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TIMING OF THE BALTIC SALMON RUN IN THE GULF OF BOTHNIA - INFLUENCE OF ENVIRONMENTAL FACTORS ON ANNUAL VARIATION

by

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ABSTRACT

The importance of various factors in determining the timing of the Swedish salmon run in the Gulf of Bothnia was investigated. Salmon spawners arrive at the Gulf of Bothnia from their feeding areas in the Main Basin in May-August. The mean annual SD of catch date of spawners based on tagging data from three river stocks was 16-18 days. Three-year-old salmon were caught about 14 days earlier than two-year-old fish which, in their turn, started 14 days earlier than grilse. In a comparison of two catch series from 1973-92, wild salmon were on average caught 8.1 days earlier than reared fish. The timing of the run of wild salmon from a catch series and that of reared salmon from three rivers showed high positive correlation and annual variation in the mean catch in the range of maximally about 30 days. Run timing in reared stocks was highly correlated with their escapement; $r^2 = 0.68$, $p<0.001$. For each day that the run was delayed, the escapement decreased by about 4%. Similar data for wild stocks were not available. Both reared and wild stocks showed a good correlation ($r^2 = 0.6$-0.8, $p<0.001$) between the timing of their run and surface temperatures in the Main Basin in March and April, whereas the correlation with temperatures in the Gulf of Bothnia was lower.The strong correlation with temperatures in the Main Basin feeding area probably reflect the influence of water temperatures on the rate at which salmon become physiologically prepared for the spawning migration.

To preferentially save wild and older salmon, we suggest that sea water temperatures in the spring be used as the basis for setting the opening date of the coastal fishery in the Gulf of Bothnia. An additional reason for varying opening dates would be to reduce the magnitude of annual fluctuations in escapement due to differences between years in the timing of the run.

INTRODUCTION

The spawning migration of salmon has both genetic and environmental base. Thus, for example, the timing of the spawning migration varies depending on the age, sex and background of the salmon stock (Jonsson et al 1990, Hansen and Jonsson 1991).

In the Baltic, the most important salmon feeding areas are in the Main Basin (Christensen and Larsson 1979). Salmon from stocks originating in Gulf of Bothnia migrate mainly to the Main Basin for feeding (Carlin 1969). Spawners migrate northwards in the Main Basin and enter the Gulf of Bothnia in April-May (Ikonen 1986). According to scale-based surveys wild spawners are, on average, caught a few days earlier than reared salmon in the coastal fishery on spawners of mixed origin (Anon. 1992, Ikonen and Kallio-Nyberg 1993). Swedish data also show that catches outside rivers carrying wild salmon stocks into the northern Gulf of Bothnia occur about 10 days earlier than catches outside rivers carrying reared stocks (Anon. 1993).

Since wild salmon are caught earlier than reared salmon and large salmon are caught earlier than smaller ones, a closed spring fishery would selectively save the most valuable spawning migrators. Regulations of this type are now in force in Sweden for the trapnet fishery in the Gulf of Bothnia. Finland enforced similar regulations during 1986-91 and established them again in 1994. In this study we analysed some data series in an effort to estimate annual and spatial variation in timing of the run. In addition we studied the connection between run timing and run size and between run timing and environmental variables. Our purpose was partly to try to predict run timing in order to find suitable ways of regulating the coastal exploitation. Our ultimate aim is to develop a system in which the fishing season each year can be timed based on the predicted timing of the spawning run in order to maximise escapement.

MATERIAL AND METHODS

Data series and analysis

Tagging data for reared salmon smolts from the Swedish tagging data base were used for a number of purposes. Coastal tag recoveries in the Gulf of Bothnia during 1956-92 were included in the analysis. For series where a catch date was needed, all recoveries with uncertain catch dates were excluded from the anaysis.

Tagging data from the Rivers Lule älv, Ångermanälven and Indalsälven in the Gulf of Bothnia, were utilized to investigate the long-term variation in run timing. Only recoveries from the area around the river mouth were utilized. An annual mean catch date, excluding grilse and weighted based on individual fish weights, was calculated for each river stock. Finally, a single annual arithmetic mean catch date was calculated from the mean catch dates for the three individual stocks. This estimate, here called LÅI-run, was based on annual catches varying from 52 to 719 salmon.

