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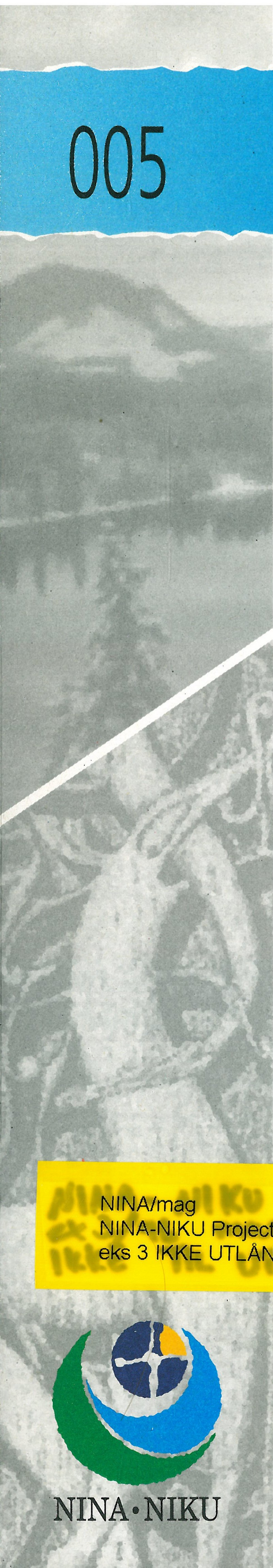
NINA•NIKU
PROJECT REPORT



Endurance of farmed and sea-ranched Atlantic salmon (*Salmo salar*) at spawning

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Referat

Thorstad, E.B., Finstad, B., McKinley, R.S., Økland, F. & Booth, R.K. Utholdenhet hos oppdrettslaks og havbeitelaks (*Salmo salar*) før og under gyting. NINA•NIKU Project Report 005: 1-13.

Formålet med denne undersøkelsen var å analysere utholdenhet hos hanner av oppdrettslaks (59-72 cm) og havbeitelaks (51-65 cm) (*Salmo salar*) i gytetida, samt undersøke om utholdenheten hos havbeitehanner endret seg de siste ukene før gyting. Havbeitehannene i undersøkelsen var signifikant mindre enn oppdrettshannene. Utholdenheten ble testet ved ulike svømmehastigheter i et svømmehastighetsrespirometer. Utholdenheten hos havbeitehannene var den samme 5-8 uker før gyting (n = 20) som i hovedgyteperioden (n = 20). I hovedgyteperioden hadde oppdrettshannene (n = 20) signifikant bedre utholdenhet enn havbeitehannene. Når det ble korrigert for forskjeller mellom havbeitelaksen og oppdrettslaksen i størrelse, fant vi imidlertid ingen signifikante forskjeller i utholdenhet. Gjennomsnittlig kroppsstørrelse varierer mellom villaksstammer, og rømt oppdrettslaks kan være mindre enn, større enn eller like stor som villaksen i ei elv. Resultatene i denne undersøkelsen indikerer at større villaks er bedre konkurrenter til oppdrettslaks enn mindre villaks.

Emneord: svømmehastighetstester - utholdenhet - oppdrettslaks - havbeitelaks.

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Abstract

Thorstad, E.B., Finstad, B., McKinley, R.S., Økland, F. & Booth, R.K. Endurance of farmed and sea-ranched Atlantic salmon (*Salmo salar*) at spawning. NINA•NIKU Project Report 005: 1-13.

The aim of this study was to analyse the endurance of farmed (59-72 cm) and sea-ranched (51-65 cm) Atlantic salmon (*Salmo salar*) males during spawning time, and if the endurance of sea-ranched males changed during the final weeks before spawning. The sea-ranched males in this study were significantly smaller than the farmed males. The fish were endurance tested at different swimming speeds in forced swim trials in a swim speed chamber. Time to fatigue recorded in sea-ranched males did not change from endurance tests 5-8 weeks before peak spawning (n = 20) to endurance tests during the period of peak spawning (n = 20). Sea-ranched males fatigued significantly earlier than the farmed males (n = 20) during spawning time. However, when the size differences between the sea-ranched and the farmed males were corrected for, we found no significant differences in endurance. Mean body size of wild salmon differs between rivers, and escaped farmed salmon may be smaller, or greater, or at the same size as the wild salmon in a river. The results in the present study indicate that wild stocks of a larger size seem to be better in competition with escaped farmed salmon than stocks of a smaller size.

