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Hydroacoustic Estimation of Salmon (*Salmo salar*) Spawning Run in the River Tornio

Project Results 1995-1996

Simo 1997

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Tiivistelmä

Tornionjokeen nousevan lohikannan koon kaikuluotausarviointia kehitettiin vuosina 1995 ja 1996 esitutkimuksilla, joita rahoittivat Riista- ja kalatalouden tutkimuslaitos, maa- ja metsätalousministeriö (maaseudun kehittämismäärärahat), työministeriö ja Lapin maaseutuelinkeinopiiri. Tornionjoen alajuoksulta etsittiin kaikuluotaukseen soveltuvia paikkoja ja testattiin lohkokeilakaikuluotaustekniikan (split-beam technique) soveltuvuutta koeluotauksilla. Luotauksiin liitettiin koekalastuksia ja muita oheisselvityksiä. Tämä raportti esittää keskeiset esitutkimusten tulokset ja johtopäätökset, joiden pohjalta vuosina 1997-1999 jatketaan EU:n rahoituksen myötä laajentunutta projektia tavoitteena luoda valmius lohikannan koon seurantaan kaikuluotauksella.

Tornionjoesta löydettiin vuonna 1995 kaksi kaikuluotaukseen alustavasti soveltuvaa paikkaa, joista toinen sijaitsee Tornion kaupungin kohdalla jokisuulla ja toinen Juoksengissa noin 100 km jokisuulta ylävirtaan. Tornion kaupungin kohdalla kaikuluotaimella havaittiin muutamien päivien aikana 83 ylävirtaan vaeltavaa loheksi epäiltyä kaikukohdetta.

Vuonna 1996 Torniossa jatkettiin aineistojenkeruuta lähes koko kesän. Luotain kattoi pienen osan joen poikkileikkauksesta ja aineistoista analysoitiin 28 vuorokautta 12.6. ja 20.8. väliseltä ajalta. Analysoiduissa aineistoissa havaittiin tuhansia kaloiksi luokiteltavia kaikukohteita. Noin tuhat kohdetta arvioitiin olevan kookkaiksi lohiksi sopivista eli vähintään 70 cm pitkistä kaloista lähtöisin. Näistä kohteista yli 40 % määritettiin kuitenkin alavirtaan liikkuviksi. Lohiksi epäiltyjä kaikukohteita havaittiin yllättävän vähän suhteessa lähes 10 000 lohen jokisaaliiseen vuonna 1996. Lohia ei kyetty tunnistamaan selkeästi muista kaikukohteista kaiun kohdevoimakkuuden tms. kaikuluotaimella mitatun tekijän avulla. Lohen vaelluspoikasten määräarviointi kaikuluotauksella havaittiin lähes mahdottomaksi johtuen luotauksen taustahäiriön korkeasta tasosta ja kalalajiston runsaudesta vaelluspoikasten kokoluokkaa olevilla kaloilla.

Nousulohien kaikuluotaus arvioitiin teknisesti mahdolliseksi Tornionjoen olosuhteissa. Lisätutkimuksia tarvitaan kuitenkin mm. lohien vaelluskäyttäytymisestä ja kaikuluotaimen toimivuudesta eri olosuhteissa, jotta lohikannan koon kaikuluotausseurannalle saataisiin luotettava perusta.

Asiasanat

Tornionjoki, lohi, kaikuluotaus, kanta-arviointi

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Abstract

In 1995 and 1996, pilot studies were carried out to explore the feasibility of using hydroacoustics to assess the size of the salmon stock in the River Tornio. During the studies, the lower course of the river was inspected in order to find sites suitable for split-beam hydroacoustic monitoring. Test soundings with different sampling configurations were conducted and additional information was obtained by test fishing and other surveys. The main results of the 1995 and 1996 studies are presented in this report. The studies were financed by the Finnish Game and Fisheries Research Institute, the Ministry of Agriculture and Forestry, the Ministry of Labour and the Lapland Rural Business District. The project will be continued in 1997-1999 with EU contribution in order to develop and introduce hydroacoustic monitoring as a new monitoring methodology to assess the size of the River Tornio salmon stock.

In 1995, two sites suitable for echo sounding were found. One of them was in Tornio, near the mouth of the river, and the other in Juoksenki approximately 100 km upstream. A total of 83 potential salmon targets migrating upstream were detected during the few days of monitoring at the Tornio site. In 1996, data was collected at the Tornio site nearly throughout the summer. The echo beam covered only part of the river transect. A total of 28 days of data, gathered between 12.6 and 20.8, were analysed and thousands of echo targets classified as fish were found. Approximately one thousand of the fish targets were considered as potential salmon targets (larger that 70 cm in length). Of these fish 40 % were moving downstream. The number of detected salmon was surprisingly low as compared to the river catch of nearly 10,000 salmon in 1996. No data provided by the echo sounder was sufficient to clearly discriminate salmon from other echo targets. Using echo sounding to count the numbers of salmon smolts was found practically impossible because of the high level of background noise in the data.

Hydroacoustic assessment technique was found suitable to estimate the size of the River Tornio salmon stock. However, extensive auxiliary studies in echo sounding, fish behaviour etc. are still required to establish a reliable basis for this new methodology.

Key words

The River Tornio, salmon, echo sounding, stock assessment

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CONTENTS

1. BACKGROUND AND OBJECTIVES OF THE STUDY

Finnish Game and Fisheries Research Institute has monitored the salmon stock in the River Tornio since 1970's. Monitoring has included catch statistics, catch samples, fish taggings and estimation of salmon parr and smolt production. Swedish authorities have also been monitoring the salmon stock.

The River Tornio salmon is one of the most extensively studied salmon stocks in the Baltic catchment. The salmon production capacity of the river is the highest of all the present Baltic salmon rivers. The environment of the River Tornio is one of the least impacted by antropogenic factors in the Baltic catchment.

Almost every wild salmon population in the Baltic has been assessed as being endangered due to overfishing. The situation has put emphasis on stock assessment methods. In spite of this, almost no direct estimates of the Baltic salmon spawning runs exist. Unfavourable conditions in the rivers during the spawning run have partly been the reason for the lack of this monitoring.