Records of trapnet catches from two sites in the Bothnian Bay were used to compare wild and reared salmon in terms of the timing of their runs. Fishermen had recorded the size of each salmon caught and its capture date as well as the number of gears that they had used throughout the season from 1973 to 1993. One of the two sites representing a fishery based mainly on wild spawners was located at the island of Haparanda Sandskär (HS), outside the River Torne älv. It is situated in the outermost archipelago, about 30 km from the river mouth. The trapnets at Sandskär are assumed to catch wild salmon from the Rivers Torne älv and Kalix älv and some reared spawners homing to the River Kemijoki. Before 1980, most salmon in this area were of wild origin, but large releases of reared smolts in the nearby River Kemijoki have increased the occurrence of reared salmon. Scale-reading surveys indicate that in recent years 40-50% of the catch has been of reared origin (Karlsson unpublished). The other catch series, which represents reared fish, is from Sandgrynnan island (LS), 15 km outside the mouth of river Lule älv. In this area about 80-90% of the salmon are of reared origin and are mainly from the River Lule älv. The median catch date of HS fish was also used for correlations with environmental variables.

To quantify escapement, we utilized records on the numbers of female salmon caught in the traps for broodstock fishery of the reared stocks in the Rivers Lule älv, Ångermanälven and Indalsälven. These traps are situated close to the lowest dam in the river. Normally the traps are operated throughout the season; thus the catch level of this fishery can be used as an index of escapement. A combined index of escapement from the three rivers (LÅI-esc) was used. First, the annual deviation from the mean level of female spawners caught in each river during 1973-92 was calculated. Then a single annual catch level was calculated as an arithmetic mean based on the three series of deviations from the mean for the individual stocks.

Monthly mean sea surface temperatures (SST), used in certain correlations and regression analyses, were obtained from Comprehensive Ocean-Atmospheric Data Set (COADS). This information, issued by the National Center of Atmospheric Research at Boulder, Colorado, USA, covered the period 1946-92. It combines data from many different "in situ" recordings at different sites. The dataset consists of monthly mean SSTs for 2° squares over the Baltic and the data are statistically processed observational measurements (i.e. cells are missing in areas where no observations were made). As a complement we used temperature records from three specific sites. A long series, from 1956 to 1992, was available from the coastal station at Hanö, at the Swedish Mainland in Subdivision 25. A shorter series is based on measurements at 3 m depth made from the ferry on the Trelleborg-Sassnitz route in Subdivision 24, in 1974-1992. A third series, covering the years 1961-1992 was obtained from Bjuröklubb, an exposed coastal station 30 km south of the River Skellefte älv in Subdivision 31.

RESULTS

Run timing as a function of age and distance from home river

Older fish were recovered earlier than young salmon, Table 1. The overall difference between mean catch dates of A.1 fish and A.3 fish was about 30 days. A.2 fish, which made up the largest part of the recoveries, were caught about midway between the grilse and A.3 runs. A.4 salmon were caught at about the same time as A.3 salmon, but in much fewer numbers. The catch of fish along the Finnish coast was, on average, much earlier than the catch along the Swedish coast, probably because spawners, to some extent, follow the Finnish coast on their northward migration from the feeding areas. The differences in catch date among salmon caught at varioius distances from the river along the Swedish coast was surprisingly small, possibly because salmon take different routes to their home river. Some fish enter the coastal area very close to their home river and are immediately caught close to their home river mouth, whereas others roam around more.

Difference in run timing between wild and reared salmon

Considerable variation in run timing among years was found for both the HS and LS catch series (Fig. 1). Median catch dates for the HS-series varied from 12 June in 1990 to 23 July in 1985, a difference of 41 days. The two catch series resembled one another rather closely, although the catch in Haparanda was normally a few days earlier (Fig. 2). The mean difference in the date by which 25% of the catch was taken was 6.6 days, SD=6.2 days, and the difference in the median catch was 8.1 days, SD=7.2 days.

The run timing series based on tagging data (LÅI-run) and the wild salmon catch series (HS) were fairly well correlated in the years 1973-1992, $r=0.74$, $p<0.001$. This indicates, not surprisingly, that the catch series and the tagging series resemble each other in their run timing patterns.

