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ESTIMATES OF THE SMOLT RUN IN THE RIVER TORNE ÄLV 1987-1993

by

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ABSTRACT.

The river Torne älv is the largest wild salmon river in the Baltic. The estimated potential annual production is about 500000 wild salmon smolts. However, since the 1960 s´ salmon stock has declined to a low level.
The smolt run was estimated by using the mark-recapture method following the capture of smolts in a fyke-net trap. The efficiency of the trap was negativly correlated with water discharge,with a normal variation between 3 to 17 %.
The run of wild salmon smolts was estimated to be about 65000 in the years 1988 and 1990, which is only 13 % of the estimated potential production. The smolt run increased to about 125000 in the year 1993, about 25 % of the potential production. The smolt production is therefore well below the capacity of the river.
The survival of stocked one year old parr to three year old smolts was found to be between 10-25 %.
Stocking of parr was found to be an effective method at times of poor reproduction.
The proportion of wild smolts in the total smolt run (wild and reared) varied between 40-65 %.
The large number of reared parr and smolts in relation to the small number of wild smolt could cause genetic problem.
The method used to estimate the smolt runs in this study, show promise for assessment of large rivers but further improvements to the technique are needed.
Monitoring of the smolt run should continue in order to get data on the status of the wild salmon stocks in the river, especially to assessing the effects of "M-74 syndrome".

I. INTRODUCTION.

The river Torne älv is the largest wild salmon river in the Baltic area. The area of spawning habitat is estimated to be 5000 ha with the largest and the highest quality areas situated in the middle and the upper parts of the river. Salmon can migrate up to 450 km to the uppermost parts of the river. (Fig.1, Karlström 1977a). The potential annual production of the river is estimated to about 500 000 smolts. Salmon catches and the spawning stock of the river have declined since the 1950's, and have been at a low level since the 1970 s'.(Karlström 1983,1989). The reason for this is the high level of fishing mortality, especially in the sea. (Larsson 1983). However there has been an increase in salmon catches from 1990 (Karlström 1994). Electro-fishing surveys have indicated that salmon parr densities were low in the 1970's and in the 1980's . Parr densities have, however, increased in recent years but in 1992 and 1993 low numbers of one-summer old parr were found (Karlström 1983, 1994). This syndrome is characterized by high mortality at the alevin stage and was first identified in Swedish salmon hatcheries in the Baltic. (Börjesson 1993).

In order to increase the juvenile population in the river, stocking of one year old parr has been carried out annually in a Finnish-Swedish project since 1980 in areas where juvenile salmon were absent or present at low densities. A total of about 1.5 million parr were planted in the river during 1980-1993 in addition to the direct release of about 0,4 million reared smolts in the same period.

Few investigations have been conducted on the smolt run of rivers in the Baltic area. In Sweden investigations were carried out in 1960 s' in the small river Rickleån with a smolt trap across the whole river (Österdahl, 1969) and in the river Mörrumsån in southern Sweden with smolt trap closing a part of the river. No investigations have been carried out in the largest salmon rivers in the Baltic.
This investigation was carried out partly to investigate methods to estimate trap the smolt run in large rivers and partly to get a better knowledge of the smolt run in the largest salmon river in the Baltic for management purposes.

II. MATERAL AND METHODS.

The river Torne älv rises in the Scandinavian mountains and flows into the Bothnian Bay. The river is about 500 km long and salmon can ascend to the uppermost parts of the river. (Fig.1). The mean discharge in the river (measured near the river mouth) is 340 m^3/s (mean high 1800, mean low 70). The ice breaks up at the beginning of May. There is a high water discharge in May ("wood-land" or inland flow), decreasing mostly in June and often followed by a "mountain" flow at the end of June. After that water discharge gradually declines to autumn and winter. The river is ice-covered in October. During the period of these investigations water discharge varied between 400 -1600 m^3/s.

The smolt trap was located at the Kuivakangas village, about 80 km upstream from the river mouth. This is one of the few places in the river with a combination of suitable substrate for bottom fixed fyke-nets and sufficient water velocity to

adequately sample the smolt run. The smolt trap used was a modified ciscoe-herring type fyke-net with two side arms 130 metres long in total.
The side arms were set at an angle of about 30°(outer arm) and 50°(inner arm) to the river flow. The width of the river at the site of the trap is about 500 metres. The trap was placed from the river side to the main stream of the river and covered about 15-20 % of the river width. (Fig 2). Since 1989 the side arms of the trap have been fixed closer to bottom resulting in a higher efficiency of the trap. The mesh size in the fyke-net was 11 mm (from knot to knot) and 20 mm in the side-arms. Fish larger than about 12 cm were estimated to be caught in the trap.
Investigations were carried out between 1987 to 1993 from the end of May to the middle of July. In 1987 and 1992 the first part of the smolt run was not sampled because of extemly high water.

Smolts were caught in the trap and the mark-recapture method was used to estimate the total run. The smolts were removed from the fyke-net, anaesthetised, finclipped and transported by boat to the place of release, approximatly about 6 km upstream from the trap. Very low smolt mortality was found in the trap, even in tests for several days. The smolts were dispersed in the whole river at the release site. Between the point of release and the trap the river is moderately fast flowing without any large areas of smooth water. The trap was inspected and the smolts removed 1-3 times per day depending on the size of the catch; always in the morning, in the evening, and, when catches were high, also in the afternoon. When the trap was not fishing for any reason the daily number of trapped smolts was calculated as a linear increase or decrease between the last daily catch before and the first daily catch after, except in 1991, when the calculated number of trapped smolts was calibrated against catches in a Finnish smolt trap downstream.
This was necessary because there was a period of five days, when the trap was not in operation and it was the first year when it was possible to calibrate catches in this way.

The effecicency (p) of the smolt trap was calculated (with 95 confidence intervals) using equation (1) where r is the number of recaptures and n is the number of marked and released smolts.

$$p = \frac{r}{n} \pm 2\sqrt{\frac{p(1-p)}{n}} \qquad (1)$$

III. RESULTS.

1.General pattern of the smolt run.

There are three different kinds of smolts in the river:
a/ smolts originating from natural spawning in the river, refered to as "wild (w) smolts".
b/ smolts originating from reared parr, stocked as one-year old fish in the river

(see section I). Most of these fish spend two years in the river before migration. They were adipose fin-clipped as parr and can therefore be separated from wild smolts. They are refered to as "parr-stocked (p) smolts".
c/ smolts released as reared smolts, refered to as "reared (r) smolts".

The catches of wild and parr-stocked smolts in the trap are shown in Fig 3 a-g.