To date the salmon escapement in the River Tornio has been estimated using catch statistics from the river as rough indices of the run size. Finnish Game and Fisheries Research Institute has been exploring methods to provide more accurate and timely adult salmon passage estimates in the river. Hydroacoustic method has been seen to be the most promising way to proceed. The research activities using hydroacoustics started in 1995, and the studies have layed a basis for large scale endeavours to establish a hydroacoustic monitoring system in the River Tornio.

The 1995-1996 studies were financed by Finnish Game and Fisheries Research Institute, the Finnish Ministry of Agriculture and Forestry, the Finnish Ministry of Labour and the Lapland Rural Business District. The 1995-1996 studies have been pilot studies with the main objective of exploring the applicability of the hydroacoustic methodology.

European Commission has started to finance the project in 1997 and the objective of the project has been set to establishment of the monitoring by 1999, when the EC contribution will end. This report summarises the main results achieved during the years 1995-1996 and draws guidelines for the future activities in the River Tornio hydroacoustic project.

Many people have been somehow involved with the project, e.g., the members of the project executive group, project group, consultants, special expert, administrators and financiers. We would like to thank all of you. Markus Ylikärppä has helped to organize the field studies and Mari Nykänen has helped in the report preparation. Special thanks to you.

2. STUDY AREA

2.1 General view of the river and the salmon stock

The River Tornio system is located in the northernmost part of the Baltic Sea (Fig. 1). Its catchment area is 40,000 km^2, of which about one third is located in Finnish Lapland and two thirds in Swedish Lapland. Salmon uses the main reach and some of the largest tributaries for reproduction. The furthest spawning grounds are located about 450 km upstream from the river mouth. The mean discharge of the River Tornio is 381 m^3/s (Vesihallitus 1980).

There are about 5,000 ha of salmon nursery habitat in the river system, the annual salmon production capacity of these areas being about half a million smolts. The River Tornio salmon migrate to the southern Baltic Sea during the feeding migration.

The River Tornio salmon stock has been overharvested mainly by sea fishery, and the status of the stock has been severely weakening since the second world war. The stock was weakest in the 1980's. At that time the river produced only 50,000 - 75,000 wild smolts annually. Since then the annual smolt production has increased concurrently with the indices of the spawning run up to 100,000 - 200,000 smolts/ year. However, the recent incidence of the M74 -phenomen has caused an excess mortality of salmon alevins, leading to a decline of the smolt production to the level of 50,000 - 100,000 smolts/year.

Fishery restrictions have improved the status of River Tornio salmon. In 1996, Finland enforced substantially stronger regulation of the Finnish coastal fishery. It induced a remarkable increase in the salmon runs in all the rivers of the northern Baltic.

3. METHODS

3.1 Hydroacoustic surveys

Recently, there has been some success in counting adult salmon in rivers using fixed-location echosounding techniques (e.g., Vaught & Skvorc 1993, Johnston & Ransom 1994). In an ideal case the river cross-section can be covered satisfactorily with one horizontally aimed transducer. Split-beam systems that directly track fish in three dimensions in real-time are more usefull than single- or dual-beam techniques (Burwen & Bosch 1995).

Hydroacoustic studies on the River Tornio were conducted with a 200 kHz *Model 240 Split Beam Hydroacoustic System* in 1995 (Nealson & Johnston 1995). A more advanced *Model 243* with 2 transducers was used in 1996. These equipment have been used in many riverine hydroacoustic studies on salmonids. HTI (1996) has provided technical specification of the equipment. Sound beams of the transducers were elliptical; 2.8x10° (port 1) and 4x10° (port 2). The up-down and left-right aiming of the transducers could be changed by rotators.

In 1995, the main objective of the hydroacoustic research was to carry out a short pilot study on the feasibility of using split-beam technique in the River Tornio circumstances (Nealson & Johnston 1995). For this purpose a hydroacoustic system with one horizontally aimed split-beam transducer was used to examine potential monitoring sites along the river. In 1996, two transducers were mounted and used simultaneously at the Tornio bridge site (Fig. 2). The objective of the 1996 studies was to further examine the applicability of the hydroacoustic technique by concentrating the sampling in one site and covering the sampling over the expected period of the salmon run.

A tungsten carbide sphere (Ø= 38.1 mm) was used for TS-testing of both transducers before data collection. The minimum target strength threshold was set to -35 - -33.5 dB during the most of the monitoring periods ensuring a full beam detection of targets larger than -29 - -27.5 dB (about 60-70 cm long fish according to the Love's equation). The threshold was once lowered to -45 dB in order to study the possibilities of counting salmon smolt run.

The ping rate of the echo sounder was usully 10 pings/second in 1995 and 7 pings/second in 1996. The data was collected as a round-the-clock monitoring in 15 min sequences; first 15 min from port 1, second from port 2, third from port 1 etc. Hydroacoustic data was collected between June 30 and July 7 in 1995 and from June 3 to August 26 in 1996. However, adjustment of the position of the transducers and system settings and test arrangements interrupted data collection especially in the early part of June in 1996.

The hydroacoustic data was post-processed using the HTI's manual tracking software TRAKMAN in order to separate fish from background noise, river bottom irregularities and other unwanted hydroacoustic targets. The whole 1995 data was post-processed, but it was assumed that half of the 1996 data was adequate for evaluation of the study results and that nothing will be gained by putting more effort on the data processing. Consequently, 28 days of the 57 days of comparable data collected in 1996 was post-processed.

Target strength (TS) distributions were based on the average TS of each fish (Nealson & Johnston 1995). All conversions between fish length and TS followed Love's (1977) equation for side aspect.

In 1995, targets within the range of the TS values from -29 to -22 dB were considered as potential salmon targets. In 1996, the potential salmon targets were assumed to be between -27.5 and -17.5 dB, targets consisted of more than 4 echoes and the standard error of the TS values originating from the target had to be less than 1.5.

3.2 Test fishing

Test fishing was carried out only in 1996. The objectives of the test fishing were to

a. Estimate the fish species composition at the hydroacoustic monitoring site

b. Explore migration of fish species

c. Estimate the size distribution of the fish species

The set of gears and the fishing consisted of

a. Smolt trap (a specially constructed trapnet) set up in the middle of the river 3 km upstream from the hydroacoustic installation.

b. Several trapnets located near shore within 3 km up- and downstream from the hydroacoustic installation.

c. Purse seine, which was occasionally used within 300 meters from the hydroacoustic installation.

d. Standing gill nets,which were used only twice and they were set up within 500 meters from the hydroacoustic installation near the river banks.

