galeata. However, in Lake Songsjøen it is no indication of improved food condition for each individual fish. The continued studies in 1985 and 1986 using gill nets of mesh sizes from 12 to 39 mm in all habitats, showed populations of relatively high densities in the order of magnitude of 10000 brown trout and 5000 Arctic char. The calculations of the condition coefficient support that the fishing in Lake Songsjøen did not increase the growth rate for neither brown trout nor Arctic char.

The general management procedure for Norwegian char-trout lakes is to fish with large-meshed gill nets regulated by a lower permissable limit commonly set at a 30-mm mesh size. Use of a smaller mesh size is prohibited. This method of highly selective, high-intensity, gill-net fishing combined with rod and troll fishing (which is probably selecting for active, fast-growing fish) may be the reason for the maintenance of dense stocks of small, sexually mature brown trout and Arctic char in the lakes. This hypothesis is supported by the experiment performed in the lakes Øvre Stavåtjønn and Songsjøen. Therefore, we propose that the management program for char-trout lakes should include an upper mesh size limit of e.g. 29 mm for gill nets as a regulatory measure for populations of Arctic char and brown trout with high natural recruitment capasity.

ACKNOWLEDGEMENT

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Table 1. Catches of Arctic char larger than 15 cm in gill nets of mesh sizes 15.7, 19.6, 22.4 and 26.1 mm in Lake Øvre Stavåtjønn, 1979-1984.

Year	Effort (net-nights)	Number caught	Total weight (kg)	Weight per hectare (kg)	Mean fish weight (g)
1979	58	1.065	71.8	18.0	67
1980	106	899	68.3	17.1	76
1981	128	583	51.6	12.9	89
1982	35	496	36.9	9.2	74
1983	30	259	23.7	5.9	91
1984	14	158	12.1	3.0	76

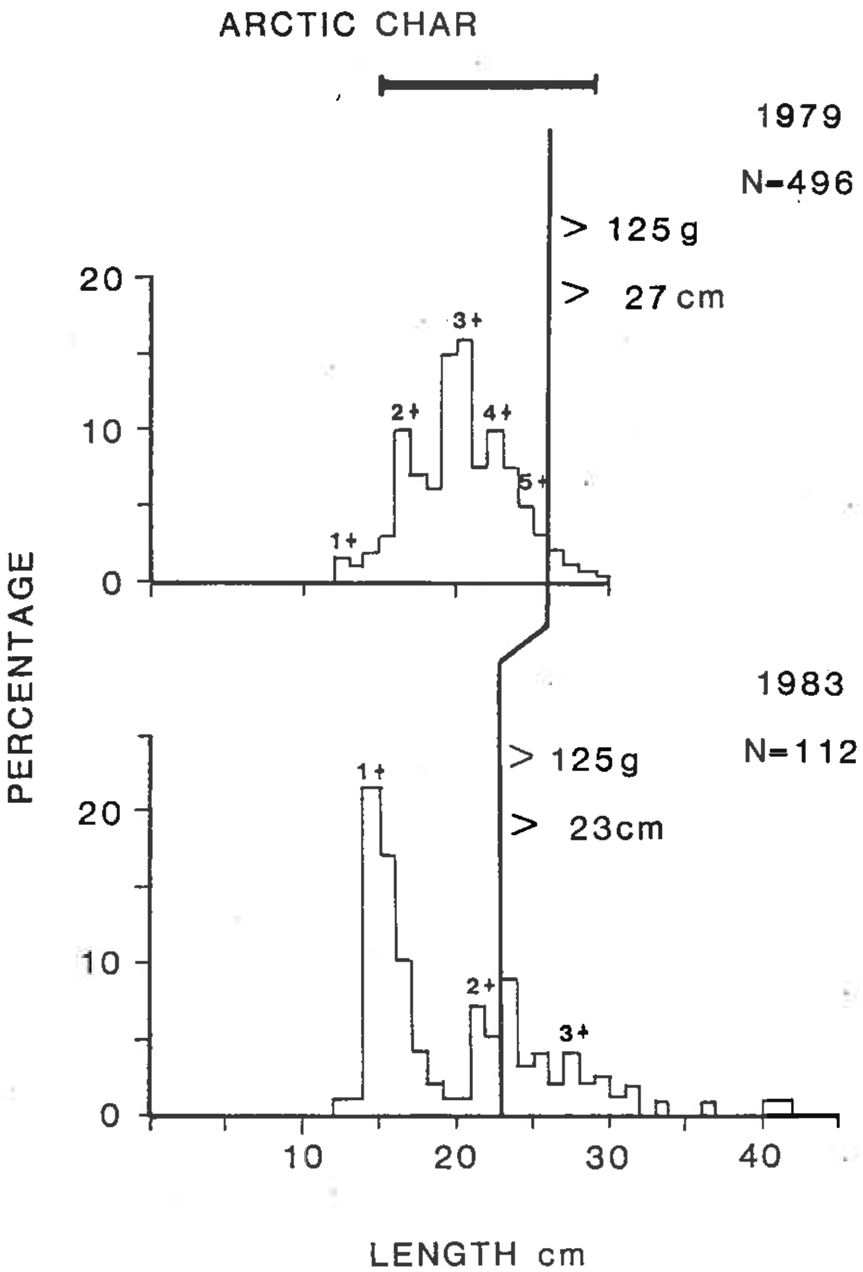
Table 2. Effort, yield, number (N), and weight (W, g) per net (mesh sizes, 22-35 mm) per night (n), weight of the largest fish caught (W_{max}), and mean individual weight ($\overline{W}$) for Arctic char over 125 g in Lake Øvre Stavåtjønn, 1979-1984.