In most years the smolt run commenced at the end of May and lasted until about 10-15 July. The main run occured during a period of about 10-14 days in the middle of June, when the water temperature was between 10 -14° C. From the end of June onwards the number of migrating smolts was small. Low river discharge occured in the years 1988 and 1990 and high flow in the years 1987,1989 and 1993. The increase in water temperature was earlier in the years 1988,1990 and 1992. The smolt run occured as water temperature was increasing, while water discharge could be both increasing or decreasing at the time of the main smolt run. There were differences between years in the timing of the run. The smolt run occured earlier in the years 1988,1990 and 1992 and later in the years 1989,1991 and 1993. The difference between the years in the main run time was up to 7-10 days. Wild smolts migrated earlier than smolts planted as parr. Parr are planted out in the upper parts of the river which may explain the later arrival at the trap of the smolts originating from these parr. The timing of the smolt run in relation to discharge and water temperature will be further analysed in a subsequent paper.

2.Calculation of the efficiency of the smolt trap.

The efficiency of the trap was negatively correlated with water discharge (Table 1). Therefore we used linear regression of ln(p) against water discharge to calculate the efficiency of the trap at different water discharges. The efficiency (p) is thus a function of water discharge (d) with 95 % confidence limits as (2).

$$(2) \qquad p = a\, e^{-b\, d \,\pm\, T_{0.025}^{(n-2)} S \sqrt{1/n + (d-\bar{d})^2 / \Sigma (d_i - \bar{d})^2}}$$

However there was a poor fit using all values ($r^2 = 0.11$, $n=21$) because there is also a variation in the efficiency of the trap between years (Table 1). We therefore allocated the values into three groups: 1989 ($r^2=0.87$, $n=4$), 1990-92 ($r^2=0.69$, $n=8$) and 1993 ($r^2=0.59$, $n=9$). (Fig 4 a-c).
Since regression lines should only be used between the interval where values are measured the following restrictions in efficiences were also used.(Table 2.)

By considering the variation in efficiency with water discharge the total smolt run was then calculated as the sum of the catch for each 2-day period divided by the efficiency value for the mean water discharge during this two-day period. For the years 1987 and 1988 the slope of the regression line of the years 1990-1992 was used, but the equation was adjusted to match the very low efficiency of 1988 ($p=0.031$, $n=958$, discharge 752 m^3/s). See method for the reason of the low efficiency. The minimum efficiency value used for these two years was 0.01.

The efficiency-functions can be checked against catches of the reared smolts that were released in the river above the trap. The calculated efficiency functions of the wild smolts were thus used to calculate the number of released smolts above the trap. The calculated numbers are lower than the actual released numbers.(Table 3). The relationship between the calculated number and the number actually released varies between 60-80 %. The difference may be explained by the fact that the release place was situated about 50 - 100 km upstream from the smolt trap and that the reared smolts can suffer mortality during the downstream migration and some smolts may also remain in the river. The markedly different results obtained in 1989 will be discussed later.

3. The smolt run.
3.1. Wild smolts.

There are differences in the estimated smolt run between years (Table 4). In 1987 and 1992 the smolt trap was not in operation at the beginning of the smolt migration, and particularly in 1992, a large part of the smolt run had passed the sampling site before the trap could be installed.
Low efficiency and only one mark-recapture trial (1988) means that the estimated catches in 1987 and 1988 are less reliable than those in later years. The estimated number of smolts was exceptionally low in 1989. The calculated wild smolt run was approximately: 66000 in 1988, 63000 in 1990, 87000 in 1991 and 123000 smolts in 1993. The confidence limits are wide but there is a trend of increasing numbers of smolt from 1988 to 1993.

3.2. Parr stocked smolts.

Since 1980 one year old parr have been stocked in the middle and the upper parts of the river in order to increase the production of salmon in areas with low densities of parr. Stocking was carried out with approximatly 500 parr per 100 m river length (one side). The size of the stocked parr was initially 50-70 mm; but in later years it was 60-75 mm. The size of the one summer old wild parr in the river is 40-60 mm in the autumn. Most of the stocked parr migrate as three year old smolt. The number of smolts in the years 1988-93 originating from parr stocked two years earlier (1986-91) is shown in Table 5.
From the number of stocked parr and the estimated size of the smolt run the survival from parr to smolt can be calculated. If the years 1989 and 1992 are excluded the survival from parr to smolt varied from 9-27 %, with survival around 20 % in recent years. (Table 5).

3.3. Total smolt run.

In addition to stocking of one year old parr, direct releases of reared smolts have also been carried out. Smolts originating from stocked parr are adapted to river life and are belived to have similar survival rates to wild smolts. The total estimated smolt run varied between 110 000 - 190 000. (Table 6, Fig 5).
In the years 1987 and 1992 no estimate of the total smolt run could be made (see section 3.1.). The proportion of wild to reared smolt varied between 40 -67 %.

4.Smolt age and smolt length.

Only preliminary data are available concerning smolt age and smolt length. Wild and parr-released smolts were predominatly three years old (80-90 %) but there were also two and four year old smolts. The mean size of wild smolts was between 15 -16 cm. Futher analysis of the smolt age and smolt size will be presented in a subsequent paper.

IV. DISCUSSION.

Estimating the size of the smolt run in large rivers is difficult. Traps across the whole river are almost impossible to build so partial trapping combined with the mark-recapture method must be used. There are other types of fish-counters, but they are expensive and there use is limited in large rivers.
A ciscoe-herring type fyke net was adapted for smolt-trapping for this study. The efficiency of the trap was found to be negatively correlated with water discharge. The variation in efficiency was remarkably high, from 1 to 25 per cent, indicating that the efficiency of the smolt trap was very sensitive to water discharge. There is also a variation in efficiency between years. It is not possible to locate the smolt trap in exactly the same location every year and the construction of the trap itself can vary (angle between the side-arms a.s.o.) Thus variation in efficiency between years, unrelated to water discharge is to be expected. This means that mark-recapture trials have to be conducted for separate years and water discharge. In the years 1989 and 1993 it was possible to calculate efficiency curves separately.
However as the number of mark-recapture trials was too small in the years 1990-92 they were combined together. Methodologically the best estimates would be expected in the year 1993 and 1989. The results in 1989 are however unusual. The efficiency curve for this year is much higher resulting in a low smolt run estimate.

The efficiency could be tested in relation to releases of reared smolts in the river upstream of the smolt-trap. The estimated number, calculated by trap-efficiency, varied between 60-80 % of the actual number released. They were however at a logical level,bearing in mind the fact that the releases are carried out at least 50-100 km upstream from the trap and that, compared to wild smolts, direct released reared smolts, may suffer higher predation, and to some extent remain in the river because not all are fully smoltified. However again the year 1989 stands out; only 6 % in calculated number compared to the actually released number. This indicates that there is likely to be some error with the estimated efficiency this year (too high) and hence too low estimate of the smolt run. The reason for this can not be fully explained, but it is likely to be related to a technical aspect. The estimate for the year 1989 must therefore be viewed with caution and have therefore been excluded from the analyses.