Run timing, escapement and seawater temperature

The escapement index, LÅI-esc, varied considerably over the 20-year period (Fig. 3). Escapement patterns for the three different stocks resembled each other closely, particularly in the later part of the period. LÅI-esc was well correlated with LÅI-run, the index of run timing from the same rivers, for 1973-92 (Fig. 4). The relation between them, with escapement as dependent variable can be described by the equation:

LÅI-esc = 7.62 - 0.034 x LÅI-run

($r^2=0.67$, $p<0.001$). This relation suggests that escapement increased by about 4% for each day of advance in run timing. Thus, when the salmon run was early, escapement was high and when the run was late, escapement was low.

SSTs from the coastal station at Bjuröklubb in the Gulf of Bothnia in May and June, when spawners enter the Gulf of Bothnia, were not significantly correlated with run timing (Table 2). Surprisingly, these SSTs were not even significantly correlated to the area-based data from COADS in the Gulf of Bothnia for the same months. All other SSTs showed significant, but varying, degrees of correlation with each other. Both SSTs from COADS in the Gulf of Bothnia and the Main Basin were significantly correlated to run timing. The correlations were lower with SSTs from the Gulf of Bothnia than with SSTs from the Main Basin. Correlations for the full series from 1956-92 were not as high as those based on the partial series (1974-92), suggesting that the fit was poorer in the earlier period. For the 1974-92 period, the Main Basin data were well correlated to run timing, showing correlation coefficients of about 0.8 for February to April. An even slightly higher correlation was found for SSTs measured from the ferry offshore in the Main Basin. In this case the correlations increased gradually from January to April and then decreased in May and June. The April temperature graph and the LÅI-run series were included in Figure 5a, and a scatterplot is shown in Fig. 5b. The linear regression was as follows:

(Mean catch julian day) = 212 - 4.6 x (Water temperature in April)

($r^2=0.769$, $p<0.001$). There are no obvious outliers in the data set, indicating that sea water temperature is a good predictor of run timing. Maximum and minimum of run timing values differed by 27 days. Within each year most of the catch takes place within a short period. The mean annual SD of catch date calculated based on tagging data from the river stocks was 16.0, 16.6 and 18.2 days for the Lule älv, Ångermanälven and Indalsälven, respectively. If the catch is normally distributed, then 68.2 % of the entire catch would be taken within mean ± SD or 32, 33 and 36 days respectively.

Influence of run timing on the geographical location of the fishery on spawners
To determine whether run timing can influence the location of the fishery on spawners we analysed Swedish tagging data from the Gulf of Bothnia once again. Tag recoveries of spawners in the Gulf of Bothnia were sorted by catch year and areal breakdown: Finnish coast, Swedish coast far from the home rivers, close to the river mouth, in the river, Fig. 6. From 1956 to 1992 the proportion of spawners caught in the rivers tended to decrease, while the proportion caught in the river mouth remained rather constant. By contrast, the proportion caught along the Swedish and Finnish coast increased during this period. None of the four different proportions was significantly correlated with LÅI-run, even when year of catch was included as a covariate. An annual index of the following type was developed:

0*(Percent catch in river) + 1*(Percent catch in river mouth)+2*(Percent catch along Swedish coast) + 3*(Percent catch along Finnish coast)

An analysis of index values shows that over time the index values increased. There was only a trivial correlation between the index and LÅI-run, regardless of whether year of catch was included as covariate.

DISCUSSION

Our results indicate that run timing varies greatly with both age and origin (wild or reared). That the timing of migration in salmon varies with age is wellknown in the Baltic (Carlin 1969, Kallio-Nyberg and Ikonen 1992) and in the North Atlantic area (Jonsson et al. 1990). The wild and reared salmon from two sites in the northern Gulf of Bothnia showed a rather constant difference in arrival to the fishing sites, with the wild salmon normally being 5-10 days earlier. This result agrees with findings from earlier investigations based on scale reading surveys of spawners migrating along the Finnish coast (Ikonen and Kallio-Nyberg 1993). Similarly, wild salmon were, on average, caught a few days earlier than reared fish in the mouth of the River Ume, which has both reared and wild salmon stocks (Andersson 1988).

