NINA•NIKU
007
PROJECT REPORT

A comparative study of life histories of Atlantic salmon in two Norwegian and two Russian rivers

Arne J. Jensen
Alexander Zubchenko
Nils Arne Hvidsten
Bjørn Ove Johnsen
Evgeni Kashin
Oleg Kuzmin
Tor F. Næsje

NINA•NIKU
Foundation for Nature Research and Cultural Heritage Research

A comparative study of life histories of Atlantic salmon in two Norwegian and two Russian rivers

Arne J. Jensen
Alexander Zubchenko
Nils Arne Hvidsten
Bjørn Ove Johnsen
Evgeni Kashin
Oleg Kuzmin
Tor F. Næsje

Foundation for Nature Research and Cultural Heritage Research

Norwegian Institute for Nature Research (NINA) and Norwegian Institute for Cultural Heritage Research (NIKU) issue the following publication in English:

NINA-NIKU Project Report
This series presents the results of both institutes' projects when the results are to be made available in English. The series may include reports on original research, literature reviews, analysis of particular problems or subjects, etc. The number of copies printed will depend on demand.

In addition to this report series published in English, NINA-NIKU publish the following series in Norwegian:

NINA Fagrapport (Scientific Report)
NIKU Fagrapport (Scientific Report)

NINA Oppdragsmelding (Assignment Report)
NIKU Oppdragsmelding (Assignment Report)

NINA Temahefte (Topic Report)
NIKU Temahefte (Topic Report)

NINA Faktaark (Fact Sheet)
NIKU Faktaark (Fact Sheet)

In addition, NINA's and NIKU's staff publish their research results in international scientific journals, symposia proceedings, popular science journals, books, newspapers, and other relevant publications. NINA-NIKU also has a WWW home page: http://www.nina.no

Jensen, A.J., Zubchenko, A., Hvidsten, N.A., Johnsen, B.O., Kashin, E., Kuzmin, O. & Næsje, T.F. 1997. A comparative study of life histories of Atlantic salmon in two Norwegian and two Russian rivers. - NINA•NIKU Project Report 007: 1-44.

Trondheim, June 1997

ISSN 0807-3082
ISBN 82-426-0825-3

Management field:
Sustainable yield, fish

Editor:
Tor G. Heggberget
NINA•NIKU, Trondheim

Layout and design
Synnøve Vanvik

Stock: 350

Contact address:
NINA
Tungasletta 2
7005 Trondheim
Tlf: 73 58 05 00
Fax: 73 91 54 33

Availability: Open

Project no.: 13210 Lakseforskning, Norge - Russland

Signature of personal responsible:

Assignment for:

The Directorate for Nature Management, Norway

Abstract

Jensen, A.J., Zubchenko, A., Hvidsten, N.A., Johnsen, B.O., Kashin, E., Kuzmin, O. & Næsje, T.F. 1997. A comparative study of life histories of Atlantic salmon in two Norwegian and two Russian rivers. NINA·NIKU Project Report 007: 1-44.

This report presents results from a joint research program between the Polar Institute of Marine Fisheries and Oceanography (PINRO) and The Norwegian Institute for Nature Research (NINA). The main goal of this program has been a comparative study of life histories of Atlantic salmon in four rivers, two Russian (the Rivers Varzuga and Kola) and two Norwegian (the Rivers Alta and Orkla). Growth, density and heavy metal analyses of parr, strategies during smolt migration, and growth and age structure of adult salmon have been included. Results from 1993-1995 are presented.

The four rivers are among the most important salmon rivers in Norway and northern Russia. Annual average catches of 9, 13, 25 and 72 tonnes have been reported in the Rivers Orkla, Alta, Kola and Varzuga, respectively. However, spawning runs and catches have been influenced by several factors, like hydropower development, mining industry, variable exploitation rates in the sea, and temperature conditions at sea.

The estimated densities of Atlantic salmon parr were higher in the two Norwegian than the two Russian rivers, while annual growth rate seemed to be highest in the two Russian rivers. However, variations in density estimates were large among years in all rivers.

The mean smolt age of Atlantic salmon was approximately three years in the River Varzuga, 3.5 years in the Rivers Kola and Orkla, and slightly less than four years in the River Alta. The mean size of smolts was about 10 cm in the River Varzuga, 13 cm in the Rivers Alta and Orkla, and 15 cm in the River Kola. The smolt age reflects a combination of annual growth rate and smolt size. The low smolt age in the River Varzuga is probably a result of high annual growth rate and smaller smolt size than in the other rivers. Similarly, the annual growth rate of salmon parr in the River Kola is higher than in the two Norwegian rivers. However, because of the large smolt size, the mean smolt age is similar to that in the River Orkla.

The mean concentrations of heavy metals in Atlantic salmon parr in the Rivers Varzuga, Kola and Alta were usually within the range of concentrations observed in uncontaminated areas. Also at the uppermost location in the River Orkla similar low concentrations were observed. However, at the location downstream from the confluence with the River Raubekken, which drains the Løkken mines, concentrations of cadmium, copper and selenium where high, especially in the parr livers. In contrast to the other rivers, concentrations of nickel and arsenic were higher than the detection limits in the River Kola.

Smolt migration in the Rivers Varzuga, Kola and Alta occurred at the same time and five weeks later than in the River Orkla. Several proximate triggers seemed to regulate smolt descent, but in different combinations in each river. Increasing water flow is the most important proximate trigger in the River Orkla. In the River Alta small increases in discharge can initiate smolt migration, while in the River Varzuga smolt descent is inhibited by increased water discharge. In the Rivers Varzuga and Alta water temperatures were higher than in the River Orkla during smolt migration. In the River Varzuga peak migration occurred during periods with 14 °C or greater, in the River Alta the smolt migrated at 10 °C, while in the River Orkla most smolts descended at temperatures between 2 and 8 °C. Smolt migration occurred during daytime in the River Varzuga; in the River Alta smolt descent occurred both day and night; and in the River Orkla the smolts migrated at night. The main smolt run in the Rivers Varzuga and Alta occurred at increasing moon phases, peaking at new and full moon.

The River Varzuga is mainly a grilse river. Most fish, i.e. more than 90 % of both males and females, returned to the river after only one winter at sea. Also in the other rivers most males were grilse. However, in the other rivers females were usually 2SW or 3SW fish. The River Varzuga is the most abounding of the four rivers in water, and hence, river discharge can hardly explain the large proportion of grilse in the river. The sea-age composition of the River Alta salmon is different. In this river most males are grilse, while most females are 3SW fish.

The seasonal run dynamics in the River Varzuga differ from the other rivers. There are two peaks in migration of Atlantic salmon, one during summer and one during autumn. Almost all fish entering the river later than 20 August are immature. The autumn run usually contributes to about 70 % of the total annual run. It is supposed that immature Atlantic salmon migrating during autumn stay in the river during the whole winter and also the next summer without feeding, and then spawn during September. This life history should be more thoroughly investigated.

Key words: Atlantic salmon - Norway - Russia - population structure - catch - growth - smolt migration - heavy metals.

Arne J. Jensen, Nils Arne Hvidsten, Bjørn Ove Johnsen and Tor F. Næsje, Norwegian Institute for Nature Research (NINA), Tungasletta 2, N-7005 Trondheim, Norway.
Alexander Zubchenko, Evgeni Kashin and Oleg Kuzmin, Knipovich Polar Institute of Marine Fisheries and Oceanography (PINRO), 6, Knipovich Street, 183763 Murmansk, Russia.

Preface

The Norwegian Directorate For Nature Management (DN), with reference to the Russian-Norwegian Environmental Commission, invited the Polar Institute of Marine Fisheries and Oceanography (PINRO) to participate in a joint Russian-Norwegian research program on anadromous fish on 25 June 1992. The Norwegian Institute for Nature Research (NINA) was proposed as the Norwegian institution to participate in the joint project. PINRO gave a positive answer in a letter dated 9 July 1992. NINA invited three scientists from PINRO to visit Norway in August 1992, with a return visit to PINRO at the Kola Peninsula in September the same year. During these meetings, a Protocol of Intents between PINRO and NINA was signed, and a proposal for a joint research program was formed and sent to DN for funding.

Since 1993, this joint program has been subordinated to the Russian-Norwegian Working Group on the Marine Environment of the Barents Region, which is subordinated to the Russian-Norwegian Environmental Commission.

Due to existing large survey programs, the Rivers Orkla, Alta, Kola and Varzuga were chosen as study rivers. Hence, extra costs to carry out field sampling have been considerably reduced. We are grateful for the permission to use the comprehensive data from these four rivers in this report, and we thank all those persons who have participated in the field work and preparation of data.

Oleg Kuzmin and Arne J. Jensen have been the Russian and Norwegian project leaders, respectively, while Alexander Zubchenko (PINRO) and Nils Arne Hvidsten and Bjørn Ove Johnsen (NINA) have taken part in the project meetings. Oleg Kuzmin died 31 August 1996. After that, Alexander Zubchenko took over as the Russian project leader, and Evgeni Kashin (PINRO) was also involved in the project. Two project meetings have been arranged each year, and interpreter Elena Samoilova (PINRO) has played an important role in these meetings.

We are grateful for the financial support from DN during these years.

Trondheim and Murmansk, February 1997

Arne J. Jensen   Alexander Zubchenko

Contents

1 Introduction

Concern over the future of the Atlantic salmon, *Salmo salar*, was expressed more than 100 years ago (see MacCrimmon & Gots 1979), and the nominal catches of Atlantic salmon throughout its distribution area on both sides of the Atlantic ocean have continued to decline during the last 25 years (Anon. 1996). Reductions in populations may be closely linked with changes within home rivers, especially the loss of spawning and nursery grounds, resulting from a variety of human activities. Most evident among the human impacts are the presence of dams and chemical pollutants that have prevented access of adult fish to former breeding and smolt production areas (MacCrimmon & Gots 1979). Also atmospheric pollution (Watt et al. 1983, Hesthagen & Hansen 1991), deforestation, mining (Sorensen 1991), and in later years the aquaculture industry (Hansen et al. 1991, Heggberget et al. 1993, Heggberget 1996) have been a threat to the wild salmon.

While several Atlantic salmon populations in southern Europe have declined during this century, some of the richest populations are still found in Norway and northern Russia. In Norway, salmon is still present in 594 rivers (Anon. 1995), and 127 rivers with salmon are found in northern Russia (Kazakov et al. 1993). Therefore, Norway and Russia have a special responsibility to the international community to care for their salmon resources.

Because of the several threats to salmon populations, it is important to carry out survey programs in the most significant rivers. Such programs are in progress in both countries. However, some of the methods and equipment in use differ. Therefore, it was most useful both for NINA and PINRO to exchange knowledge and technology about the respective countries salmon surveys, in addition to treatment of material and data. The aims of the joint program have been: 1) to exchange knowledge and technology about surveys in Atlantic salmon rivers, and handling of material, including harmonising of methods and equipment, 2) to survey selected Atlantic salmon populations to get information about changes in population size and composition, which may indicate changes in the environment, 3) to obtain information about parasites on Atlantic salmon, especially *Gyrodactylus salaris* and salmon lice. Since 1995 the Russian Academy of Science, Karelian Research Centre, Petrozavodsk, has also been included in the joint research on *G. salaris*.

The main goal with this program has been a comparative study of the life history of Atlantic salmon in four rivers, two Russian (the Rivers Varzuga and Kola) and two Norwegian (the Rivers Alta and Orkla). Growth, density and heavy metal analyses of parr, strategies during smolt migration, and growth and age structure of adult salmon have been included. Results from 1993-1995 are presented in this report.

2 Study areas

The present study was carried out in four rivers with Atlantic salmon: the Rivers Varzuga and Kola in Russia and the Rivers Alta and Orkla in Norway (**Figure 1**). These rivers were chosen due to their existing large surveying programs. In this way sampling costs were kept to a minimum. During this study, we harmonised methods and equipment both during field studies and in handling of material and data.

2.1 River Varzuga

The River Varzuga is the second longest salmon river (next to the River Ponoy) on the Kola Peninsula. It originates in Varzugskoe Lake located in the south-eastern part of the peninsula and drains into the White Sea in the vicinity of the village of Kuzomen (**Figure 2**). There are two villages on the River Varzuga: Varzuga and Kuzomen. Kuzomen is located close to the outlet of the river, and the village of Varzuga is located 24 km upstream. The position of the headwaters is 67°06' N and 36°38' E, and the outlet of the river is located at the White sea at 66° 16' N and 36° 58' E. The catchment area consists of 3 % lakes, 50 % wetlands and 45 % forest. More than 20 tributaries join the River Varzuga. The biggest are the Rivers Pana (114 km), Kitsa (51 km), Polisarka (secondary tributary, 42 km), Yoziya (41 km), Serga (38 km), and Indel (secondary tributary, 23 km). The catchment area of the River Varzuga in the north borders the catchment of the River Voronja, in the west the River Umba catchment area, and in the north-east and east the catchment areas of the Rivers Ponoy and Strelna. The length of the River Varzuga is 254 km, and the drainage area is about 9836 km^2. The mean water discharge near the village of Varzuga is 76.5 m^3s^{-1}.

The drainage area of the River Varzuga is a marshy tundra, plain with occasional heights. Vegetation is dominated by moss (reindeer moss), Arctic birch and shrubs. On some locations, primarily on heights, coniferous trees can be found. Surface soils are represented by peat and sand, occasionally by rocks. The river is meandering, branchy and riffled. The river often splits into branches with sandy islands covered with water during floods. In the upper stretches of the river, shoals and small riffles of 25-40 m predominate, and in the middle stretches, large pools become more common and some large rapids are found. Large rapids are especially frequent in the lower stretches. There are 13 large rapids, of which Sukhoi Iovsa Rapid is 3 km long. River width is 2-6 m at headwaters. It increases to 20-40 m in the upper stretches, 60-150 m in the middle stretches and to 200 m in the lower stretches. On the lower 20 km stretch, the river width is 300-400 m, and at some locations up to 600-800 m. Depth in pools are 2.0-3.0 m, and at rapids and shoals 0.3-0.8 m.

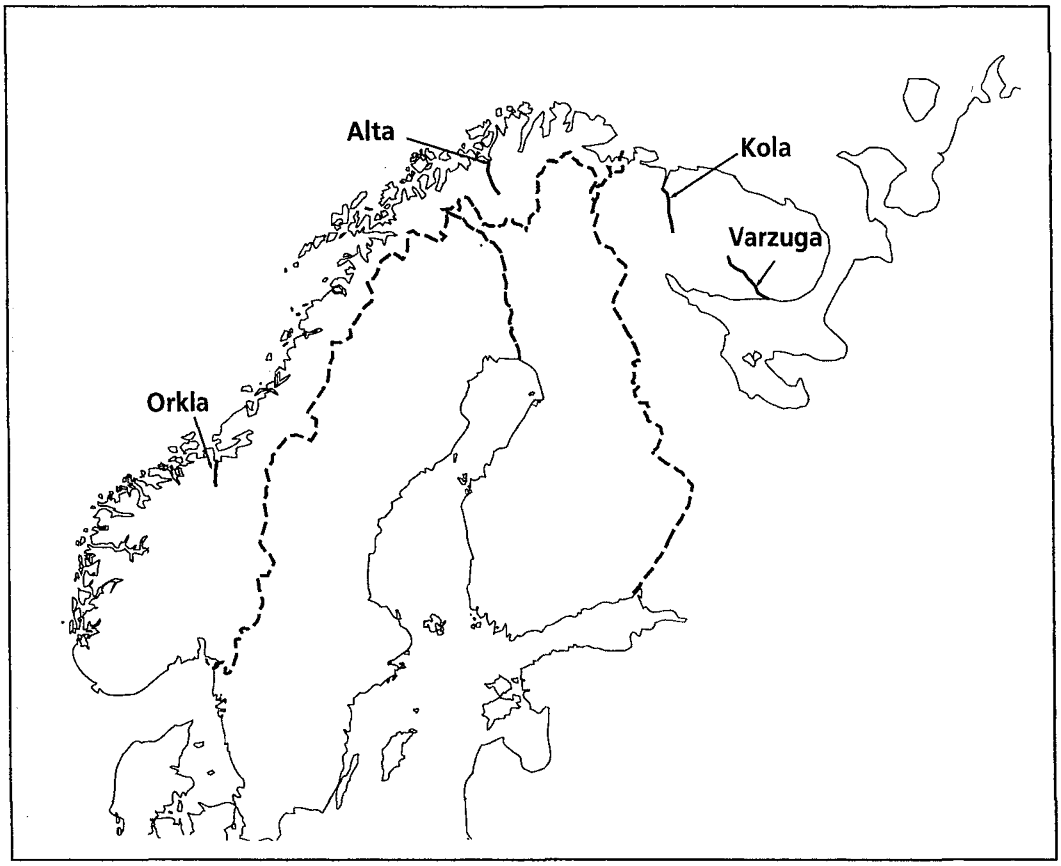


***Figure 1**. Map of Norway and northern Russia, with the locations of the four rivers*

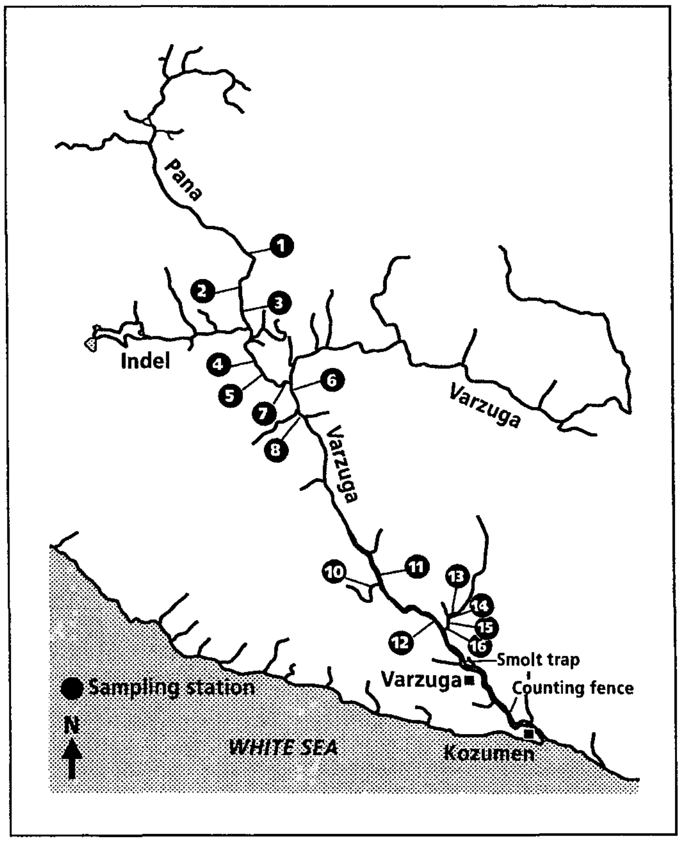


***Figure 2**. Map of the River Varzuga, with locations of the counting fence, smolt trap, and sampling stations for presmolt Atlantic salmon.*

The yearly variations in water level are characterised by a spring flood, low water levels during summer, an autumn freshet and low water levels in the second half of winter (**Figure 3**). A spring flood normally occurs in May and June and lasts for 15-40 days with the highest water levels of 2.0-2.5 m in the upper part and 3.0-3.5 m in the lower part of the river. The lowest water level during summer is most often observed in July and occasionally interrupted by rain freshets of 10 to 30 days duration. The highest water level in this period is 0.5-1.5 m. During frost the water level can be quite unsteady and rise by 0.3-1.0 m. In early January a steady period begins with low water levels. The river freezes in October-November. Rapids and shoals become covered with ice 20-40 days later than pools. Rough rapids freeze only during the most severe winters. Bottom ice may form on riffled stretches. On pools the ice cover is plane, and by the end of winter it is as thick as 50-80 cm. Ice break-up occurs in May. The ice drift lasts from 3 to 10 days. The major part of the ice thaws before break-up. The water temperature rises rapidly during May, and increases to a maximum of about 17 °C in July (**Figure 4**).

Figure 3. Annual water flow regime (m³/s) in the River Orkla at Syrstad (1983-1994), the River Alta at Kista (1990-1995), the River Kola at the site «1429 km» (1988-1|993) and the River Varzuga at the village of Varzuga (1980-1985). Mean values for ten day intervals.

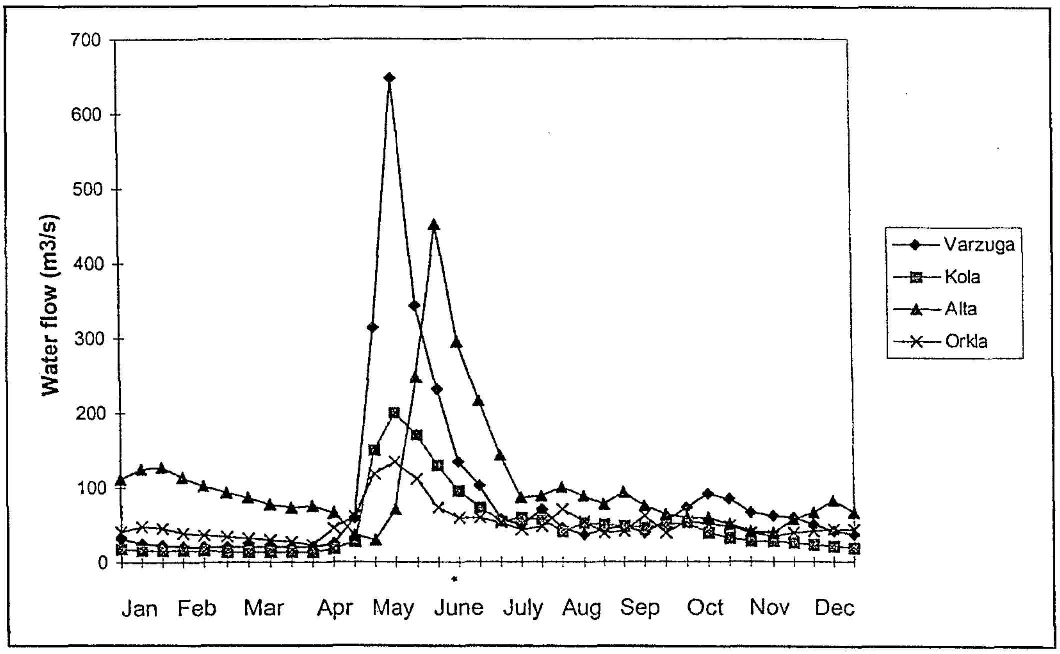
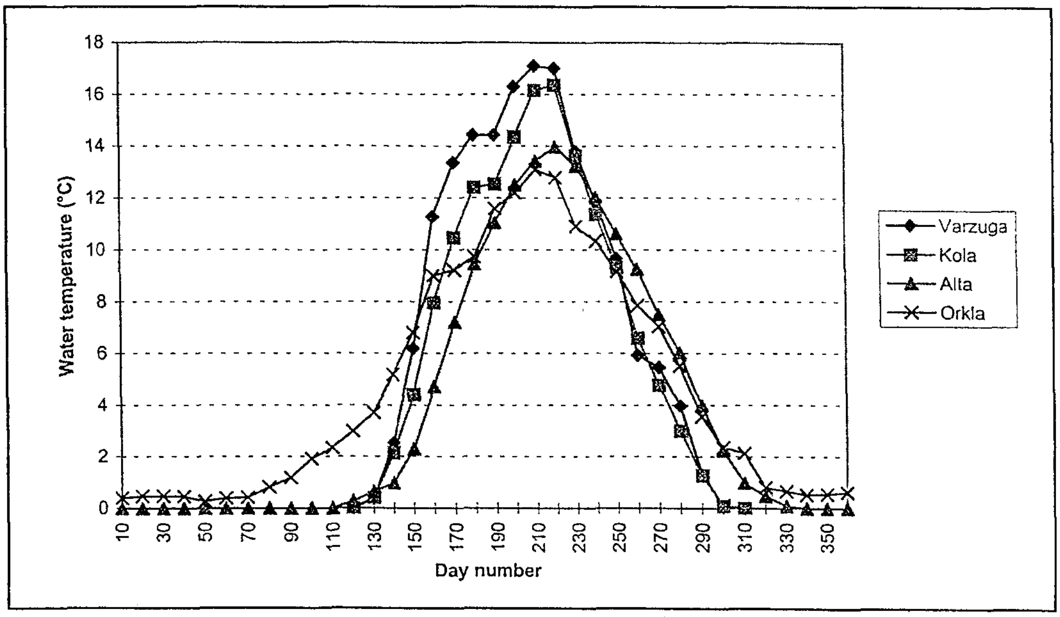


Figure 4. Water temperature (°C) in the Rivers Varzuga, Kola, Alta and Orkla. The data are mean values for ten day intervals during 1993-1995 in the River Varzuga at the village of Varzuga and the River Kola at the site «1429 km», 1981-1994 in the River Alta at Gargia and 1990-1994 in the River Orkla at Meldal.