Key words: swim speed tests - endurance - farmed Atlantic salmon - sea-ranched Atlantic salmon.

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Forord

Dette prosjektet har vært et samarbeidsprosjekt mellom Norsk institutt for naturforskning (NINA) og University of Waterloo, Canada. Svømmehastighetsrespirometeret som ble brukt i eksperimentet, er utviklet og bygd i Canada.

Vi vil takke alle som har bidratt økonomisk og praktisk til prosjektet. Staben ved NINA Forskningsstasjon, Ims har vært behjelpelig under oppmontering av respirometeret og utførelse av eksperimentene. Prosjektet ble finansiert av Direktoratet for naturforvaltning (DN), Energiforsyningens Fellesorganisasjon (EnFo), Lotek Engineering Inc., Norsk institutt for naturforskning (NINA), og University of Waterloo. Lorraine Fleming har forberedt den engelskspråklige teksten.

Bildene er tatt av Finn Økland og Bengt Finstad, og Svein T. Nilsen har redigert billedmaterialet.

Bengt Finstad
(Prosjektleder, Norge)

Robert Scott McKinley
(Prosjektleder, Canada)

Trondheim, mai 1996

Preface

This project has been a collaboration between the Norwegian Institute for Nature Research (NINA) and the University of Waterloo, Canada. The swim speed chamber used in this experiment was developed and built in Canada.

We would like to thank all contributors to the project. The staff at NINA Research Station at Ims provided assistance and support during the experiments. Financial support was provided by the Norwegian Directorate for Nature Management (DN), the Norwegian Electricity Federation (EnFo), Lotek Engineering Inc., the Norwegian Institute for Nature Research (NINA) and the University of Waterloo. Lorraine Fleming provided assistance with the English.

The pictures are taken by Finn Økland and Bengt Finstad, and edited by Svein T. Nilsen.

Bengt Finstad
(Project leader, Norway)

Robert Scott McKinley
(Project leader, Canada)

Trondheim, May 1996

Content

1 Introduction

The fish farming industry in Norway has increased rapidly during the last two decades (Tilseth et al. 1991). Large numbers of farmed Atlantic salmon (*Salmo salar*) have accidentally been released, and proportions of 20-38 % of farmed salmon have been recorded in the rivers during spawning time (Lund et al. 1994).

Escaped farmed salmon enter the rivers later than wild salmon during return migration (Eriksson & Eriksson 1991, Gausen & Moen 1991, Gudjonsson 1991, Lund et al. 1991, Økland et al. 1993, McKinell et al. 1994). Spawning of escaped farmed salmon has been confirmed by the presence of synthetic carotenoids in eggs and alevins (Lura & Sægrov 1991, 1993, Webb et al. 1991, 1993, Lura & Økland 1994, Lura 1995). The spawning success of farmed salmon in nature seems reduced compared to wild salmon (Lura & Sægrov 1993, Økland et al. 1995), especially among the males (Jonsson & Fleming 1993). The observed differences between wild and escaped farmed salmon may be related to differences in behaviour, genetics and/or physical fitness (Heggberget et al. 1993). Farmed salmon often have eroded fins and other morphological defects (Lund et al. 1989); they have poor physical conditioning in the net pens and they probably have a higher fat content than wild salmon. Thus, farmed salmon are expected to show a poorer physical performance than wild salmon.

The aim of this study was to compare the endurance of farmed and sea-ranched males during the period of peak spawning. The fish were endurance tested at different swimming speeds in forced swim trials in a swim speed chamber. Sea-ranched males were also endurance tested 5-8 weeks before peak spawning to examine possible changes in endurance during the final weeks before spawning.

2 Material and methods

2.1 The swim speed chamber

Endurance tests were carried out in a Blazka type swim speed chamber, which is characterised by a tube within a tube design (**Figure 1** and described in Booth et al. 1995). The cross sectional diameter of the inner tube is 24 cm and of the outer tube 44 cm. The total volume of the chamber is 120 litres. A propeller driven by a variable speed electric motor (3 hp) connected to an impeller pulls water past the fish in the inner tube. The water is returned to the front of the swim chamber via the outer tube after it is deflected by a domed end cap. Water velocities are rheostatically controlled. Water velocities within the chamber can be generated up to 2.6 $msec^{-1}$ within two seconds (Booth et al. 1995). The edge effect is less than 4 cm at any speed (Booth et al. 1995). During the endurance tests, untreated river water was supplied to the chamber via an external pump.