The low efficiencies during periods of high flows makes the estimates of total catches in these periods particularly uncertain with wide significance levels. This means that the values of smolt migration only give the magnitude and long-term trends of the smolt run. There is therefore a need for further investigations to improve the methods so as to obtain better estimates of the smolt run.

The main smolt-run occured in the middle of June with a variation in time of up to 10 days between the years.The smolt run seemed to be assosiated with a rise in water temperature. (Fig 3 a-g). No correlation with water discharge, was apparent.
Small numbers of smolts migrate as late as the middle of July. The migration is about two weeks earlier in the river Torne älv than in the river Rickleån, a northern Baltic salmon river, about 400 km to the south. (Österdahl 1969).

Parr-stocked smolts migrate later than wild smolts. The reason for this could be that stocking was carried out in the upper parts of the river resulting in later arrival at the trap. Another reason may be that the parr come from mixed stocks, mainly from those in the lower part of the river, and that these fish has a different migration pattern.

The best estimates of the actual smolt run are those in the years 1990, 1991 and 1993. There is an increase in the number of smolts which is in accordance with the results of electro-fishing surveys, which have indicated increasing parr densities in the river from 1988-89 onwards (Karlström 1994). To estimate the smolt run in the whole river, the smolt production below the trap must be included. and on the basis of available habitat, this was estimated to be 5-10 % of the total production area. Futhermore, the smolt mortality to the river mouth must be taken into account. If the results of migration losses from released reared smolts (section III.2. and 3.3.) are estimated together with the higher survival of wild smolts (up to double as many investigations have shown), the migration loss may be estimated to be about 10 % from the trap to the river mouth. Toivonen (1975) estimated 10 % migration loss of reared smolts per 100 km river length in large rivers. The smolt run at the site of the trap may thus be estimated to give the smolt number in the river mouth.

Parr were stocked in the first part of June in the upper and middle parts of the river. They stay in the river mostly for two years and migrate as three year old smolts. The migration distance to the smolt trap is between 100 to 300 km. The survival from stocking to migration was about 20 % in recent years. The mortality occurs both at the parr stage in the river (two years) and during the smolt migration. The results indicate that stocking of parr gave satisfactory results and is a good method to increase the production of smolts in a northern river with weak reproduction.
However long-term stocking in wild salmon rivers rises genetic concerns especially at high levels of stocking (30-60 %) and with parental stocks of mixed origin. There is a risk of mixing of the various subpopulations found in the river (Ståhl 1981). This problem also requires regulation of the fishery so as to preserve the wild salmon in the river.
The low level of reproduction, which has prevailed for 20-30 years, could cause loss of genetic material and loss of subpopulations in the river. Added to this long-term problem, there is the present problem of "M-74 syndrome", characterized by high mortality at the alevin stage.
The wild smolt production was about 15-25 % of the potential production (500 000 smolts) in 1990 to 1993. There is an increase in later years but the loss is still of about 350 000 - 400 000 smolts corresponding to 300-400 tons of salmon (one wild salmon

in the Baltic gives a catch of one kg salmon). This low level of production in the largest salmon river in the Baltic calls for urgent action to increase the spawning stock and the salmon reproduction in the river. The best way to achieve this is to restrict the salmon fishery.

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Table 1. Mark-recapture trials used to calculate the functions of efficiency (p) against water discharge of the smolt trap.
(n): number of released smolts. (d): mean discharge (m3/s) during trial.

year	n	d	p	+-95%
1989	195	1261	0.12	0.049
	584	1528	0.09	0.024
	588	1329	0.16	0.030
	262	972	0.32	0.058
1990	1476	776	0.25	0.022
1991	757	869	0.15	0.026
	529	938	0.17	0.033
	518	951	0.17	0.033
	117	1056	0.05	0.041
1992	70	1175	0.04	0.047
	153	1061	0.04	0.031
1993	50	786	0.12	0.028
	323	822	0.09	0.032
	547	1020	0.09	0.025
	350	1091	0.07	0.028
	.264	1116	0.04	0.024
	112	1304	0.01	0.018
	94	1121	0.05	0.046
	323	970	0.03	0.019
	369	960	0.04	0.021

Table 2. Restrictions in the use of efficiency. (p-values).

	discharge (m3/s)	p	p+c.i.	p-c.i.
1989	<950	0,38	1	0,14
	>1500	0,127	0,279	0,058
1990-1992:	<750	0.34	0.82	0.14
	>1150	0.046	0.096	0.022
1993:	<790	0.10	0,215	0.046
	>1500	0.013	0.031	0.005

Table 3. Calculated number of released reared smolts by catch-efficiency method in the trap compared with the actual released numbers.

year	number of smolts released	number of smolts calculated	95 % c.i.	% calculated: relased
1988	17200	10931		64
1989	4400	263	142-492	6
1990	46517	26445	11152-63149	57
1991	14927	11980	7113-20363	80
1992	8500	6039	3289-11315	71
1993	27672	20120	11846-35032	73

Table 4. The estimated total smolt run estimated using the mark-recapture method 1987-1993.

	Wild smolt		Parr planted smolt		
Year	n	95 % c.i	n	95 % c.i.	Sum n
1987	43036		47648		90168
1988	65646		24166		89987
1989	8952	4122-20079	10923	4809-25494	34707
1990	63176	27130-148062	12447	4942-27048	88150
1991	86733	50418-152150	59784	29150-96494	174978
1992	4567	2539-8403	6871	3233-10018	11438
1993	123235	68212-230938	33149	18591-61439	156384

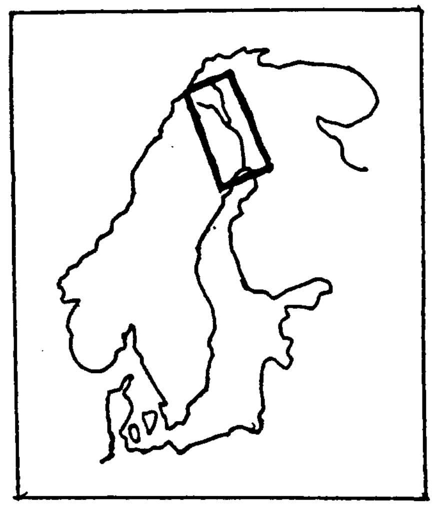
Table 5. Number of planted smolts and the survival from parr to smolt.

Year	Numberof p-smolts	Number of planted parr two years earlier	% survival
1988	24200	260200	9.3
1989	10900	138000	7.9
1990	12500	68600	18.2
1991	59800	222700	26.9
1992	4600	270700	1.7
1993	33100	159700	20.8

Table 6. Estimated smolt run in the river 1988 - 93.