A total of 17 different fish species are found in the River Varzuga (**Table 1**). In addition, introduced pink salmon enter the river occasionally. The predominant anadromous species is Atlantic salmon. The Atlantic salmon may migrate 160 km up the river to an altitude of 127 m. The slope of this part of the river is 0.08 % (**Figure 5**). Before 1958, nets were used to fish for salmon in the River Varzuga. They were operated in the lower areas and partitioned not less than 2/3 of the river width. From 1958, a counting fence has been used. It is installed annually at a site located 12 km upstream from the river outlet. According to fish regulations, at least 50 % of the spawners must be let through the fence to the spawning grounds.

***Table 1**. Fish species present in the Rivers Varzuga, Kola, Alta and Orkla. In all four rivers both anadromous and resident brown trout are present (Berg & Pravdin 1948, Surkov 1966, Heggberget et al. 1984, and unpublished).*

Species	River Varzuga	River Kola	River Alta	River Orkla
Lamprey (*Lampetra japonica* Martens)	+	+		
Atlantic salmon (*Salmo salar* L.)	+	+	+	+
Brown trout (*Salmo trutta* L.)	+	+	+	+
Arctic char (*Salvelinus alpinus* (L.))			+	
Pink salmon (*Oncorhynchus gorbuscha* (Walbaum))	+	+		
Whitefish (*Coregonus lavaretus* (L.))	+	+	+	
Vendace (*Coregonus albula* L.)	+	+		
Grayling (*Thymallus thymallus* (L.))	+	+	+	
Pike (*Esox lucius* L.)	+	+	+	
Roach (*Rutilus rutilus* (L.))	+			
Dace (*Leuciscus leuciscus* (L.))	+			
Ide (*Leuciscus idus* (L.))	+			
Minnow (*Phoxinus phoxinus* (L.))	+	+	+	+
Eel (*Anguilla anguilla* (L.))			+	+
Burbot (*Lota lota* (L.))	+	+	+	
Perch (*Perca fluviatilis* L.)	+	+	+	
Ruffe (*Acerina cernua* (L.))	+			
Threespined stickleback (*Gasterosteus aculeatus* L.)	+	+	+	+
Ninespined stickleback (*Pungitus pungitus* (L.))	+	+	+	
Flounder (*Platichtys flesus* (L.))	+		+	+

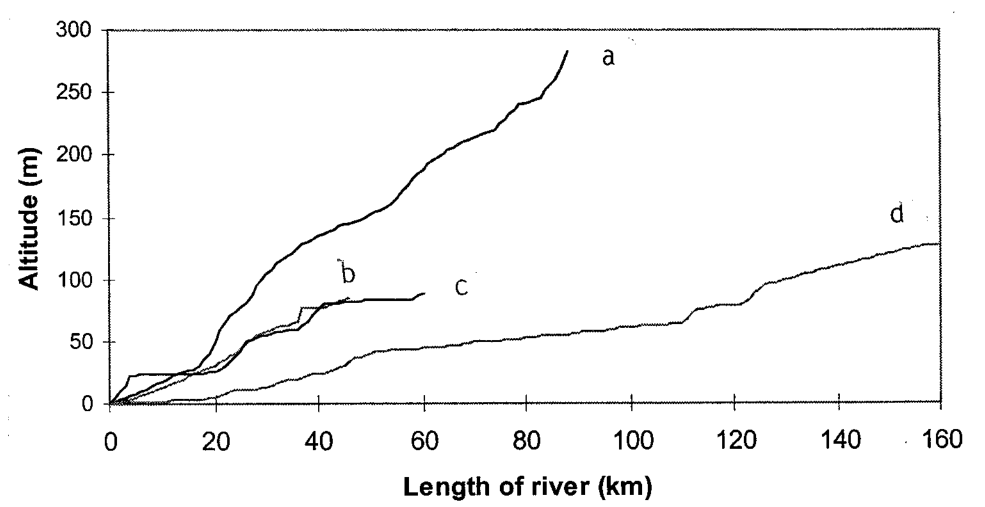


***Figure 5**. Profile of a) River Orkla (88 km), b) River Alta (46 km), c) River Kola (60 km) and d) River Varzuga (160 km). Only the parts of the rivers asseccible for salmon are included.*

2.2 River Kola

The River Kola is one of the most important salmon rivers in Russia. It begins at the Kolozero Lake, situated almost in the central part of the Kola Peninsula, and drains into the Kola fjord of the Barents Sea (**Figure 6**). The river is located in the hollow of the transversal break extending along the line - the Imandra Lake/the Kola fjord. The catchment area of the River Kola borders the drainage area of the Imandra Lake to the south, the River Tuloma to the west, and the Rivers Voronya and Teriberka to the east. The mouth of the River Kola is located at 68°53'N and 33°02'E. The river is 83 km long. The drainage area is 3846 km² and the annual mean discharge is 41.2 m³/s (**Figure 3**). The drainage area consists of 6 % lakes, 15 % wetlands, and 55 % woodlands. The main tributaries are the Rivers Medvezhya (15 km), Bolshaya Kitsa (77 km), Tyukhta (35 km), and the Kildinsky Brook (23 km). The largest lakes (Kolozero, Pulozero, Murdozero) are located in the upper part of the river system.

The bottom of the River Kola is mostly stony, and boulders appear out of the water at the rapids. The bottom is covered with gravel and sand, sometimes with silt in the pools. Ice development usually commences in October. The river freezes around 28 October (average for 1928-80). The earliest recorded date for development of ice-cover was 7 October (in 1928), while the latest was 24 November (in 1944). Drift of ice commences, on average, 15 May and varies between 26 April (in 1960) and 29 May (in 1958). Drift of ice usually lasts no longer than 3-4 days. The longest durations were recorded in 1974 and 1980 (10 days), the shortest (1 day) in 17 % of the years (1928-80). The water temperature increases rapidly during May-June and reaches a maximum of 16-17 °C in July-August (**Figure 4**).

There are several communities located on the river banks. The largest is the town of Kola (about 50 000 people) situated at the river mouth. The railway connecting Murmansk and St. Petersburg runs along most of the entire river length.

Twelve fish species are found in the river. In addition introduced pink salmon occurs occasionally (**Table 1**). Atlantic salmon is the most predominant species. The part of the river accessible for salmon is 60 km, and the slope of this part of the river is 0.15 % (**Figure 5**).

To reduce illegal fishing and to improve the system to safeguard the spawning grounds, a counting fence has been installed annually since 1959. The counting fence is placed 25 km upstream from the river mouth and consists of a net which completely closes the river. A trap, rectangular form, is mounted in the centre of the fence. The counting fence is installed after the spring flood (late May - early June) and is operated until steady frosts (September-October). During operation, the counting fence retains all spawners. Therefore, only those salmon which have passed the site during the spring flood before the fence is installed can migrate further upstream in the River Kola. Between 110 000 and 370 000 juvenile Atlantic salmon of differing ages have been released

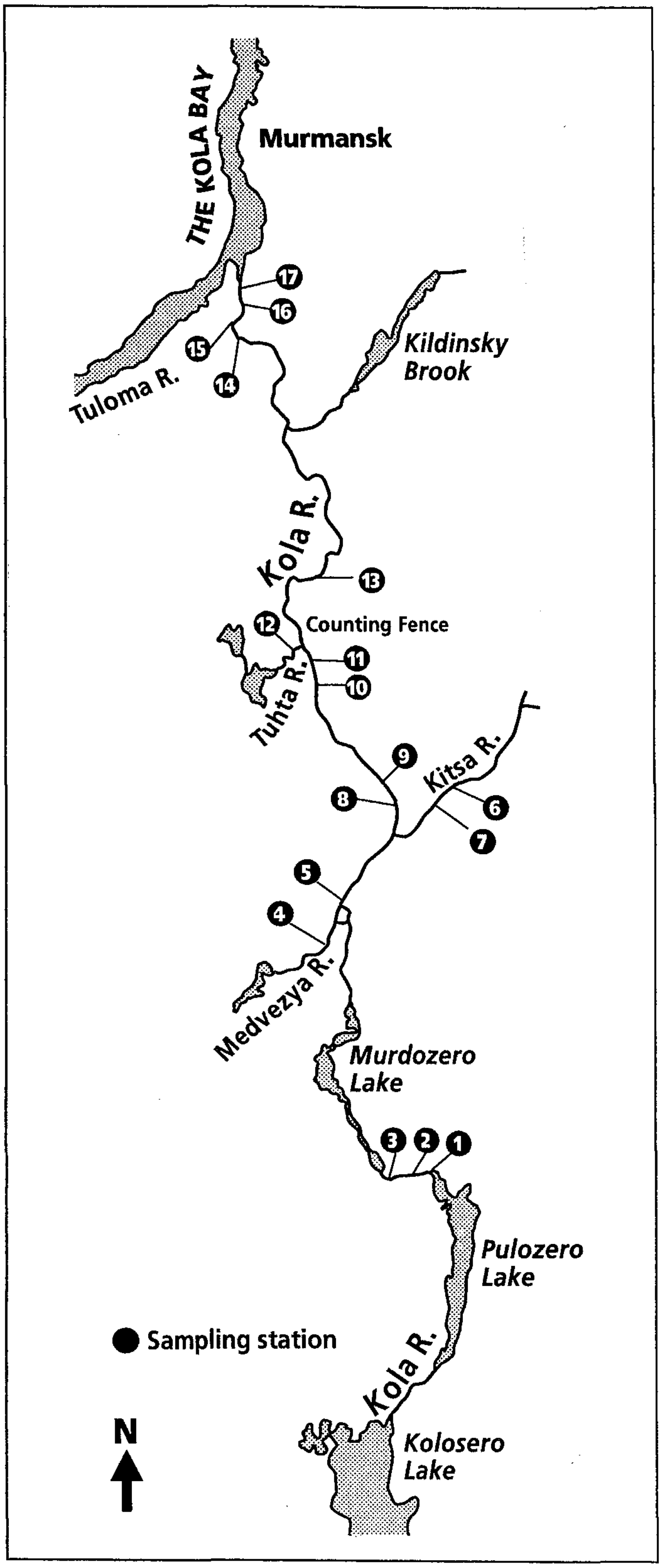


Figure 6. Map of the River Kola, with the locations of the counting fence and sampling stations for presmolt Atlantic salmon.

annually into the river since 1934. These juveniles have been produced by the Taibola hatchery, located about 70 km upstream from the river mouth.

2.3 River Alta

The River Alta is situated in northern Norway in the County of Finnmark at 70° N, 23° E. The river has its origin on Finnmarksvidda at Kautokeino and then runs to the north, emptying into the sea at Alta, in the innermost part of the Alta fjord (**Figure 7**). The catchment area is 7 400 km², and consists of birch forests, mountains or other areas with low productivity, and some farm land in the lower parts.

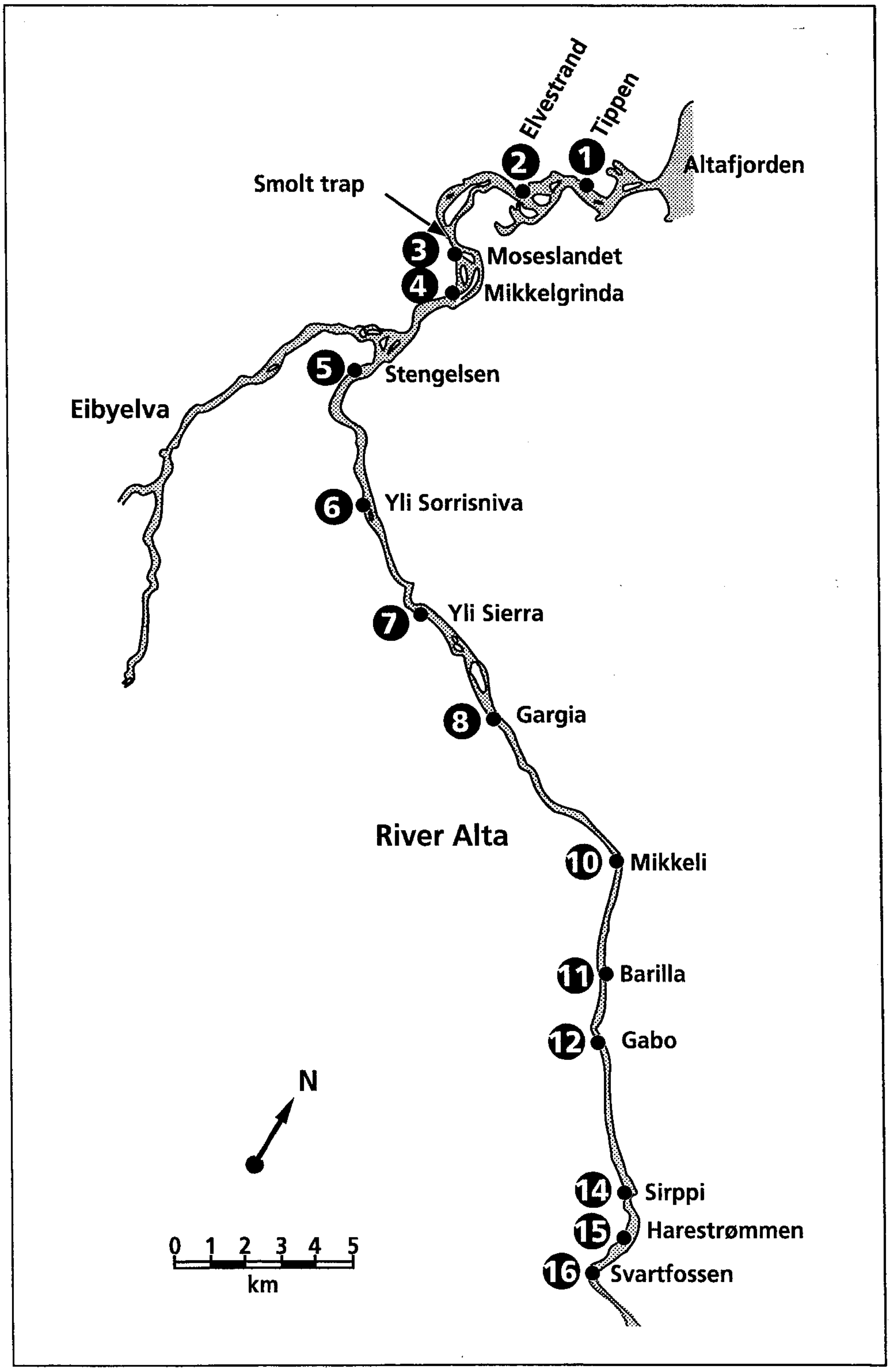


***Figure 7**. Map of the River Alta, with locations of the smolt trap and sampling stations for presmolt Atlantic salmon.*

About 17 000 people live in the catchment area. Most of them live in Alta (9 000 people) at the river mouth, and in Kautokeino (2 900 people) 130 km from the outlet. The contamination of the river is low. The river is moderately polluted only in a restricted area, a few km downstream from Kautokeino (Traaen at al. 1983).

The River Alta has been utilised for hydroelectric purposes since 1987. A 110 m high dam was constructed across the main river 5 km downstream from the outlet of the Lake Virdnejavre, 46 km from the outlet. This lake is used as a reservoir, and its surface has been elevated by 15 m. The power station is located close to the dam. The outlet of the power station is located at the end of the salmon producing area. The annual flow regime has changed due to the hydropower development, with higher water discharge during winter and slightly lower water discharge during the spring flood. The average annual water discharge is 74.5 m^3s^{-1}, with a peak during the spring flood in May-June (**Figure 3**). The river is covered by ice from November to May. However, 5-7 km of the river just below the outlet of the power station is usually without ice during most of the winter. The water temperature increases during June, and reaches a maximum of about 14 °C in August (**Figure 4**). After the hydropower regulation, the water temperature has decreased 1-2 °C during June and July, while it increased up to 3 °C in late summer. Beneath the power station the water temperature has increased 1-2 °C during winter.

Anadromous fishes can migrate 46 km upstream from the sea to about 85 m above sea level. The average slope of this part of the river is 0.18 % (**Figure 5**). A thorough description of the river is given by Berg (1964). Atlantic salmon is the dominant fish species. The mean annual catch during the last ten years has been approximately 13 tons, with a mean weight of 8 kg for individual salmon. Only sport fishing is allowed in this river. Twelve other fish species exist in the river (**Table 1**), but together they constitute only about 2 % of the total catch by electrofishing (Heggberget et al. 1984).

2.4 River Orkla

The River Orkla is situated in central Norway in the County of Sør-Trøndelag (**Figure 8**) and empties into the sea at Orkanger (63°17' N, 9°50' E). The drainage area is about 2 700 km^2, and consists of birch and spruce forests (44 %), mountains or other areas with low productivity (51 %), and some farm land in the lower parts (4 %). About 12 000 people are living in the catchment area, of which about 4 000 resides in Orkanger at the river mouth.

The catchment area consists mainly of sedimentary minerals from the cambro-silur period. The content of chalk is relatively high and easily decomposed. Some heavy decomposed eruptives are also found. Sulphur ore deposits occur in several places, and mining operations have been frequent in the area.

The richest occurrence of copper pyrite in Norway is found within the Orkla catchment area, at Løkken. The exploitation of this ore deposit started in 1654, and the mine was operated for 333 years until it was closed in 1987. A tributary to the River Orkla (the River Raubekken) drains the catchment near the copper mine. This tributary transports high concentrations of heavy metals, mainly copper, zinc, cadmium and iron, into the main river. Since the early 1980s several measures have been taken to reduce the seeping of polluted water into the tributary. Among these are the covering of the slag heaps from the mine.

Except for high concentrations of some heavy metals (zinc, cadmium, copper, iron) in the lower 15 km, the water quality in the main river is rather good, with slightly alkaline water (pH values of 7.1-7.6), high calcium values (about 10 mg/l), small amounts of phosphorus (3-10 g TOT-P/l), and a conductivity of 6-8 mS/m (Grande & Romstad 1993).

Eighty-eight km of the river is accessible for anadromous fishes. The average slope of this part of the River Orkla is about 0.32 %, which is considerably steeper than the other three rivers (**Figure 5**). Atlantic salmon is the predominating fish species. Brown trout (both anadromous and resident), eel, threespined stickleback, and flounder are also present (**Table 1**). In the river the fish are harvested by sport fishermen using rod and line. The river is one of the most important salmon rivers in Norway. The mean annual catches the last ten years (1985-1994) have been 15 tons and 1.1 tons for Atlantic salmon and anadromous brown trout, respectively.

Since 1983, the River Orkla has been utilised for hydroelectric purposes. Several reservoirs were built in the mountains in tributaries to the River Orkla. The Ulset, Litlefossen, Brattset and Grana power plants utilise the elevation difference from these reservoirs to the main river (**Figure 8**). In addition, the Svorkmo power plant utilises a drop of 99 m on a 15 km stretch of the main river between Bjørset and Svorkmo.

Mean annual water discharge at Meldal is 48.4 m^3/s. Before hydropower development, the water flow was very low during winter, with a median lowest flow of 3.7 m^3/s, and flows below 1.0 m^3/s were observed. Highest flows occurred during melting of snow in spring, with a median highest flow of about 270 m^3/s in June. After hydropower development, the minimum water flow is 10 m^3/s between Berkåk and Meldal, while the discharge during spring flow is reduced (**Figure 3**).

The River Orkla is completely covered by ice during cold winters only. The ice cover has been reduced after hydropower regulation, especially downstream of the outlet of the power stations. The water temperature increases during March-April from close to zero to about 3 °C, and continues to increase until a maximum of about 13 °C in late July or early August (**Figure 4**).

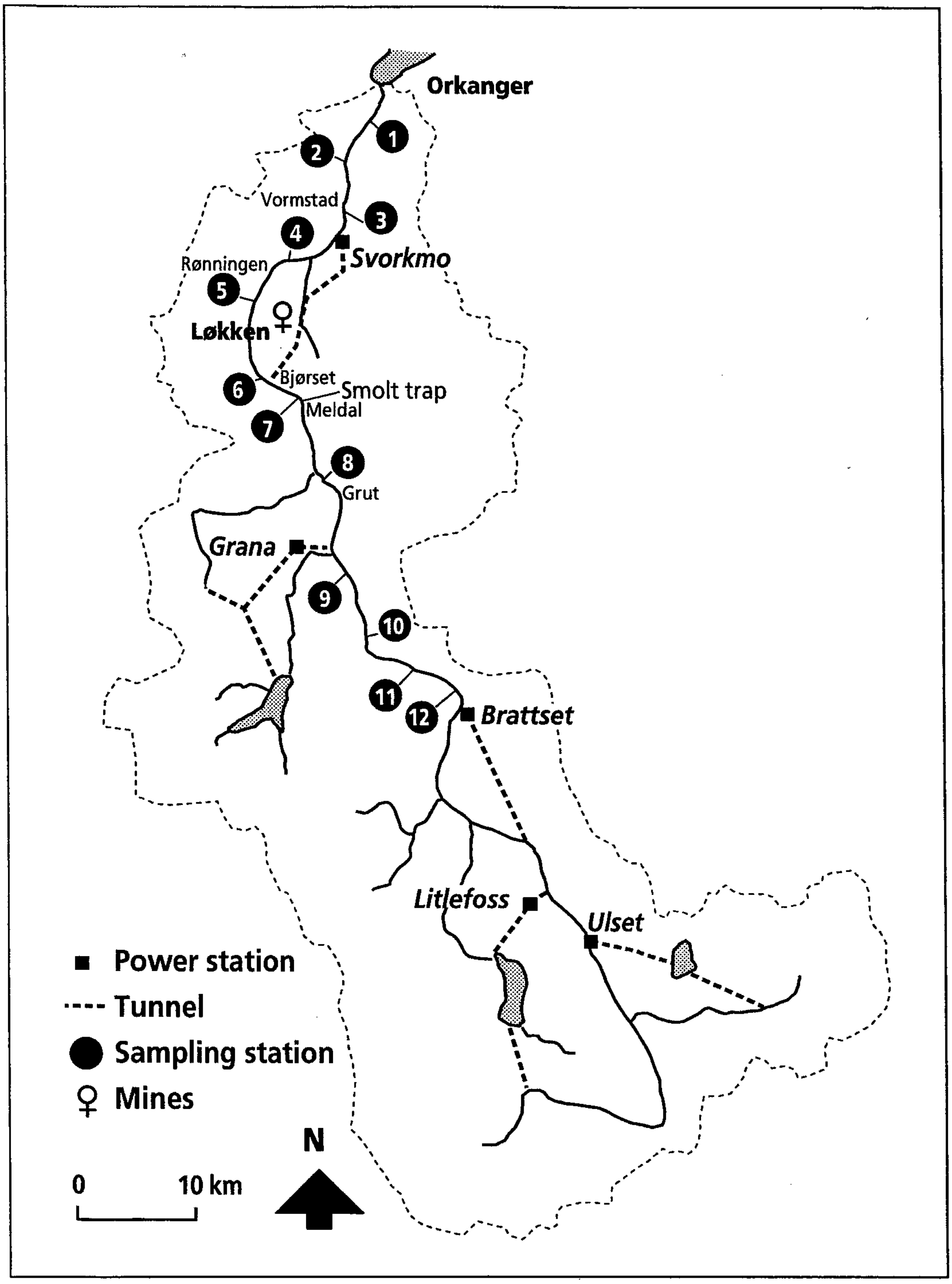


***Figure 8**. Map of the River Orkla, with locations of the smolt trap and sampling stations for presmolt*

3 Material and methods

3.1 Density estimates of juvenile salmon

Densities of juvenile salmonids were analysed during August/September in 1993, 1994 and 1995 by successive removal (Zippin 1956) using electrical fishing gear (model FA2, Ing. Steinar Paulsen, Trondheim) at 17 (15 in 1993), 14, and 12 sites in the Rivers Kola, Alta and Orkla, respectively. In the River Varzuga density estimates were carried out at 12 sites during July in 1994 and 1995. The area of each sampling site was usually 60-200 m^2 (25-50 m^2 in the River Varzuga in 1994), and the total area examined each year was 400-1150, 1160-1275, 2200-2800, and 1200 m^2 in the Rivers Varzuga, Kola, Alta and Orkla, respectively. The same localities were sampled each year. Three successive removals at about half-hourly intervals were carried out as standard procedure. Young-of-the-year were not included in the density estimates because of their small size, low catchability, and high mortality during the first year of life.