The test fishing was started during the last days of May and ended by the mid-July. The fishing period was assumed to cover the main part of the period of the salmon run.

3.3 Catch statistics and catch samples

Data of the salmon run in 1996 was provided by local fishermen, who collected voluntarily catch statistics in certain sites of the river and catch samples for age determination. An estimate of the total catch level of the Finnish river fishery is provided as part of the long-term monitoring programme in the river.

Voluntary catch statistics were assumed to display the timing and intensity of the salmon run in that specific area where catch data was compiled. The total catch estimate of the Finnish river fishery displays the magnitude of the total salmon run. Catch samples displays the size distribution of salmon.

The information from catch statistics and catch samples were compared with the hydroacoustic data in order to see if similarities could be found in regard to the size distribution of salmon and the timing of the salmon run. The Finnish total catch estimate as a rough index of the run size was compared with the number of potential salmon targets observed by the echo sounder.

4. RESULTS AND DISCUSSION

4.1 Studies in 1995

4.1.1 Hydroacoustic survey

Details of the 1995 studies have been reported by Nealson & Johnston (1995). This section shortly summarises that report.

Approximately 18 potential monitoring sites from the river mouth up to Kolari were visually inspected at the River Tornio in 1995. In this 200 km part of the river seven locations were selected for short hydroacoustic data collection.

A site at the east end of the Tornio River bridge at Tornio town seemed to be the most suitable for hydroacoustic monitoring (Fig. 1 and 2). At this site the river was 250 m wide and the $depth_{max.}$ was 8 m.

Every salmon entering the River Tornio and migrating up must pass this site. However, exact migration routes of salmon along the river channel are not known. There is obviously a multi-species migration of fish of almost the same size as salmon at this site, which means that there are probably difficulties in species separation in the hydroacoustic data. The large size of northern pike (*Esox lucius* L.) indicates that especially this species is difficult to distinguish from salmon on the basis of echo target strength.

A total of 488 targets were observed to move downstream and 454 upstream during the seven days sampling at the Tornio bridge site. Of the upstream-migrant targets 83 were larger than -29dB (60 cm) and they were classified as upstream migrant salmon. The majority (79) of these targets were near the bottom approximately 75 m offshore.

Upstream-migrant salmon targets were more bottom oriented than downstream-migrant targets. Lower water velocities near the bottom may minimize the energy required for upstream migration.

Definite trends in mean hourly passage were not observed in the combined data set. However, a peak passage was observed for the upstream-migrant salmon targets between 15 and 16 hours in the afternoon.

A Simrad split-beam system was shortly tested at the Tornio bridge site in October 1995 (Brede & Solli 1995). There was no spawning migration in the river at that time and only one large -30 dB fish was observed to be moving upstream during a two-hour monitoring. The fish swam approx. 55 m offshore at the depth of 3 m.

4.2 Studies in 1996

4.2.1 Hydroacoustic survey

Several thousands of targets were tracked in the post-processing of 28 days data sampled between June 12 and August 20 1996 at the Tornio River bridge site. Of these targets, 980 were larger than -27.5 dB (fish longer than 70 cm according to the Love's equation) and fullfilled also the other selection criteria to be regarded as potential salmon targets. Of these targets, 437 were moving downstream and 543 upstream (Table 1).

Table 1. The number of potential salmon targets (-27.5 < TS < -17.5 dB) migrating through the transducer beams at the east bank location of the Tornio River bridge station in 1996.

	Inshore transducer			Offshore transducer			
Julian date	Downstream	Upstream	Total	Downstream	Upstream	Total	**Grand total**
164	8	8	16	11	0	11	**27**
166	7	7	14	8	1	9	**23**
167	13	12	25	10	3	13	**38**
168	6	11	17	8	4	12	**29**
170	5	12	17	9	6	15	**32**
171	3	5	8	2	4	6	**14**
173	5	8	13	6	3	9	**22**
175	7	5	12	13	7	20	**32**
177	3	2	5	3	1	4	**9**
178	3	4	7	9	6	15	**22**
181	2	15	17	11	12	23	**40**
182	5	11	16	9	12	21	**37**
183	4	11	15	13	8	21	**36**
184	4	6	10	3	6	9	**19**
185	3	16	19	13	25	38	**57**
186	2	8	10	18	15	33	**43**
187	7	13	20	12	32	44	**64**
189	2	7	9	20	13	33	**42**
191	7	7	14	12	18	30	**44**
195	23	30	53	12	13	25	**78**
197	3	9	12	7	4	11	**23**
199	1	8	9	11	6	17	**26**
202	5	6	11	15	14	29	**40**
203	3	5	8	9	10	19	**27**
207	8	6	14	9	19	28	**42**
214	1	17	18	13	6	19	**37**
221	7	6	13	14	10	24	**37**
233	4	24	28	6	6	12	**40**
Total	**151**	**279**	**430**	**286**	**264**	**550**	**980**

The total number of potential salmon targets was surprisingly low, and the proportion of downstream migrating targets was unexpectedly high. There are several possible reasons for this, e.g.,

- salmon did not use the monitored transection of the river for upstream migration

- milling behaviour of fish (the same fish moving up and down several times) or
- high abundance of salmon kelts or other species like pike, which were migrating to the sea

No clear peak could be found in the upstream movement of the potential salmon targets during the sampling period. The upstream movement was also low during the time of the highest salmon catches in the lower part of the river (see chapter 4.2.3).

The diel distribution of potential salmon targets showed only minor peaks in the early morning and late afternoon (Fig. 3).

Upstream migrants were bottom-oriented especially in the mid-channel of the river (Fig. 4). Downstream migrants were more or less uniformally distributed.

The longer the distance between the target and the transducer, the higher was the estimated speed of the target (Fig. 5). This phenomen was very clear for the offshore transducer and downstream moving targets, which could be explained by the water velocity. However, as a general trend for all the targets, the origin of the phenomen must be of technical nature, leading to an in some way biased estimation of the target speed. According to the manufacturer this is due to the inaccuracy of measurement estimates of fish coordinates leading to an error in angular velocity estimates. These are amplified by the function of distance when transformed to actual velocity estimates.

The feasibility of using the echo sounder to count smolt run was tested in early June. The TS threshold settings for target detection were lowered to a level where smolts should have been detected. However, the background noise level was too high for the settings and it is apparent that hydroacoustic estimation of the smolt run is quite impossible in these circumstances.