Year	Effort (net nights)	Yield (kg)	Percent of total	N/n	W/n	W_{max}	$\overline{W}$
1979	11	0.7	1	0.5	65	160	143
1980	16	2.1	3	0.8	131	200	174
1981	50	16.8	33	2.0	337	322	168
1982	8	5.4	15	3.5	668	520	191
1983	22	14.6	63	3.4	665	780	195
1984	10	8.8	73	4.8	879	645	183

Table 3. Efforts, number (N), mean individual weight ($\bar{w}$, g) and yield (kg ha^{-1}) of brown trout and Arctic char caught in bottom-set gill nets in Lakes Songsjøen, 1968-1984.

		Brown trout			Arctic char			Yield		
	Efforts	N	$\bar{w}$	yield	N	$\bar{w}$	Yield	kg ha^{-1} (%)		
Year	(net nights)		g	kg		g	kg	Brown trout	Arctic char	Sum
1968	940	1712	141	241	447	109	49	3.4 (83)	0.7	4.1
1969	893	1736	146	253	598	123	74	3.6 (77)	1.1	4.7
1970	674	1180	163	192	572	128	73	2.7 (71)	1.1	3.8
1971	100	428	152	65	174	125	22	0.9 (75)	0.3	1.2
1972	900	1298	148	192	382	123	47	2.7 (79)	0.7	3.4
1973	936	1015	113	115	349	116	41	1.6 (73)	0.6	2.2
1974	884	1344	105	141	629	96	60	2.0 (69)	0.9	2.9
1975	676	1173	109	128	271	97	26	1.8 (82)	0.4	2.2
1976	780	1020	110	112	298	82	24	1.6 (84)	0.3	1.9
1977	936	1288	122	157	266	87	23	2.2 (88)	0.3	2.5
1978	1114	1527	123	188	280	100	28	2.7 (87)	0.4	3.1
1979	862	1020	122	124	387	105	41	1.8 (75)	0.6	2.4
1980	650	777	130	100	173	100	17	1.4 (87)	0.2	1.6
1981	832	526	128	67	189	115	22	1.0 (77)	0.3	1.3
1982	1224	2053	150	308	520	102	53	4.4 (85)	0.8	5.2
1983	559	1864	130	242	1073	92	99	3.5 (71)	1.4	4.9
1984	234	601	127	76	346	80	28	1.1 (73)	0.4	1.5
Mean 17 years			130			105				2.9

Figure 1.



ARCTIC CHAR
1979
N=496
> 125 g
> 27 cm
20
10
0
3+
2+
4+
5+
1+
1983
N=112
> 125 g
> 23cm
20
10
0
1+
2+
3+
10
20
30
40
PERCENTAGE
LENGTH cm