2.2 Experimental animals

Endurance tests were carried out on sea-ranched males of the Imsa stock salmon and farmed males of the Norwegian NFA strain.

The Imsa salmon were released as smolts in the River Imsa and caught during return migration in a Wolf trap 100 m above the mouth of the river. The River Imsa is situated near the city of Stavanger in Southwestern Norway. The river is 1 km long and mean annual water discharge is 5.1 m^3sec^{-1} (Jonsson et al. 1988). Peak spawning usually takes place during the last three days of November and the first three days of December (Heggberget 1988).

Endurance tests were carried out on 18 adult Imsa males 5-8 weeks before the period of peak spawning in the river (**group 1**), on 20 adult farmed males just prior to peak spawning (**group 2**) and on 20 adult Imsa males during the period of peak spawning (**group 3**).

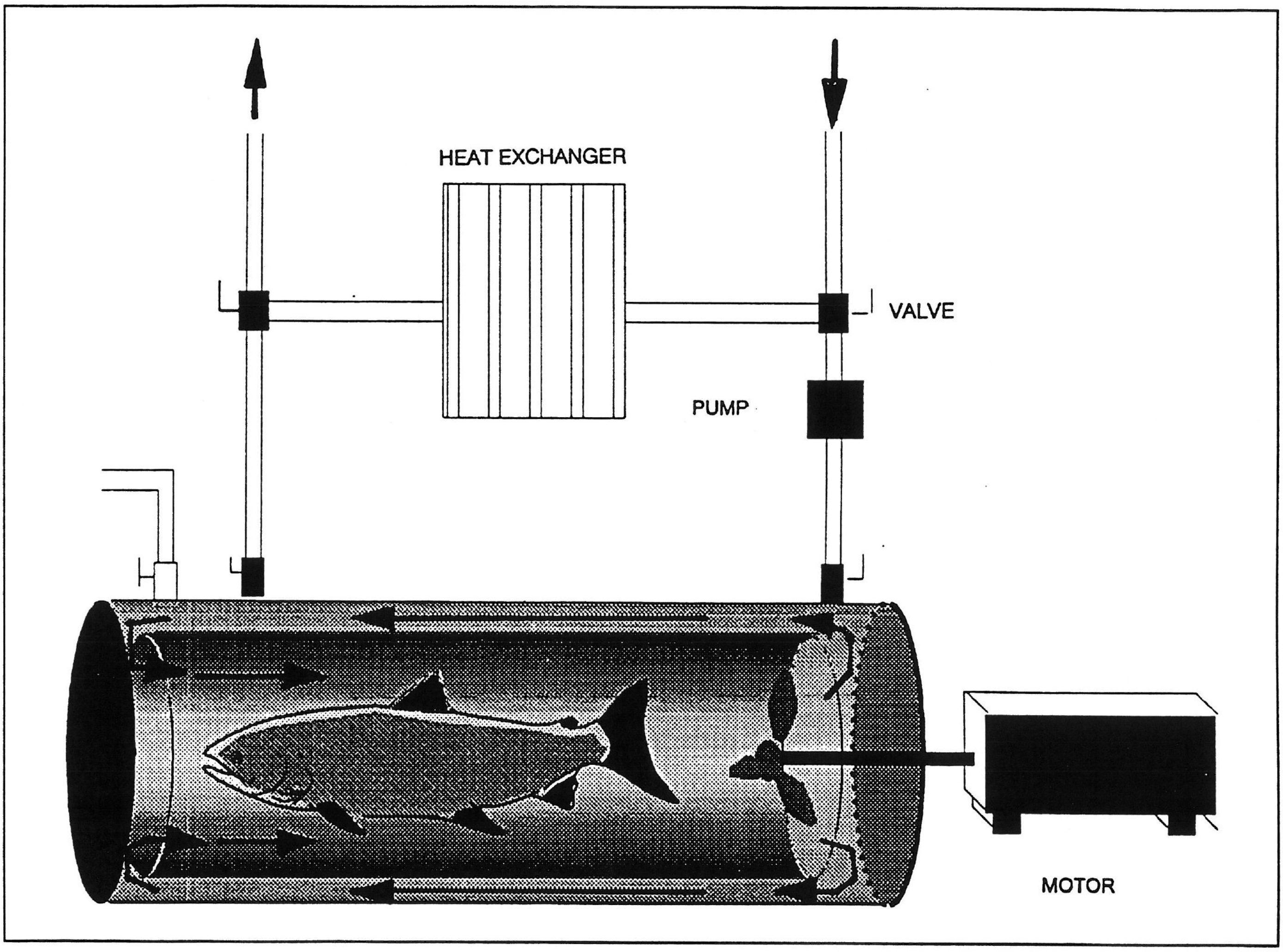

Figure 1.
Illustration of the swim speed chamber used in the present study. Black arrows show the direction of the water flow.

Group 1: The fish were caught in the River Imsa during the period 25 September-16 October (**Appendix 1**). Mean total length of the fish were 57.2 cm (range 51 to 62 cm, SD = 3.5) (Appendix 1). **Group 2**: The fish were brought from a nearby fish farm on 3 October. Mean total length of the fish were 65.7 cm (range 59 to 72 cm, SD = 3.3) (**Appendix 1**). **Group 3:** The fish were caught in the River Imsa during the period 25 September-28 November (**Appendix 1**). Mean total length of the fish were 58.7 cm (range 51 to 65 cm, SD = 3.6) (**Appendix 1**).

The fish were held in 4 000 l holding tanks at the NINA Research Station at Ims until endurance tests were carried out. A current was generated in the holding tanks to avoid degenerating the physical condition of the fish.

2.3 Endurance tests

Individuals were acclimated for two hours in the swim chamber at swimming speed approximately one fish length per second. Endurance tests were initiated by increasing the swimming speed from acclimation speed to test speed within two seconds. Time from reaching the test speed to fatigue was noted. The fish were stimulated to swim during the tests by rapidly decreasing and increasing the speed when the fish was leaning on the downstream screen. The fish were considered fatigued when they failed to leave the downstream screen within four minutes after the last decrease and increase of the swimming speed.