Large numbers of small to medium sized targets were observed even though the high threshold value in the system settings considerably reduced the detection of targets smaller than -27.5 dB. Small to medium sized fish were obviously numerous at the monitoring site.

4.2.2 Test fishing

The total catch of the test fishing excluding smolt trapping and very large catches of sticklebacks was 5,937 fish (Table 2). Of these fishes, roach was clearly the most abundant species. Most of the species were highly abundant at the same size class as salmon smolts (lenght of 13-20 cm). Pike was almost the only species at the same size class as adult salmon. Although catches were good through the whole fishing period, the largest catches were caught during the first half of June.

Table 2. The total catch of test fishing excluding smolt trapping.

	Catch in numbers			
	Trapnets	Standing gill nets	Purse seine	**Total**
Roach	5,052	48	7	**5,107**
Perch	361	8	1	**370**
Pike	25	3	1	**29**
Whitefish	13	1	50	**64**
Vendace	21	3	74	**98**
Bleak	27	4	104	**135**
Ide	5	0	0	**5**
Three-spined stickleback	Tens of thousands	0	100	Tens of thousands
Burbot	1	0	0	**1**
Dace	19	0	0	**19**
Ruff		7	1	**8**
Salmon (smolt)	0	0	1	**1**
Total	**5,524+sticklebacks**	**74**	**339**	**5,937+sticklebacks**

The total catch of smolt trapping was 8,820 salmon and 388 trout smolts, large numbers of sticklebacks and whitefish fry. Also some roaches, bleaks etc. were caught occasionally. Mark -recapture experiments indicate that a total of almost 200,000 salmon and trout smolts passed the trap during the trapping period. The smolt catches were high from early June to early July.

The absence of adult salmon and sea trout in the catch of the test fishing indicates that the test fishing did not show the true composition of the fish fauna at the monitoring site. This is a more or less expected result because of the restrictions of test fishing. For instance, almost all the fishing gears had to be placed near the river banks because of the deep main channel with fast flowing water.

The test fishing showed the diversity of the fish fauna especially in the size category under 30 cm long fish. Together with the hydroacoustic data, these results indicate that the estimation of the smolt run by an echo sounder is extremely difficult or impossible to be carried out in these circumstances. The results indicate also the high abundance of the small to medium sized fish in the river, which is in coherence with the hydroacoustic data.

4.2.3 Catch statistics and catch samples

Records of 149 adult salmon caught near Tornio and hundreds of salmon caught elsewhere in the lower reach of the river system were available for the examination of the salmon run.

Most of the salmon were caught between the 10 and 30 June near Tornio (Figure 6). The peak in the catches took place around June 20. Most of these salmon were caught about 35 km upstreams from the hydroacoustic monitoring site. Comparable hydroacoustic data collection was started around June 10, and it seems obvious that the data collection missed part of the run.

Few of the caught salmon were shorter than 70 cm and the mode of the size distribution was 85-90 cm (Figure 7). An extraordinary large part of the salmon run was 2-sea-winter fish. The size distribution of the salmon run suggests that there should be a peak in the TS distribution of the observed salmon around -25 - -26 dB. However, no such peak was found. One explanation for this could be the high abundance of small to medium sized fish, which would mask the size distribution of salmon in the hydroacoustic data.

The estimated total salmon catch in the Finnish river fishery was 30-35 tonnes (over 5,000-6,000 individuals) in 1996. When taking into account the Swedish river fishery, 40-60 tons of salmon (7,000-10,000 individuals) were caught altogether. The total salmon run could have easily been up to several times higher than the catch. In this sense, the total number of potential salmon targets in the hydroacoustic data was very low.

5. CONCLUSIONS

(1) Successful implementation of hydroacoustic estimation of salmon spawning run may be possible in the River Tornio. However, extensive field surveys including hydroacoustic data collection, fish behaviour studies, numerous test arrangements etc. are required to accomplish this.

(2) There are at least two potentially suitable sites in the River Tornio for hydroacoustic monitoring. The Tornio bridge site is acoustically one of the best, and its site logistics are the best found. However, the diverse species composition and the presence of several migratory species give rise to species separation problems in hydroacoustic data. Therefore, future studies must focus on species identification and salmon behaviour at the Tornio bridge site and an alternative monitoring site further upstream must be kept under consideration.

(3) The large dimensions of the river and the absence of clearly documented migration routes of salmon mean that a hydroacoustic system has to be placed on both banks of the river and that several transducers are needed to provide information on fish migration. Weirs should be used to artificially reduce the river transection available for fish migration.

(4) The sample volume of each transducer must be estimated *in situ* and the river transection not covered by echo sounder must be evuluated in terms of estimation of salmon run.

(5) The migration routes of salmon must be described at the monitoring site.

(6) The necessary background data on the variables (weather conditions, water level, temperature and velocity etc.) possibly influencing the hydroacoustic monitoring and the migratory behaviour of salmon must be available.

(7) The validity of the hydroacoustic data and its post-processing should be checked. This includes *in situ* observations of known fish passing the echo sounder and test arrangements for TS-measurements and post-processing.

(8) As long as no well-established method exists to estimate adult salmon run in the River Tornio, no effort should be put to study hydroacoustic estimation of the smolt run.