There was no evidence that the exploitation pattern in the Gulf of Bothnia varied geographically in response to run timing. In all cases the catches in the river mouth and in the river itself dominated. It should be noted, however, that because exploitation is gradually decreasing in rivers and increasing in coastal areas far from rivers, it might be difficult to observe any superimposed variation due to run timing.

There was a clear connection between run timing and escapement - i.e. escapement tended to be low in years with late runs and vice versa. We have not determined the degree to which the variation in escapement levels was explained by differences in age at maturity, survival of smolt year classes and annual exploitation rates. Age at maturity is often related to growth (Alm 1959, Gardner 1976) and growth in salmon is partly determined by winter temperatures. If the winter temperature is low, salmon grow slower (Christensen and Larsson 1979). Saunders (1983) reported evidence supporting a critical first seawinter temperature minima as a determinant of maturation of salmon. Connections between winter severity and age at maturity were also found in Icelandic salmon stocks (Scarnecchia *et al.* 1989). Their findings are partly in accordance with the correlation between run timing and spring temperatures and run timing and escapement found in the present study. A high spring temperature could induce a higher number of maturing salmon. On the other hand, the large annual variation in run timing and rather small standard deviation suggest that the level of coastal fishery exploitation could differ greatly between years with early and years with late runs.

Run timing showed a high correlation with SSTs in the feeding area in the Main Basin, and a moderate correlation with SSTs in the Gulf of Bothnia, which the spawners normally enter first during their spawning migration. The gradual increase in the degree of correlation from January to the peak in March-April suggests that the water temperature in the Main Basin may regulate the rate at which the physiological changes required for migration occur. The spawning migration starts in April-May and the water temperature immediately before the migration may be expected to be most influential in determining the exact timing of the departure from the Main Basin.

Since water temperatures in March-April were well correlated with run timing, they might be used as the basis for setting the opening date for the coastal fisheries each year in order to preferentially save wild and old salmon. Moreover, the annual variation in escapement would be lowered compared to if there are closures in the coastal fishery in the spring with a fixed opening date. One simple manner of implementing this scheme would be to shift the opening date by 14-20 days forward or backward, depending on whether the water temperature in the Main Basin in April is below or above 4.0 °C. The decision could be announced to fishermen in early May, more than one month before the earliest start of the fishery in the south of Finland. Thus, there would be sufficient time for them to be able to prepare for the fishery in a relaxed mannner.

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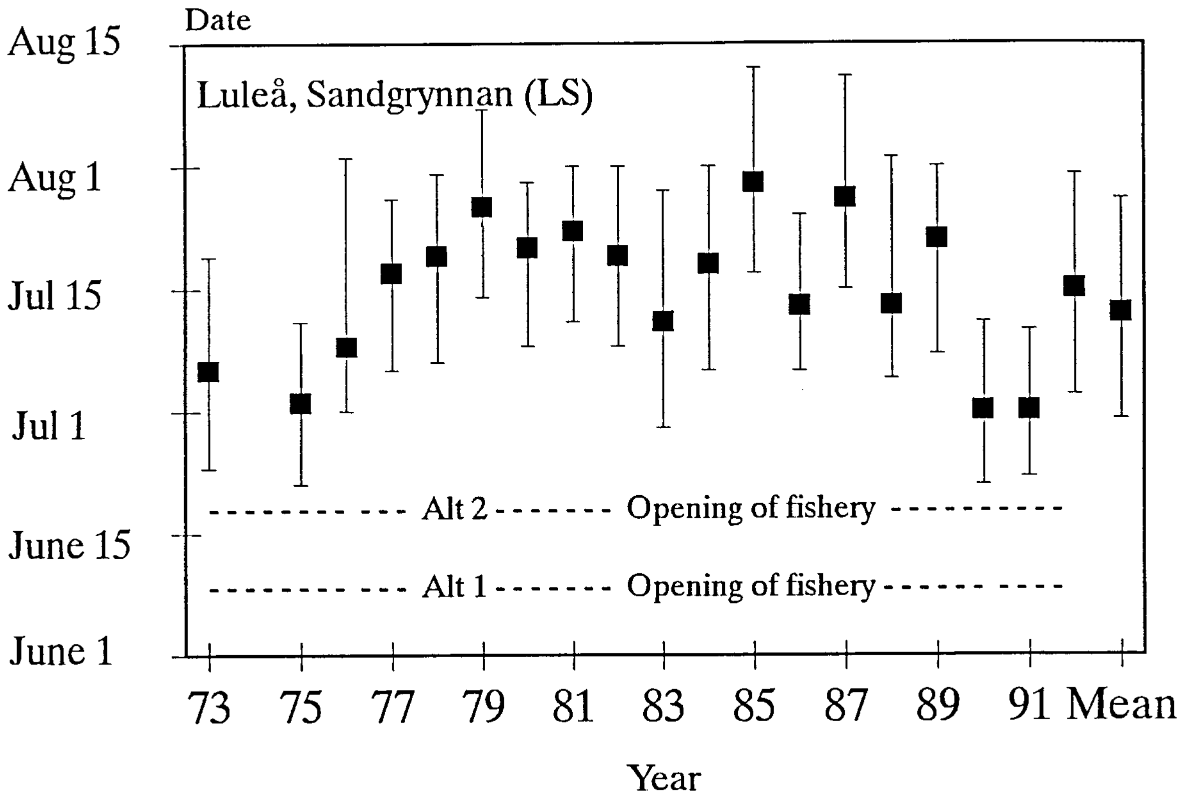
Table 1. Mean day of the coastal catch of tagged reared salmon spawners, smolt year classes 1975-91, from seven swedish rivers in the Gulf of Bothnia. The area north and south of the river mouth covers a variable distance depending on local situations.