Year	Number w-smolt	Number p-smolt	Number r-smolt	Sum all smolt	Relation wild:reared
1988	65600	24200	18700	108500	60:40
1989	(9000)	(10900)	4400		
1990	63200	12400	86000	161600	39:61
1991	86700	59800	40300	186800	46:54
1992	(4600)	(6900)	23000		
1993	123200	33100	27500	183800	67:33

Fig 1. Salmon reproduction and site of smolttrap



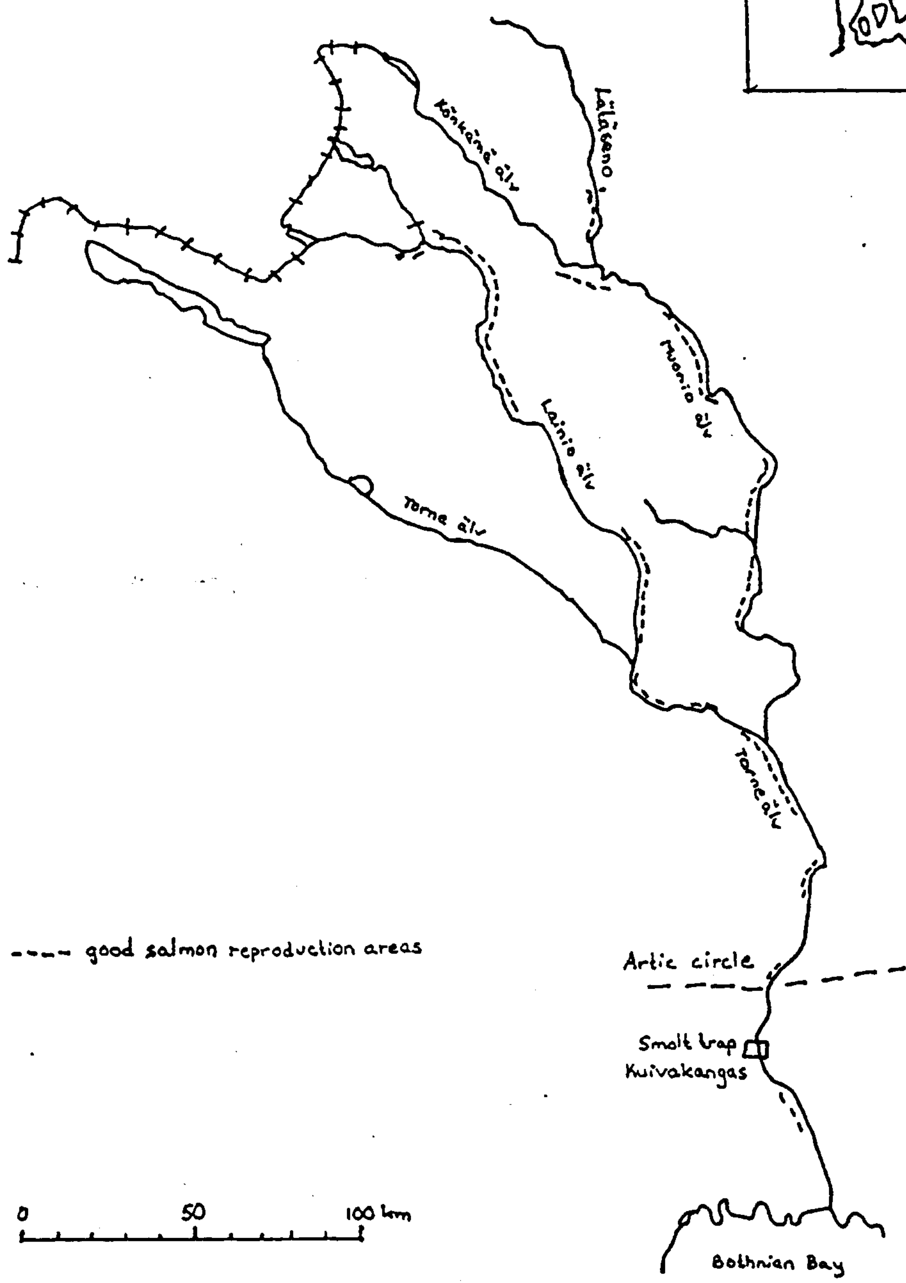