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Figures

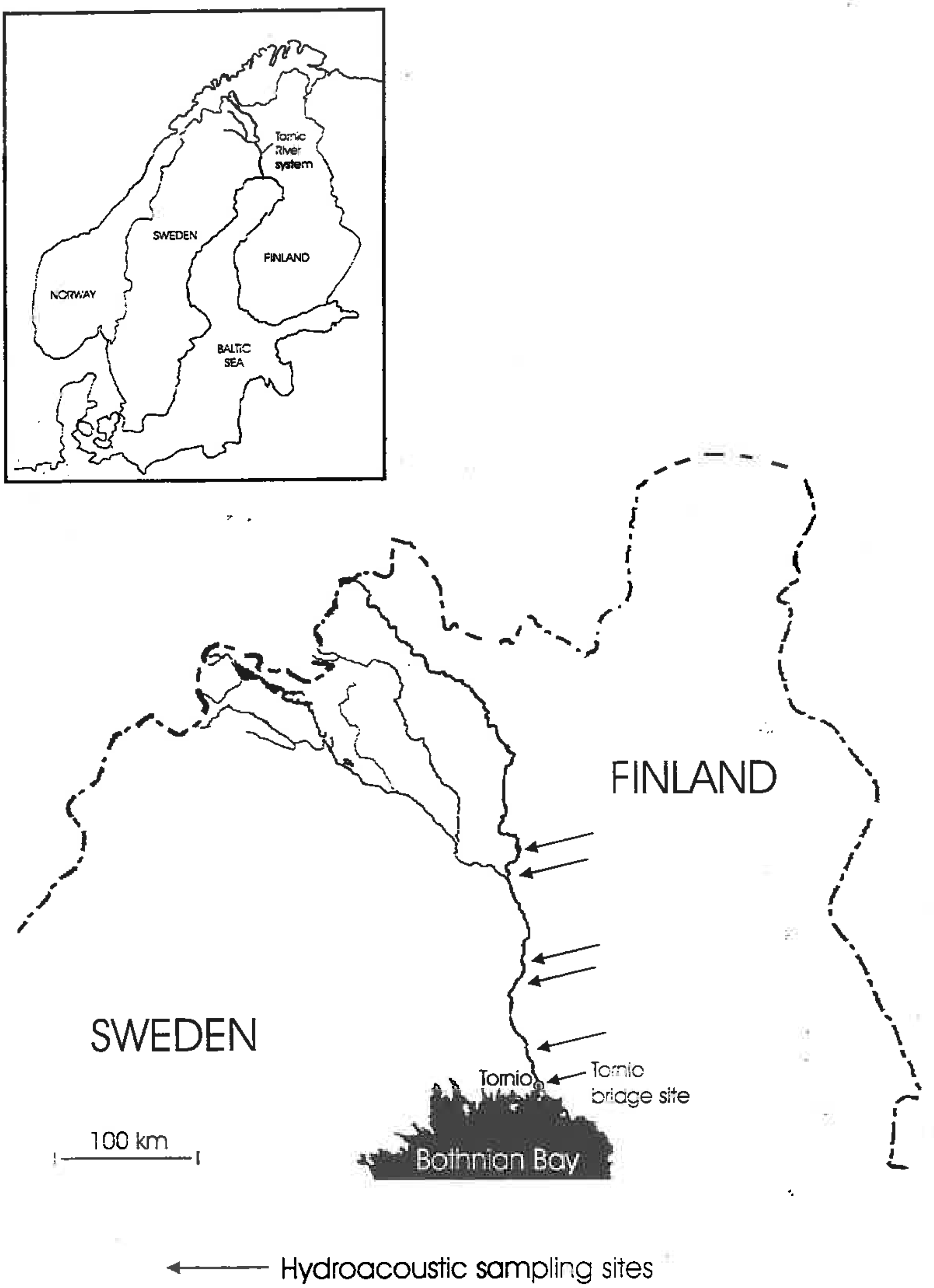


Figure 1. The location of the River Tornionjoki system and the hydroacoustic sites in 1995-1996 studies.

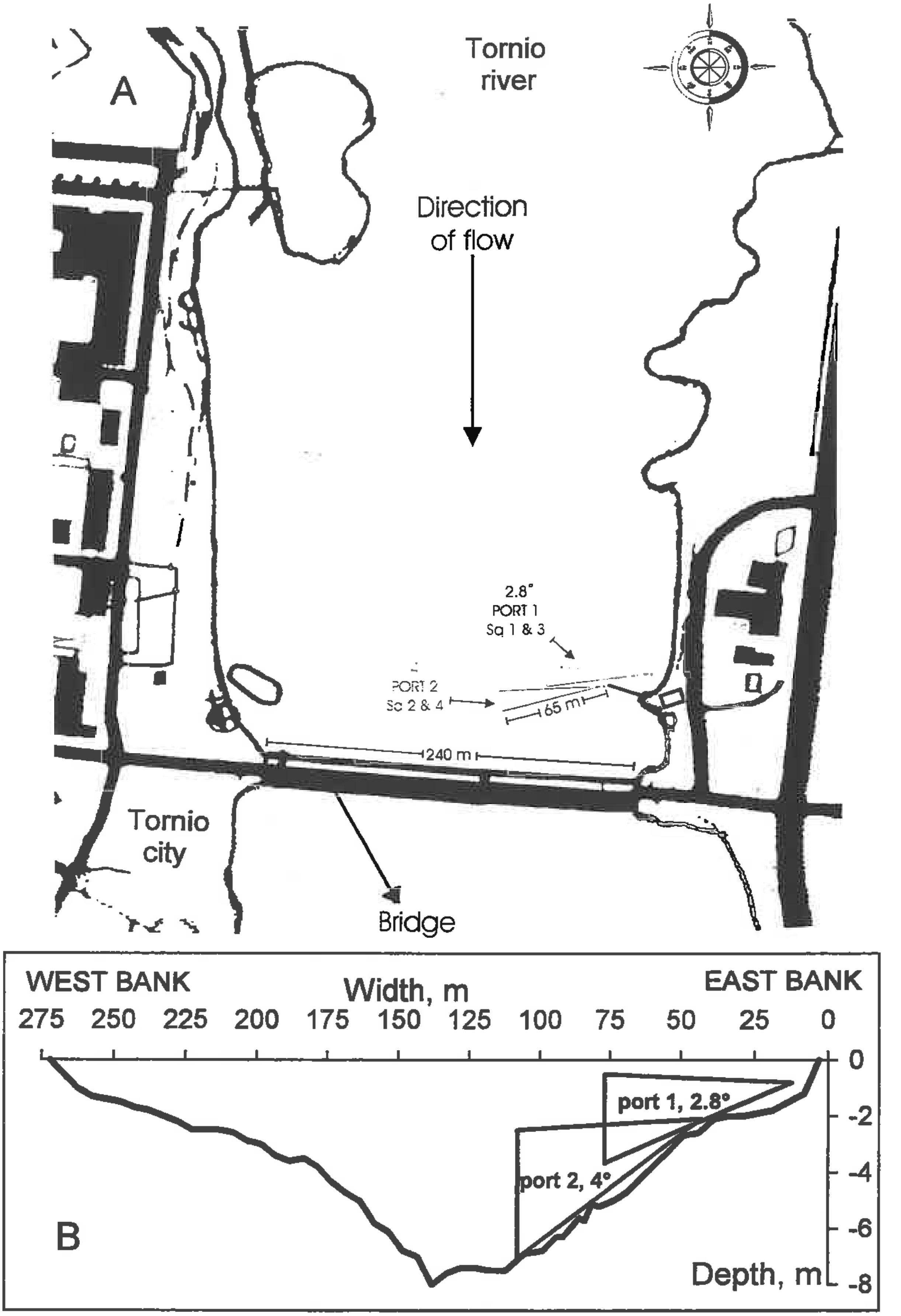
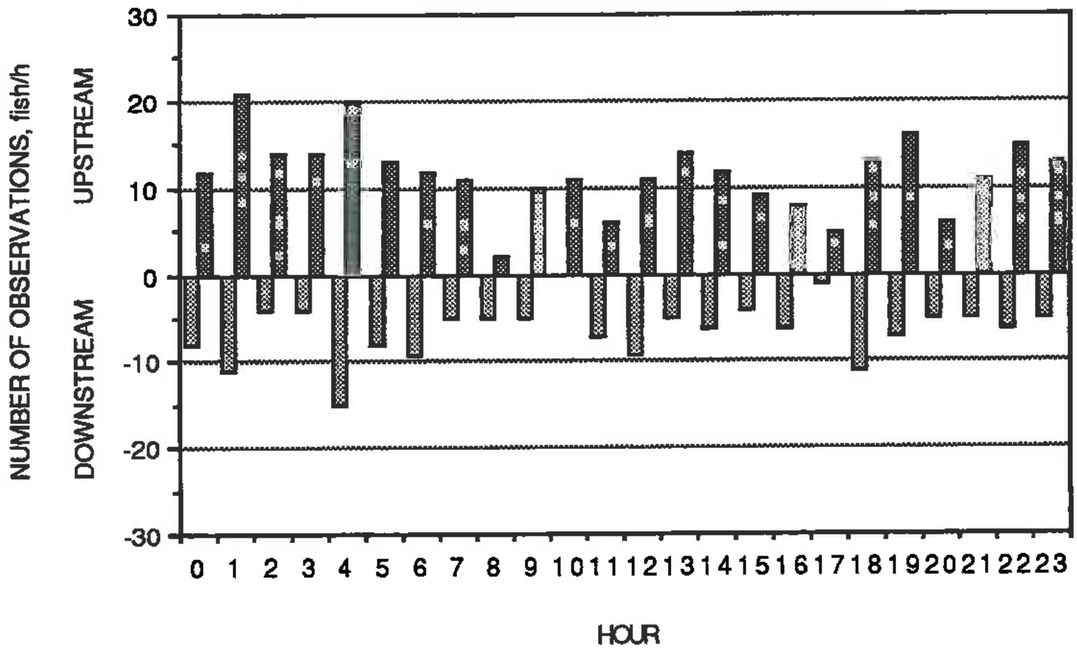