Place	Age	N	Julian mean day of catch	SD	Age	N	Julian mean day of catch	SD
Finnish coast	1	158	188	44	2	368	167	43
Swedish coast	1	499	219	24	2	944	195	23
North-south river mouth	1	1371	221	19	2	2552	201	19
River mouth	1	301	221	20	2	595	199	22
In river	1	1047	232	18	2	781	213	26
Place	Age	N	Julian mean day of catch	SD	Age	N	Julian mean day of catch	S D
Finnish coast	3	66	155	33	4	6	162	35
Swedish coast	3	331	182	22	4	33	191	33
North-south river mouth	3	722	187	18	4	86	190	19
River mouth	3	169	187	22	4	20	199	26
In river	3	266	200	27	4	28	203	36

Table 2. Correlation between monthly SSTs measured at three different sites or area-based SSTs in the Baltic and Julian mean day of coastal catch in two data series, LÅI-run and HS, in the Gulf of Bothnia. The upper value is the correlation coefficient, the lower value shows the number of data points (years). Significance levels are as follows: p>0.05,no symbol;0.05≥p>0.01,* ;0.01≥p>0.001,**;0.001≥p,***. Shaded cells indicate correlation coefficients >0.80.

Temperature measurements	Series	Temperature measurements in:									
		Jan	Feb	Mar	Apr	May	Jun	Jul	Feb-Apr	Mar-May	Apr-May
Bjuröklubb, coast, Gulf of Bothnia, 1956-92	LÅI-run				ice cover	-0.16 30	-0.18 33				
	HS				ice cover	0.02 17	-0.18 18				
Area-based SST, Gulf of Bothnia, 1956-92	LÅI-run				-0.47 28*	-0.22 35	-0.17 36	0.01 36			
	HS				-0.56 19*	-0.62 19**	-0.26 19	-0.07 19			
Area-based SST, Gulf of Bothnia, 1974-92	LÅI-run				-0.74 19***	-0.71 19***	-0.28 19	-0.12 19			
	HS				-0.55 18*	-0.61 18**	-0.26 18	-0.02 18			
Area-based SST, Main Basin, 1956-92	LÅI-run	-0.63 36***	-0.64 36***	-0.61 36***	-0.62 36***	-0.59 36***	-0.32 36				
	HS	-0.59 19**	-0.60 19**	-0.61 19**	-0.68 19**	-0.48 19*	-0.27 19				
Area-based SST, Main Basin, 1974-92	LÅI-run	-0.76 19***	-0.81 19***	-0.83 19***	-0.78 19***	-0.71 19***	-0.33 19				
	HS	-0.59 18**	-0.60 18**	-0.62 18**	-0.69 18**	-0.48 18*	-0.26 18				
Hanö, coast, Main Basin, 1956-92	LÅI-run	-0.62 36***	-0.65 36***	-0.57 36***	-0.57 36***	-0.70 36***	-0.28 36				
	HS	-0.51 19*	-0.52 19*	-0.62 19**	-0.67 19**	-0.62 19**	-0.20 19				
Ferry, offshore, Main Basin, 1974-92	LÅI-run	-0.68 19**	-0.77 19***	-0.83 19***	-0.88 19***	-0.71 19***	-0.46 19*		-0.85 19***	-0.87 19***	-0.85 19***
	HS	-0.44 18	-0.47 18*	-0.58 18*	-0.67 18**	-0.59 18**	-0.16 18		-0.59 18**	-0.66 18**	-0.68 18**

