Aquat. Living Resour. 13 (2000) 349−354

S0990744000010834/FLA

Spawning run of Atlantic Salmon (*Salmo salar*) in the River Tornionjoki monitored by horizontal split-beam echosounding

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Accepted 11 April 2000

Abstract − Fixed location split-beam horizontal echosounding was used to assess the size and timing of the Atlantic salmon (*Salmo salar*) spawning run in the River Tornionjoki. Four transducers, two on each river bank, were mounted across the river at the study site 4 km upstream from the river mouth. Net weirs were used on both shores to direct the passage of fish through the acoustic beams. Hydroacoustic monitoring covered 40–50% of the river cross-sectional area. Also test fishing and yearly catch statistics of salmon were used as an indication of the size of the spawning run in the river. Altogether, 7 700, 5 300 and 4 300 salmon-sized targets (target strength, $TS \geq -29$ dB) moving upstream were detected in 1997, 1998, and 1999, respectively. The fish migration began in all the years by early June and peaked during the second half of the month; the migration period of large salmon lasted until mid-July. The observations made by the echosounding and catch statistics were similar in this respect. In 1998 and 1999, however, more targets of $TS \geq -29$ dB were detected during late summer than could be expected by the river catches of salmon. It may be that the large targets in late summer were, in fact, whitefish whose run occurred during the same time. Hydroacoustic estimation of the total salmon run at the study site was found difficult. The numbers of salmon-sized targets detected were almost the same as the numbers of salmon caught each year by fishermen. Therefore, only an index of the run timing and the size of the stock can be produced from the data. It was clear that a considerable amount of fish escaped the acoustic monitoring by using areas uncovered by the beam, such as gaps in the bottom and the surface layers of the water column near the shores. Moreover, it was found that species recognition based on *TS* only is not adequate in multispecies environments. Assessment of spawning runs remains, however, a key issue in the management of Baltic salmon, and with further development, the hydroacoustic monitoring may be the most viable means of doing it. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

splitbeam acoustics / target strength (*TS*) / *Salmo salar* / migration / River Tornionjoki / Baltic Sea

Résumé − La remontée du saumon pour le frai dans le fleuve Tornionjoki, suivie au moyen d'un sonar à double faisceau horizontal. Un sonar à double faisceau horizontal fixe a été utilisé pour déterminer les périodes de pontes et la taille du saumon Atlantique (*Salmo salar*) du fleuve Tornionjoki. Quatre transducteurs, deux sur chaque rive, ont été mis en place en travers du fleuve, sur le site étudié à 4 km de l'embouchure. Des filets barrages ont été utilisés sur les deux rives pour diriger le passage des poissons vers le sondeur acoustique. Le contrôle hydroacoustique couvre 40 à 50% de la section transversale du fleuve. Des pêches tests et des statistiques annuelles de pêche de saumon ont aussi été utilisées comme indications de la taille du stock de géniteurs dans ce fleuve. Près de 7 700, 5 300 et 4 300 indices de réflexion (≥ -29 dB) de saumons remontant le fleuve ont été détectés en 1997, 1998 et 1999, respectivement. Tous les ans, la migration des poissons commence début juin et atteint un maximum à la mi-juin ; la période de migration des grands saumons dure jusqu'à la mi-juillet. Les observations effectuées par hydroacoustique et d'après les statistiques sont similaires. En 1998 et 1999, cependant, un plus grand nombre d'indices de réflexion ≥ -29 dB a été détecté vers la fin de l'été, que ne le laissaient prévoir les captures de saumon durant cette période. Les plus grands indices de réflexion pourraient correspondre à des corégones dont la période de reproduction se déroule en même temps. L'estimation hydroacoustique de la totalité des géniteurs semble difficile sur le site étudié. Le nombre d'indices de réflexion de saumons détectés était presque le même que le nombre de saumons capturés chaque année par les pêcheurs. Par conséquent, seul un indice de la période de ponte et de la taille du stock peut être produit à partir des données. Il est clair qu'un nombre considérable de poissons échappe à la détection acoustique, dans les zones non insonifiées, situées près du fond et en surface près des berges. De plus, il est reconnu que l'identification des espèces basée uniquement à partir de l'indice de réflexion n'est pas adéquate dans le cas de milieu