Figure 2. (A) Tornio bridge site and the two hydroacoustic beams, (B) Transection of the river and the expected beam coverage.

A. INSHORE TRANSDUCER



B. OFFSHORE TRANSDUCER

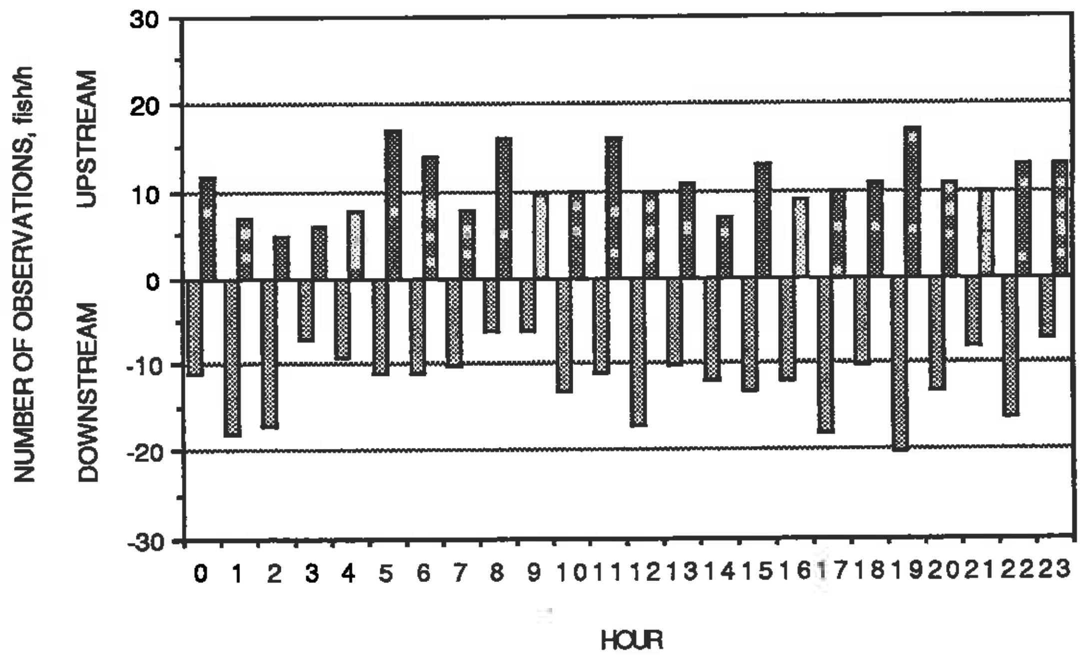


Figure 3. Diurnal distribution of the timing of the fish migration. (A) Inshore transducer (B) Offshore transducer.