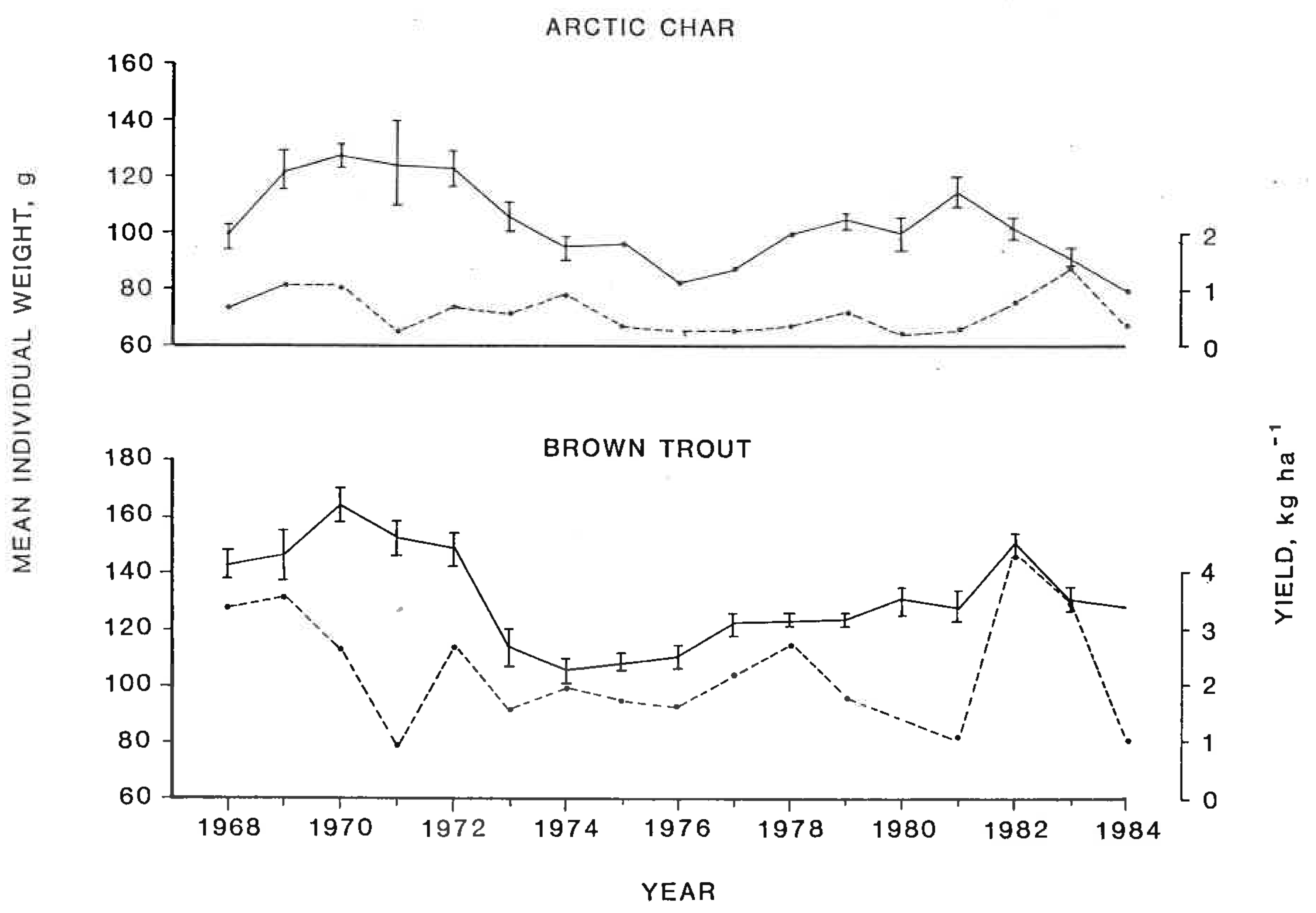
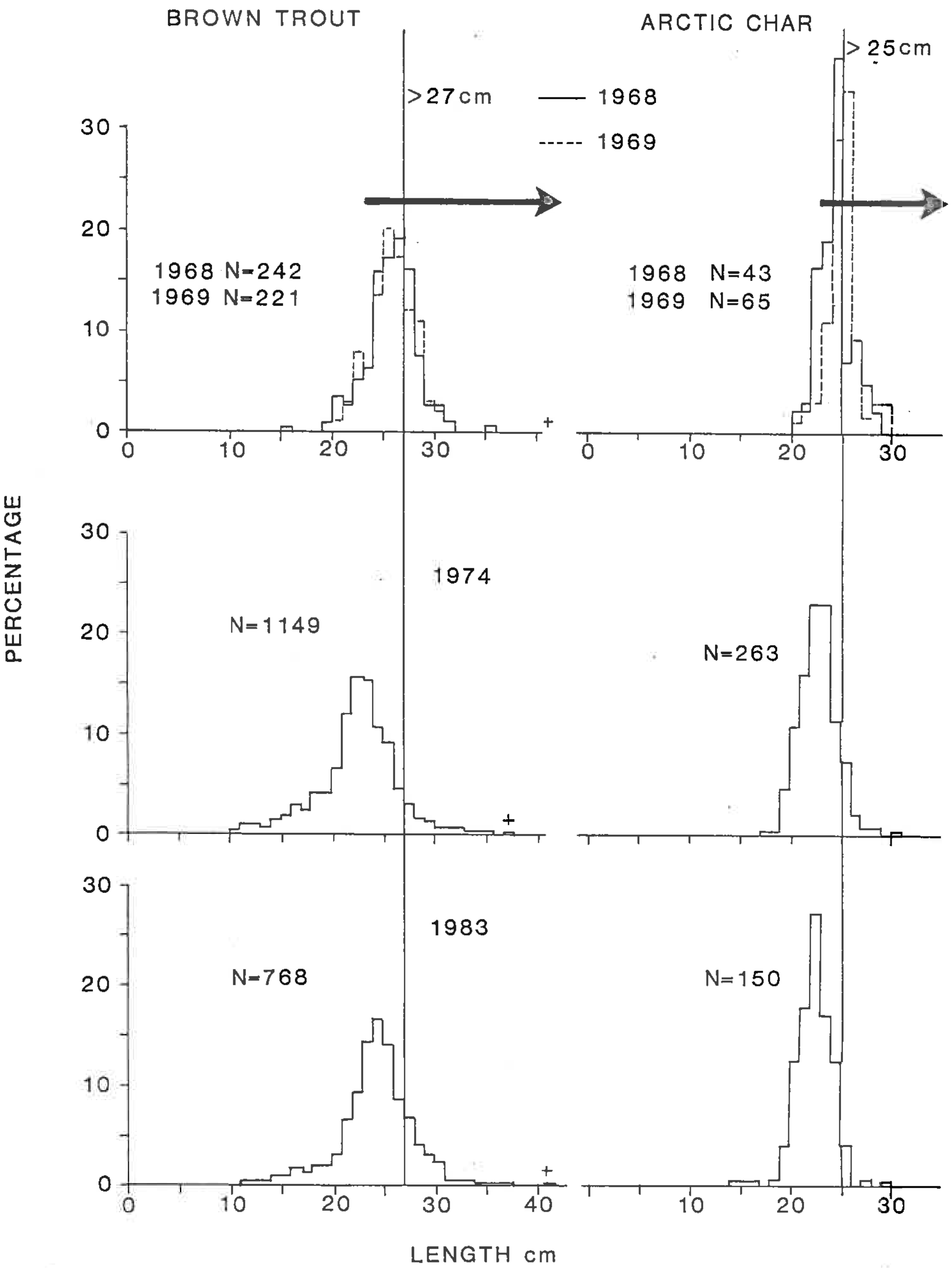