From all 12 sites in the River Orkla and from four sites in the River Alta (sites no. 4, 8, 12, 16) all fish were conserved in alcohol, and brought to the laboratory for determination of age, length (natural tip), sex and gonadal development. In the River Kola, fresh fish were brought to the laboratory and analysed. In 1993, fish from eight sites (2, 4, 6, 8, 10, 12, 14 and 16) were analysed, while in 1994 and 1995 all fish from all stations were analysed. Age was determined from scale analyses, but in cases of doubt otoliths also were used. At the remaining sites all fish were returned alive to the river after the third successive removal. The age of these fish was estimated according to the length frequency distribution of the fish. In the River Varzuga, growth data exist only for salmon collected in 1994. The total number of Atlantic salmon parr sampled during density estimates is given in **Table 2**.

3.2 Growth of parr

In order to compare growth of fish in the Norwegian and Russian rivers, a model for fish growth of fish in relation to water temperature and ration size was used. When the yolk sac is absorbed, growth is mainly dependent on nutrient conditions, water temperature, and fish weight (Donaldson & Foster 1940, Brett et al. 1969, Elliott 1975a, b, Spigarelli et al. 1982). When food is present in abundance, estimated optimum temperatures for growth vary among species (Brett et al. 1969, Elliott 1975a, b, Hokanson et al. 1977). In sockeye salmon (*Oncorhynchus nerka*) optimum growth at excess rations occurs at 15°C, and progressively shifts to a lower temperature at reduced rations (Brett et al. 1969). A corresponding model for brown trout has been developed by Elliott (1975a, b), and was later improved (Elliott et al. 1995). For brown trout, the optimum temperature for growth at excess rations was found to be 13.1 °C, while growth commences at 4 °C and 19.5 °C.

A similar model for growth of Atlantic salmon has been published recently by Elliott & Hurley (1997):

$$W_t = [W_0^b + bc(T - T_{LIM})\, t/\{100(T_M - T_{LIM})\}]^{1/b}$$

where W_0 is the initial weight of the salmon, W_t is the final weight of the fish after t days at T °C, and $T_{LIM} = T_L$ if $T < T_M$ or $T_{LIM} = T_U$ if $T > T_M$. They found the optimum temperature for growth of Atlantic salmon to be T_M = 15.94 °C, while lower and upper limits for growth is T_L = 5.99 °C and T_U = 22.51 °C, respectively. The other parameters were: b = 0.313 and c = 3.531.

Mean instantaneous growth rate per year (G_{wa}) was computed according to the following equation:

$$G_{wa} = \ln W_t - \ln W_0$$

where W_0 (g) is the mean wet weight of fish caught in August (the River Alta) or September (the Rivers Kola and Orkla) one year, and W_t (g) the mean weight of fish of the same cohort collected one year later.

Table 2. *Total number of Atlantic salmon parr sampled for density estimates in the Rivers Varzuga, Kola, Alta and Orkla during 1993-1995. The number of fish from which age estimates and growth analyses have been performed are also given.*

Locality	1993		1994		1995	
	Density estimates	Age analyses	Density estimates	Age analyses	Density estimates	Age analyses
River Varzuga	-	-	801	485	688	-
River Kola	374	280	293	301	83	139
River Alta	1003	344	1914	808	961	451
River Orkla	533	533	750	750	693	693

The mean weight W (g) of the fish is computed from mean length L (mm) using the equation:

$$W = k*L^3$$

We used $k = 9.27 * 10^{-6}$, which was the mean value for 225 fresh Atlantic salmon parr collected in August in three Norwegian rivers (Orkla, Nidelva and Saltdalselva). Data for growth analysis were collected three times at one year intervals in the Rivers Kola, Alta and Orkla, and one time in the River Varzuga (**Table 2**).

3.3 Analyses of heavy metal contents of parr

Concentrations of heavy metals were analysed in gills, skeletal muscle, liver, and kidney of fifteen Atlantic salmon parr from two different localities (Kvåle and Grut) in the River Orkla on 28 September 1993, fifteen fish from one locality in the Rivers Varzuga (Kivitem on 22 June 1994) and Alta (Gargia on 11 September 1995), and fifteen fish from the River Kola (23 October 1995). In the River Kola, a total of 56 salmon parr from three different localities were sampled on 23 October 1995, but only a sub-sample of fifteen 3 year old fish were utilised for heavy metal analysis.

One of the two localities in the River Orkla (Grut) is located 37 km upstream from the outlet of the Svorkmo power plant, and the other (Kvåle) is located 7 km downstream. The fish were collected with electrical fishing gear. The mean length of the samples from Kvåle and Grut was 132 (range 116-152) mm and 130 (range 119-143) mm, respectively, while the mean age was 2.7 (range 2-3) years and 2.9 (range 2-3) years at Kvåle and Grut, respectively.

In the River Varzuga, the fish were collected in a smolt trap 31 km upstream from the river outlet (7 km upstream from the village of Varzuga). Mean natural tip length was 122 (range 116-134) mm, and mean age was 3.1 (range 2-4) years.

In the River Kola samples of 10, 24 and 22 fish were collected at three sites on 23 October 1995. The first sample was taken 18 km from the river mouth, the second at the mouth of the River Tyukhta, 26 km from the River Kola outlet and the third 40 km from the river mouth. Fifteen 3+ fish were analysed for heavy metals, consisting of 5, 8 and 2 fish from the three localities, respectively. Mean natural tip length was 140 (range 126-160) mm.

In the River Alta, parr were collected at Gargia, 24 km upstream from the river mouth on 11 September 1995. Fifteen fish, all of them age 3+, were analysed for heavy metals. The mean length was 114 (range 106-127) mm.

Concentrations of lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), arsenic (As), mercury (Hg), nickel (Ni), and selenium (Se) were analysed at the NINA laboratory. Only titanium tools were used when dissecting the fish. These tools were routinely rinsed with 1 mol HNO_3. About 1.2 g (wet weight) of skeletal muscle was used in each sample. For gills, liver and kidney the whole organ was used. The samples were dried for about 17 hours by a Christ LDC-1 freeze-dryer. Each sample was dissolved in 4.5 ml Scan pure concentrated (14.4 mol) nitric acid (HNO_3) by a microwave oven (Milestone MLS 1200). Concentrations of the different elements were determined by atomic absorption spectroscopy (Perkin Elmer Model 1100B). For the lead analyses a graphite furnace (HGA 700) with an automatic sampler (AS 70) was used. For Hg analyses a hydride system (FIAS 200) with an automatic sampler (AS 90) was used. All values are given as µg/g wet weight. The accuracy of the analytical procedures was checked against the National Bureau of Standard (NBS) Bovin liver (Cd, Zn, Cu, Se), Dogfish muscle (Cd, Zn, Cu, Pb, As, Se Hg) and Dogfish liver (Cd, Zn, Cu, As, Se, Hg) samples.

3.4 Smolt migration

In the Rivers Orkla and Alta smolts were caught by traps consisting of a steel frame with an opening of 1 m^2 (Hesthagen & Garnås 1986, Hvidsten & Ugedal 1991). A net pouch, 5.6 m long (mesh size 10.5 mm), with a removable bag was fastened to this frame. One or two traps were operated from movable racks fastened to a bridge. A winch mounted on the rack made it easy to lower the trap into the river. During operation, about 90 % of the trap was submerged. To make the trap more stable at high-water discharge, a 25 kg weight was attached under the trap. In the River Orkla the traps were mounted to the Meldal Bridge, and in the River Alta they were mounted to the Øvre Alta Bridge, 42 and 8 km upstream from the river mouths, respectively. The trap in the River Orkla has been operating for 14 years between 1980 and 1995. In this report results from 1993-95 are given, and during this period 4062 Atlantic salmon smolts were caught (**Table 3**). During the same period 1886 Atlantic salmon smolts were caught in the trap in the River Alta (**Table 3**). Results from 1989-1992 also exist for the River Alta.

In the River Varzuga descending smolts were caught in a funnel shaped basket (**Figure 9**). The trap was located 35 km upstream from the river mouth. As water flow varied during smolt descent, the trap was continuously moved perpendicular to the shore line and kept at a water depth of 40-70 cm. The opening of the trap varied between 4 and 6 m. Total width of the river at the sampling site is 180 m. The efficiency of the trap at different water levels is unknown. The trap was usually examined every second hour in the period 1 June to 15 July. A total of 8812 smolts were caught during the period 1993-95 (**Table 3**). The trap was operated for six years between 1988 and 1995, and data from all these years were applied when comparing smolt run with environmental factors. All smolts were released after registration, except for up to 30 individuals which were taken daily for analyses.

Table 3*. Number of Atlantic salmon smolts caught during descent in the Rivers Varzuga, Kola, Alta and Orkla in the period 1993-1995, as well as numbers of these smolts analysed for age and size.*

	1993		1994		1995	
Locality	Catch	Age/size analyses	Catch	Age/size analyses	Catch	Age/size analyses
River Varzuga	1002	100	4490	36	3320	100
River Kola	-	-	92	92	25	25
River Alta	894	724	224	224	768	-
River Orkla	989	977	1335	1329	1738	1199

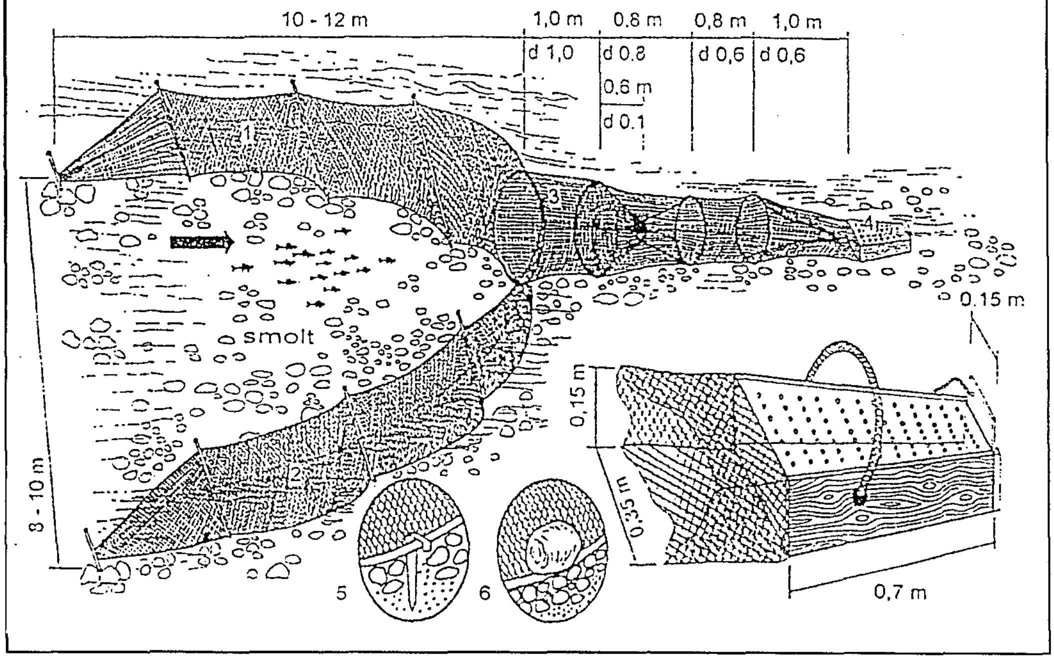


Figure 9*. The fyke net used for catching Atlantic salmon smolts during migration in the River Varzuga.*

Attempts to study the migration of Atlantic salmon smolts in the River Kola have been tried on several occasions. However, due to the difficult hydrologic conditions and the rough bottom they have not been successful. In the period 1993-1995, a smolt trap identical to that used on the River Varzuga was operated. The opening of the trap was about 10 m. In 1993 the trap was set 2 km upstream from the river outlet and operated from 5 June to 26 July. However, due to high water level and unfavourable siting this attempt was also unsuccessful. In 1994-95 the trap was installed 28 km from the river outlet and 400 m upstream from the counting fence. In 1994 the trap was operated from 16 June to 15 July. A total of 92 smolts were caught. In 1995 the trap was in operation from 13 June to 11 July, and 22 smolts were caught. In both cases all fish were kept for analysis.

3.5 Adult fish

Scale samples of adult Atlantic salmon were collected in all four rivers (**Table 4**). In the Norwegian rivers, scale samples were collected by sport fishermen. In the Russian rivers they were taken from the commercial catch in counting fences located in the lower part of the rivers. Weight, length and sex were analysed from each fish.

All ascending salmon were kept as commercial catch each day in the River Kola, and each second or third day in the River Varzuga during the migration period. The ascent the next day(s) in the River Varzuga was assumed to be similar to the day before. Hence, estimates of total migration are present from the Russian populations. In the Norwegian rivers total annual catches of Atlantic salmon are according to Official Statistics.

Table 4. Number of scale samples of adult Atlantic salmon from the Rivers Varzuga, Kola, Alta and Orkla in the period 1993-1995.

Locality	1993	1994	1995
River Varzuga	1658	2278	1385
River Kola	499	920	876
River Alta	653	348	633
River Orkla	479	611	599

4 Results

4.1 River Varzuga

4.1.1 Growth and density of parr

In early July 1994, young-of-the-year (0+) Atlantic salmon in the River Varzuga were on the average 26.4 mm long (**Table 5**). The mean length of 1+ salmon was 52.2 mm, and that of 2+ salmon was 69.3 mm. Since growth data only exist for 1994, it is not possible to estimate growth increment of the same cohort from one year to the next, and we did not compare the data with the growth model for Atlantic salmon parr (Elliott & Hurley 1997). However, at the sampling time in 1994, the average length difference between 1+ and 0+ salmon and between 2+ and 1+ salmon were 25.8 mm and 17.1 mm, respectively.

Table 5*. Mean natural tip length (l, mm ± 95 % confidence limits) of different age groups of Atlantic salmon parr collected by electrofishing in the River Varzuga in July 1994. Sample sizes are given in parentheses.*

Age (year)	5-13 July 1994	
0+	26.4 ± 0.5	(397)
1+	52.2 ± 0.5	(70)
2+	69.3 ± 1.5	(16)
3+	99.5	(2)

Estimated densities of Atlantic salmon parr (excluding fry) in the River Varzuga were 28.8 ± 12.0 and 19.3 ± 5.9 individuals per 100 m^2 in 1994 and 1995, respectively (**Table 6**). The values for the two years are not quite comparable, because the sites differed. The highest densities were found at sites number 1, 9 and 10, but densities were also high at sites 2, 3, 6, 7, 15 and 16 (**Figure 10**). The lowest densities were recorded at sites number 8 and 14.

4.1.2 Heavy metal contents of parr

Cadmium was detected in the highest mean concentrations in kidney and liver (0.052 and 0.040 ppm wet weight, respectively), while the concentrations in muscle were low (0.003 ppm, **Table 7**). Copper, selenium and zinc were all found in the highest concentrations in liver (6.80, 0.615 and 57.6 ppm, respectively), while mercury was detected in the highest concentrations in muscle (0.049 ppm). Concentrations of nickel, arsenic, and lead were below the detection limit in all samples.

***Table 6**. Number of Atlantic salmon parr of different age groups caught at twelve stations in the River Varzuga, and densitiy estimates (Zippin method, number per 100 m²) during electrofishing with three successive removals in July 1994-1995. The area (m²) of each station is also given. Brown trout were not caught during this survey.*

		Area	Atlantic salmon				Density estimates of fish (except 0+)			
Site	Date	(m²)	0+	1+	Older	Sum	1. fishing	2. fishing	3. fishing	Zippin estimate
1994										
1	05.07.94	30	6	7	6	19	8	3	2	48.4
2	06.07.94	42	56	7	3	66	5	4	1	28.0
3	06.07.94	42	36	8	1	45	5	2	2	27.3
4	06.07.94	42	103	1	1	105	1	1	0	5.2
5	07.07.94	35	85	5	0	90	3	1	1	16.8
6	07.07.94	21	21	4	0	25	2	1	1	28.4
7	07.07.94	30	116	7	2	125	6	2	1	31.9
8	08.07.94	40	7	2	0	9	2	0	0	5.0
9	09.06.94	23	118	7	2	127	5	3	1	44.3
10	10.07.94	30	40	16	4	60	11	6	3	78.3
11	10.07.94	30	115	2	1	118	2	1	0	10.2
12	13.07.94	30	6	6	0	12	4	1	1	21.9
Mean (numbers per 100 m²):										28.8 ± 12.0
1995										
1	25.06.95	100	5	11	2	18	12	1	0	13.0
3	26.06.95	100	33	31	2	66	30	3	0	33.0
4	27.06.95	100	194	13	5	212	9	7	2	21.4
7	27.06.95	100	25	12	2	39	11	2	1	14.2
9	28.06.95	100	67	8	8	83	12	1	3	16.9
10	29.06.95	250	60	27	6	93	33	0	0	13.2
11	30.06.95	100	34	14	4	52	13	3	2	18.7
12	19.06.95	100	25	18	2	45	14	6	0	20.4
13	01.07.95	58	6	5	0	11	4	0	1	9.1
14	01.07.95	35	3	1	0	4	1	0	0	3.0
15	01.07.95	38	18	10	2	30	8	4	0	32.8
16	01.07.95	77	10	23	2	35	13	8	3	36.3
Mean (numbers per 100 m²):										19.3 ± 5.9

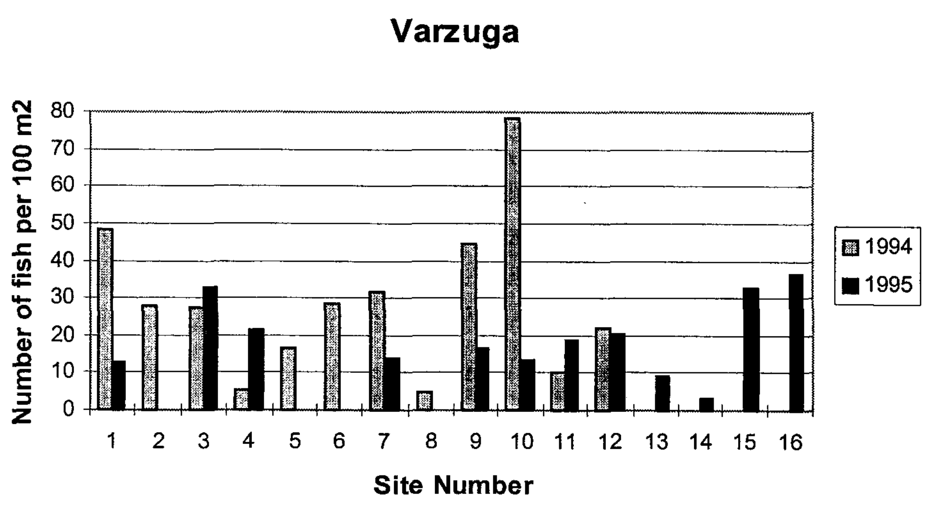


***Figure 10**. Density estimates (Zippin method) of Atlantic salmon parr (excluding fry) at each of the 16 sites in the River Varzuga 1994-1995. Only 12 sites were sampled each year (1-12 in 1994 and 1, 3, 4, 7 and 9-16 in 1995).*

***Table 7**. Mean concentrations (ppm, wet weight ± 95 % confidence limits) of Cd, Cu, Se, Zn and Hg in gills, muscle, liver and kidney of Atlantic salmon parr collected in the Rivers Varzuga, Kola, Alta and Orkla. The sample from the River Orkla is collected at Grut, upstream from the confluence with the River Raubekken. The concentrations given are mean values for 15 fish from each river.*

Metal/Organ	River Varzuga	River Kola	River Alta	River Orkla
Cadmium (Cd)				
Gills	0.012 ± 0.008	0.039 ± 0.003	0.008 ± 0.001	0.031 ± 0.004
Muscle	0.003 ± 0.001	0.002 ± 0.001	0.001 ± 0.000	< 0.006
Liver	0.040 ± 0.004	0.066 ± 0.008	0.037 ± 0.003	0.051 ± 0.017
Kidney	0.052 ± 0.011	0.128 ± 0.019	0.079 ± 0.015	0.066 ± 0.010
Copper (Cu)				
Gills	0.497 ± 0.065	0.450 ± 0.033	< 0.28	0.546 ± 0.116
Muscle	0.509 ± 0.037	0.250 ± 0.021	0.295 ± 0.076	0.394 ± 0.034
Liver	6.80 ± 2.12	6.44 ± 2.20	5.92 ± 1.68	8.06 ± 2.51
Kidney	< 0.88	0.819 ± 0.099	< 0.80	0.787 ± 0.117
Selenium (Se)				
Gills	0.255 ± 0.036	0.176 ± 0.018	< 0.20	< 0.27
Muscle	0.240 ± 0.036	0.160 ± 0.070	0.155 ± 0.012	0.245 ± 0.015
Liver	0.615 ± 0.262	0.940 ± 0.208	0.634 ± 0.148	0.573 ± 0.564
Kidney	< 0.35	0.591 ± 0.014	< 0.49	< 0.13
Zinc (Zn)				
Gills	118.0 ± 13.1	112.8 ± 16.8	145.0 ± 12.8	127.6 ± 12.1
Muscle	14.19 ± 0.95	7.58 ± 0.84	8.20 ± 0.63	11.79 ± 1.28
Liver	57.60 ± 6.31	60.55 ± 5.33	60.81 ± 7.75	58.12 ± 7.76
Kidney	55.64 ± 3.77	49.16 ± 12.37	59.18 ± 8.33	33.63 ± 3.73
Mercury (Hg)				
Gills	0.028 ± 0.004	0.026 ± 0.003	0.017 ± 0.009	< 0.009
Muscle	0.049 ± 0.004	0.043 ± 0.009	0.025 ± 0.002	0.018 ± 0.001
Liver	0.030 ± 0.004	0.033 ± 0.005	0.021 ± 0.005	< 0.018
Kidney	0.048 ± 0.007	0.039 ± 0.010	0.024 ± 0.004	< 0.014

Heavy metal concentrations in Atlantic salmon parr in the River Varzuga were, with the exception of mercury, low compared to fish in the Rivers Kola and Orkla, and similar to those in the River Alta.