Individual fish within a group were endurance tested only once, except two individuals in group 1 that were tested at two different swimming speeds (**Appendix 1**). Five individuals were included in both group 1 and group 3 (**Appendix 1**).

Group 1: Endurance tests were carried out during the period 6-21 October (**Appendix 1**). Endurance was recorded at the swimming speeds 1.4 ms^{-1} (n = 4), 1.6 ms^{-1} (n = 3), 1.8 ms^{-1} (n = 3), 2.0 ms^{-1} (n = 4), 2.1 ms^{-1} (n = 3) and 2.2 ms^{-1} (n = 3) (corresponds to 2.3-4.2 fish lengths per second) (**Appendix 1**). The water temperatures were in the range of 10.5-12.0 °C both in the holding tanks and in the swim speed chamber.

Group 2: Endurance tests were carried out during the period 15-27 November (**Appendix 1**). Endurance was recorded at the swimming speeds 1.6 ms^{-1}, 1.8 ms^{-1}, 2.0 ms^{-1} and 2.1 ms^{-1} (corresponds to 2.3-3.6 fish lengths per second); five individuals at each speed (**Appendix 1**). The water temperatures were in the range of 4.5-6.4 °C both in the holding tanks and the in swim speed chamber.

Group 3: Endurance tests were carried out during the period 28 November-5 December (**Appendix 1**). Endurance was recorded at the swimming speeds 1.6 ms^{-1}, 1.8 ms^{-1}, 2.0 ms^{-1} and 2.1 ms^{-1} (corresponds to 2.6-4.1 fish lengths per second); five individuals at each speed (**Appendix 1**). The water temperatures were in the range of 4.2-6.2 °C both in the holding tanks and in the swim speed chamber.

3 Results

3.1 Size of the fish

Total length of the fish in group 1 (sea-ranched males before spawning) and group 3 (sea-ranched males during spawning) were not significantly different (Mann-Whitney u-test, $u = 148.5$, $p = 0.16$). Total length of the fish in group 3 were significantly smaller than total length of the fish in group 2 (farmed males during spawning) (Mann-Whitney u-test, $u = 11.0$, $p < 0.001$).