Figure 1. Annual run timing in two coastal catch series. The bars show when 25, 50 and 75 % of the catch (in weight) was recorded. Two suggested opening dates for the fishery are shown. a. Outside River Lule älv, mainly reared salmon. b. Outside River Torne älv, mainly wild salmon.



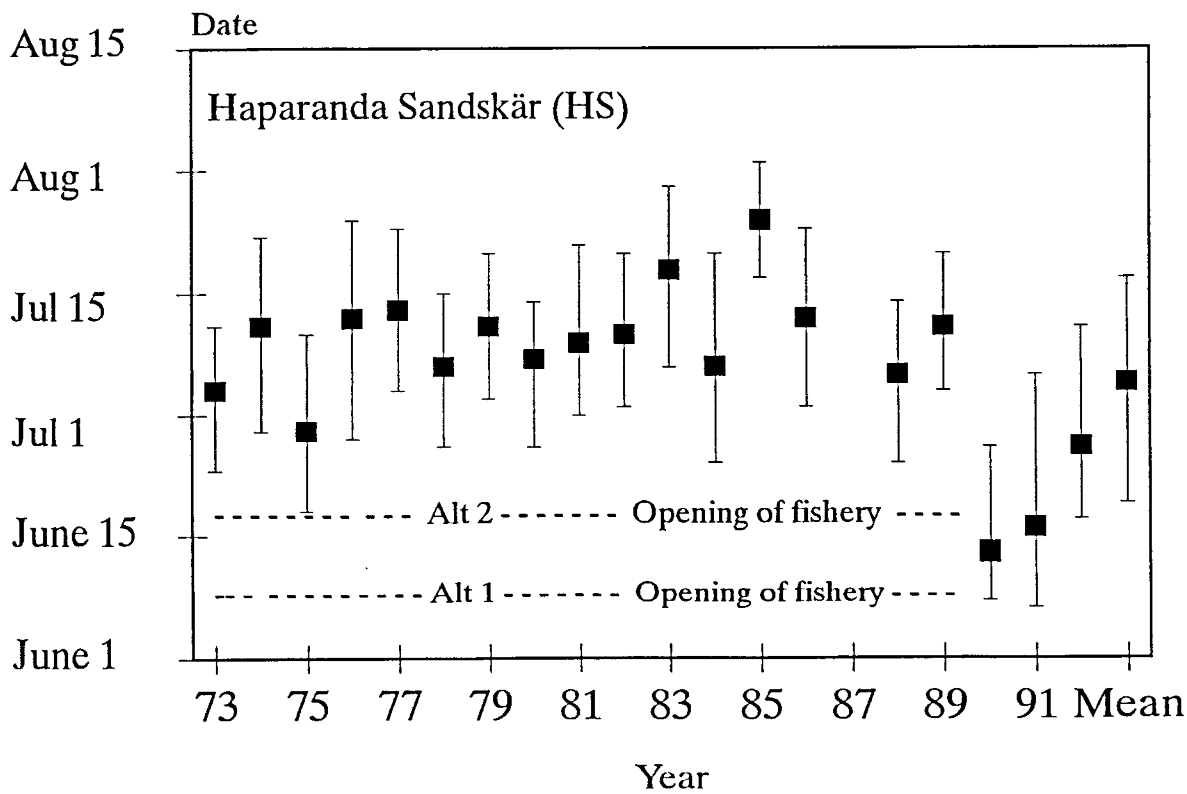


Figure 2. Annual difference in run timing in days between HS and LS, see Fig. 1. Q1= 25% of catch. Med= 50 % of catch.