4.1.3 Smolt migration

The smolt migration in the River Varzuga lasted from 16 to 26 days. Median date of 50 % smolt descent for the six years analysed was 23 June. With the exception of 1995, smolt migration peaked once during spring. Maximum descent lasted between five and nine days. In 1995 the smolts descended in two peaks (**Figure 11**).

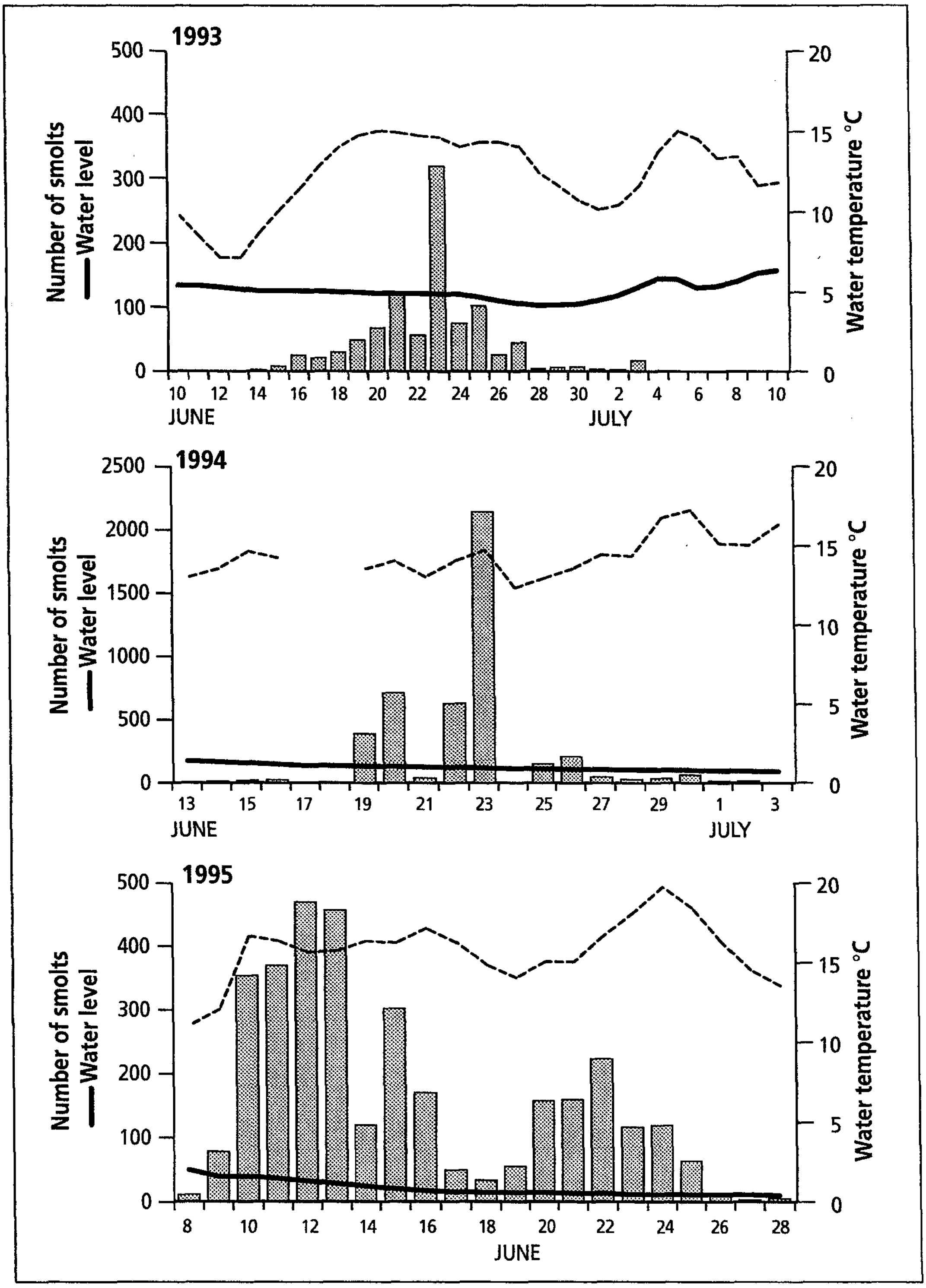
Smolt migration commenced at a water temperatures varying from 8.5 °C to 12.5 °C. Most smolts migrated at temperatures ranging from 14-18 °C. Significantly more smolts descended with increasing than with decreasing water temperatures ($p < 0.001$). Most smolts migrated with decreasing rather than increasing water flow ($p < 0.01$). The smolts migrated during the first two quarters of the moon, during the period when moon phase increased from new to full moon. Migration peaks occurred at new and full moon.

Smolt migration peaked during day time. Ninety-five percent of the smolts were caught between 6 a.m. and 10 p.m. Peak migration (53 %) occurred in the period 4 p.m.-8 p.m. Very few smolts descended between midnight and 4 a.m..

Daily peak migration usually occurred 3 hours after maximum illumination and close to the period of maximum water temperature of the day.

Underwater observations close to the trap in the River Varzuga revealed shoals of up to 40 individuals (16 shoals were observed) swimming with their heads pointed downstream during descent. In front of the smolt trap they turned against the current with their heads pointed against the current and after a while, the smolts slowly drifted tail-first downstream into the fyke net and were trapped.

Figure 11. *Daily descent (in numbers) of Atlantic salmon smolts in the River Varzuga in the period 1993-1995, as well as water level (cm) and water temperature (°C).*



4.1.4 Status of adult stock

During 1961-94, the number of Atlantic salmon ascending the River Varzuga varied between 18 482 (1978) and 137 419 (1987), with an average of 50 956 fish (**Figure 12**). Until 1987, all ascending fish were caught for commercial purposes in the counting fence which operated every second day, while on alternate days they were allowed to migrate freely to the spawning grounds. Therefore, the annual catch of salmon was usually about 50 % of the total spawning run (**Figure 12**). From 1987 onwards, the counting fence has been operated each third day or less frequently, and a larger proportion of the fish have been allowed to migrate to the spawning areas. The last few years a recreational sport fishery has been permitted at three sites on the river. This is a catch and release fishery, but each person with a licence may keep one salmon weekly. The harvest of salmon in the fishing camps is not included in the catch data **in Figure 12**.

During 1961-89, the catch varied between 9 241 salmon (1978) and 50 666 salmon (1987). The annual average catch during this period was 25 000 fish, corresponding to

72.5 tonnes (33.4-161.2 tonnes). The last years the catches in the counting fence have been considerably reduced in favour of the recreational sport fishery.

4.1.5 Population structure

The smolt age of Atlantic salmon from the River Varzuga varied between two and five years, with 64-81 % of the fish being three years old when they migrated to sea. The mean smolt age varied between 2.89 ± 0.03 and 3.03 ± 0.03 years (**Table 8**). The smolts were unusually small at descent, with the mean length varying between 93 and 106 mm (**Table 8**).

The River Varzuga is mainly a grilse (one-sea-winter fish) river. Most fish, more than 90 % of both males and females, returned to the river after only one winter at sea. There were 4 % and 9 % two-sea-winter fish (2SW) fish, respectively among males and females, while 3SW fish were rare (**Figure 13**). The proportion of males constituted 50 % of the catches.

The mean weight of grilse varied between 2123 ± 42 g and 2404 ± 50 g, and 2SW fish between 4563 ± 257 g and 5196 ± 318 g (**Table 9**).

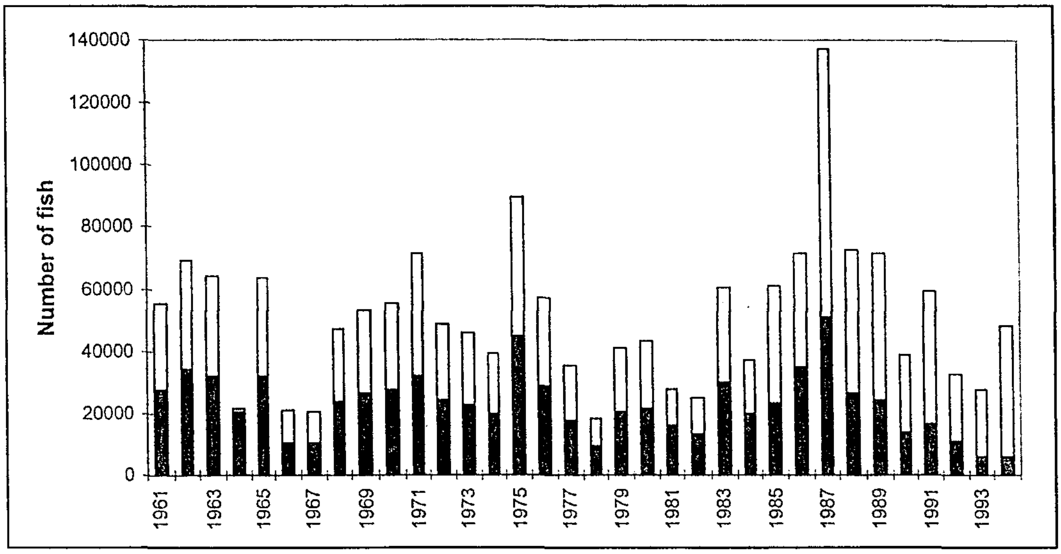


Figure 12*. Total ascent (numbers) of adult Atlantic salmon in the River Varzuga during 1961-1995. The lower, black part of the bars indicate fish which were kept, and the upper, white part indicates fish which were released.*

Table 8*. Age and size (± 95 % confidence limits) of Atlantic salmon at smolt migration from the Rivers Varzuga, Kola, Alta and Orkla in the period 1993-1995, analysed from scale samples. Distribution of smolt ages are given as percentages.*

River/ year	Sample size	Smolt age 2 years	3 years	4 years	5 years	6 years	Mean smolt age (yr)	Mean smolt size (mm)
Varzuga								
1993	293	24	64	12	< 1		2.89 ± 0.03	93 ± 0.8
1994	297	7	81	11	< 1		3.03 ± 0.03	102 ± 1.0
1995	302	9	72	19	< 1		3.01 ± 0.04	106 ± 0.8
Kola								
1993	245	7	50	36	1		3.41 ± 0.05	160.9 ± 1.5
1994	239	5	53	35	8		3.45 ± 0.05	146.0 ± 1.3
1995	343	5	39	48	9		3.60 ± 0.04	146.0 ± 1.1
Alta								
1993	625	< 1	25	67	7	< 1	3.83 ± 0.05	131.4 ± 1.5
1994	340		18	70	12		3.94 ± 0.06	138.3 ± 2.3
1995	607	< 1	24	61	15	< 1	3.92 ± 0.07	136.5 ± 1.0
Orkla								
1993	417	1	52	45	2		3.48 ± 0.06	133.6 ± 2.0
1994	602	2	54	42	2		3.45 ± 0.05	132.4 ± 1.7
1995	593	1	54	44	1		3.40 ± 0.04	137.6 ± 1.7

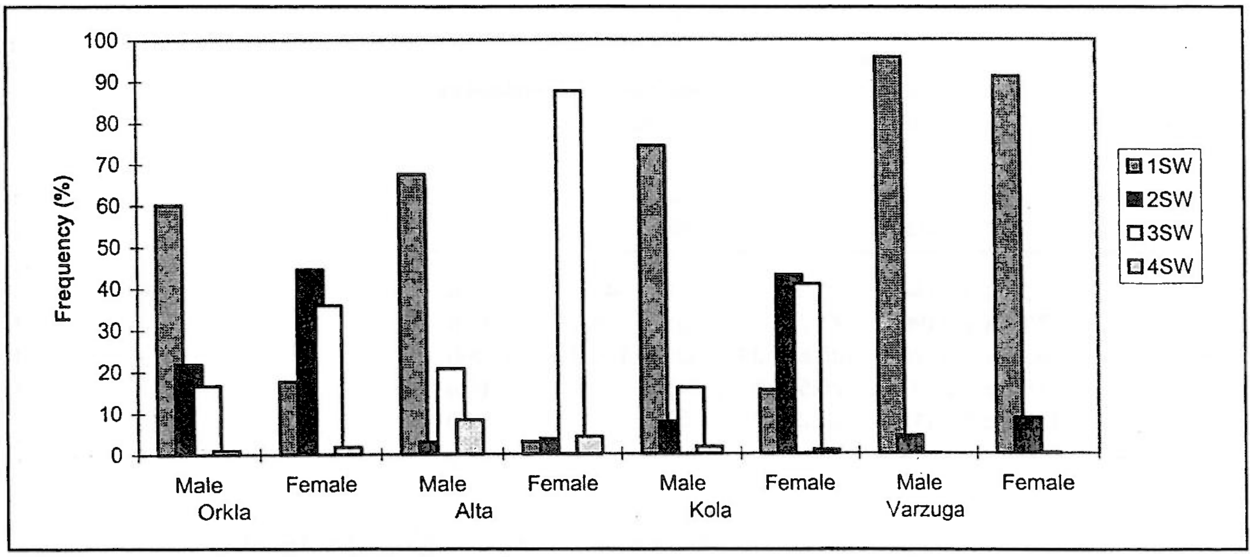


***Figure 13**. Sea age distribution of male and female Atlantic salmon in the four rivers during 1993-1995.*

***Table 9**. Mean weight (g ± 95 % confidence limits) of 1SW, 2SW, 3SW and 4SW Atlantic salmon from the Rivers Varzuga, Kola, Alta and Orkla. Sample sizes are given in parentheses.*

River/year	1SW	2SW	3SW	4SW
Varzuga				
1993	2404 ± 50 (1502)	4563 ± 257 (125)	-	-
1994	2382 ± 42 (2136)	5196 ± 318 (94)	-	-
1995	2123 ± 42 (1273)	4939 ± 440 (94)	-	-
Kola				
1993	2131 ± 52 (286)	4981 ± 235 (95)	9694 ± 352 (108)	14720 ± 1590 (10)
1994	2288 ± 51 (493)	5257 ± 171 (210)	9694 ± 257 (211)	13383 ± 3166 (6)
1995	2374 ± 49 (521)	5769 ± 203 (207)	9508 ± 332 (145)	-
Alta				
1993	2203 ± 60 (220)	6486 ± 670 (14)	10959 ± 205 (354)	14868 ± 1496 (31)
1994	1914 ±103 (88)	6565 ± 595 (26)	10330 ± 258 (177)	15058 ± 1048 (38)
1995	1967 ± 40 (189)	6491 ± 904 (11)	10664 ± 195 (337)	15028 ± 1198 (29)
Orkla				
1993	1979 ± 101 (188)	5475 ± 236 (107)	9236 ± 365 (105)	10200 ± 1568 (50)
1994	2255 ± 51 (389)	5501 ± 331 (52)	8994 ± 349 (105)	13162 ± 3402 (8)
1995	1982 ± 126 (77)	6047 ± 110 (335)	8862 ± 280 (157)	10414 ± 2704 (7)

There were two peaks in the migration of Atlantic salmon to the River Varzuga, one during summer and one during autumn. Almost all fish entering the river later than 20 August are immature. Usually the autumn migration is most intense during the middle of October, but a significant part of the stock migrates as late as November. The autumn run usually comprises about 70 % of the total annual run. It is believed that immature Atlantic salmon migrating during autumn stay in the river during the winter and into the next summer without feeding, and then spawn during September.

4.2 River Kola

4.2.1 Growth and density of parr

In early September, young-of-the-year salmon in the River Kola were on average 45-47 mm long (**Table 10**). The mean annual growth increments the next three years were 32-34 mm, 32-38 mm and 29-32 mm, respectively. Compared to the model for growth of Atlantic salmon parr fed on maximum rations at the same temperature regime (Elliott & Hurley 1997), the growth was 87-92 % of the model from

***Table 10**. Mean natural tip length (l, mm ± 95 % confidence limits) of different age groups of Atlantic salmon parr collected by electrofishing in the River Kola in August/September 1993-1995. Sample sizes are given in parentheses.*

Age (year)	1-10.09.1993	23.08-06.09.1994	16.08-4.09.1995
0+	45.7 ± 1.0 (64)	45.8 ± 1.6 (24)	47.0 ± 3.0 (8)
1+	73.4 ± 2.0 (96)	77.7 ± 2.0 (86)	80.0 ± 3.3 (18)
2+	93.9 ± 3.8 (78)	105.8 ± 3.0 (152)	115.9 ± 4.0 (59)
3+	118.1 ± 6.2 (31)	125.5 ± 6.6 (34)	134.5 ± 3.0 (48)
4+	129.2 ± 9.1 (11)	132.2 ±14.0 (5)	144.5 ± 12.8 (6)

September 1993 to September 1994, and 83-107 % from September 1994 to September 1995 (**Table 11**). This high growth rate indicates that food conditions for Atlantic salmon parr in the River Kola are good, and that the growth rate is mainly determined by temperature.

Atlantic salmon is the predominant species in the River Kola. In 1993, no other species was observed, while a few brown trout were caught in 1994 and 1995. They were all found at the three uppermost sites (no. 1, 2 and 3), upstream of Murdozero Lake (**Figure 6, Table 12**).

The mean densities of Atlantic salmon parr (excluding fry) were 32.6 ± 10.3, 33.3 ± 19.8, and 8.2 ± 5.4 individuals per 100 m^2 in 1993, 1994 and 1995, respectively (**Table 13**). The highest densities of salmon parr were observed at site 5 and 11, and densities were also high at sites 4, 8, 12, 13 and 14. In the upper part of the river (sites no. 1, 2 and 3) densities were very low (**Figure 14**).

4.2.2 Heavy metal contents of parr

Cadmium was detected in the highest mean concentrations in kidney and liver (0.128 and 0.066 ppm wet weight, respectively), while the concentrations in muscle were low (0.002 ppm, **Table 7**). Copper was present in all four organs analysed, but in the highest concentrations in liver (6.44 ppm). Selenium and zinc were also found in the highest concentrations in liver (0.94 and 60.55 ppm, respectively), while the highest concentrations of mercury were observed in muscle (0.043 ppm).

In contrast to the other three rivers, nickel was found in concentrations above the detection limit in all four organs of fish from the River Kola. The concentrations were 0.332 ± 0.164, 0.042 ± 0.006, 0.367 ± 0.058 and 0.406 ± 0.083 ppm wet weight in gills, muscle, liver and kidney, respectively. Also concentrations of arsenic in gills and muscle of some fish were above the detection limit, while lead was not traceable in any organ.

4.2.3 Smolt migration

A total of 92 smolts were caught in the River Kola during 16 June to 12 July 1994. They were caught at decreasing water flow and increasing temperature. Most smolts were caught at temperatures between 10 and 15 °C (**Figure 15**).

4.2.4 Status of adult stock

The fishing for salmon in the catchment of the River Kola has been conducted as long as people have lived in this area. Reliable information dates back to the 17-th century, when about 400 tonnes of salmon were caught in the vicinity of the River Kola (Ovsyannikov 1938). Later, in the period from 1898 to 1902 the catch of salmon in the Kola fjord varied from 13.8 to 58.9 tonnes (Soldatov 1903). In 1916-28, the catches were 16.5-41.6 tonnes (Ovsyannikov 1938), and in the period from 1944 to 1957 they were 9.6-22.7 tonnes (Azbelev 1960). There are no data available on the abundance of salmon caught in the River Kola itself. However, Azbelev (1960), based on the counts of salmon, pointed out that in 1950-58 the abundance of salmon in the River Kola ranged from 1700 to 5300 fish.

In 1959-94, the catch of salmon in the River Kola varied from 9.1 tonnes (1965) to 57.5 tonnes (1984), with an average of 24.8 tonnes. Numbers of salmon varied between 1558 fish in 1964 and 14 225 fish in 1974, with an average of 6 470 fish (**Figure 16**). These data show that the initiation of concentrated fishing for salmon at the counting fence in 1959, and the introduction of more stringent measures to safeguard the river had a favourable influence on the salmon population in the River Kola. Hence, the population increased noticeably in the 1970's. In subsequent years, the growth of the salmon population continued and presently it can be considered to have stabilised at a relatively high level.

Considering the status of the River Kola stock we must bear in mind that a certain part of the catch is composed of hatchery-reared fish. The data analysis indicated, that in certain years such fish contributed significantly to the catch. Along with this, it should be mentioned that only fish with a

***Table 11.** Mean weight (W_1) of 0+, 1+ and 2+ Atlantic salmon sampled in August 1993 and 1994 in the River Alta, and September 1993 and 1994 in the Rivers Kola and Orkla, and mean weight (W_2) of the same year-class one year later, mean instantaneous growth rates per year (G_{wa}) of these fish, and the corresponding rates computed from the model for growth of Atlantic salmon fed on maximum rations (Elliott & Hurley 1997) at the same temperature regimes. The ratio between recorded and computed growth rate (in percent) is also given.*

River/year	Initial and final weight		Inst. Growth rate per year (G_{wa})		Ratio observed/
age	W_1 (g)	W_2 (g)	Observed	Computed	computed (%)
River Kola, Sept. 1993 - Sept. 1994					
0+	0.89	4.35	1.59	1.73	92
1+	3.67	10.98	1.10	1.21	91
2+	7.67	18.32	0.87	1,00	87
River Kola, Sept. 1994 - Sept. 1995					
0+	0.89	4.75	1.67	1.67	100
1+	4.35	14.43	1.20	1.12	107
2+	10.98	22.56	0.72	0.87	83
River Alta, Aug. 1993 - Aug. 1994					
0+	0.43	2.32	1.69	1.84	92
1+	2.10	6.65	1.15	1.24	93
2+	5.73	13.77	0.88	0.95	93
River Alta, Aug. 1994 - Aug. 1995					
0+	0.45	1.93	1.46	1.84	79
1+	2.32	5.61	0.88	1.22	72
2+	6.65	11.71	0.57	0.92	62
River Orkla, Sept. 1993 - Sept. 1994					
0+	0.74	3.36	1.51	1.80	84
1+	3.70	9.41	0.93	1.21	77
River Orkla, Sept. 1994 - Sept. 1995					
0+	0.76	3.09	1.40	1.31	107
1+	3.36	7.92	0.86	0.88	98

clipped adipose fin were counted and after 1988 only 30 % of the fish released for stocking were fin-clipped. Hence, the proportion of hatchery-reared fish in the catch since 1989 has been at least three times as much as that reported. Overall the mean number of hatchery-reared salmon was 1231 fish, which accounted for 14.7 % of the mean number of fish in the catches in 1982-94.

Despite the stable status of the salmon stock, one of the main problems for the River Kola is illegal fishing or poaching. It was noted as early as the 1950's (Azbelev 1960), that the reduction in salmon abundance in the River Kola "has nothing or almost nothing in common with the periodical fluctuations of abundance", and was due to the influence of local factors, in particular, poaching. This problem is acute at present.

4.2.5 Population structure

The smolt age of Atlantic salmon in the River Kola varied between 2 and 5 years, with three and four year old smolts being most common. The mean smolt age varied between 3.41 ± 0.05 and 3.60 ± 0.04 years during 1993-95 (**Table 8**). The smolts were unusually large at descent, having a mean length between 146 and 161 mm (**Table 8**).

Grilse, 2SW and 3SW salmon were frequent in the river, and some 4SW were also observed. The proportion of males in the 1993-1995 runs was 57 %. Among males, grilse predominated (75 %), but there was also a significant proportion (16 %) of 3SW fish (**Figure 13**). Most of the females were 2SW fish (43 %) or 3SW fish (41 %), while only a few female grilse were observed (**Figure 13**). The mean weights of grilse, 2SW, 3SW and 4SW fish are given in **Table 9**.

Table 12. Number of Atlantic salmon and brown trout parr caught at twelve stations in the River Kola in August/September 1993-1995. The area (m²) of each station is also given.