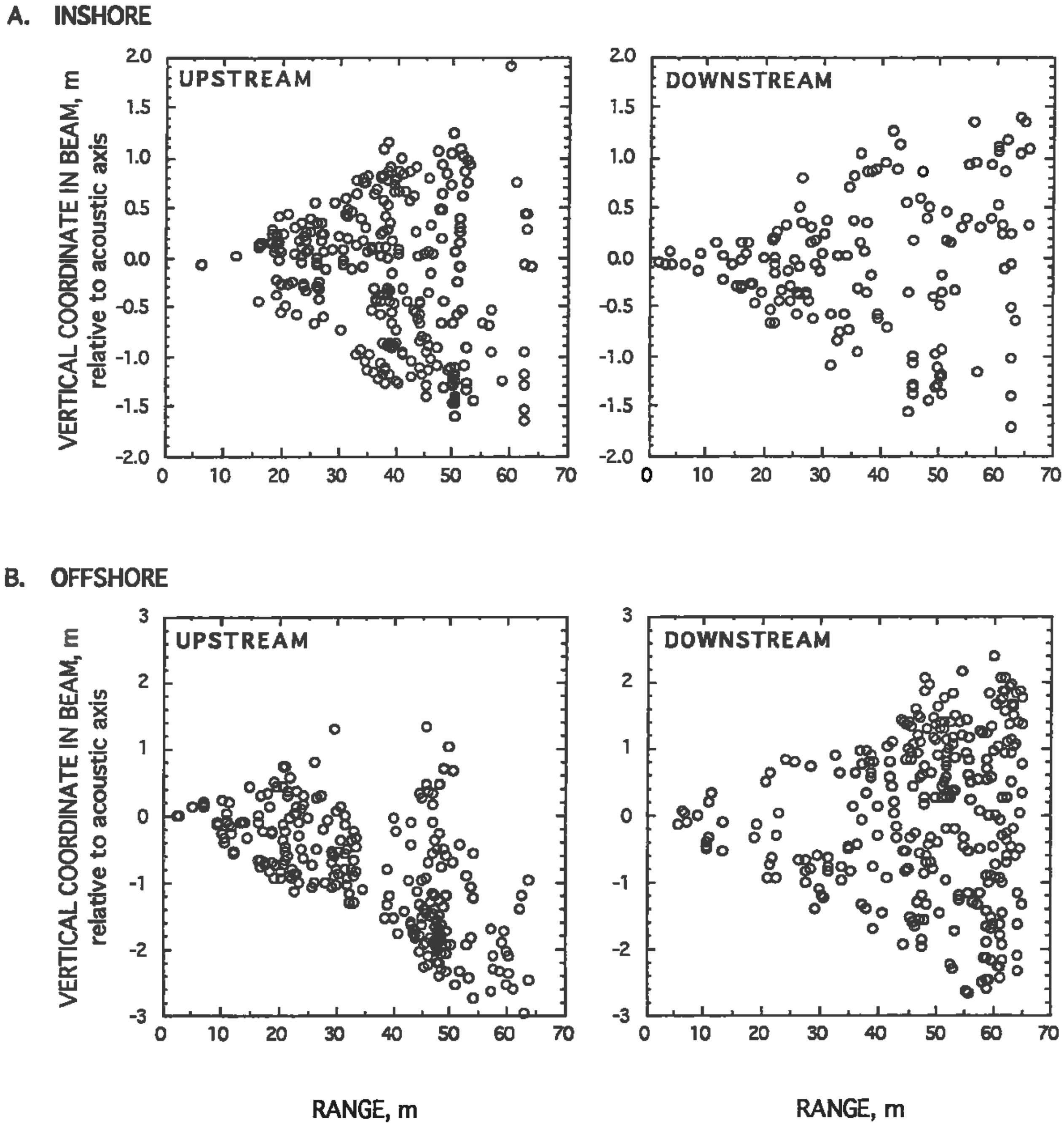


Figure 4. Location of the fish observations in the transducer beams. (A) Inshore transducer (B) Offshore transducer.

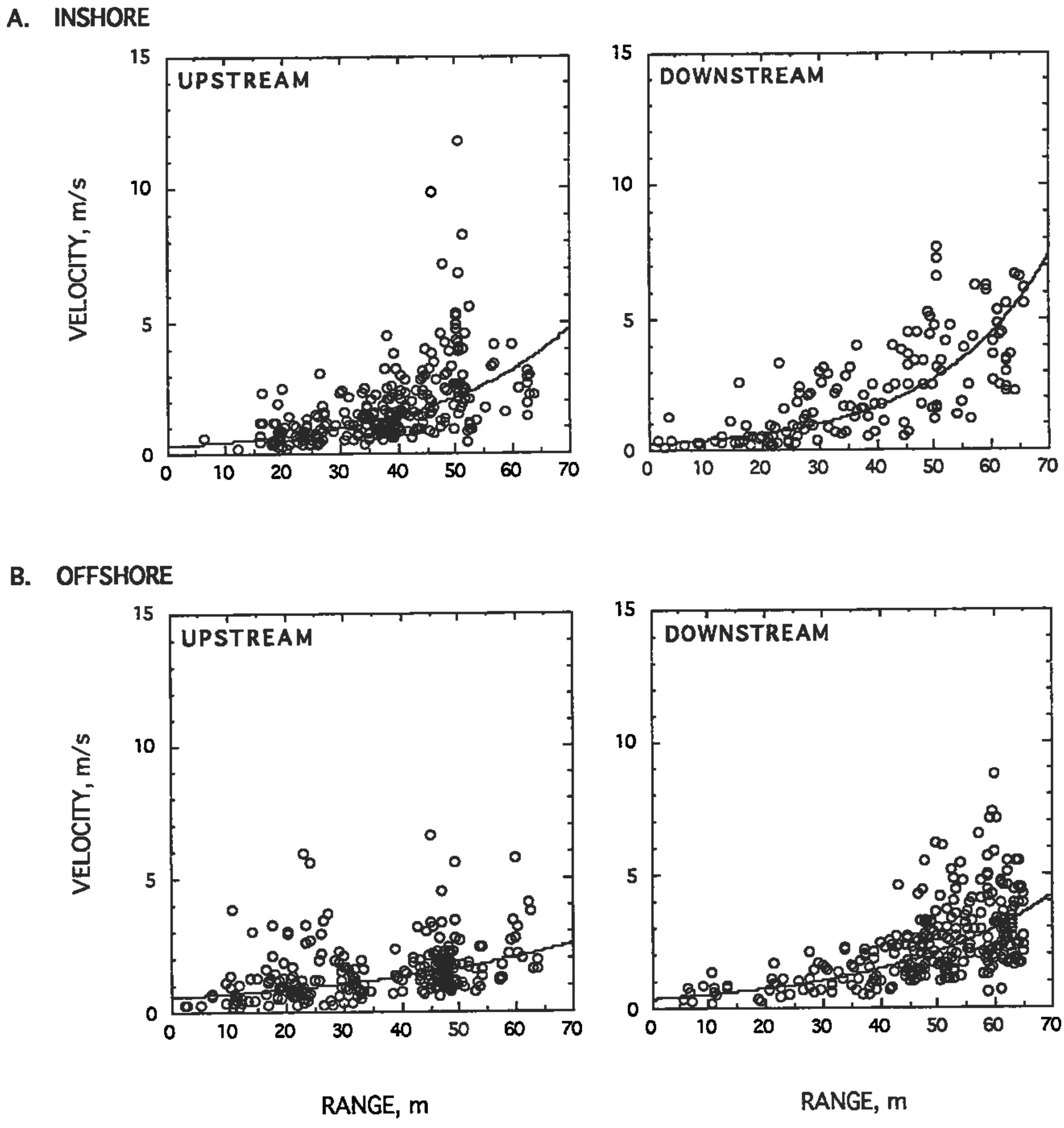


Figure 5. The estimated velocity versus the distance of the target from the transducer. (A) Inshore transducer (B) Offshore transducer. Log-linear regression model fitted:

log(velocity)= a+b*range, $p<0.001$ for all the models.