3.2 Endurance tests

Time to fatigue recorded in the sea-ranched males did not change from endurance tests 5-8 weeks before the period of peak spawning to endurance tests during the period of peak spawning (**Figure 2**). The water temperatures were significantly higher 5-8 weeks before spawning than during the period of peak spawning (Mann-Whitney u- test, $u = 0.0$, $p < 0.001$).

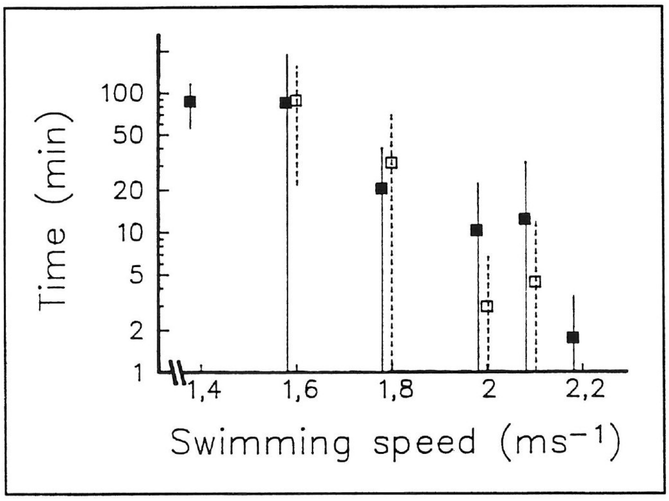

Figure 2.
*Mean fatigue time of sea-ranched Atlantic salmon (*Salmo salar*) (51-65 cm) during forced swim trials in a swim speed chamber 5-8 weeks before the period of peak spawning (**group 1**, filled markers) and during the period of peak spawning (**group 3**, open markers). The lines give the standard deviations. In **group 1** four individuals were tested at each of the swimming speeds 1.4 ms^{-1} and 2.0 ms^{-1}, and three individuals at each of the swimming speeds 1.6 ms^{-1}, 1.8 ms^{-1}, 2.1 ms^{-1} and 2.2 ms^{-1} (water temperatures were in the range 10.5-12.0 °C). **In group 3** five individuals were tested at each of the swimming speeds 1.6 ms^{-1}, 1.8 ms^{-1}, 2.0 ms^{-1} and 2.1 ms^{-1} (water temperatures were in the range 4.2-6.4 °C).*

The sea-ranched males fatigued earlier than the farmed males (Mann-Whitney u-test, $u = 89.0$, $p = 0.0026$) (**Figure 3**). However, when swimming speed were expressed as fishlengths per second (**Figure 4**) no differences were found between sea-ranched and farmed salmon (Mann-Whitney u-test of fish at swimming speeds 2.5-3.0 lengthsec^{-1}: sea-ranched males $n = 7$, farmed males $n = 8$, $u = 17.0$, $p = 0.20$. Mann-Whitney u-test of fish at swimming speeds 3.0-3.5 lengthsec^{-1}: sea-ranched males $n = 8$, farmed males $n = 7$, $u = 16.0$, $p = 0.16$).

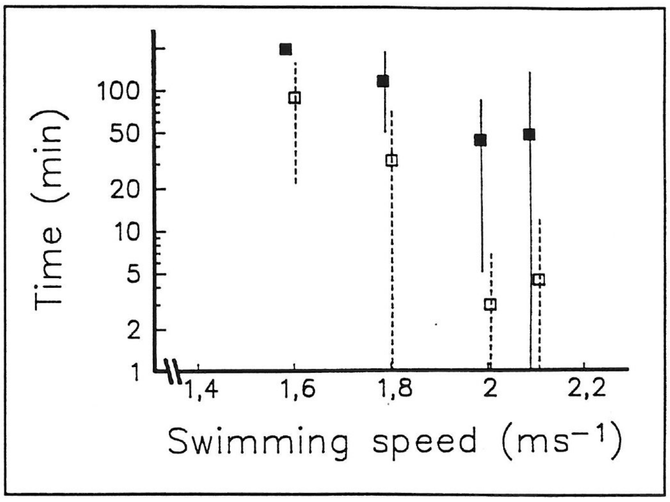

Figure 3.
*Mean fatigue time of farmed (**group 2**, filled markers) and sea-ranched (**group 3**, open markers) Atlantic salmon (*Salmo salar*) during forced swim trials in a swim speed chamber. The lines give the standard deviations. Five individuals of each group were tested at each swimming speed just prior to and during the period of peak spawning (water temperatures were in the range 4.2-6.4 °C). Total length of the fish in **group 2** were in the range 59 to 72 cm, and total length of the fish in **group 3** were in the range 51 to 65 cm.*