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où se côtoient plusieurs espèces. L’estimation du nombre de géniteurs reste cependant un point-clé dans la gestion du saumon de la Baltique, et avec de futurs développements, le contrôle par hydroacoustique peut être le meilleur moyen d’effectuer cette estimation.

hydroacoustique à double faisceau / indices de réflexion / *Salmo salar* / migration / fleuve Tornionjoki / mer Baltique

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1. INTRODUCTION

A crucial precondition for proper management of salmon fisheries is the ability to assess the wild salmon spawning populations in individual rivers. So far, there have been very few studies on the number of salmon ascending the Baltic rivers to spawn (ICES, 1996; McKinnell et al., 1994). Unfavourable conditions for counting fences and other commonly used assessment methods have been one important reason for the lack of such endeavours. Total counting has been established in the river Umeälven/Videlälven, Sweden, by trapping salmon in a fish ladder (McKinnell et al., 1994), but usually wild Baltic salmon rivers do not have any construction which would help the establishment of run counting. Therefore other methods need to be found to count spawning runs in natural river channels.

The largest Baltic wild stock of Atlantic salmon (*Salmo salar*) is in the River Tornionjoki. The Tornionjoki salmon is one of the most extensively studied stocks in the Baltic and the information on the status of the stock plays a major role in Atlantic salmon management. The spatial correlation in the abundance of Atlantic salmon populations recently demonstrated by McKinnell and Karlström (1999) supports the use of index rivers such as the River Tornionjoki for population monitoring. However, it has not been possible to calculate the size of the spawning run into the river because of the lack of a feasible method.

This study is the first attempt to assess the spawning run of salmon in the Baltic catchment by hydroacoustics. Hydroacoustics were used to estimate the timing and the amount of migratory salmon in the River Tornionjoki. In addition, these estimates were compared with catch statistical indices, to evaluate the suitability of hydroacoustic-assessment techniques for Atlantic salmon.

2. MATERIALS AND METHODS

2.1. Study area

The River Tornionjoki forms the border between Finland and Sweden, and it flows into the northern end of the Baltic Sea (*figure 1*). Its annual mean discharge is about 380 $m^3 \cdot s^{-1}$. The river is frozen from December to May. During the spring flood (May–June) the discharge often exceeds 1 000 $m^3 \cdot s^{-1}$. The difference in water elevation between the spring flooding and the lower water period in late summer (August) is usually 2–3 m at the study site. There is practically no tidal influence in the estuary of the River Tornionjoki (Magaard and Rheinheumer, 1974).

Figure 1. The River Tornionjoki in the northernmost part of the Baltic Sea. The arrow shows the approximate location of the study site.

In 1995 and 1996, a pilot study was carried out to explore the lower course of the river in order to find sites suitable for hydroacoustic monitoring (Nealson and Johnston, 1995; Romakkaniemi et al., 1996). In the summers of 1997, 1998, and 1999 hydroacoustic systems were set up at the study site 4 km up from the river mouth (*figure 2*). The river here is 280 m wide and its maximum depth is 10 m. Mud, clay and sand are the dominant bottom materials outside the mid-channel, while the bottom in the mid-channel mainly consists of coarser material.

According to test fishing by trap nets, gill nets, and purse seine from the end of May until mid July, the fish assemblage of the study site mostly consisted of roach (*Rutilus rutilus*) and perch (*Perca fluviatilis*) (Romakkaniemi et al., 1996). Pike (*Esox lucius*) was almost the only species of the same size class as adult salmon. From mid July onwards, abundant run of whitefish (*Coregonus lavaretus*) and grilse (one-sea-year-old salmon) takes place.

2.2. Hydroacoustic counting

Two sets of a digital splitbeam system were used, one for each bank of the river. A set consisted of an HTI (Hydroacoustic Technology Inc.) 200-kHz echo-

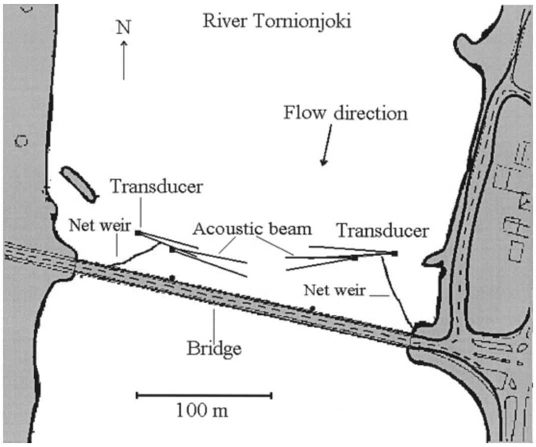

Figure 2. The study site at the town of Tornio 4 km upstream from the river mouth and the location of the transducers in 1998.