		Area			Atlantic salmon						Brown trout			
Site	Date	(m²)	0+	1+	2+	3+	older	Sum	0+	1+	2+	3+	older	Sum
1993														
1	31.08.93	100						0						0
2	31.08.93	100						0						0
3	no data													
4	09.09.93	100	17	22	2	7	1	49						0
5	09.09.93	60	13	13	10	3	2	41						0
6	02.09.93	60	3	4	14	7		28						0
7	02.09.93	80	5	8	14	6		33						0
8	02.09.93	60	9	7	18	8		42						0
9	02.09.93	100	16	14	10	3	2	45						0
10	06.09.93	100	8	10	1			19						0
11	06.09.93	45	4	2	5	3	1	15						0
12	06.09.93	75	2	9	8	3	2	24						0
13	10.09.93	80	11	18	2			31						0
14	01.09.93	50		3	7	9	3	22						0
15	01.09.93	40		4	8	1		13						0
16	01.09.93	66	1	2	3	1		7						0
17	01.09.93	60			2	2	1	5						0
1994														
1	24.08.94	100	2		1	1		4			2	1	1	4
2	24.08.94	100	3					3		1				1
3	24.08.94	100	5					5	1 7	1	2			11
4	23.08.94	65	4	22	11	3	3	43						0
5	23.08.94	45	11	24	17	8		60						0
6	25.08.94	60		1	1			2						0
7	25.08.94	80		7	13			20						0
8	05.09.94	75		13	24	4		41						0
9	05.09.94	30		6	7	6		19						0
10	05.09.94	100		2	1			3						0
11	05.09.94	30			22			22						0
12	05.09.94	75		2	26	4	1	33						0
13	06.09.94	80	1	8	16	2		27						0
14	26.08.94	60			6	1		7						0
15	26.08.94	60			1	1		2						0
16	19.08.94	100						0						0
17	19.08.94	75			2			2						2
1995														
1	16.08.95	100						0	6	2				8
2	16.08.95	100						0	2					2
3	16.08.95	100						0	2					2
4	17.08.95	65		6	3	3		12						0
5	17.08.95	45	8	2	3	7	1	21						0
6	16.08.95	60						0						0
7	16.08.95	80			6	1		7						0
8	21.08.95	75			7	9	2	18						0
9	21.08.95	30		2	1	1	1	5						0
10	23.08.95	100						0						0
11	23.08.95	30						0						0
12	23.08.95	75		1	4	6		11						0
13	21.08.95	80		6	3			9						0
14	24.08.95	100						0						0
15	24.08.95	60						0						0
16	24.08.95	75						0						0
17	24.08.95	100						0						0

***Table 13**. Catch of Atlantic salmon and brown trout parr (excluding fry) in the River Kola in the first, second and third successive fishing, and density estimates (Zippin method, number per 100 m²) in August/September 1993-1995. The area of each site is given in Table 12.*

Site	Atlantic salmon				Brown trout			
	1. fishing	2. fishing	3. fishing	Zippin estimate	1. fishing	2. fishing	3. fishing	Zippin estimate
1993								
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
4	13	14	5	47.7	0	0	0	0
5	10	8	10	>46.7	0	0	0	0
6	13	9	3	49.0	0	0	0	0
7	21	3	4	36.6	0	0	0	0
8	23	6	4	58.0	0	0	0	0
9	18	8	3	31.3	0	0	0	0
10	6	4	1	12.4	0	0	0	0
11	8	1	2	26.2	0	0	0	0
12	9	8	5	52.3	0	0	0	0
13	17	11	3	43.6	0	0	0	0
14	13	6	5	61.2	0	0	0	0
15	9	3	1	38.8	0	0	0	0
16	4	1	1	10.0	0	0	0	0
17	4	1	0	8.3	0	0	0	0
Mean (numbers per 100 m²):				32.6 ± 10.3				0
1994								
1	2	0	0	2.0	4	0	0	4.0
2	0	0	0	0	1	0	0	1.0
3	0	0	0	0	7	3	0	11.4
4	22	11	6	69.8	0	0	0	0
5	24	19	6	132.0	0	0	0	0
6	2	0	0	3.3	0	0	0	0
7	14	5	1	25.8	0	0	0	0
8	20	16	5	67.1	0	0	0	0
9	16	3	0	63.7	0	0	0	0
10	1	2	0	3.8	0	0	0	0
11	11	6	5	103.0	0	0	0	0
12	24	6	3	45.5	0	0	0	0
13	22	4	0	32.6	0	0	0	0
14	5	2	0	11.8	0	0	0	0
15	2	0	0	3.3	0	0	0	0
16	1	1	0	2.2	0	0	0	0
17	0	0	0	0	0	0	0	0
Mean (numbers per 100 m²):				33.3 ± 19.8				1.0 ± 1.4
1995								
1	0	0	0	0	8	0	0	8.0
2	0	0	0	0	2	0	0	2.0
3	0	0	0	0	2	0	0	2.0
4	5	6	1	23.5	0	0	0	0
5	8	4	1	31.0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	5	1	1	9.3	0	0	0	0
8	11	7	0	24.9	0	0	0	0
9	4	1	0	16.7	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	5	4	2	22.3	0	0	0	0
13	6	3	0	11.5	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
Mean (numbers per 100 m²):				8.2 ± 5.4				0.7 ± 1.0

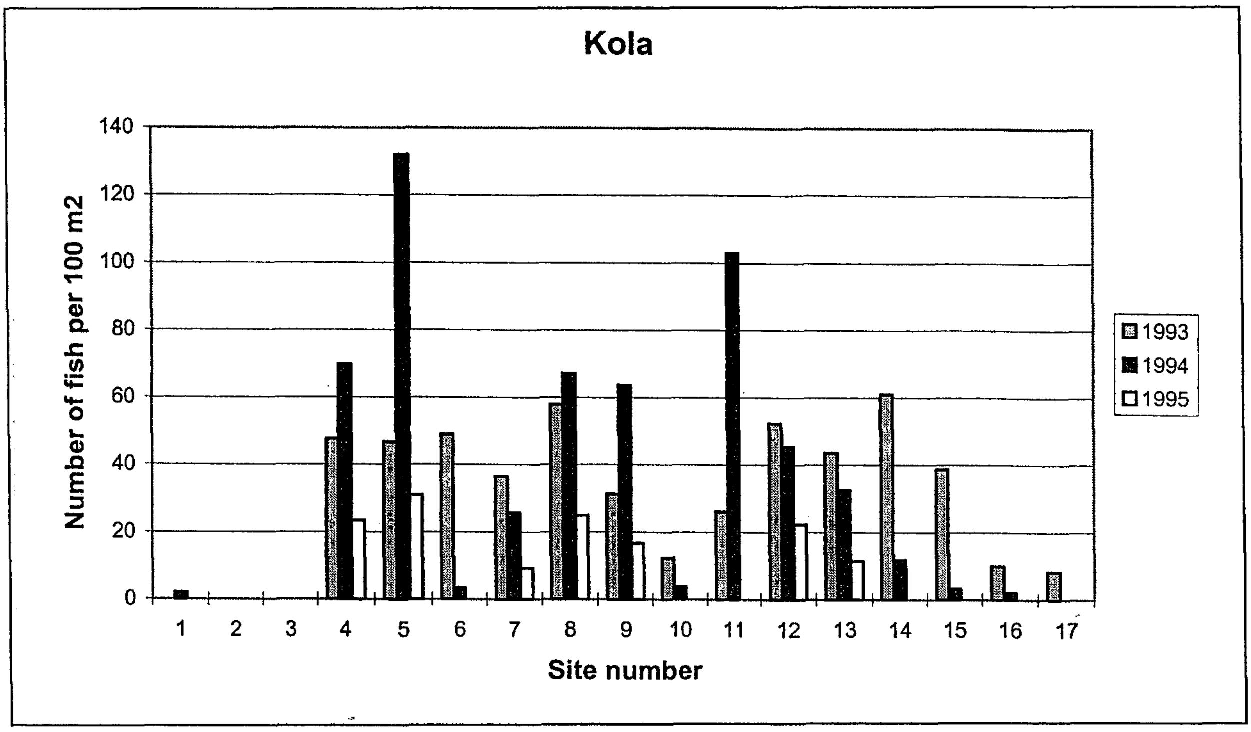


Figure 14. Density estimates (Zippin method) of Atlantic salmon parr (excluding fry) at each of the 17 sites in the River Kola 1993-1995.

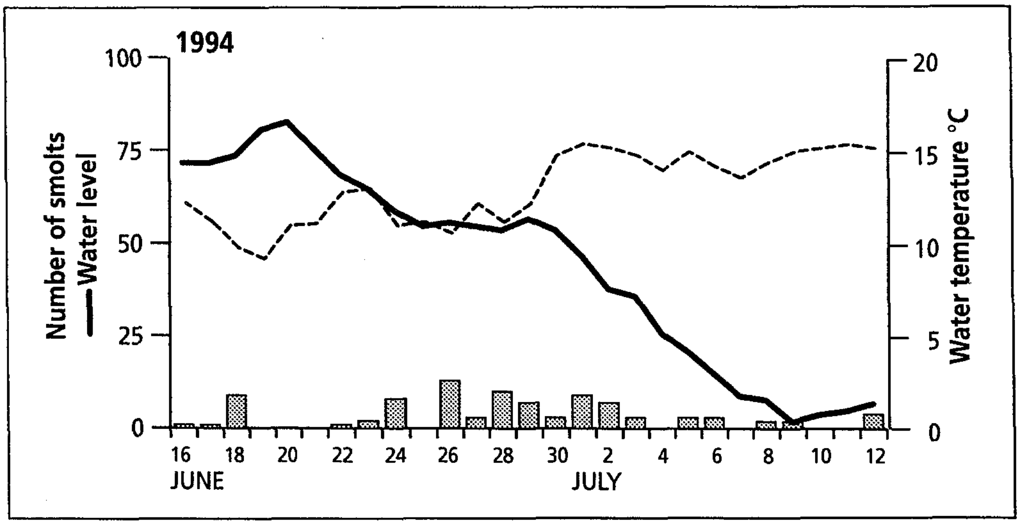


Figure 15. Daily descent (in numbers) of Atlantic salmon smolts in the River Kola in 1994, as well as water level (cm) and water temperature (°C).

4.3 River Alta

4.3.1 Growth and density of parr

In the middle of August, young-of-the-year salmon in the River Alta were on average 34-36 mm long **(Table 14)**. The mean annual growth increment of 0+, 1+ and 2+ salmon from August 1993 to August 1994 was 27-29 mm, while that from August 1994 to August 1995 was only 19-23 mm. Compared with the model for growth of Atlantic salmon parr fed on maximum rations at the same temperature regime (Elliott & Hurley 1997), the growth was 92-93 % of the model from August 1993 to August 1994, but only 62-79 % of the model from August 1994 to August 1995 **(Table 11)**. The temperature was similar during these two periods, and hence, the reason for the poor growth during the latest year is probably unfavourable food conditions.

Atlantic salmon was the predominant species in the River Alta. Brown trout constituted 1-2 % of the electrofishing catches **(Table 15, Table 16)**. Other fish species were seldom observed.

Estimated densities of Atlantic salmon parr (excluding fry) in the River Alta were to 32.1 ± 19.7, 60.2 ± 28.6, and 61.4 ± 31.6 individuals per 100 m^2 in 1993, 1994 and 1995, respectively **(Table 16)**. The corresponding densities of brown trout were less than 1 per 100 m^2 in all three years. The

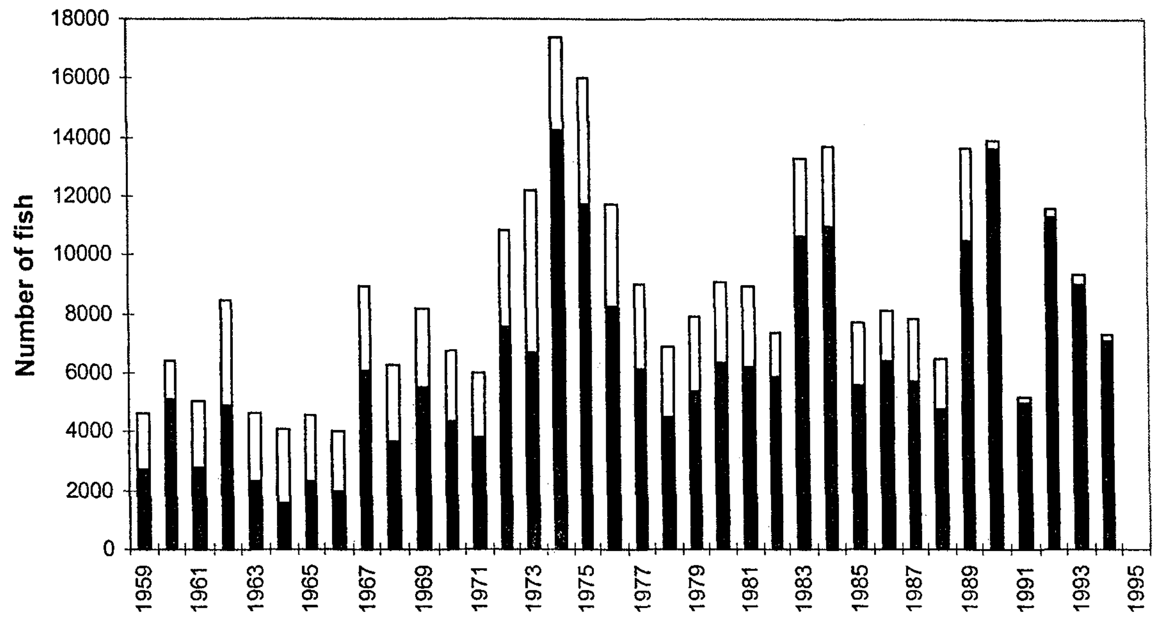


***Figure 16**. Total ascent (numbers) of adult Atlantic salmon in the River Kola in the period 1959-1995. The lower, black part of the bars indicates fish which were kept, and the upper, white part indicates fish which were left for spawning.*

***Table 14**. Mean natural tip length (l, mm ± 95 % confidence limits) of different age groups of Atlantic salmon parr collected by electrofishing in the River Alta in August 1993-1995. Sample sizes are given in parentheses.*

Age (year)	13-15 August 1993	15-18 August 1994	14-18 August 1995
0+	36.1 ± 0.4 (183)	36.5 ± 0.3 (363)	34.3 ± 0.6 (79)
1+	61.0 ± 1.1 (71)	63.0 ± 0.8 (250)	59.3 ± 1.1 (179)
2+	85.2 ± 1.8 (75)	89.5 ± 1.4 (118)	84.6 ± 1.4 (128)
3+	104.1 ± 4.7 (15)	114.1 ± 1.9 (73)	108.1 ± 2.1 (63)

highest densities of salmon parr were observed at sites 5-12. At sites 1-3 and 14 densities of salmon were low (**Figure 17**).

4.3.2 Heavy metal contents of parr

Except for zinc, concentrations of heavy metals in parr were low in the River Alta (**Table 7**). The highest concentrations of cadmium were found in kidney (0.079 ppm) and liver (0.037 ppm), while in gills and muscle only very low concentrations were detected (0.008 and 0.001 ppm, respectively).

Only trace amonts of copper and selenium were found in liver and muscle, and concentrations were low compared to the other rivers. The concentrations of mercury (0.017-0.025 ppm) in all organs were higher than those in the River Orkla, but lower than those in the two Russian rivers (**Table 7**).

Zinc was found in the highest concentrations in gills (145 ppm), but high values were also recorded in liver (60.8 ppm) and kidney (59.2 ppm). The zinc concentrations in gills of salmon parr from the River Alta were similar to those from the lower part of the River Orkla (147 ppm), but higher than those from the two Russian rivers (113-118 ppm).

Nickel, arsenic and lead were below the detection levels in all fish from the River Alta.

4.3.3 Smolt migration

Median date of 50 % cumulative smolt decent for the seven years analysed was 25 June.

Smolt migration started at water temperatures of 6 °C or higher, with the majority of smolts migrating when the water temperature reached 10 °C (**Figure 18**). The smolts migrated after maximum spring flood and at water discharges well below it. In 1993, the smolt migration was late (50 % cumulative descent occurred 11 July). This was probably due to low water temperatures during June, and a late spring flood. Smolt migration occurred both night and day, with 56 % of the fish descending between 11 p.m. and 7 a.m. daily (1993-95).

*Table 15. Number of Atlantic salmon and brown trout parr caught at fourteen stations in the River Alta in August 1993-1995. The area (m²) of each station is also given. * indicates that 2+ and older fish are pooled.*

		Area	Atlantic salmon						Brown trout					
Site	Date	(m²)	0+	1+	2+	3+	older	Sum	0+	1+	2+	3+	older	Sum
1993														
1	16.08.93	231	42	4			6*	52	4	1				5
2	16.08.93	200	15	1				16						0
3	16.08.93	305	4				1*	5	4					4
4	15.08.93	274	53	16			19*	88	13	4			1*	18
5	16.08.93	105	74	6			7*	87						0
6	15.08.93	140	24	49			58*	131		2			2*	4
7	15.08.93	204	5	21			19*	45	1	2			2*	5
8	15.08.93	171	45	30			59*	134					2*	2
10	13.08.93	207	27	45			23*	95						0
11	13.08.93	126	30	17			22*	69						0
12	13.08.93	297	47	15			35*	97						0
14	14.08.93	61	14	1				15	2					2
15	14.08.93	181	48	12			9*	69	1					1
16	14.08.93	315	54	12			24*	100	1					1
1994														
1	15.08.94	193	57	10			1*	68	1					1
2	15.08.94	123	5	3			7*	15						0
3	15.08.94	275	38	7			3*	48					1*	1
4	15.08.94	236	130	85	9	1		225	7		1			8
5	16.08.94	86	130	67	28			225						0
6	16.08.94	158	40	77			66*	183						0
7	16.08.94	184	2	58			35*	95						0
8	16.08.94	174	49	73	50	44	3	219		2	1			3
10	18.08.94	156	80	108			32*	220		1				1
11	18.08.94	120	90	53			43*	186						0
12	18.08.94	294	108	54	45	21	1	229	1					1
14	17.08.94	41	40					40	1					1
15	17.08.94	130	42	2			2*	45	1					1
16	17.08.94	152	72	27	10	7		116						0
1995														
1	16.08.95	120	6	12				18						0
2	16.08.95	144	10	8			1*	19						0
3	17.08.95	198						0						0
4	15.08.95	209	49	85	23			157	1					1
5	17.08.95	104	17	59			20*	96						0
6	17.08.95	101	2	75			70*	147		2			1*	3
7	17.08.95	152		20			45*	65						0
8	15.08.95	161	21	24	33	35	2	113						0
10	18.08.95	117	9	27			20*	56						0
11	18.08.95	242	9	30			31*	70						0
12	18.08.95	200	9	35	43	22		109	1	1				2
14	18.08.95	33	14	3				17						0
15	14.08.95	158	3	32			14*	49						0
16	14.08.95	255		16			29*	45					1*	1

__Table 16__. Catch of Atlantic salmon and brown trout parr (excluding fry) in the River Alta in the first, second and third successive fishing, and density estimates (Zippin method, number per 100 m²) in August 1993-1995. The area of each site is given in Table 15.

	Atlantic salmon				Brown trout			
Site	1. fishing	2. fishing	3. fishing	Zippin estimate	1. fishing	2. fishing	3. fishing	Zippin estimate
1993								
1	9	1	0	4.3	0	1	0	> 0.4
2	0	1	0	*0.5	0	0	0	0.0
3	0	1	0	*0.3	0	0	0	0.0
4	17	11	7	17.5	4	1	0	1.8
5	6	5	2	16.3	0	0	0	0.0
6	52	38	17	97.5	3	1	0	2.9
7	17	16	7	29.2	2	2	0	2.1
8	49	27	13	61.2	2	0	0	1.2
10	41	18	9	36.7	0	0	0	0.0
11	16	12	13	120.1	0	0	0	0.0
12	23	11	16	35.9	0	0	0	0.0
14	1	0	0	1.6	0	0	0	0.0
15	10	7	4	16.0	0	0	0	0.0
16	24	6	6	12.5	0	0	0	0.0
Mean (numbers per 100 m²):				32.1 ± 19.7				0.6 ± 0.5
1994								
1	7	3	1	6.1	0	0	0	0.0
2	7	1	2	8.9	0	0	0	0.0
3	6	3	1	4.0	1	0	0	0.4
4	39	41	15	59.0	1	0	0	0.4
5	44	31	20	161.1	0	0	0	0.0
6	79	32	32	115.4	0	0	0	0.0
7	49	28	16	62.8	0	0	0	0.0
8	102	40	29	113.3	3	0	0	1.7
10	76	41	23	107.7	0	1	0	> 0.6
11	50	23	23	110.3	0	0	0	0.0
12	58	36	27	60.0	0	0	0	0.0
14	0	0	0	0.0	0	0	0	0.0
15	1	1	1	> 2.3	0	0	0	0.0
16	26	13	5	32.1	0	0	0	0.0
Mean (numbers per 100 m²):				60.2 ± 28.6				0.2 ± 0.3
1995								
1	6	4	2	12.8	0	0	0	0.0
2	7	1	1	7.3	0	0	0	0.0
3	0	0	0	0.0	0	0	0	0.0
4	66	27	16	58.6	0	0	1	> 0.5
5	43	26	10	88.4	0	0	0	0.0
6	75	49	21	174.1	0	3	0	> 3.0
7	25	19	21	193.2	0	0	0	0.0
8	45	34	15	75.5	0	0	0	0.0
10	26	12	9	49.3	0	0	0	0.0
11	37	16	8	27.9	0	0	0	0.0
12	48	27	22	69.4	0	0	1	> 1.7
14	2	1	0	9.3	0	0	0	0.0
15	17	18	11	68.0	0	0	0	0.0
16	22	12	11	26.3	0	1	0	> 0.4
Mean (numbers per 100 m²):				61.4 ± 31.6				0.4 ± 0.4

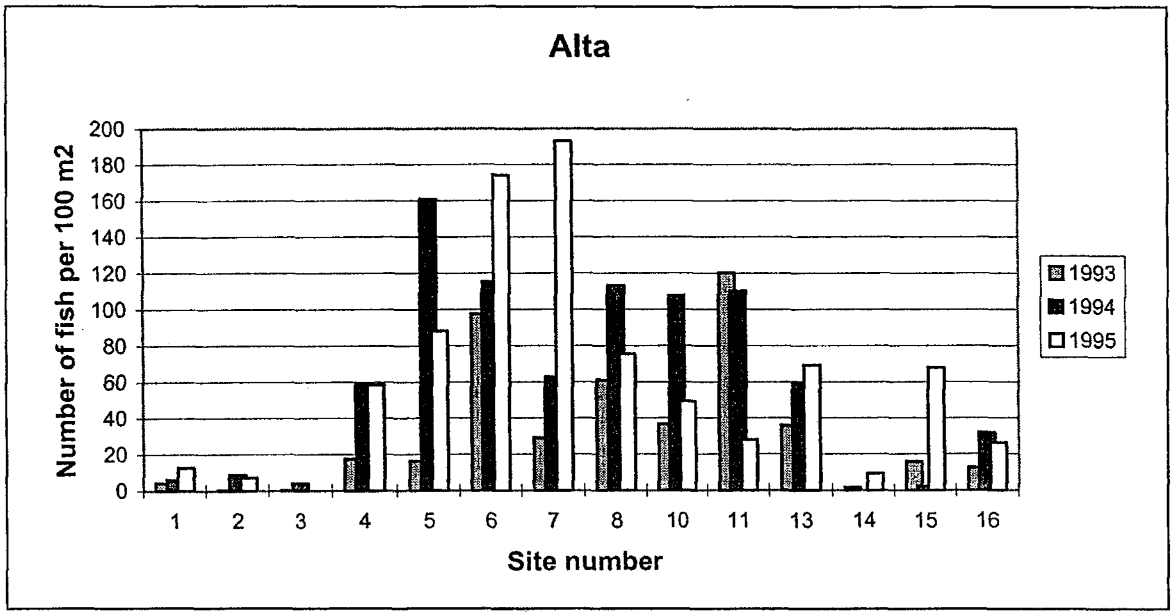


Figure 17. Density estimates (Zippin method) of Atlantic salmon parr (excluding fry) at each of the 14 sites in the River Alta 1993-1995.