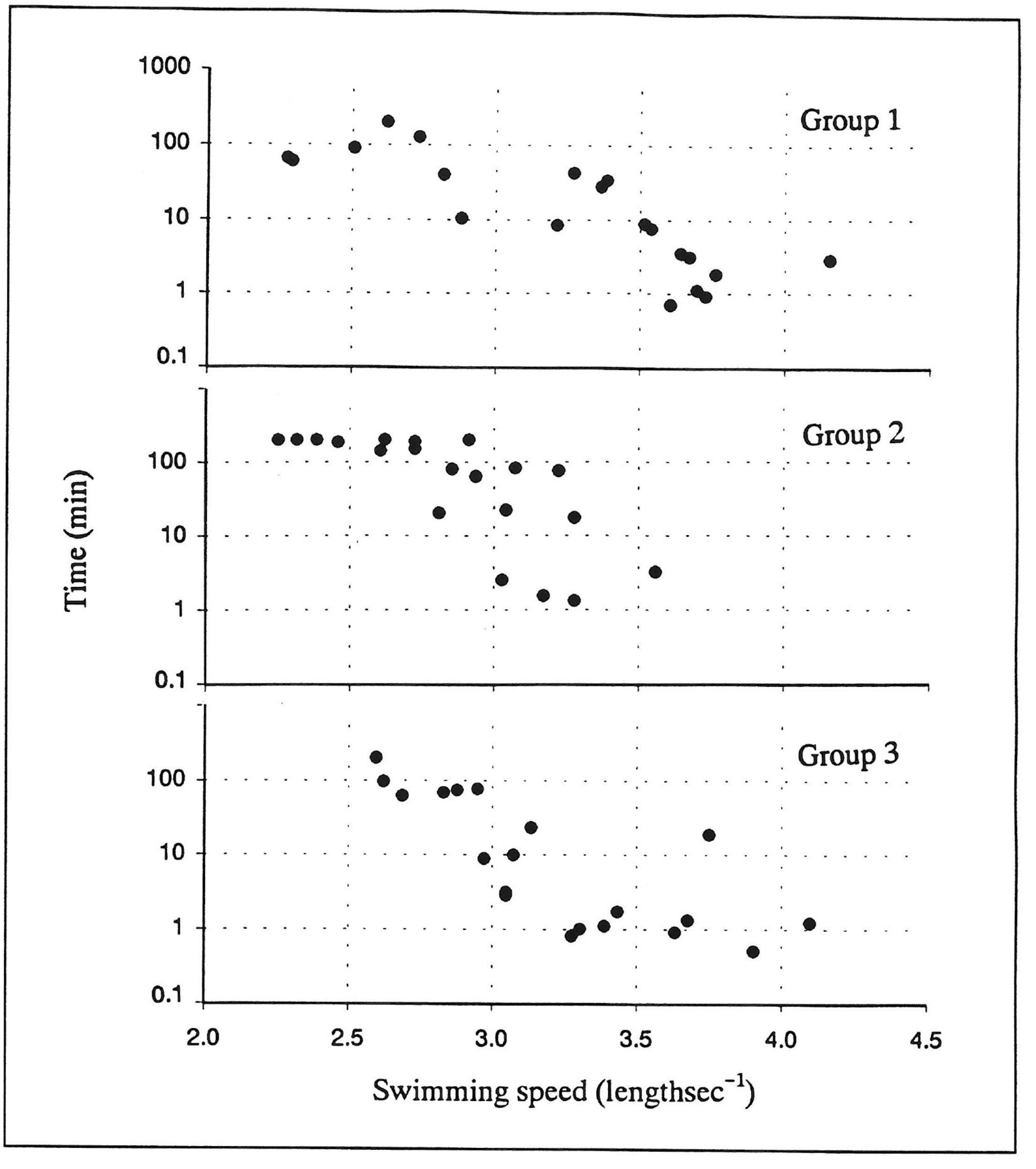

Figure 4.
*Fatigue time of individual Atlantic salmon (*Salmo salar*) during forced swim trials in a swim speed chamber. Swimming speeds are expressed as fish lengths per second. Sea-ranched males (51-65 cm) were endurance tested 5-8 weeks before the period of peak spawning (**group 1**, n = 20, water temperatures were in the range 10.5-12.0 °C) and during the period of peak spawning (**group 3**, n = 20, water temperatures were in the range 4.2-6.2 °C). Farmed males (59-72 cm) were endurance tested just prior to peak spawning (**group 2**, n = 20, water temperatures were in the range 4.5-6.4 °C).*

4 Discussion

Sea-ranched males fatigued significantly earlier than farmed males in forced swim trials during the period of peak spawning. Physical conditioning prior to measuring endurance usually influences the results in endurance experiments (Beamish 1978). Reimers (1956) found that fatigue times of unconditioned hatchery-reared rainbow trout (*Oncorhynchus mykiss*) forced to swim in a flume were significantly less than those of stream conditioned trout. Unexercised young coho salmon (*O. kisutch*) were found to fatigue earlier and had lower prolonged swimming speeds than physically conditioned individuals (Brett et al. 1958). Hammond & Hickman (1966) found that conditioning rainbow trout resulted in a marked increase in time required to fatigue fish subjected to strenuous exercise. The sea-ranched salmon in the present study were caught when returning from feeding in the ocean, and the farmed salmon were collected from net pens in a fish farm. Thus, the sea-ranched salmon were more conditioned than the farmed salmon and were expected to perform better in the endurance tests. A higher fat content may also reduce the endurance of farmed salmon. Vincent (1960) and Green (1964) found that wild stocks of brook trout (*Salvelinus fontinalis*) out-performed domestic stocks in stamina tests. Both attributed the domestic stock's poorer performance to their higher fat content.

The farmed salmon in this study were significantly larger than the sea-ranched salmon. Size is one of the most important constraints on performance capacity, and the relationship between body length and swimming speed varies among species, swimming speeds and size groups of the fish (Beamish 1978). When it is not practical to determine the precise relationship, the swimming speed expressed as fish lengths per second sometimes allows for comparison of fish of different lengths (Bainbridge 1958, Beamish 1978). When swimming speeds in the present study were expressed as fish lengths per second, we found no significant differences in endurance between sea-ranched and farmed salmon.