Fig 2. The site and the construction of the fyke-net smolt trap

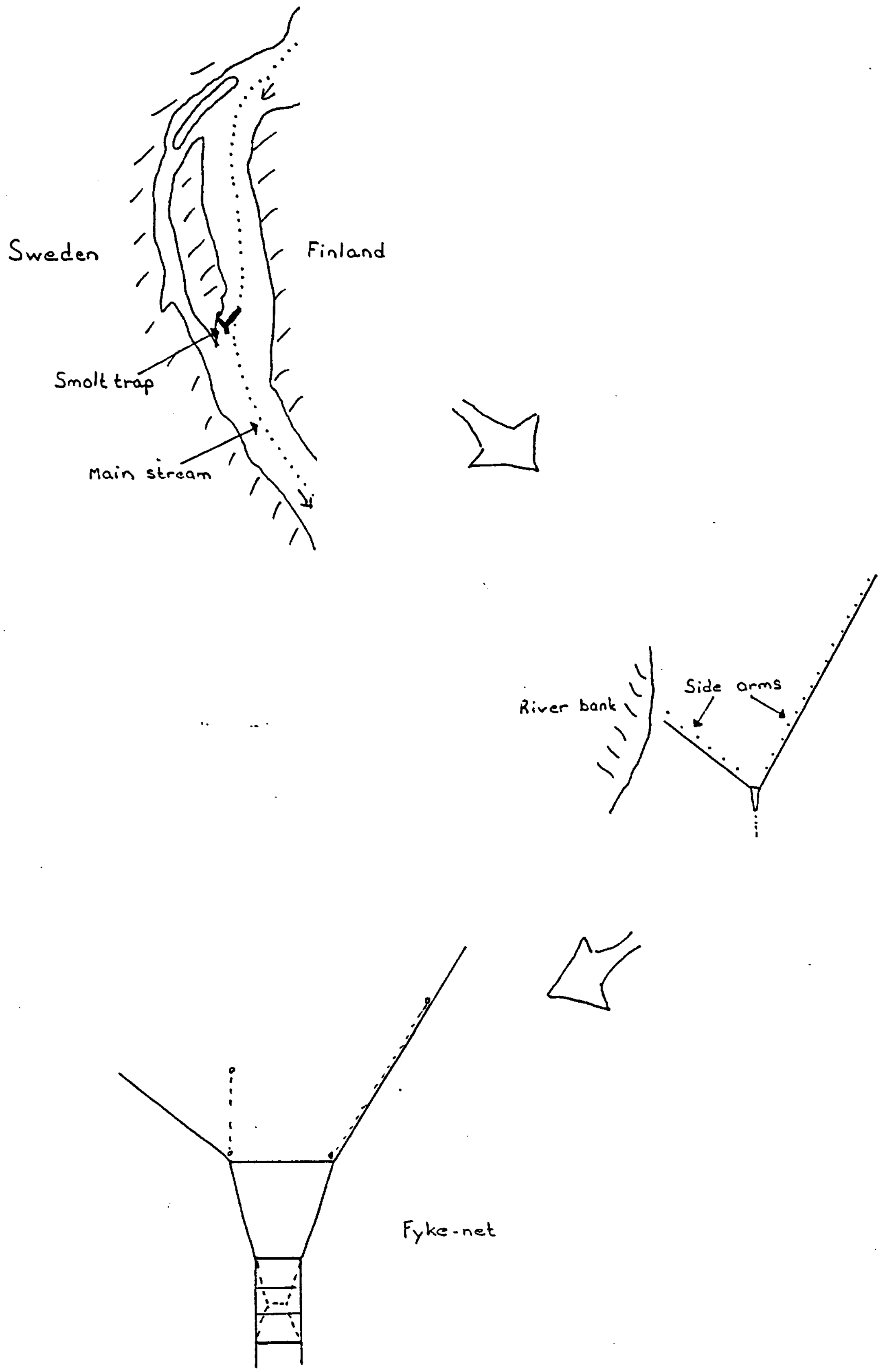
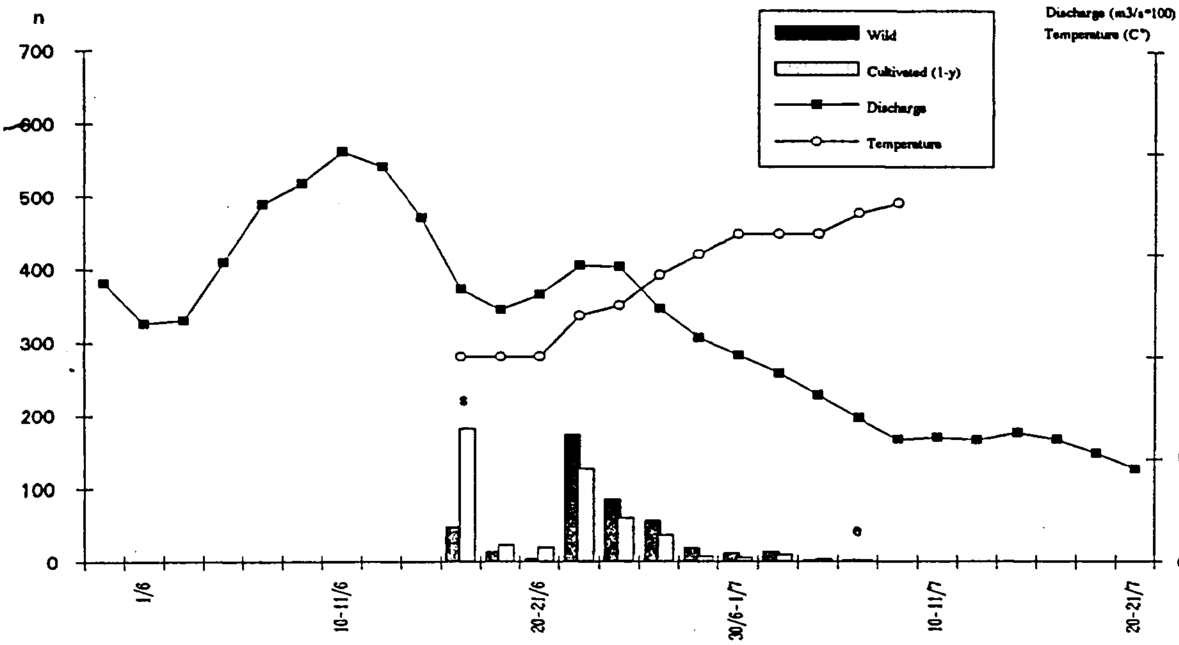


Fig. 3 a-g. Number of trapped wild and reared parr released smolts (cultivated) water discharge and water temperature in twodays periods in the years 1987-1993.
s: first search, e: last search and *: not in function.