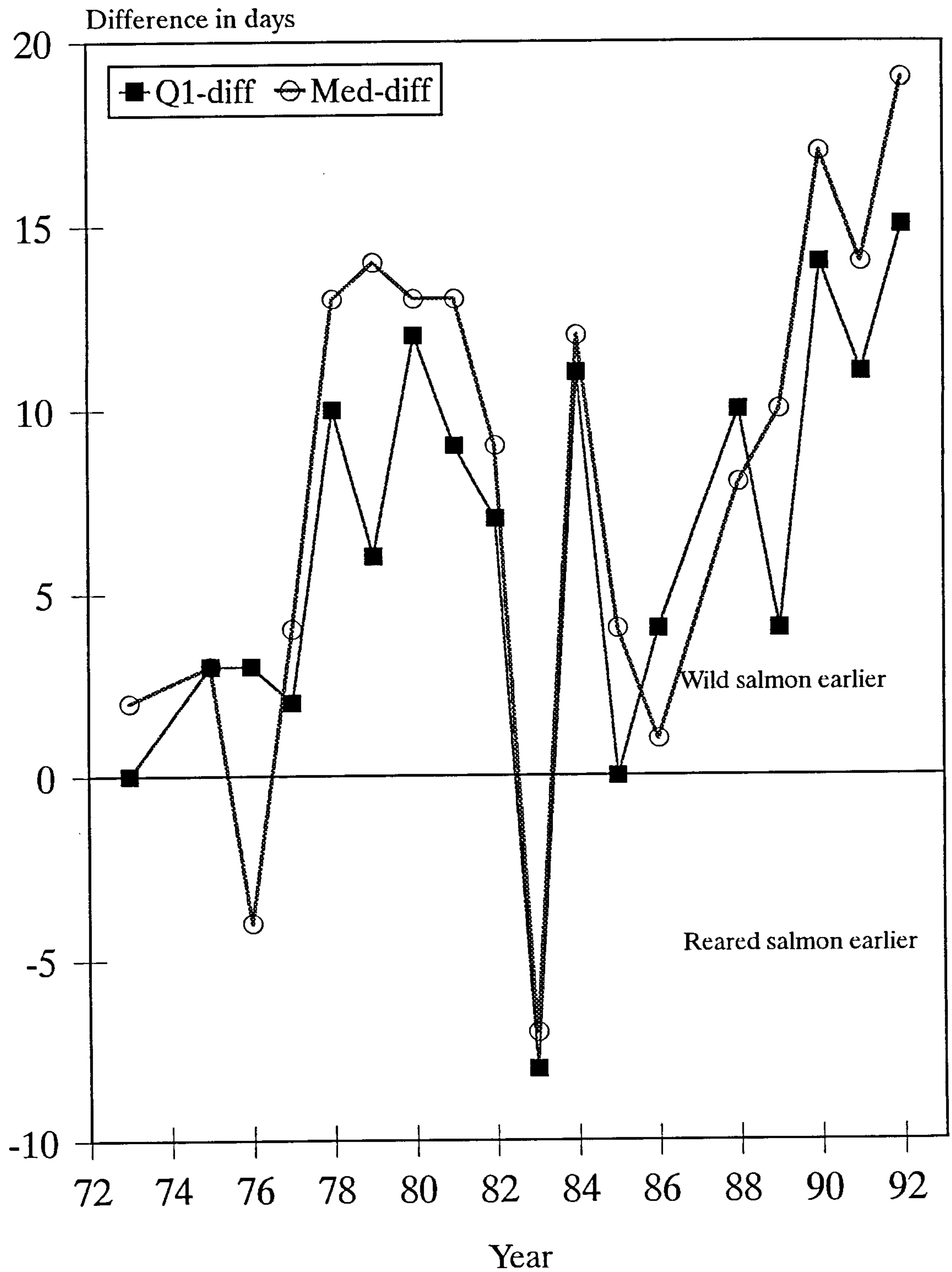


Figure 3. Catch of female salmon in broodstock traps in three rivers in the Gulf of Bothnia and an escapement index, LÅI-esc, based on these catches.