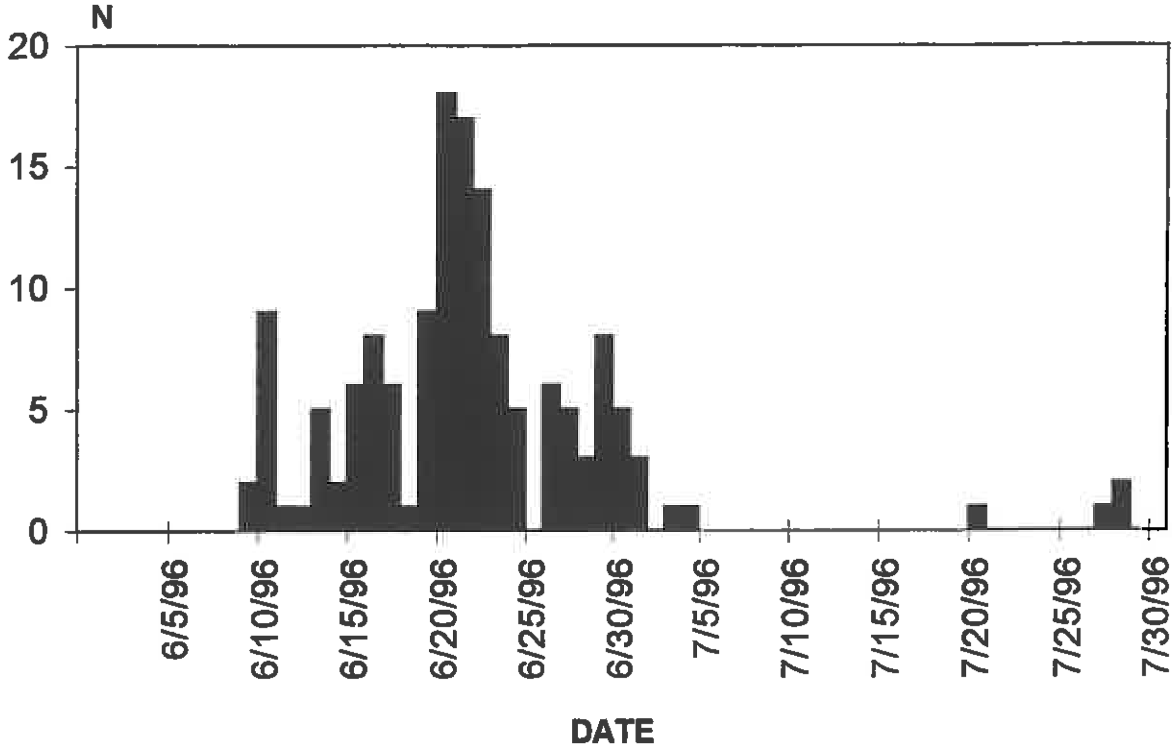


Figure 6. The timing of the salmon river catches near Tornio in 1996.

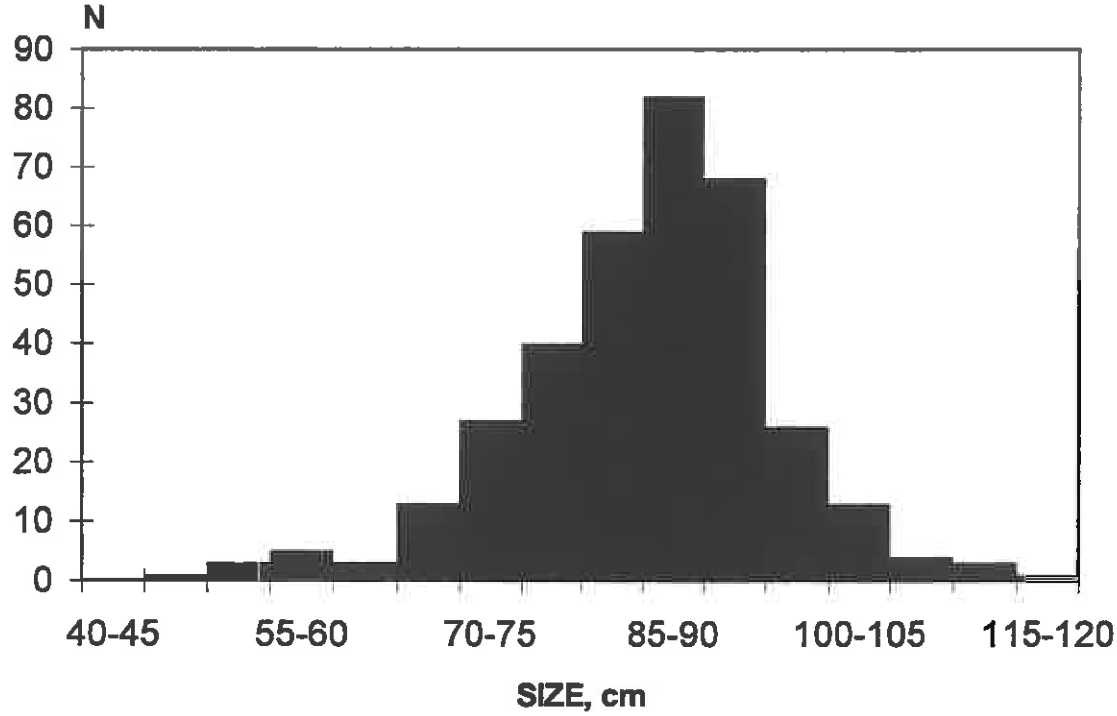


Figure 7. The size distribution of the caught salmon in the River Tornio in 1996.