4.3.4 Status of adult stock

Reported catches of adult Atlantic salmon from the sport fishery varied between 2.3 (1970) and 32.5 tons (1975) in the River Alta, with an average of 13.0 tons for the period 1966-95 (**Figure 19**). The average catch of brown trout during the same period was 0.9 tons, varying between 0.1 and 2.0 tons. Since 1974, the sport fishermen have had to pay a deposit for their licence to fish. This deposit is refunded when they return their licence, including a detailed catch report. Therefore, the catch statistics for the River Alta since 1974 are considered the most reliable.

After the building of the hydropower station in 1987, densities of juvenile salmon have decreased significantly (ca 85 %) in the upper 15 % of the salmon producing part of the River Alta (the Sautso area). In lower parts of the river, densities of presmolt salmon remain unchanged or have increased. Another effect of the power plant is reduced catches of salmon in the sport fisheries in the Sautso area. Catches of grilse have declined relative to catches in lower regions of the river, while catches of 3SW fish have declined in absolute numbers. The negative development in catches are probably caused by increased mortality in juvenile stages (Forseth et al. 1996).

4.3.5 Population structure

Smolt ages between two and six years have been observed in the River Alta. Mean ages have been slightly less than four years, and mean smolt lengths have been 131-138 mm (**Table 8**).

In the period 1993-95 more females (54 %) than males (46 %) were caught during the sport fishery. Among males, grilse were most frequent (68 %), but 3SW fish also made a significant contribution (21 %) to the male population. Among females, 3SW fish predominated (88 %). Some 4SW fish of both sexes also occurred, while 2SW fish were scarce (**Figure 13**). Mean weight of the different age groups is given in **Table 9**.

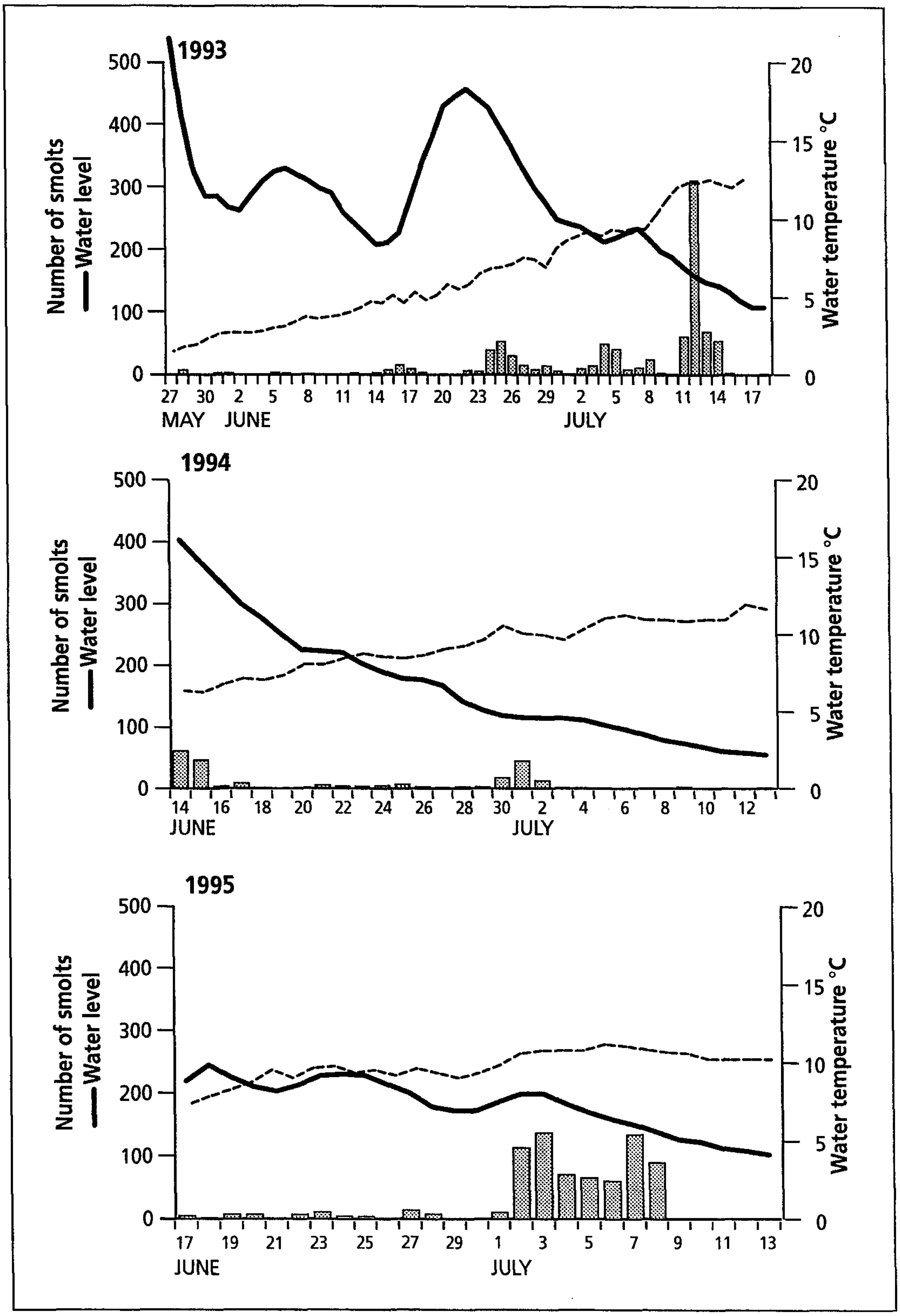
4.4 River Orkla

4.4.1 Growth and density of parr

Mean lengths of 0+ Atlantic salmon parr collected in the River Orkla in September 1993-95 were 42.4-43.4 mm (**Table 17**). At the same time, one year old fish were 69.3-73.6 mm, and two year old fish were 94.9-102.0 mm. During September 1993 to September 1994 the mean growth increments of the 1993 and 1992 year-classes were 28.2 and 26.9 mm, respectively. Correspondingly, the annual increases from September 1994 to September 1995 of the two youngest year-classes were 25.9 and 23.6 mm, respectively.

The annual growth of salmon parr from September 1993 to September 1994 was 77-84 % of the corresponding growth estimated by the growth model for Atlantic salmon parr fed on maximum rations at the same temperature regime (Elliott & Hurley 1997, **Table 11**). In the period from September 1994 to September 1995 the corresponding growth was 98-107 % of the estimated values. Hence, the conditions for growth, i.e. nutrient conditions, seemed to be most favourable during this period.

Figure 18. *Daily descent (in numbers) of Atlantic salmon smolts in the River Alta in the period 1993-1995, as well as water flow (m^3/s) and water temperature (°C).*



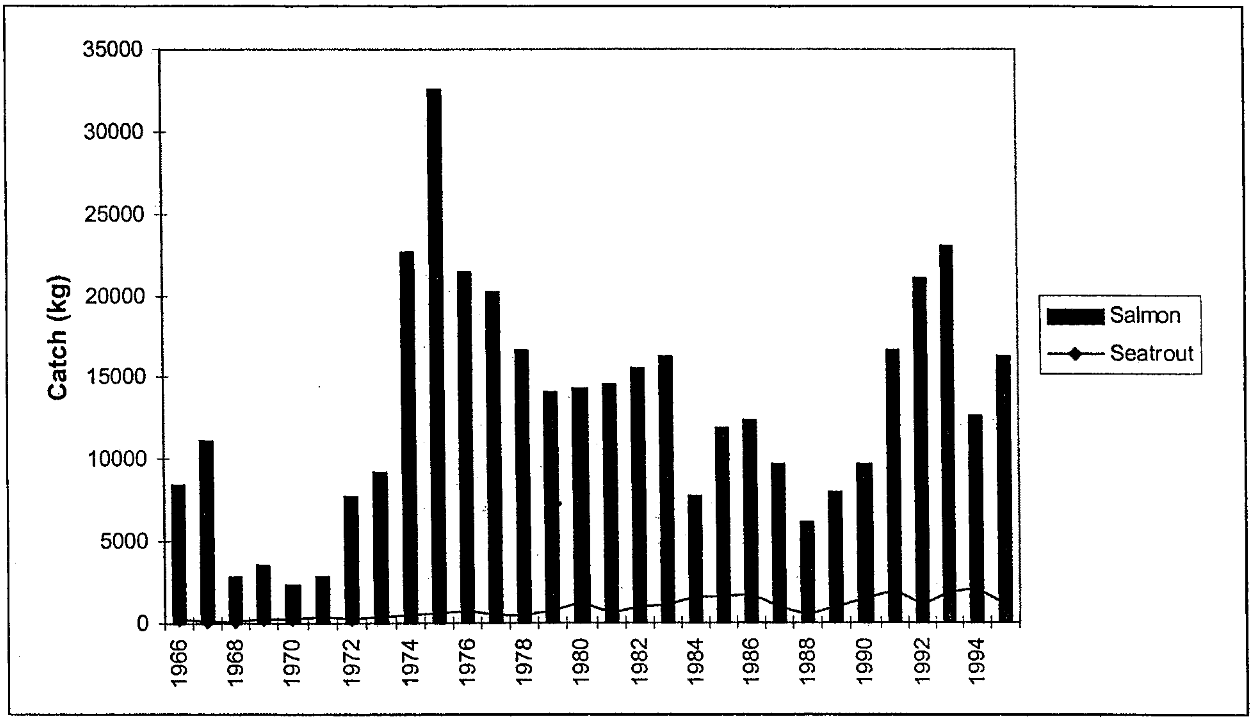


***Figure 19**. Catches (kg) of adult Atlantic salmon (bars) and sea trout (line) in the River Alta during 1966-1995.*

***Table 17**. Mean natural tip length (l, mm ± 95 % confidence limits) of different age groups of Atlantic salmon parr collected by electrofishing in the River Orkla in September 1993-1995. Sample sizes are given in parentheses.*

Age (year)	10-13 September 1993	12-14 September 1994	19-22 September 1995
0+	43.1 ± 0.6 (175)	43.4 ± 0.8 (173)	42.4 ± 0.9 (98)
1+	73.6 ± 1.0 (167)	71.3 ± 0.7 (359)	69.3 ± 1.0 (241)
2+	102.0 ± 2.1 (125)	100.5 ± 1.7 (173)	94.9 ± 1.3 (309)
3+	117.5 ± 2.6 (66)	121.6 ± 2.7 (43)	117.6 ± 2.7 (45)

The mean densities of Atlantic salmon parr (excluding fry) were 33.2 ± 8.3, 61.6 ± 27.8, and 55.9 ± 20.0 fish per 100 m^2 in 1993, 1994 and 1995, respectively (**Table 18, Table 19**). Similar estimates for juvenile brown trout were 12.1 ± 6.2, 16.0 ± 8.5 and 12.7 ± 8.5 fish per 100 m^2. The highest densities of salmon were observed on site number 8 (**Figure 20**). Sites number 1, 5 and 9 also had high densities.

Densities of Atlantic salmon parr were higher in 1994 and 1995 than in 1993. This is partly because of the strong 1993 year-class (**Table 18**), which is included in the 1994 and 1995 estimates, but not in the 1993 estimates. However, higher water flow during field work in 1993 than in 1994 and 1995 could be an alternative reason for the lower estimates in 1993. High water flow during electrofishing is known to hinder the catch of Atlantic salmon parr (Jensen & Johnsen 1988).

4.4.2 Heavy metal contents of parr

Concentrations of cadmium, copper and selenium were higher in Atlantic salmon parr in samples downstream of the confluence with the River Raubekken than farther upstream (**Table 20**). Significantly higher concentrations of all these metals were found in samples from liver downstream of the River Raubekken. Selenium was also higher in kidney, while cadmium was significantly higher both in liver, kidney and gills ($p < 0.01$-0.001).

Zinc was found in the highest concentrations in the gills. It was significantly higher in fish below the River Raubekken than upstream from it ($p < 0.05$). However, in both liver and muscle, concentrations of zinc were highest upstream of the tributary ($p < 0.001$, **Table 20**).

***Table 18**. Number of Atlantic salmon and brown trout parr caught at twelve stations in the River Orkla in September 1993-1995. The area (m²) of each station is also given.*

		Area			Atlantic salmon							Brown trout		
Site	Date	(m²)	0+	1+	2+	3+	Older	Sum	0+	1+	2+	3+	Older	Sum
1993														
1	10.09.93	100	15	24	16	1		56	24	14		1	1	40
2	10.09.93	100	19	32	11			62	33	20	2			55
3	10.09.93	100	3	3	2	3		11	2	2	1			5
4	03.09.93	100	5	9	8	7		29	3	3				6
5	03.09.93	100	21	21	11	2		55	6	2				8
6	03.09.93	100		5	12	2		19	4	21	4			29
7	11.09.93	100	9	19	10	1		39	16	1				17
8	11.09.93	100	28	12	24	20		84	68	19	3			90
9	13.09.93	100	27	13	22	6		68	18	13				31
10	13.09.93	100	35	15	1	1		52	25					25
11	13.09.93	100	6	8	5	11		30	2					2
12	11.09.93	100	7	6	3	12		28	11	10	2			23
1994														
1	14.09.94	100	8	39	20	2		69	23	6	4	1		34
2	14.09.94	100	11	19	20	1		51	22	28	5			55
3	14.09.94	100		14	18			32	4	7				11
4	13.09.94	100	2	2	9	5		18	18	6	3			27
5	13.09.94	100	49	59	11	2		121	29	3	2			34
6	13.09.94	100	7	8	15	8	1	39	18	4	1			23
7	13.09.94	100	15	39	9			63	52					52
8	12.09.94	100	30	81	44	20	1	176	96	41	2			139
9	12.09.94	100	6	38	4	2		50	41	24	6			71
10	12.09.94	100	16	15	3			34	42					42
11	12.09.94	100	12	29	10	2		53	4	4				8
12	12.09.94	100	17	16	10	1		44	36	18	6			60
1995														
1	19.09.95	100	3	45	48	11		107	5			2		7
2	19.09.95	100	18	27	22	4		71	25	7	1	2		35
3	19.09.95	100	2	22	20	1		45	2	2				4
4	20.09.95	100	3	28	29	6		66		3				3
5	20.09.95	100	7	36	27	4		74	16	4				20
6	20.09.95	100	3	12	15			30	13					13
7	21.09.95	100	45	9	10	1		65	23					23
8	21.09.95	100	4	38	63	10		115	29	15	3			47
9	21.09.95	100	4	2	20	3		29	12	30	4			46
10	21.09.95	100	1	11	27	1		40	27	4				31
11	22.09.95	100	2	2	15	2		21	1	23	2			26
12	22.09.95	100	6	9	12	3		30	8	15	1	1		25

***Table 19**. Catch of Atlantic salmon and brown trout parr (excluding fry) in the River Orkla in the first, second and third successive fishing, and density estimates (Zippin method, number per 100 m²) in September 1993-1995. The area of each site is given in Table 18.*

	Atlantic salmon				Brown trout			
Site	1. fishing	2. fishing	3. fishing	Zippin estimate	1. fishing	2. fishing	3. fishing	Zippin estimate
1993								
1	27	6	8	45.7	8	6	3	23.0
2	29	13	1	44.3	15	4	2	21.9
3	5	2	1	8.7	1	1	1	4.0
4	13	8	3	27.9	2	1	0	3.1
5	22	10	2	35.7	1	0	1	3.0
6	15	4	0	19.1	16	6	3	27.0
7	19	8	3	32.2	1	0	0	1.0
8	33	20	3	60.1	14	4	4	24.7
9	23	12	6	47.7	7	2	4	20.2
10	9	6	2	19.8	0	0	0	0.0
11	11	10	3	30.6	1	1	0	2.2
12	10	6	4	26.7	6	6	1	15.6
Mean (numbers per 100 m²):				33.2 ± 8.3				12.1 ± 6.2
1994								
1	40	13	8	65.9	8	3	0	11.1
2	30	8	2	40.8	20	12	1	34.8
3	22	7	3	33.6	4	3	0	7.4
4	9	4	3	19.4	4	3	2	14.4
5	48	15	9	76.9	2	1	2	(8.4)
6	22	7	3	33.6	2	1	2	(8.4)
7	32	12	4	50.6	0	0	0	0.0
8	73	56	17	175.1	35	4	4	43.7
9	17	14	13	138.1	20	6	4	32.2
10	11	4	3	20.4	0	0	0	0.0
11	21	13	7	51.6	3	1	0	4.0
12	14	9	4	32.8	15	5	4	27.0
Mean (numbers per 100 m²):				61.6 ± 27.8				16.0 ± 8.5
1995								
1	68	27	9	110.0	2	0	0	2.0
2	31	14	8	60.6	6	2	2	11.7
3	27	11	5	46.7	1	1	0	2.2
4	34	24	5	70.8	2	1	0	3.1
5	38	16	13	81.3	2	2	0	4.4
6	22	5	0	27.1	0	0	0	0.0
7	17	2	1	20.1	0	0	0	0.0
8	61	40	10	124.8	7	7	4	34.3
9	14	8	3	28.3	17	13	4	40.8
10	28	9	2	40.0	3	1	0	4.0
11	10	7	2	21.9	12	10	3	30.7
12	11	7	6	39.3	10	5	2	19.0
Mean (numbers per 100 m²):				55.9 ± 20.0				12.7 ± 8.5

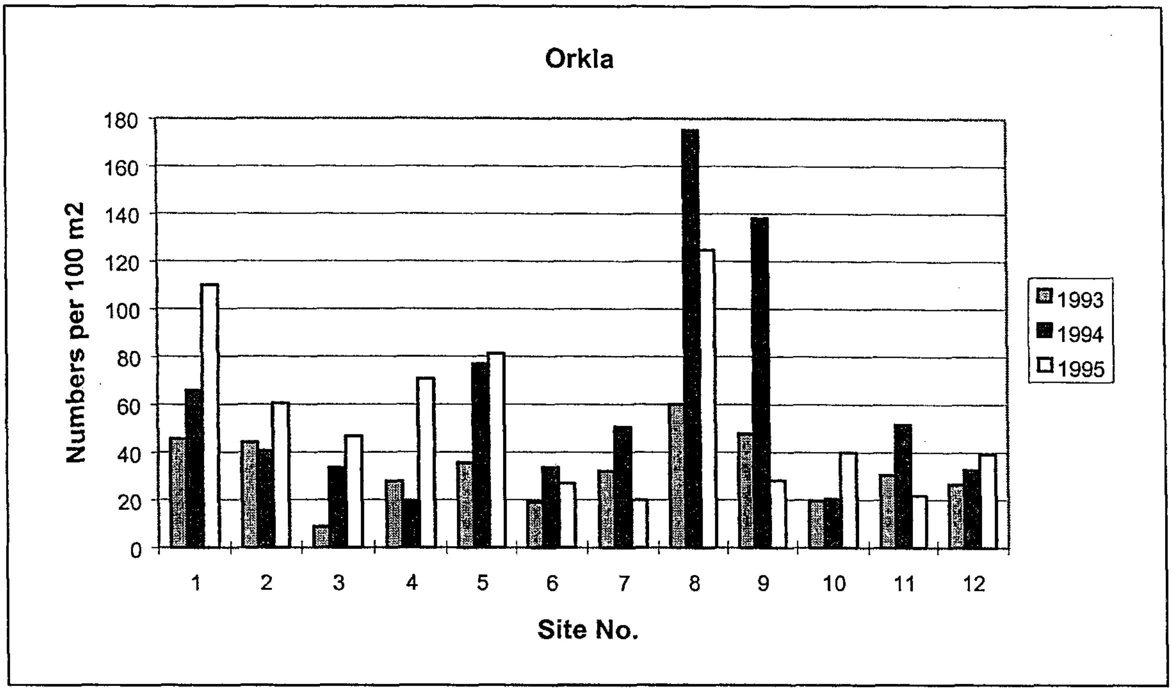


***Figure 20**. Density estimates (Zippin method) of Atlantic salmon parr (excluding fry) at each of the 12 sites in the River Orkla 1993-1995.*

***Table 20**. Concentrations (ppm, wet weight ± 95 % confidence limits) of Cd, Cu, Se, Zn and Hg in gills, muscle, liver and kidney of Atlantic salmon parr collected in the River Orkla downstream (Kvåle) and upstream (Grut) of the confluence with the River Raubekken.*

Metal/Organ	Kvåle	Grut	Significance level
Cadmium (Cd)			
Gills	0.443 ± 0.063	0.031 ± 0.004	p < 0.001
Muscle	< 0.006	< 0.006	
Liver	0.407 ± 0.082	0.051 ± 0.017	p < 0.001
Kidney	0.800 ± 0.241	0.066 ± 0.010	p < 0.001
Copper (Cu)			
Gills	0.568 ± 0.156	0.546 ± 0.116	n.s.
Muscle	0.398 ± 0.041	0.394 ± 0.034	n.s.
Liver	30.65 ± 13.17	8.06 ± 2.51	p < 0.01
Kidney	0.831 ± 0.202	0.787 ± 0.117	n.s.
Selenium (Se)			
Gills	< 0.31	< 0.27	
Muscle	0.226 ± 0.014	0.245 ± 0.015	n.s.
Liver	2.721 ± 0.509	0.573 ± 0.564	p < 0.001
Kidney	0.477 ± 0.315	< 0.13	p < 0.01
Zinc (Zn)			
Gills	146.8 ± 13.7	127.6 ± 12.1	p < 0.05
Muscle	7.52 ± 1.28	11.79 ± 1.28	p < 0.001
Liver	30.46 ± 6.08	58.12 ± 7.76	p < 0.001
Kidney	33.99 ± 7.82	33.63 ± 3.73	n.s.
Mercury (Hg)			
Gills	< 0.010	< 0.009	
Muscle	0.016 ± 0.002	0.018 ± 0.001	n.s.
Liver	0.017 ± 0.010	< 0.018	
Kidney	0.015 ± 0.003	< 0.014	

Mercury was detected in muscle only, where it was found in low, and not significantly different concentrations at Kvåle and Grut ($p > 0.05$, **Table 20**). Concentrations of nickel, arsenic, and lead were below the detection limit in all organs of all fish, both at Kvåle and Grut.

4.4.3 Smolt migration

Smolt migration in the River Orkla lasts for about one month, and mainly occurs in May. The median date of 50 % smolt descent for 14 years of analysis was 19 May. Smolt migration started at water temperatures between 1.7 and 4.4 °C and the smolt run was finished when the water temperature had reached 10 °C. Most smolts migrated at temperatures between 2 and 8 °C.

Peaks in migration lasted from one to three days and tended to be associated with high and increasing water discharges (**Figure 21**). Analysis of eleven years of smolt descent showed that water flow, water temperature, decreases in water temperature, increases in water flow and moon phase influenced the smolt migration significantly (Hvidsten et al. 1995). Smolt migration occurred at night, with 87 % of the smolts migrating between 10 p.m. and 2 a.m.

4.4.4 Status of adult stock

Reported catches of adult Atlantic salmon from the sport fishery varied between 0.9 (1969) and 26.9 tons (1987) in the River Orkla, with an average of 9.3 tons for the period 1966-1995 (**Figure 22**). The average catch of brown trout during the same period was 1.1 tons, varying between 0.3 and 2.2 tons.

The River Orkla was developed for hydroelectric purposes in the early 1980's. After the hydropower development, minimum water flows as high as 10 m^3/s between Berkåk and Meldal have been provided, and Atlantic salmon smolt production in this part of the river has increased (Hvidsten & Ugedal 1991).