ARCTIC CHAR
BROWN TROUT
MEAN INDIVIDUAL WEIGHT, g
YIELD, kg ha^{-1}
YEAR
160
140
120
100
80
60
180
0
1
2
3
4
1968
1970
1972
1974
1976
1978
1980
1982
1984

Figure 2.

Figure 3.


BROWN TROUT
ARCTIC CHAR
>27cm
>25cm
1968
1969
1968 N=242
1969 N=221
1968 N=43
1969 N=65
1974
N=1149
N=263
1983
N=768
N=150
PERCENTAGE
LENGTH cm

Text of figures

Figure 1. Percent length-frequency distributions (total length, cm) of catches of Arctic char in Lake Øvre Stavåtjønn 1979 and 1983. Ages (years) are shown above the modes. Fish larger than 125 g shown by a vertical line, horizontal line indicate the effect of gill net selectivity on the fish length. N=number of fish.

Figure 2. Mean individual weight (whole line) and yield (kg ha^{-1} stippled line) of Arctic char and brown trout in Lake Songsjøen, 1968-1984. 2 times standard error shown by a vertical line.

Figure 3. Percent length-frequency distributions (total length, cm) of catches of Arctic char and brown trout in Lake Songsjøen, 1968, 1969, 1974, 1983. Fish length of 27 cm (left) and 25 cm (right) shown by a vertical line, horizontal line indicate the effect of gill net selectivity on the fish length. N=number of fish.