(a) 1987



(b) 1988

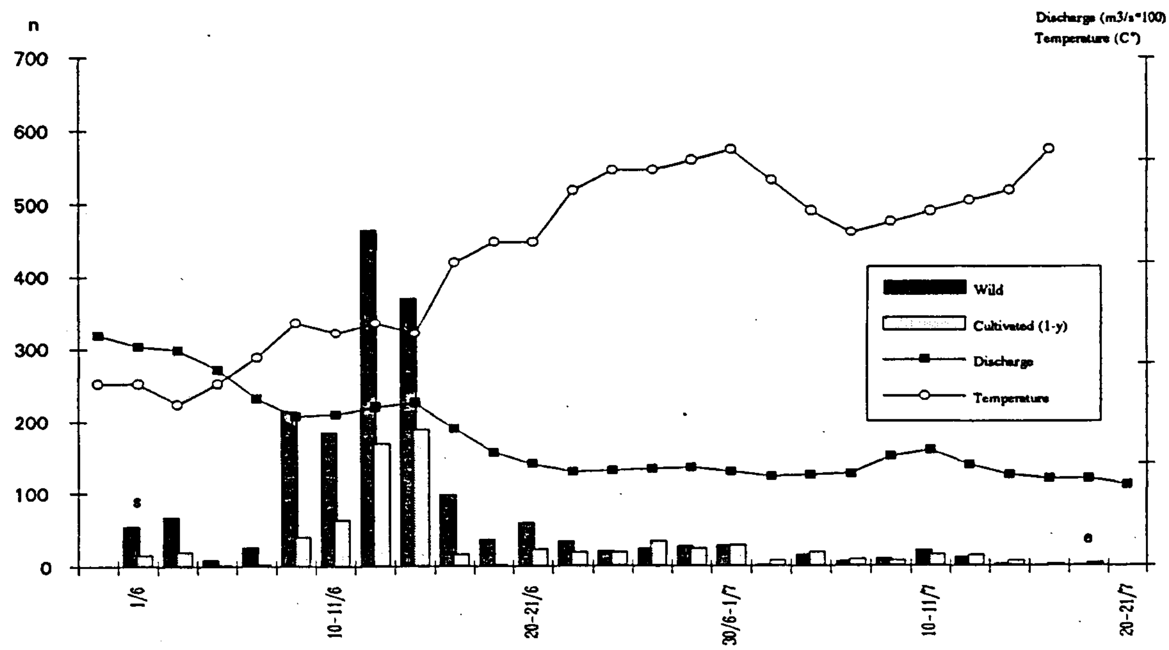
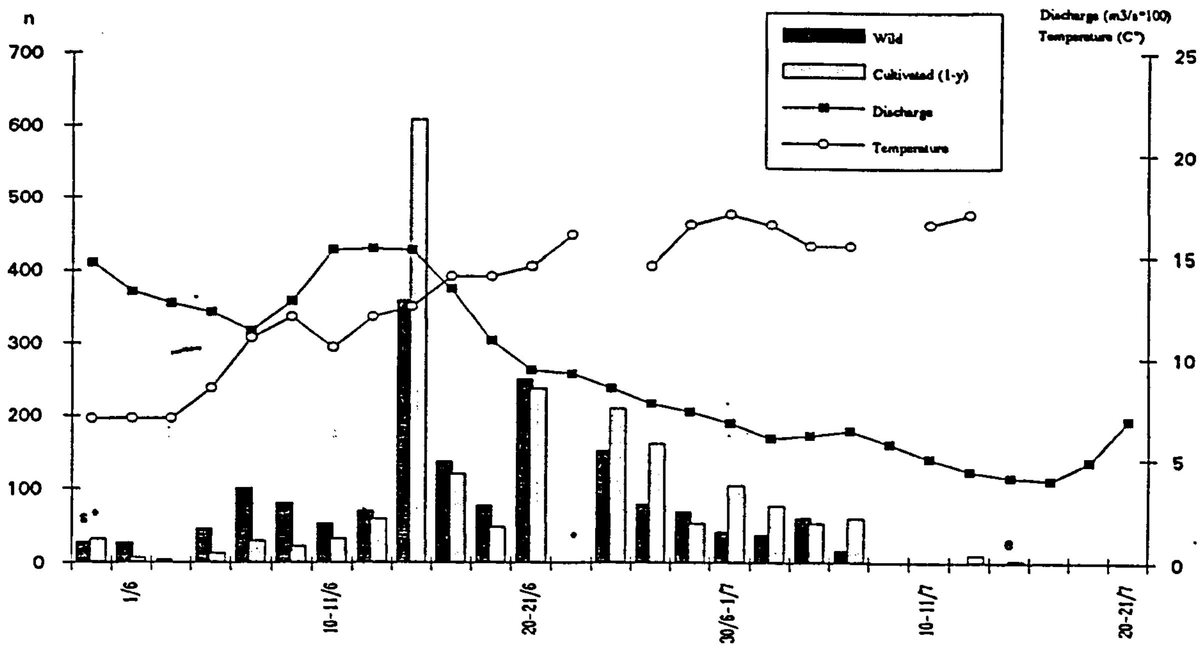


Fig. 3 (c) 1989



(d) 1990

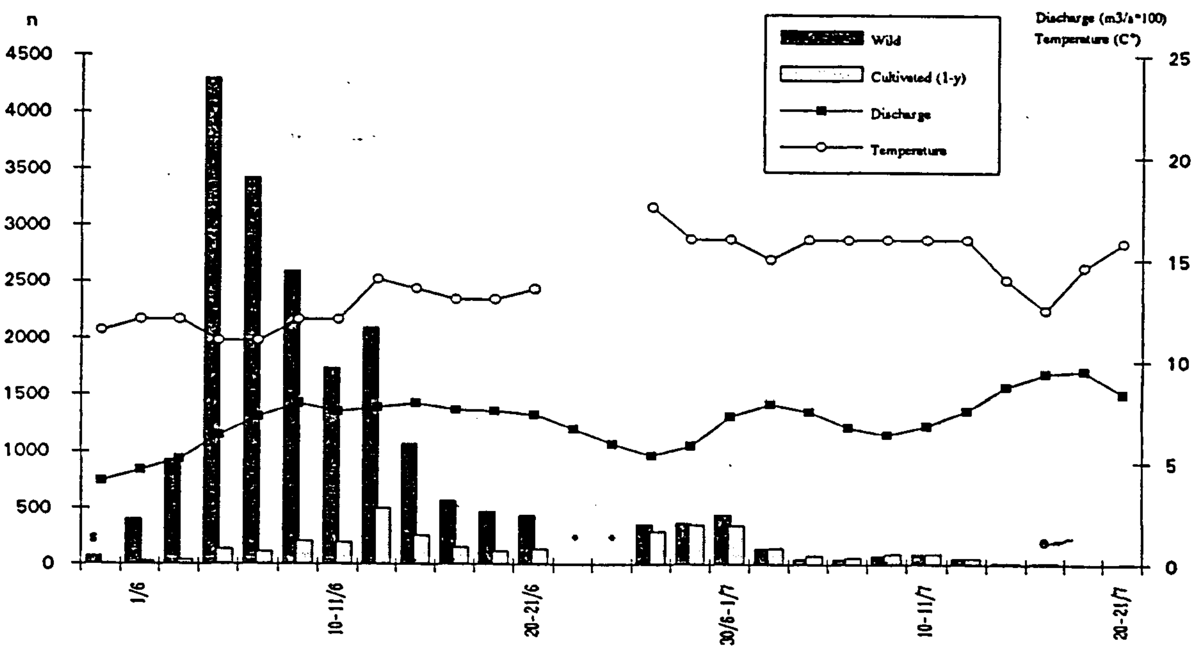
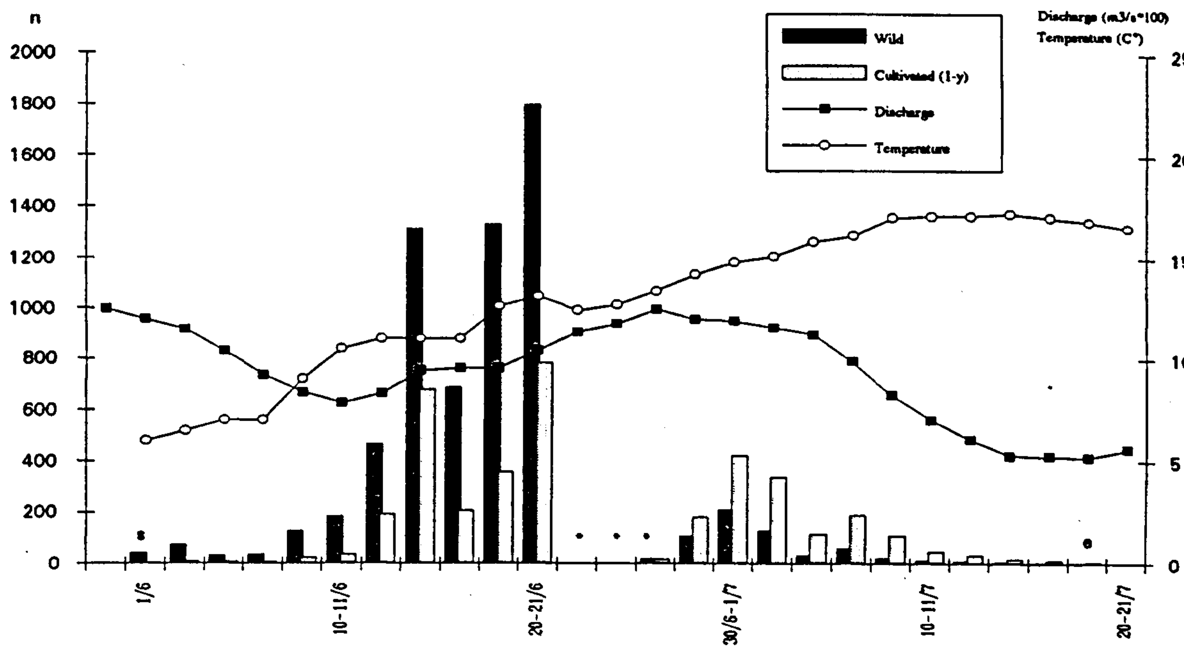