sounder (Model 243), 2.8 × 10° and 4 × 10° elliptical splitbeam transducers, dual-axis transducer rotators, a digital audio tape recorder, an oscilloscope, a matrix printer and a computer. The transmitter pulse length and transmit output power were 1.25 ms and 25 W respectively and the through-system gain was set to –171.97 to –167 dB (at 1 m). The sampling rate varied from 3 to 8 pings·s^{-1}.

The target strength (*TS*) for each returning echo can be calculated by the split-beam technique (Traynor and Ehrenberg, 1990). The target strength (TS_i) for an individual echo '*i*' was estimated using the formula

$$TS_i = -SL - G_0 - R_G + 20\,\mathrm{Log}_{10}(U_i) - B(\phi, \theta) \quad (1)$$

where SL = source level (dB), G_0 = through-system gain (dB), R_G = receiver gain (dB), U_i = peak amplitude of echo '*i*' (V), and $B(\phi, \theta)$ = beam-pattern factor (dB). All echoes exceeding the threshold values (–42 to –35 dB, depending on transducer, range, and year) set in the digital echo processor were collected, processed, and recorded on a computer disk in real-time. The echosounders produced raw files from the echoes, which met the echo selection criteria set by the manufacturer. Fish traces were manually picked out from the raw files using a post-processing program (TRAKMAN) provided by HTI.

In situ calibration tests were carried out using a 38.1-mm diameter tungsten-carbide calibration sphere annually during the field season. The *TS* of the sphere was determined at two to four different distances from the transducers. In 1997, test results indicated that the mean *TS* of the targets were underestimated by 0.2 to 3.5 dB, depending on the transducer. The data were corrected according to the observed bias and the sounders were delivered to the manufacturer for laboratory calibration after the field season. In 1998–1999, the in situ test results obtained with the calibration sphere indicated that the echosounders were performing properly.

Hydroacoustic data were collected from the beginning of June until August in 1997–1998 and until late July in 1999, i.e. almost over the entire period of spawning migration of salmon into the Bothnian Bay Rivers (McKinnell et al., 1994; Nordqvist, 1924). Four elliptical transducers were mounted across the river and, once properly mounted, kept stationary. A fifth transducer was used in 1998–1999 and it was re-mounted at intervals in order to sample data outside the detection area of the previous transducers. The sampling range varied from 32 to 65 m, depending on the transducer and the year. Sampling did not cover the 30–40 m-wide area in the mid-channel because of the increased background-noise level preventing extended detection ranges.

The fit of the echobeams to the bottom contour was studied periodically during the years by measuring the dimensions of the beams with an artificial movable target. Gaps up to 60 cm were measured between the bottom and the lower edge of the echobeams. The fit of the echobeams to the bottom contour could be improved during the study years, yet gaps of 10–40 cm in height were regularly found even after improved fit. Net weirs were used to direct the passage of fish through the echobeams (*figure 2*).

The echosounders were in operation 24 h a day. Usually each transducer collected data in turn for 12–15 min once an hour. The total passage estimates were obtained by expanding the results over the unsampled time separately for each transducer. Field tests, remounting of transducers, etc., occasionally interrupted the monitoring for some hours. Missing data was afterwards interpolated hourly on the basis of the nearest observations in the hydroacoustic data. On the basis of the length distribution of the salmon catch and the relationship between *TS* and fish length (Love, 1977; Lilja et al., 2000), salmon was separated from non-target species:

$TS \geq -27$ dB	Large salmon (multi-sea winters)
$TS \geq -29$ dB	Salmon including grilse

2.3. Salmon catch

Finnish salmon catches in the River Tornionjoki were estimated in 1998 by mail surveys addressed to a random sample of fishermen in the river. The sample size was 3 931 fishermen, which is 31% of the sampling frame. In 1998, the effect of non-response on the mail survey was studied by a telephone survey. Catch estimates based on mail surveys also exist for other years (preliminary estimate for the year 1999), but the sampling was not as extensive as in 1998, and therefore these estimates are somewhat less accurate. Independent indices of the timing and composition of the salmon run and records of the species composition of ascending fish were collected by catch records, catch samples, and test fishing.