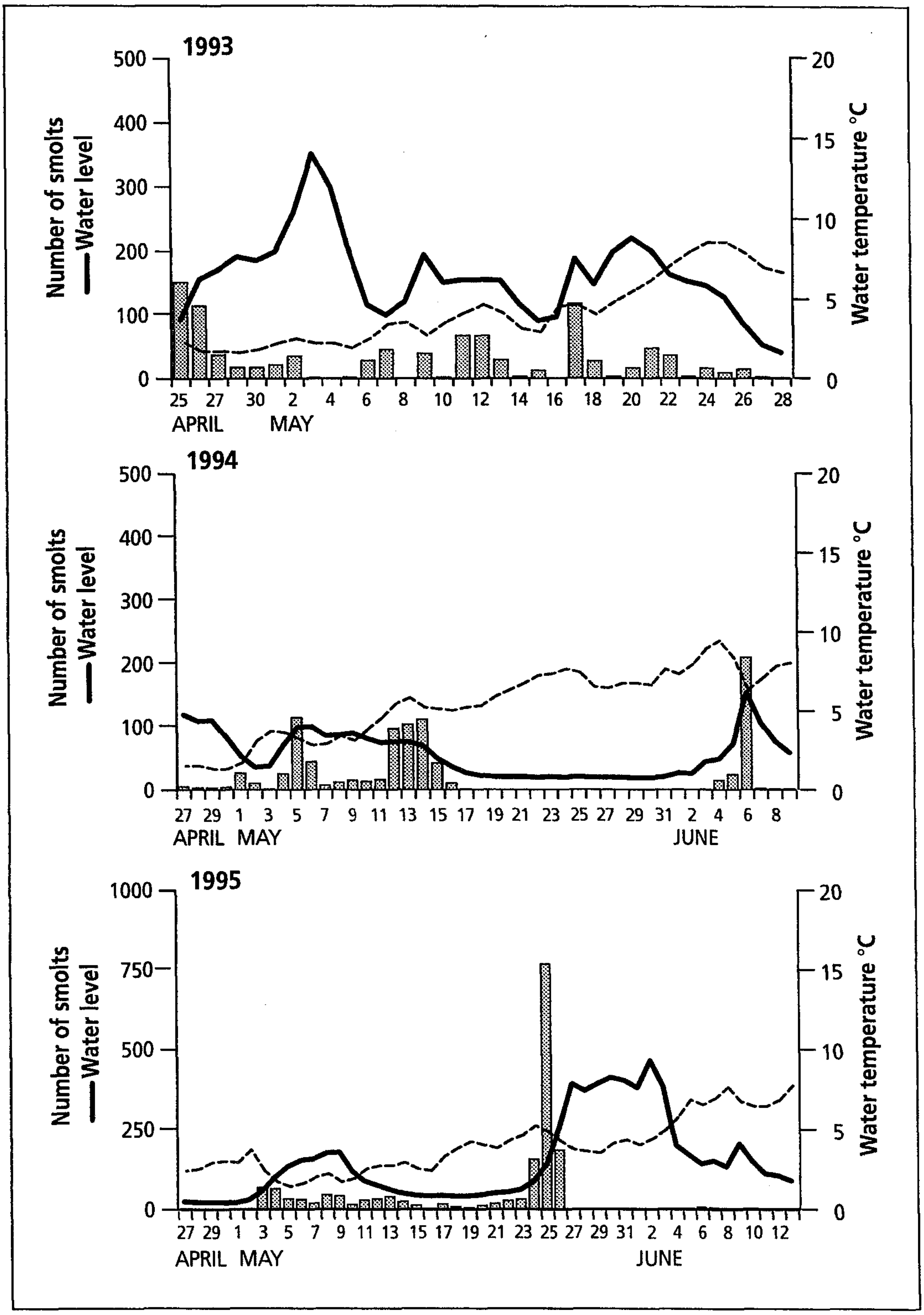
In the lower 15 km of the River Orkla, juvenile salmonid populations have been considerably reduced because of heavy metal pollution from the Løkken copper mine. A small tributary, the River Raubekken, drains the catchment near the copper mine. This tributary transported high concentrations of heavy metals, mainly copper, zinc, iron and cadmium, into the main river. When the river was utilised for hydroelectric purposes in the early 1980's, the opportunity was taken to mix water from the tributary with discharge water from the Svorkmo power plant before it reached the main river. At the same time measures were taken in the mining area, which partially prevented polluted water from seeping into the Raubekken. In addition, the hydropower company maintains a rather high minimum flow in the river. As a consequence, the concentrations of copper, zinc, iron, lead and cadmium have declined in the lower part of the main river since 1982. During the same period, densities of juvenile Atlantic salmon in the lower part of the river have increased to levels almost similar to those upstream from the tributary. Heavy metal analyses of juvenile Atlantic salmon have shown that concentrations of cadmium, copper and selenium are still higher in fish downstream than those upstream of the tributary. Hence, living conditions for salmonids in the lower 15 km of the River Orkla are now greatly improved (Jensen et al. 1995).

4.4.5 Population structure

The smolt age of Atlantic salmon from the River Orkla varied between two and five years. Most fish were three or four years at smoltification. The mean smolt age varied between 3.40 ± 0.04 and 3.48 ± 0.06 years, and the mean length of smolts was 132-138 mm (**Table 8**).

Both grilse, 2SW and 3SW salmon were frequent in the river, and some 4SW were also observed. The proportion of males was 58 % for the 1993-1995 runs. Among males, grilse predominated (60 %), but there was also a significant proportion of 2SW (22 %) or 3SW (17 %) fish (**Figure 12**). Most of the females were 2SW (45 %) or 3SW fish (36 %), while only a few female grilse were observed (**Figure 12**). The mean weights of grilse, 2SW, 3SW and 4SW fish are given in **Table 9**.

Figure 21. Daily descent (in numbers) of Atlantic salmon smolts in the River Orkla in the period 1993-1995, as well as water flow (m³/s) and water temperature (°C).



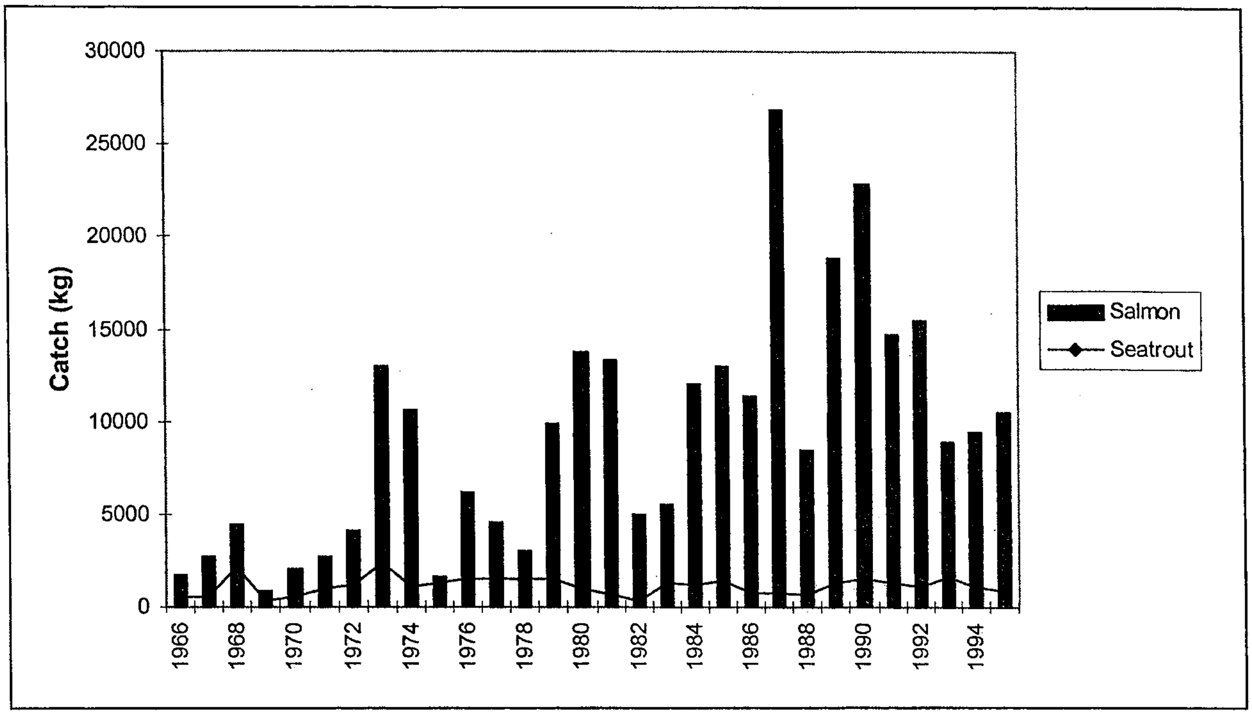


***Figure 22**. Catches (kg) of adult Atlantic salmon (bars) and sea trout (line) in the River Orkla in the period 1966-1995.*

5 Discussion

5.1 Growth of parr

Once the yolk sac has been absorbed, growth is mainly dependent on nutrient conditions, water temperature, and fish weight (Donaldson & Foster 1940, Brett et al. 1969, Elliott 1975a, b, Spigarelli et al. 1982). For Atlantic salmon, the optimum temperature for growth at excess rations has been found to be 15.9 °C, while growth commences at 6.0 °C and 22.5 °C (Elliott & Hurley 1997). Therefore, the annual river temperature regime is important for the scope for growth. The length of the growth season, i.e. the number of days above 6 °C, is shortest in the River Kola (about 100 days), a few days longer in the Rivers Alta (about 105 days) and Varzuga (about 110 days), and of longest duration in the River Orkla (130 days).

During most of the summer, temperatures are higher and closer to the optimum for growth in the two Russian rivers than in the two Norwegian rivers (**Figure 4**). We incorporated the temperature regime of the four rivers into the growth model for Atlantic salmon fed on excess rations (Elliott & Hurley 1997), starting with a 50 mm (1.16 g) salmon parr. According to the model, one year later this fish would have increased to 92.2, 86.6, 81.2 and 79.7 mm (7.26, 6.02, 4.97 and 4.70 g) respectively, in the Rivers Varzuga, Kola, Alta and Orkla. Slower growth than this indicates unfavourable food conditions.

The annual growth increment was considerably higher in the River Kola than in the two Norwegian rivers (**Figure 23**), and in both years close to the estimated values (**Table 11**). Also, the observed growth rates of salmon in the River Alta in the period August 1993-August 1994 were close to the estimated ones, but considerably lower (62-79 %) in the second period (**Table 11**). In the River Orkla the observed growth rates were 77-84 % of the estimated ones in the first period, but exceeded the estimated values in the second period (**Table 11**).

5.2 Densities of parr

The estimated densities of Atlantic salmon parr were higher in the Norwegian than the Russian rivers (**Figure 24**). However, for several reasons the results are not quite comparable. Habitat, i.e. bottom conditions, depth and water velocity, influences the catch of fish during electrofishing, and parr densities, therefore, can vary considerably among sites (**Figure 10, Figure 14, Figure 17, Figure 20**). Hence, mean density estimates for a river may change according to the location of each site and the time of sampling. Moreover, water discharge during the field work may affect the results, particularly at high water flows (Jensen & Johnsen 1988).

The size of the spawning population may significantly influence the densities of juveniles if the population is below carrying capacity. The conditions for survival during early life, producing strong or weak cohorts of salmon, may also affect densities of juveniles. In the River Orkla the 1993 year-class of salmon was stronger than average, and that was one reason for the higher density estimates of salmon parr in 1994 and 1995, than in 1993 (**Figure 20**).

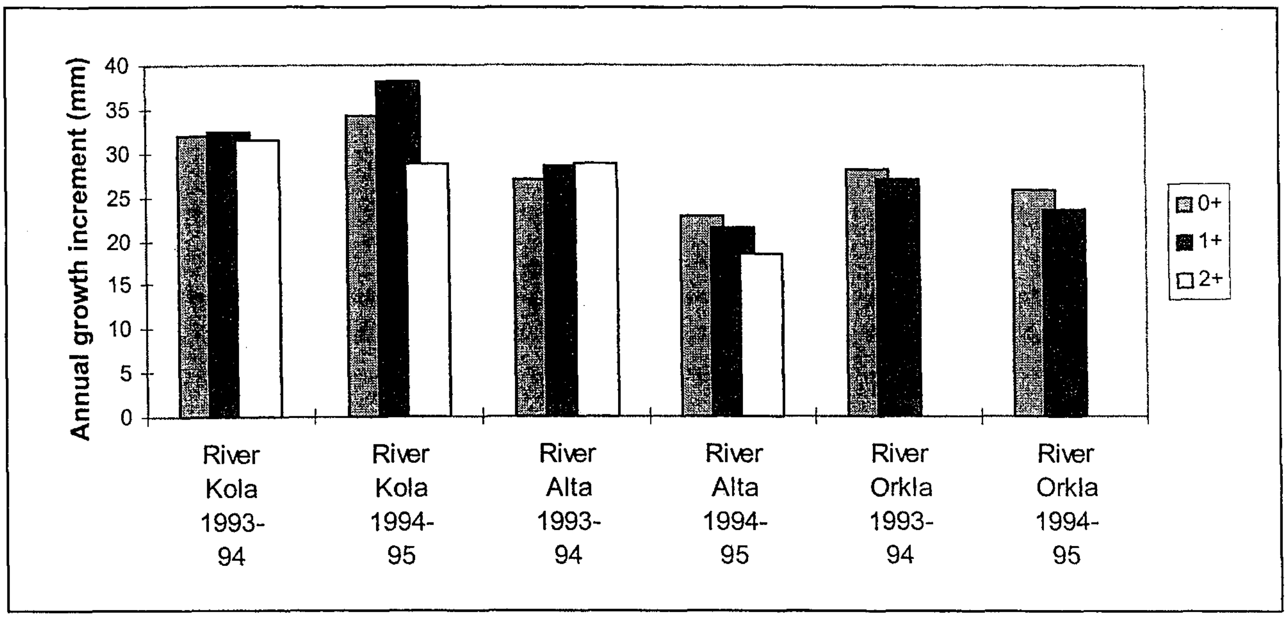
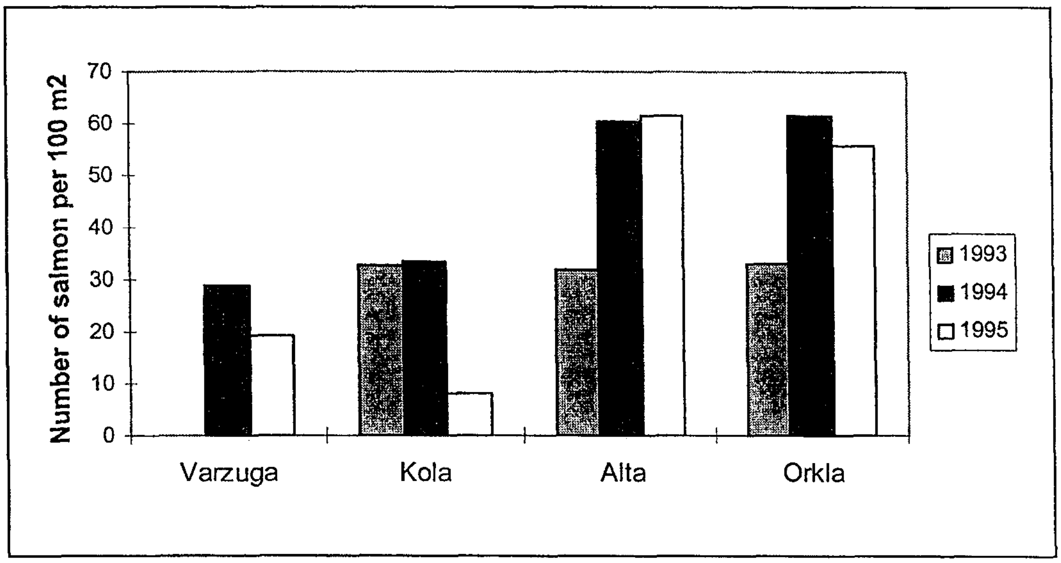


***Figure 23**. Mean annual growth increment (mm) of 0+, 1+ and 2+ Atlantic salmon parr in the Rivers Kola and Orkla (September 1993-94 and 1994-95) and the River Alta (August 1993-94 and 1994-1995).*

***Figure 24**. Mean density estimates (numbers per 100 m²) of Atlantic salmon parr (excluding fry) in the River Varzuga in the period 1994-1995 and in the Rivers Kola, Alta and Orkla in the period 1993-1995.*



5.3 Heavy metal contents of parr

The mean concentrations of heavy metals in Atlantic salmon parr in the Rivers Varzuga, Kola and Alta were usually within the range of concentrations observed in uncontaminated areas (Jensen et al. 1995). The uppermost location in the River Orkla also had similar low concentrations, while downstream of the confluence with the River Raubekken, which drains the Løkken mines, concentrations of cadmium, copper and selenium where high, especially in the liver (**Table 7, Table 20**). In contrast to the other rivers, concentrations of nickel and arsenic were above the detection limits in the River Kola.

Concentrations of cadmium were highest in kidneys and lowest in muscle in all four rivers. In the lower part of the River Orkla concentrations of cadmium were much higher than elsewhere. This is not surprising, because each year about 100 kg of cadmium are transported from the Løkken area by the River Raubekken and into the River Orkla (Grande & Romstad 1993).

Copper was observed in much higher concentrations in liver than in other organs. In the River Orkla, downstream from the confluence with the polluted tributary, concentrations were about 30 ppm, while upstream from that tributary, and also in the other three study rivers, concentrations in the liver were 6-8 ppm. In other organs, concentrations were usually less than 1 ppm.

Concentrations of selenium were also highest in liver. Except for the lower station in the River Orkla (2.7 ppm), concentrations of selenium in liver were less than 1 ppm, and in other organs less than 0.6 ppm. Concentrations in the River Kola were slightly higher than in the Rivers Varzuga and Alta, as well as in the upper part of the River Orkla.

Concentrations of zinc were highest in gills and lowest in muscles. In gills, the highest values were observed in the lower part of the River Orkla (147 ppm), and in the River Alta (145 ppm), while values of 113-128 ppm were observed at the other locations. In liver and kidney, concentrations of 49-61 ppm were measured in the three northernmost rivers, and in the upper part of the River Orkla (liver only). Low concentrations of zinc were found in liver and kidney of fish from the lower, polluted part of the River Orkla, which may seem strange. However, similar observations of low concentrations of zinc in these organs have been made in other polluted areas (Grande et al. 1985, Sørstrøm & Rikstad 1985). Zinc appears to be displaced by cadmium in contaminated areas, however, the cause is not understood.

The concentrations of mercury were slightly higher in the Russian than in the Norwegian rivers. In all rivers concentrations were higher in filet than in other organs, but the differences were small.

5.4 Smolt migration

Smolt migration in the Rivers Varzuga, Kola and Alta occur concurrent in time and five weeks later than in the River Orkla. The smolt descent occurs later in the season at increasing latitudes along the Norwegian coast (Hvidsten, Jensen & Heggberget, MS).

The smolt migration is regulated by ultimate and proximate triggers. One of the most important triggers is day length. Within a population, salmon smolts may descend within one month (Ruggles 1980). During this period, different proximate triggers regulate the smolt migration. In the Rivers Varzuga and Alta, water temperatures are higher compared to that in the River Orkla during smolt migration. In the River Varzuga peak migration occurs during periods of 14 °C or higher. In the River Alta, the smolts migrate at 10 °C. Most smolts in the River Orkla migrate at temperatures between 2 and 8 °C, and the smolt run ends when the water temperature reaches 10 °C. Water temperatures of 10 °C or more are presumed to be those normally preferred by migrating salmon smolts (Österdahl 1969, Forsythe 1967, Solomon 1978, Karlstrøm & Bystrøm 1994).

Water flow is the most important proximate trigger regulating smolt migration in the River Orkla. Increases in water discharge will normally initiate smolt migration. In the River Alta, small increases in discharge can initiate smolt migration (Saksgård et al. 1992). In the River Varzuga, however, smolt descent is inhibited by increases in water discharge. Most smolts migrate at decreasing water discharge in the River Varzuga. Cues in different rivers may be the same, but thresholds and the combined effects of these physical variables seems to vary.

In the River Orkla, social facilitation appear to occur among smolts. Smolts from upstream areas seem to initiate the migration of smolts further downstream (Hvidsten et al. 1995). Other authors have made similar observations. Releases of hatchery reared smolts are reported to initiate smolt runs in wild smolt populations (Kennedy et al. 1984, Hansen & Jonsson 1985). The recapture rate of tagged silvery eels also increased with increasing numbers of descending eels (Vøllestad et al. 1994). Social behaviour and interaction between individual smolts might be an important trigger ensuring a coordinated descent.

The main smolt run in the River Varzuga occurred at increasing moon phases, peaking at new or full moon. These results are in accordance with results from the River Alta (Saksgård et al. 1992). As most of the smolts migrate during the day, light from the moon would be of little significance for smolts. Rather, the lunar phases may be cues used to synchronise migration through endocrine rhythms as shown for silver eels (Boetius 1967). Large numbers of descending smolts at new and full moon may indicate that they reach the sea at high tides. This may ensure a more rapid displacement into the sea than at other moon phases. This may accord with reported smolt feeding in the estuary of the River Varzuga prior to seaward migration (Kazakov 1994).

Smolt migration occurred during daytime in the River Varzuga; in the River Alta smolt descent occurred both day and night; and in the River Orkla the smolts migrated at night. Predation pressure is expected to have a strong selective effect on smolt behaviour during migration. Predatory pike and burbot are found in the River Varzuga. In the neighbouring River Porja, Bakshtansky et al. (1976a) suggested that the migration pattern was a defence against predatory pike. In this river, smolts migrated during day time, when they could see the pike and avoid predation (Bakshtansky et al. 1976a). It is likely that the occurrence of burbot in addition to pike has caused an anti-predator behaviour in the River Varzuga. Jacobsson & Jærvi (1977) described anti-predator behaviour of salmon parr and smolts in relation to pike and burbot. The smolts migrated in a period of good visibility, but after peak illumination in the River Varzuga.

In the River Alta small amounts of pike and burbot are found in the river. Predation pressure has not been analysed, but is expected to be low.

Differences in recaptures rates of adult salmon from upstream and downstream releases of smolts in the River Orkla were insignificant. Therefore, predation from mammals, birds and fishes is expected to be low. Migration during night at high water discharge is expected to give the best survival in the estuary. Predation from cod in the estuary of the River Orkla has been estimated to be 20 % (Hvidsten & Lund 1988).

5.5 Status of adult stock

The four rivers are among the most important salmon rivers in Norway and northern Russia. The highest catches of salmon are reported from the River Varzuga, and this river seems to be one of the most important salmon rivers (Kazakov et al. 1993). In the period 1961-1989, the annual average catch in the River Varzuga was about 72.5 tonnes. In 1987, as much as 161 tonnes were caught, while a similar amount of salmon was allowed to migrate to the spawning grounds. In the Rivers Kola, Alta and Orkla reported annual catches as high as 57.5 tonnes, 32.5 tonnes and 26.9 tonnes have been recorded, respectively. However, catches in Russian and Norwegian rivers can not be compared, because about 50 % of the declared catch in Norway is harvested in the sea.

There have been some environmental changes in the two Norwegian rivers during the 1980's, which have affected the salmon populations. Both rivers have been regulated for hydroelectric purposes. In the River Orkla this has resulted in increased Atlantic salmon smolt production (Hvidsten & Ugedal 1991), while in the River Alta densities of juveniles have decreased in upper reaches (Forseth et al. 1996). Juvenile salmonid populations have been reduced considerably in the lower 15 km of the River Orkla, because of heavy metal pollution from the Løkken copper mine. During the 1980's, however, extensive labour to reduce the seeping of heavy metals from the mine has occurred. In recent years densities of juvenile Atlantic salmon in the lower part of the river have increased to almost similar levels as those farther upstream (Jensen et al. 1995).