For a precise measurement of swimming speed in a swim speed chamber it is necessary to correct for the blocking effect that arises, because the fish are narrowing the water channel (Bell & Terhune 1970, Smit et al. 1971). The blocking effect results in an accelerated water flow over the fish body, and an increased cross sectional area of the fish leads to increased water velocity over the fish. The blocking effect can be accounted for by a correction of 7.5-15 %, depending on the size of the fish (Beamish 1978). We did not correct for the blocking effect in this study, thus, the swimming speeds were actually higher than stated. The observed differences between farmed and sea-ranched salmon were also greater than stated, because the farmed males were larger than the sea-ranched males.

The endurance tests were carried out during the period of peak spawning in the River Imsa. Both the sea-ranched and the farmed salmon were mature enough to spawn in the year of the experiment. The observed differences in endurance may be a result of differences in step of maturity. However, sea-ranched salmon were endurance tested also 5-8 weeks before the period of peak spawning, and performance did not change until peak spawning - even if the temperatures were higher 5-8 weeks before than during the period of peak spawning.

The present study indicates that differences between wild and escaped farmed salmon males in migratory and spawning behaviour are not a consequence of poor performance of farmed salmon in activities of prolonged swimming. When comparing endurance of wild and farmed salmon, differences in body size seem to be of great importance. We found that the sea-ranched males fatigued earlier than the farmed males, but we found no significant differences in endurance between the two groups of fish when we corrected for differences in body size. Mean body size of wild salmon differs between rivers, and escaped farmed salmon may be smaller, or greater, or at the same size as the wild salmon in a river. The results in the present study indicate that wild stocks of a larger size seem to be better in competition with escaped farmed salmon than stocks of a smaller size.