Fig. 3 (e) 1991



(f) 1992

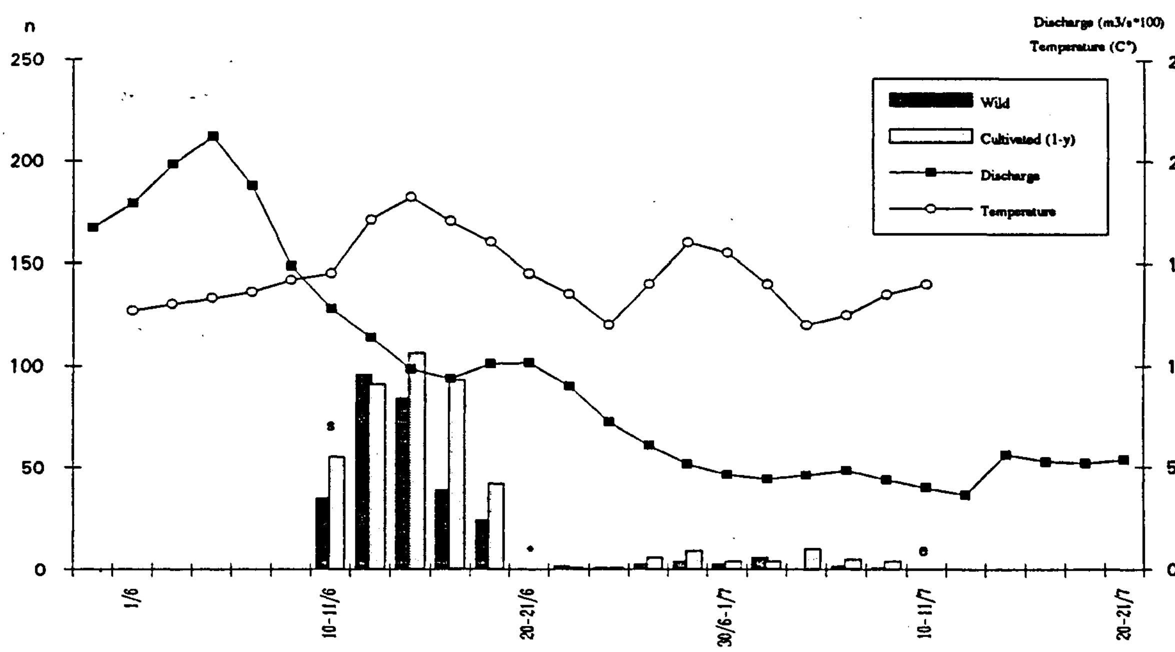


Fig 3 (g) 1993

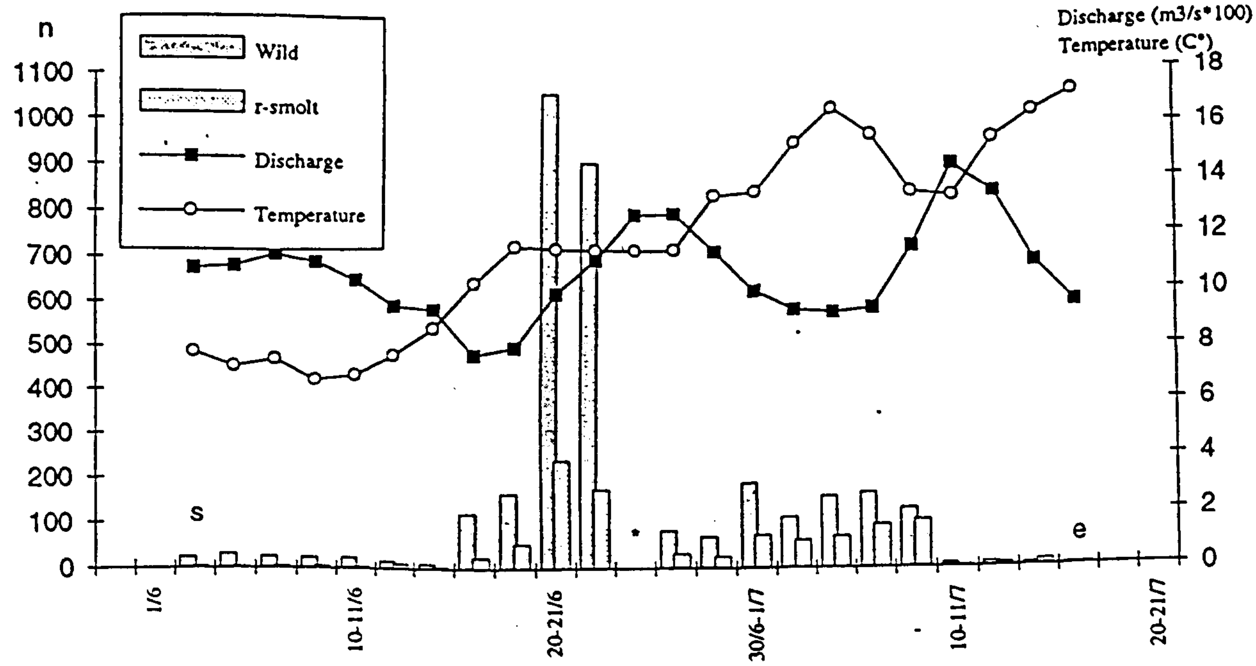

n
Wild
r-smolt
Discharge
Temperature
Discharge (m3/s*100)
Temperature (C°)
1100
1000
900
800
700
600
500
400
300
200
100
0
18
16
14
12
10
8
6
4
2
0
s
e
1/6
10-11/6
20-21/6
30/6-1/7
10-11/7
20-21/7

Figure 4 a. Efficiency (p) of the smolt trap as a function of water discharge (m^3/s) for the year 1989. ln (p) = 0.938 - 0.002 discharge, $r^2 = 0.87$, $p = 0.067$.