The Atlantic salmon has been exploited heavily both in rivers and in the sea. The number of spawners which ascend the rivers has been strongly influenced by the intensity of the sea fisheries. In Norwegian coastal areas, stationary lift nets, bag nets, bend nets, and drift nets have been the most common fishing gears. Until late 1960's bag nets were the most important gear for catching salmon in sea, and this type of net had been in use in northern Norway for more than one hundred years. In the 1960's about 88 % of the salmon in northern Norway were caught in the sea, mostly in bag nets (Berg 1964). Although drift-net fishing has been carried out for at least 80 years, offshore drift netting began in 1960. The number of drift nets increased rapidly thereafter, and catches increased to a maximum of 1007 tonnes in 1979 (Anon. 1991). During the last decades several restrictions in the salmon fishery in Norwegian home waters have been introduced, and particularly between 1979-1980, and again in 1989 when several epoch-making regulations were imposed. In 1979-1980, considerable restrictions in the drift net fishery were introduced, and diaries were ordered for drift net fishermen. Casting nets and set nets were prohibited in the sea. The closed season for fishing in the sea was extended from 1 May to 31 May, although some exceptions existed. In most rivers the closed time was expanded to 1 June. However, diminishing returns continued, and therefore new comprehensive regulations were introduced in 1989. Extensive restrictions on utilisation of bend nets were introduced, while drift nets were prohibited. In addition, the fishing season in the rivers was shortened by two weeks in the autumn, and in 74 rivers fishing for Atlantic salmon was banned (Lund *et al.* 1994).

In Russian waters the Atlantic salmon is harvested in rivers, estuaries and at a few coastal fishing stations located on the White Sea. In addition, evidence from tag recaptures have shown that Russian salmon are harvested by Norwegian and Faroese fishermen during feeding at sea and return migration to home waters (Berg 1935, Danilchenko 1938, Novikov 1953, Bakshtansky & Nesterov 1973, Bakshtansky et al. 1976b, Grinyuk 1977, Bugaev 1987, Zubchenko et al. 1995). Salmon have been tagged at several stations along the Norwegian coast. Recoveries have clearly demonstrated that Russian salmon on their migration from feeding areas in the Norwegian Sea to their natal rivers to spawn are intercepted by the Norwegian coastal fishery for salmon in northern Norway. At marking stations between the Lofoten Islands and Sør-Trøndelag, Russian salmon were observed only sporadically, while farther to the south no recoveries from Russia have been reported (Anon. 1974, L. P. Hansen, NINA, unpublished). At the marking station at Breivik, which is located at the island Sørøy 150 km SW of Nordkapp in the county of Finnmark, salmon caught in bag nets have been tagged and released during two periods, 1937-1938 and 1962-1974. Fifteen and thirteen percent, respectively, were reported from Russian rivers at the Kola Peninsula and the White Sea area (Dahl & Sømme 1938, Anon. 1974, L.P. Hansen, NINA, unpublished). Similar results were obtained at Sørvær, which is also located at Sørøy, in the period 1964-1967, were 11 % of the recoveries were Russian (Anon. 1974).

Several studies have revealed that environmental conditions at sea affect fish stocks (Jensen 1939, Scarnecchia 1984, Stergiou 1991, Jakobsson 1992). Sea-surface temperatures have been shown to alter the distribution of Atlantic salmon catches in the north-west Atlantic Ocean (Reddin & Shearer 1987). Varying Atlantic salmon catches in several countries have been explained by variable winter habitats for salmon in the Labrador Sea (Friedland et al. 1993). Scarnecchia et al. (1989) found significant relationships between mean June-July sea temperatures and the catch of grilse the following year in some Icelandic rivers. Zubchenko & Kuzmin (1989) demonstrated that the annual spawning run of Atlantic salmon to the River Tuloma is significantly related to sea temperatures in the Barents Sea, and later Antonsson et al. (1996) pointed out a similar relation for two other Barents Sea salmon stocks (Kola and Ponoy). Temperatures in the Barents Sea were for example extremely low during the period 1978-82, and in these years the spawning runs to all these rivers were less than average.

5.6 Population structure

The mean smolt age of Atlantic salmon was about three years in the River Varzuga, 3.5 years in the Rivers Kola and Orkla, and about four years in the River Alta (**Table 8**). The mean size of the smolts was about 10 cm in the River Varzuga, about 13 cm in the Rivers Alta and Orkla, and about 15 cm in the River Kola (**Table 8**). The smolt age reflects a combination of annual growth rate and smolt size. The low smolt age in the River Varzuga is probably a result of higher annual growth rate and smaller smolt size than in the other rivers. Similarly, the annual growth rate of salmon parr in the River Kola is higher than in the two Norwegian rivers, but because of large size of the smolts, the mean smolt age is similar to that in the River Orkla.

The River Varzuga is mainly a grilse river. Most fish, i.e. more than 90 % of both males and females, return to the river after only one winter at sea. In the other rivers most males are grilse. However, in the other rivers females are usually 2SW or 3SW fish. The sea-age composition of the River Alta salmon is special. In this river most males are grilse or 3SW fish, while females are predominantly 3SW fish (**Figure 13**). Several investigations have illustrated that age and size of salmonids at sexual maturity has a genetic component (Nævdal et al. 1978, Gjerde 1984, Glebe & Saunders 1986). In Atlantic salmon significant correlations have been found between sea-age and size at sexual maturity and river size in North America, Scotland, Iceland and Norway (Schaffer & Elson 1975, Thorpe & Mitchell 1981, Scarnecchia 1983, Jonsson et al. 1991). Thus, life histories seem to be adapted to local conditions in the habitats exploited by the fish.

Jonsson et al. (1991) observed that in small Norwegian rivers, body length and sea-age at sexual maturity increased with water discharge of the spawning river. However, the positive correlation did not apply to salmon from rivers with a mean annual water discharge larger than 40 m^3/s. The reason may be that the water flow in the small rivers was too low for successful ascent and spawning of large salmon. The mean annual water discharge of all the four rivers in the present study is more than 40 m^3/s (41.2-76.5 m^3/s), with the River Varzuga having the largest water flow. Hence, river discharge can hardly explain the large proportion of grilse in the River Varzuga.

The seasonal salmon run dynamics in the River Varzuga differ from the other rivers. Two peaks occur in the migration of Atlantic salmon in the River Varzuga, one during summer and one during autumn. Almost all fish entering the river later than 20 August are immature. Usually the autumn migration is most intense during the middle of October, but a significant part of the stock migrates as late as November. The autumn run usually contributes about 70 % of the total annual run. It is supposed that immature Atlantic salmon migrating during autumn stay in the river during the whole winter and through the next summer without feeding, and then spawn during September. This life history should be more thoroughly investigated.

6 Literature

Anonymous, 1974. Om virksomheten til Direktoratet for jakt, viltstell og ferskvannsfiske i 1972. - St. meld. nr. 70 (1987-74). 51 pp. (In Norwegian).

Anonymous 1991. Fishing and rearing of salmon etc. 1983 (Norwegian Official Statistics B 985), Oslo. - Kongsvinger Central Bureau of Statistics of Norway (In Norwegian with English summary).

Anonymous, 1995. Oversikt over norske vassdrag med laks, sjøaure og sjørøye pr. 1. januar 1995. Utskrift fra Lakseregistret. - Direktoratet for naturforvaltning. DN-notat nr. 1995-1, 80 pp.

Anonymous, 1996. Report of the Working Group on North Atlantic salmon, Moncton, Canada 10-19 April 1996. - ICES CM 1996/ Assess: 11, 228 pp.

Antonsson, T., Gudbergsson, G. & Gudjonsson, S. 1996. Environmental continuity in fluctuation of fish stocks in the North Atlantic Ocean, with particular reference to Atlantic salmon. - North American Journal of Fisheries Management, 16: 540-547.

Azbelev, V.V. 1960. Materials on biology and survival of Atlantic salmon over the Kola Peninsula. - Trudy PIN-RO, 12: 5-70 (In Russian).

Bakshtansky, E.L., & Nesterov, V.D. 1973. Some data to evaluate the impact of foreign fisheries on Atlantic salmon stocks. - Rybnoe khozjaistvo, 7: 18-21 (In Russian).

Bakshtansky, E., Nesterov, V. & Nekludov, M. 1976a. Predators effect on the behaviour of Atlantic salmon smolts in the period of downstream migrations. - ICES Anadromous and Catadromous Committee CM 1976/M:3.

Bakshtansky, E.L., Zaguraeva, L.F. & Nesterov, V.D. 1976b. Results of Atlantic salmon juvenile tagging in 1969-1974. - Trudy VNIRO, 113: 19-23. (In Russian).

Berg, L.S. 1935. Materials on the biology of Atlantic salmon. - Izvestiya Press/VNIORKH, 20: 3-113. (In Russian).

Berg, L.S. & Pravdin, I.F. 1948. Fishes of the Kola Peninsula. - Izvestiya VNIROH, 24, 2: 3-24 (In Russian).

Berg, M. 1964. North Norwegian Salmon Rivers. - J.G. Tanum, Oslo. 300 pp. (In Norwegian with English summary).

Boetius, J. 1967. Experimental indication of lunar activity in European silver eels *Anguilla anguilla* (L). - Meddelelser fra Danmarks Fiskeri- og Havundersøgelser 6: 1-6.

Brett, J.R., Shelbourn, J.E. & Shoop, C.T. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka,* in relation to temperature and ration size. - J. Fish. Res. Board Can. 26: 2362-2394.

Bugaev, V.F. 1987. The impact of foreign fisheries on the salmon population in the river Keret. Studies of salmonids in the European North, Petrozavodsk, p. 26-30. (In Russian).

Dahl, K. & Sømme, S. 1938. Salmon markings in Norway 1937. - Det Norske Vitenskaps-Akademi i Oslo. Matematisk-naturvitenskapelig klasse. 1938, No. 2. 45 pp.

Danilchenko, P.G. 1938. On the migration of Atlantic salmon. - Priroda, 7-8: 138-140. (In Russian).

Donaldson, L.K. & Foster, F.J. 1940. Experimental study of effect of various water temperatures on growth, food utilization, and mortality rates of fingerling sockeye salmon. - Trans. Am. Fish. Soc. 70: 339-346.

Elliott, J.M. 1975a. The growth of brown trout (*Salmo trutta* L.) fed on maximum rations. - J. Anim. Ecol. 44: 805-821.

Elliott, J.M. 1975b. The growth of brown trout (*Salmo trutta* L.) fed on reduced rations. - J. Anim. Ecol. 44: 823-842.

Elliott, J.M. & Hurley, M.A. 1997. A functional model for maximum growth of Atlantic salmon parr, *Salmo salar*, from two populations in north-west England. - Functional Ecology (In press).

Elliott, J.M., Hurley, M.A. & Fryer, R.J. 1995. A new, improved growth model for brown trout, *Salmo trutta*. - Functional Ecology 9: 290-298.

Forseth, T., Næsje, T.F., Jensen, A.J., Saksgård, L. & Hvidsten, N.A. 1996. Ny forbitappingsventil i Alta kraftverk: betydning for laksebestanden. - NINA Oppdragsmelding 392: 1-26 (In Norwegian, with English summary).

Forsythe, M. G. 1967. Analysis of the 1965 smolt run in the Northwest Miramichi River, New Brunswick. - J. Fish. Res. Board Can., Technical Report 4, 2, 73 pp.

Friedland, K.D., Reddin, D.G. & Kocik, J.F. 1993. Marine survival of North American and European Atlantic salmon: effects of growth and environment. - ICES Journal of Marine Science, 50: 481-492.

Gjerde, B. 1984. Response to individual selection for age at sexual maturity in Atlantic salmon.- Aquaculture 38: 229-240.

Glebe, B.D. & Saunders, R.L. 1986. Genetic factors in sexual maturity of cultured Atlantic salmon (Salmo salar) parr and adults reared in sea cages. - pp. 24-29 in D.J. Meerburg (editor). Salmonid age at maturity. Can. Spec. Publ. Fish. Aquat. Sci. 89.

Grande, M. & Romstad, R. 1993. Tiltaksorientert overvåking i Orkla, 1992. - Norsk institutt for vannforskning. Rapport 534/93. 53 pp (In Norwegian).

Grande, M., Iversen, E.R. & Bildeng, R. 1985. Grong Gruber A/S, Kontrollundersøkelser i vassdrag. Resultater 1984. - NIVA Rapport O-69120 (l.nr. 1732. 64 pp. (In Norwegian).

Grinyuk, I.N. 1977. Fishery, Production and forecasting of numbers of salmon spawning stock in the Ponoy River. - Trudy PINRO, 32: 156-182. (In Russian).

Hansen, L.P., Håstein, T., Nævdal, G., Saunders, R.L. & Thorpe, J.E. editors. 1991. Interactions between cultured and wild Atlantic salmon. - Aquaculture 98 (1-3): 1-324.

Hansen, L.P. & Jonsson, B. 1985. Downstream migration of hatchery-reared smolts of Atlantic salmon (*Salmo salar* L.) in the River Imsa, Norway. - Aquaculture 45: 237-248.

Heggberget, T.G., editor. 1996. The role of aquaculture in world fisheries. Proceedings of the World Fisheries Congress, Theme 6. - Science Publishers, Inc., Lebanon, USA. 244 pp.

Heggberget, T.G., Johnsen, B.O., Hindar, K. Jonsson, B., Hansen, L.P., Hvidsten, N.A. & A.J. Jensen, A.J. 1993. Interactions between wild and cultured Atlantic salmon; a review of the Norwegian experience. - Fisheries Research 18: 123-146.

Heggberget, T.G., Lund, R.A. & Veie-Rossvoll, B. 1984. Konsesjonsundersøkelser i Alta-Kautokeino-vassdraget 1981-1983 - Fisk. - Direktoratet for vilt og ferskvannsfisk. Reguleringsundersøkelsene. Report No. 5-1984. 78 pp. (In Norwegian).

Hesthagen, T. & Garnås, E. 1986. Migration of Atlantic salmon in river Orkla of Central Norway in relation to management of a hydroelectric station. - N. Am. J. Fish. Mgmt. 6: 376-382.

Hesthagen, T. & Hansen, L.P. 1991. Estimates of the annual loss of Atlantic salmon, *Salmo salar* L., in Norway due to acidification. - Aquaculture and Fisheries Management 22: 85-91.

Hokanson, K.E., Kleiner, C.F. & Thorslund, T.W. 1977. Effects of constant temperatures and diel temperature fluctuations on specific growth and mortality rates and yield of juvenile rainbow trout, *Salmo gairdneri*. - J. Fish. Res. Board Can. 24: 639-648.

Hvidsten, N.A. & Lund R.A., 1988. Predation on hatchery reared and wild smolts Atlantic salmon (*Salmo salar* L.) in the estuary of River Orkla, Norway. - J. Fish. Biol. 33: 121-126.

Hvidsten, N.A. & O. Ugedal. 1991. Increased densities of Atlantic salmon smolts (*Salmo salar* L.) in the River Orkla, Norway, after regulation for hydro-power production. - Trans. Am. Fish. Soc. Symposium. 10: 219-225.

Hvidsten, N.A., Jensen, A.J. & Heggberget, T.G. Atlantic salmon (*Salmo salar* L.) smolts enter sea water at 8 °C. - (Manuscript).

Hvidsten, N.A., Jensen, A.J., Vivås, H., Bakke, Ø. & Heggberget, T.G. 1995. Downstream migration of Atlantic salmon smolts in relation water flow, water temperature, moon phase and social interaction. - Nordic J. Freshw. Res. 70: 38-48.

Jacobsson, S. & Jærvi, T. 1977. Antipredator beteende hos tvåårig lax *Salmo salar* L. - Zoologisk Revy 38(3): 37-70. (In Swedish).

Jakobsson, J. 1992. Recent variability in fisheries of the North Atlantic. - ICES Marine Science Symposia, 195: 291-316.

Jensen, A.J. & Johnsen, B.O. 1988. The effect of river flow on the results of electrofishing in a large, Norwegian salmon river. - Verh. Internat. Verein. Limnol. 23, 1724-1729.

Jensen, A.J., Grande, M., Korsen, I. & Hvidsten, N.A. 1995. Reduced heavy metal pollution in the Orkla River, Norway: effects on fish populations. - XXVI SIL International Congress, July, 23-29, Sao Paulo, Brasil.

Jensen, A.S. 1939. Concerning a change of climate during recent decades in the Arctic and Subarctic regions, from Greenland in the west to Eurasia in the east, and contemporary biological and geophysical changes. - Bulletin from the Fisheries Research Board of Canada, 186. 70 pp.

Jonsson, N., Hansen, L.P. & Jonsson, B. 1991. Variation in age, size and repeat spawning of adult Atlantic salmon in relation to river discharge. - J. Anim. Ecol. 60: 937-947.

Karlstrøm, Ø. & Byström, P. 1994. Estimation of the smolt run in the River Torne Elv 1987-1993. - ICES Anadromous and Catadromous Committee CM 1994/M:19.

Kazakov, R.V. 1994. Juvenile Atlantic salmon in the Varzuga River (White sea basin). - J. Fish Biol. 45: 467-477.

Kazakov, R.V., Antonova, V.P., Shurov, I.L. & Kuzmin, O.G. 1993. Populational fund of Atlantic salmon, *Salmo salar* L., in Russia. - pp. 190-192 in Kazakov, R.V., Skarlato, O.A. & Noskov, G.A. editors. Proceedings of the 6th meeting on the project «Species and its productivity in the distribution area» UNESCO programme «Man and Biosphere». Zool. Inst. Ran, St. Petersburg, Russia.

Kennedy, G.J.A., Strange, C.D., Andersen, R.J.D. & Johnston, P.M. 1984. Experiments on the descent and feeding of hatchery reared salmon smolts (*Salmo salar* L.) in the River Bush. - Fisheries Management 15: 15-25.

Lund, R., Økland F. & Hansen, L.P. 1994. Trends in salmon populations in Norway preceeding and proceeding the management measurement in 1989. - NINA Forskningsrapport 54: 1-46 (In Norwegian, eith English summary).

MacCrimmon, H.R. & Gots, B.L. 1979. World distribution of Atlantic salmon, *Salmo salar*. - J. Fish. Res. Board Can. 36: 422-457.

Novikov, P.I. 1953. Atlantic salmon. - Gosizdat Press of the Karelian-Finnish SSR, Petrozavodsk, p. 134. (In Russian).

Nævdal, G., Holm, M., Ingebrigtsen, O. & Møller, D. 1978. Variation in age at first spawning in Atlantic salmon (*Salmo salar*). - J. Fish Biol. 19: 593-607.

Österdahl, L. 1969. The smolt run of a small Swedish river. - pp. 205-215 in *Salmon and trout in streams* (Northcote, T.G. ed.). H. R. Mac Millans lectures in fisheries. University of British Colombia.

Ovsyannikov, N.S., 1938. Biology of salmon from the Kola Bay. - Trudy Mosrybvtuza, 1: 87-138 (In Russian).

Reddin, D.G. & Shearer, W.M. 1987. Sea-surface temperature and distribution of Atlantic salmon in the Northwest Atlantic Ocean. - American Fisheries Society Symposium, 1: 262-275.

Ruggles, C.P. 1980. A review of the downstream migration of Atlantic salmon. - Can. Tech. Rep. Fish. Aquat. Sci. No 952. 39 pp.

Saksgård, L., Heggberget, T.G. Jensen, A.J. & Hvidsten, N.A. 1992. Utbygging av Altaelva - virkninger på laksebestanden. - NINA Forskningsrapport 034: 1-98. (In Norwegian with English summary).

Scarnecchia, D.L. 1983. Age at sexual maturity in Icelandic stocks of Atlantic salmon (*Salmo salar*). - Can. J. Fish. Aquat. Sci. 40: 1456-1468.

Scarnecchia, D. 1984. Climatic and oceanic variations affecting yield of Icelandic stocks of Atlantic salmon. - Can. J. Fish. Aquat. Sci. 41: 917-945.

Scarnecchia, D., Isaksson, A. & White, S.E. 1989. Oceanic and riverine influences on variations in yield among Icelandic stocks of Atlantic salmon. - Transactions of the American Fisheries Society, 118: 482-494.

Schaffer, W.M. & Elson, P.F. 1975. The adaptive significance of variation in life history among local populations of Atlantic salmon in North America. - Ecology 56: 577-590.

Soldatov, V.K. 1903. Report on the investigations of salmon fishing in the Kola Bay and the East Murman. - St. Petersburg: 64-152. (In Russian).

Solomon, D. J. 1978. Some observations on salmon smolt migration in a chalkstream. - J. Fish Biol. 12: 571-574.

Sorensen, E.M. 1991. Metal poisoning in fish. - CRC Press, Boca Raton, Ann Arbor, Boston. 374 pp.

Sørstrøm, S.E. & Rikstad, A. 1985. Tungmetaller i fisk i Indre Namdalen. - Fylkesmannen i Nord-Trøndelag. Miljøvernavdelingen. Rapport nr. 8, 1985. 34 pp. (In Norwegian).

Spigarelli, S.A., Thommes, M.M. & Prepejchal, W. 1982. Feeding, growth, and fat deposition by brown trout in constant and fluctuating temperatures. - Trans. Am. Fish. Soc. 111: 199-209.

Stergiou, K.I. 1991. Possible implications of climatic variability on the presence of capelin (*Mallotus villosus*) off the Norwegian coast. - Climatic change, 19: 369-391.

Surkov, S.S. 1966. General characteristic of peculiarities of the Murmansk Region ichthyofauna specific composition. - 147-151 in Fishes of the Murmansk Region. Murmansk:. (In Russian).

Thorpe, J.E. & Mitchell, K.A. 1981. Stocks of Atlantic salmon (*Salmo salar*) in Britain and Ireland: discreteness and current management. - Can. J. Fish. Aquat. Sci. 38: 1576-1590.

Traaen, T., Asvall, R.P., Brettum, P., Heggberget, T.G., Huru, H., Jensen, A.J., Johannessen, M., Kaasa, H., Lien, L., Lillehammer, A., Lindstrøm, E.A., Mjelde, M., Rørslett, B. & Aagaard, K. 1983. Basisundersøkelser i Alta-Kautokeinovassdraget 1980-82. Hovedrapport. - Norsk institutt for vannforskning. Rapport nr. 68/83. 117 pp.

Vøllestad, L. A., Jonsson, B., Hvidsten, N.A. & Næsje, T.F. 1994. Experimental test of environmental factors influencing the seaward migration of European silver eels. - J. Fish Biol. 45: 641-651.

Watt, W.D., Scott, D. & White, W.J. 1983. Evidence of acidification of some Nova Scotian rivers and its impact on Atlantic salmon, *Salmo salar*. - Can. J. Fish. Aquat. Sci. 40: 462-473.

Zippin, C. 1956. An evaluation of the removal method of estimating animal populations. - Biometrics 12: 163-189.

Zubchenko, A.V. & Kuzmin, O.G. 1989. General approach to abundance estimation of Atlantic salmon stocks of USSR origin. - ICES Working paper 1989/31, North Atlantic Salmon Working Group, 4 pp.

Zubchenko, A.V., Loenko, A.A. & Popov, N.G. 1995. Salmon rivers of the Kola Peninsula. Some data on salmon migrations and estimation of marine fishery influence. - ICES CM 1995/M:37, 12 pp.

ISSN 0807-3082
ISBN 82-426-0825-3

007

NINA•NIKU PROJECT REPORT

NINA
Norwegian Institute for Nature Research

NIKU
Norwegian Institute for Cultural Heritage Research

NINA•NIKU Headquarter
Tungasletta 2
N-7005 TRONDHEIM
Tel: +47 73 58 05 00
Telefax: +47 73 91 54 33