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Appendix 1

Atlantic salmon endurance tested in forced swim trials in a swim speed chamber. **Group 1**: sea-ranched males endurance tested 5-8 weeks before the period of peak spawning, ***group 2***: farmed males endurance tested just prior to peak spawning, ***group 3***: sea-ranched males endurance tested during the period of peak spawning.

Fish no.	Length (cm)	Group	Date of catch	Date of endurance test	Swimming speed (msec^{-1})	Endurance (min)
NZ058914	61	1	10.10	20.10	1.4	59.8
NZ041443	62	1	27.09	18.10	1.4	65.1
NZ058134	56	1	16.10	20.10	1.4	89.0
NZ059714	51	1	10.10	21.10	1.4	125.4
NZ060817	56	1	25.09	13.10	1.6	10.4
NZ054443	57	1	09.10	17.10	1.6	39.8
NZ051183	61	1	27.09	06.10	1.6	200.0
NZ053115	56	1	27.09	08.10	1.8	8.4
NZ059714	51	1	10.10	13.10	1.8	8.7
NZ058466	55	1	26.09	17.10	1.8	41.9
NZ058134	56	1	16.10	16.10	2.0	1.8
NZ051240	55	1	02.10	07.10	2.0	3.5
NZ059053	57	1	04.10	06.10	2.0	7.5
NZ054782	59	1	10.10	11.10	2.0	27.5
NZ056259	58	1	10.10	18.10	2.1	0.7
NZ051469	51	1	09.10	14.10	2.1	2.8
NZ051888	62	1	26.09	07.10	2.1	33.2
NZ053015	59	1	26.09	17.10	2.2	0.9
NZ053101	60	1	16.10	18.10	2.2	1.1
NZ054261	60	1	10.10	18.10	2.2	3.1
1	65	2	-	25.11	1.6	182.6
2	61	2	-	19.11	1.6	200.0
3	69	2	-	20.11	1.6	200.0
4	67	2	-	26.11	1.6	200.0
5	71	2	-	27.11	1.6	200.0
6	64	2	-	24.11	1.8	20.0
7	63	2	-	18.11	1.8	77.9
8	69	2	-	25.11	1.8	141.1
9	66	2	-	23.11	1.8	148.7
10	66	2	-	24.11	1.8	187.0
11	63	2	-	18.11	2.0	1.5
12	66	2	-	19.11	2.0	2.5
13	68	2	-	20.11	2.0	62.9
14	62	2	-	27.11	2.0	74.0
15	65	2	-	21.11	2.0	80.0
16	64	2	-	21.11	2.1	1.3
17	59	2	-	26.11	2.1	3.2
18	64	2	-	17.11	2.1	17.0
19	69	2	-	26.11	2.1	21.6
20	72	2	-	20.11	2.1	200.0

Appendix 1 continues

Fish no.	Length (cm)	Group	Date of catch	Date of endurance test	Swimming speed (msec^{-1})	Endurance (min)
NZ041622	51	3	26.09	28.11	1.6	23.0
NZ053101	60	3	16.10	28.11	1.6	60.7
NZ059053	57	3	04.10	28.11	1.6	67.8
NZ059133	61	3	26.09	29.11	1.6	96.1
NZ058432	62	3	10.10	30.11	1.6	200.0
NZ053015	59	3	26.09	01.12	1.8	2.8
NZ043019	59	3	25.09	30.11	1.8	3.0
NZ059297	61	3	16.10	01.12	1.8	8.8
NZ058185	63	3	27.09	01.12	1.8	72.5
NZ058914	61	3	10.10	02.12	1.8	75.2
NZ043956	61	3	28.11	30.11	2.0	0.8
NZ051169	61	3	06.10	29.11	2.0	1.0
NZ049812	59	3	26.09	03.12	2.0	1.1
NZ056259	58	3	10.10	03.12	2.0	1.7
NZ059443	65	3	27.09	01.12	2.0	9.9
NZ055329	54	3	07.11	04.12	2.1	0.5
NZ051511	58	3	02.10	05.12	2.1	0.9
NZ059194	51	3	28.09	04.12	2.1	1.2
NZ059424	57	3	10.10	05.12	2.1	1.3
NZ044365	56	3	09.10	04.12	2.1	18.5

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