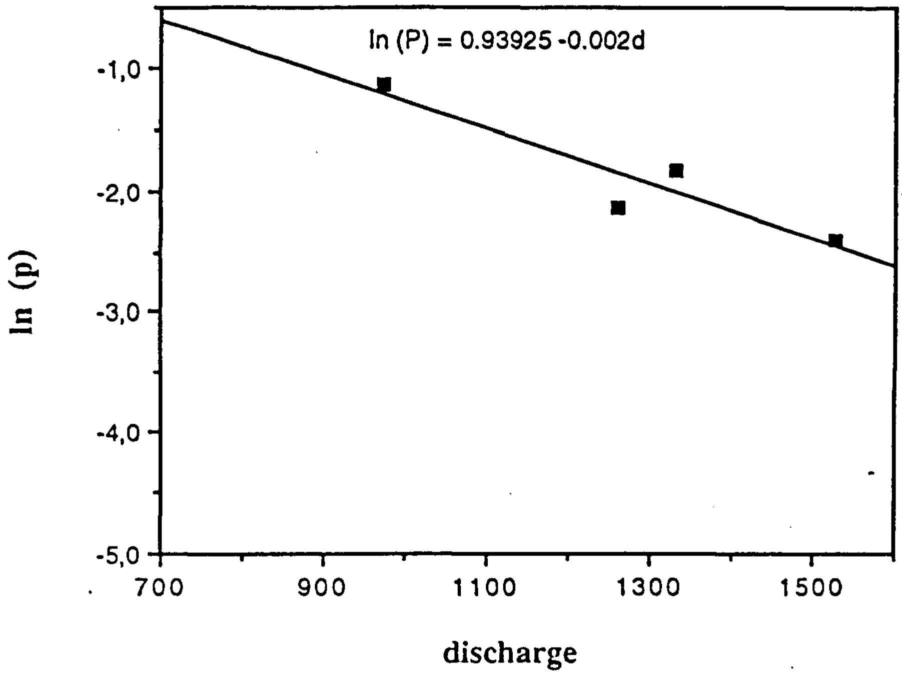


Figure 4 b. Efficiency (p) of the smolt trap as a function of water discharge (m^3/s) for the years 1990-1992. ln (p) = 2.672 - 0.005 discharge, $r^2 = 0.69$, $p = 0.01$.

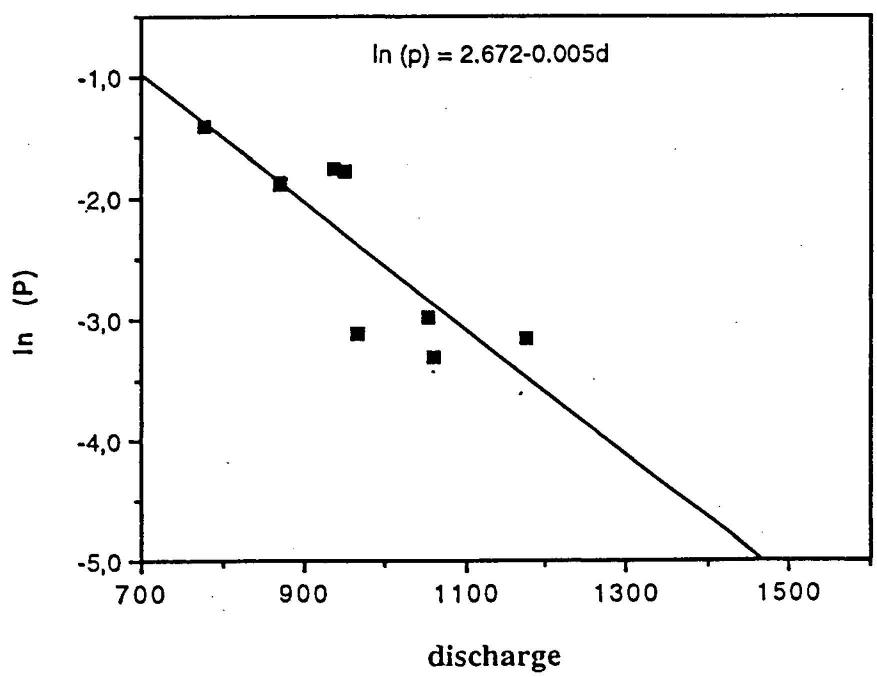


Figure 4 c. Efficiency (p) of the smolt trap as a function of water discharge (m^3/s) for the year 1993. ln (p) = 0.854 - 0.004 discharge, $r^2 = 0.59$, $p = 0.015$.

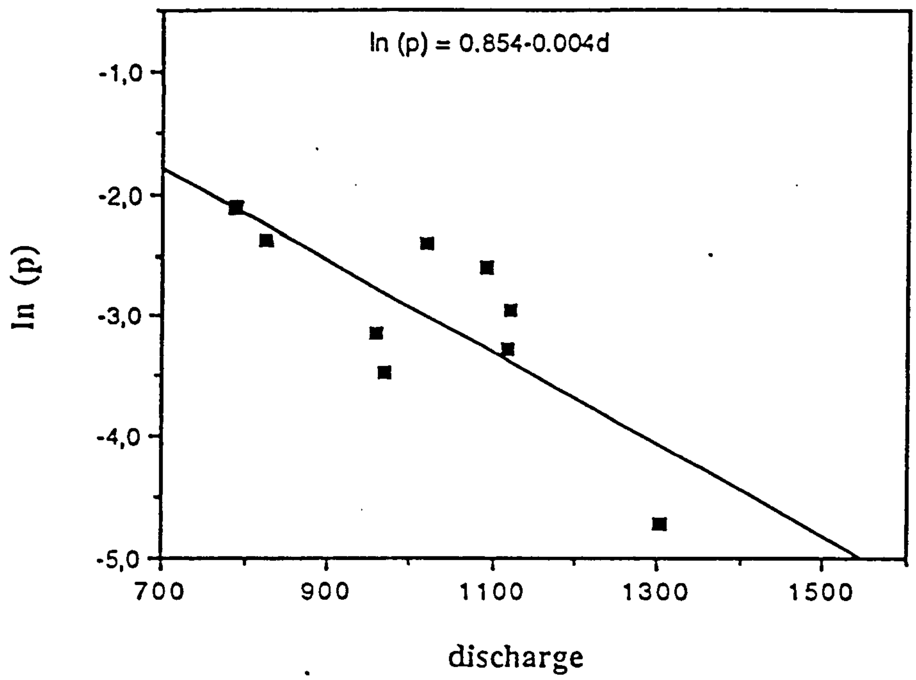


Fig.5 Smolt run in the river Torne älv 1988-93.