Table I. Number of salmon specimens in the Finnish catch, and the acoustic estimate of salmon in the River Tornionjoki in 1997–1999*.

Year	Catch	≥ –29 dB	≥ –27 dB
1997	7 880	7 670	4 400
1998	3 650	5 310	3 590
1999	2 420	4 280	2 200

* Specimens include grilse (≥ –29 dB) and large salmon (≥ –27 dB).

3. RESULTS

Altogether 7 700, 5 300 and 4 300 salmon-size targets ($TS \geq -29$ dB) were estimated to move upstream through the echobeams by July 20 in 1997, 1998 and 1999, respectively (*table I*). The migration of these targets began in early June, the major peak being around second half of June (*figure 3*). The highest daily migration of targets was observed on June 24, 1997, when approximately 515 targets with $TS \geq -29$ dB passed through the insonified cross-section of the river. The timing of the salmon-sized targets observed by the echosounders corresponded well with the catch indices and test fishing results of salmon during the early part of the spawning migration.

The *TS* of the targets moving upstream decreased in 1998 and 1999 as the size of upstream migrating salmon decreased (Spearman R = 0.83, $P < 0.001$) (*figure 4*). According to the catch records, large salmon ended their upstream migration around July 10.

In late July and August in 1998 and 1999, when grilse predominated in the salmon run and the whitefish run peaked, the echosounders detected many targets of ≥ –29 dB more than expected on the basis of the size distribution of upmigrating fish. Fairly small numbers of large targets were observed during the late season in 1997.

Monitoring covered 40–50% of the river cross-sectional area (*figure 5*). Ascending fish were observed to utilise the whole river width within the monitored ranges. Large fish in the early season were strongly bottom-oriented in the mid-channel (*figure 5*).

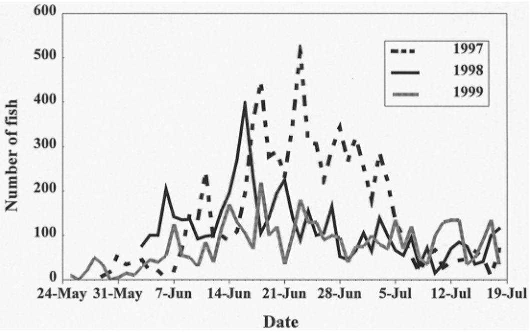

Figure 3. The timing of upmigration of salmon-sized targets (≥ –29 dB) at the study site in 1997–1999.

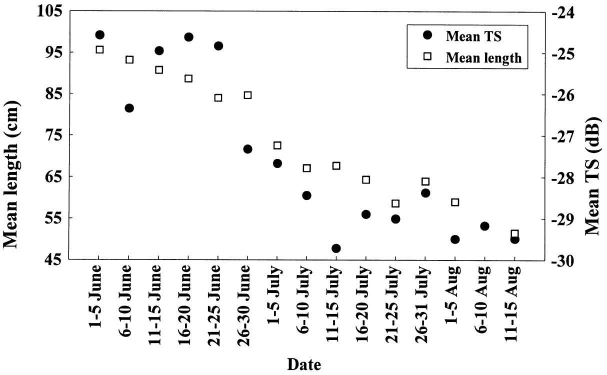

Figure 4. Mean length of upmigrating salmon caught by test fishing ($N = 122$) at the estuary of the River Tornionjoki and the mean target strength (*TS*) of upmigrating targets detected by the echosounders at five-day intervals in 1998.

Finnish fishermen caught about 4 000 multi-sea-winter salmon in 1998 in the River Tornionjoki (*table I*). During recent years, the recorded Swedish river catches of salmon have been 15–25% of the Finnish river catches (ICES, 1999). Therefore, the total river catch of multi-sea-winter salmon was close to 5 000 fish in 1998. This is almost the same as the estimated total number of salmon-sized migrants passing the insonified water column during the migration period of multi-sea-winter salmon. The estimated river catch was somewhat larger in 1997 and somewhat smaller in 1999 than the corresponding hydroacoustic estimate of the run size. River catches decreased annually by 30–50% during the study years and the decrease in the hydroacoustic estimates was almost the same.

4. DISCUSSION

The close connection between the hydroacoustic data and the other indices of run timing during the early season indicates that hydroacoustics provide an optional source of information on run timing. The association between salmon-catch estimates and hydroacoustic counts suggests that the method may also

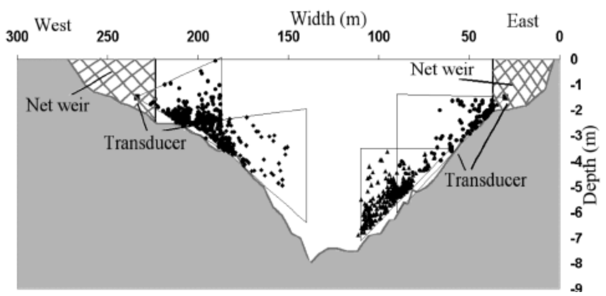

Figure 5. The location of adult salmon-sized targets (≥ –29 dB) in the beam at the study site between June 4 and July 10, 1998.

provide an index of the run size of large salmon. Hydroacoustic salmon run estimates may be less biased than catch statistics that include e.g. the effect of inter-annual variation in fishing effort. The catch per unit effort is difficult to estimate from rod fishing statistics. The hydroacoustic salmon-run index, however, needs better verification, because of the scarce data (three years) and rather arbitrary limits set for species recognition. The data collection was not well-standardised over the years either. In spite of this, in many large rivers with low fishing pressure, hydroacoustics are the only valid method to estimate fish migration (Ransom et al., 1998).

The correlation between the mean length of the salmon and the mean target strength of the upstream migrating targets gives us an opportunity to use the target strength of fish as an indicator of fish size. However, the *TS* measurements with stunned specimens of known size showed that whitefish and pike produce *TS*'s similar to a much larger salmon specimen (Lilja et al., 2000). Some of the high *TS* targets during the late season are probably whitefish and so the acoustic count of salmon is biased upwards in this period. In order to remove this bias, a better knowledge of the fish community is needed. As shown by Burwen and Fleischman (1998), distinctions other than *TS* could be found for species recognition by hydroacoustics. Also these alternative methods should be used in the River Tornionjoki.

Few sites suitable for hydroacoustic monitoring were found in the River Tornionjoki. Even the Tornio site did not have a very favourable bottom for horizontal echosounding. Bottom irregularities and occasional coarse bottom material prohibited a good fit of the echobeams to the bottom. Many salmon swimming close to the river bottom were not detected by the echosounder used recently in the United Kingdom (Jim Gregory, personal communication). The echosounders could only detect an amount of ascending salmon corresponding to the size of the river catch. Salmon fishing in the River Tornionjoki is almost entirely rod fishing and all gear regarded as more effective than rod fishing is strictly restricted. When we add to this the fact that many migrants must have avoided fishing gear because of the successful spawning in recent years (ICES, 1999), a lot of salmon apparently passed the Tornio site below the echobeams and were not detected. The results of periodical sampling outside the fixed-transducer beam coverage indicated that a substantial amount of migratory fish also seems to utilise near-surface areas on the edges of the fast flowing mid-channel. The rate of migration above the cross-section covered by the four fixed echobeams has not yet been estimated. Nor has the detection probability of salmon by the beam been estimated. Enzenhofer et al. (1998) have demonstrated that the echosounder may miss some fish passing the beam. Some upstream sites in the River Tornionjoki may provide better opportunities for monitoring because there are less non-target species present. The upper boundary of the migration of Tornionjoki whitefish is about 100 km from the river mouth. The trade-off with moving upstream is to lose part of the run and to miss the information on the timing of the river entry.

5. CONCLUSION

A hydroacoustic estimation of the total salmon run was found to be unattainable, unless methods for species determination can be improved and the detection probability of the echosounder especially in the near-bottom area can be determined. Meanwhile, indices on the run timing and total run of large salmon can be provided. In spite of the difficulties faced in the River Tornionjoki, assessment of spawning run remains a key factor in attempting to improve scientific advice for the Baltic salmon management, and hydroacoustics may be the most feasible way to do it.

Acknowledgements. This study has been carried out with financial assistance from the European Commission.

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