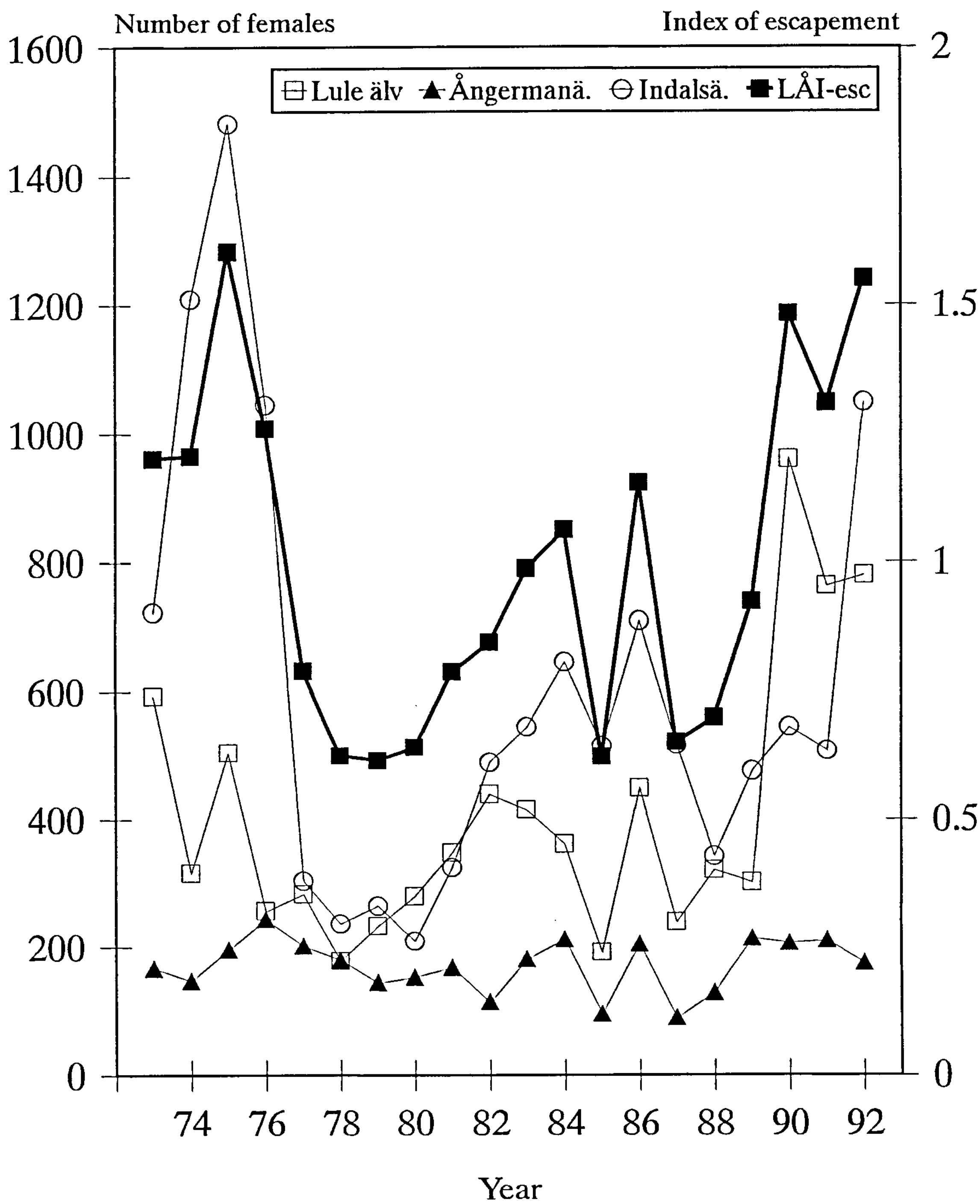


Figure 4. Scatter plot relating the annual timing of the run (LÅI-run) to the escapement index (LÅI-esc), 1973-92. The line shows the linear regression.

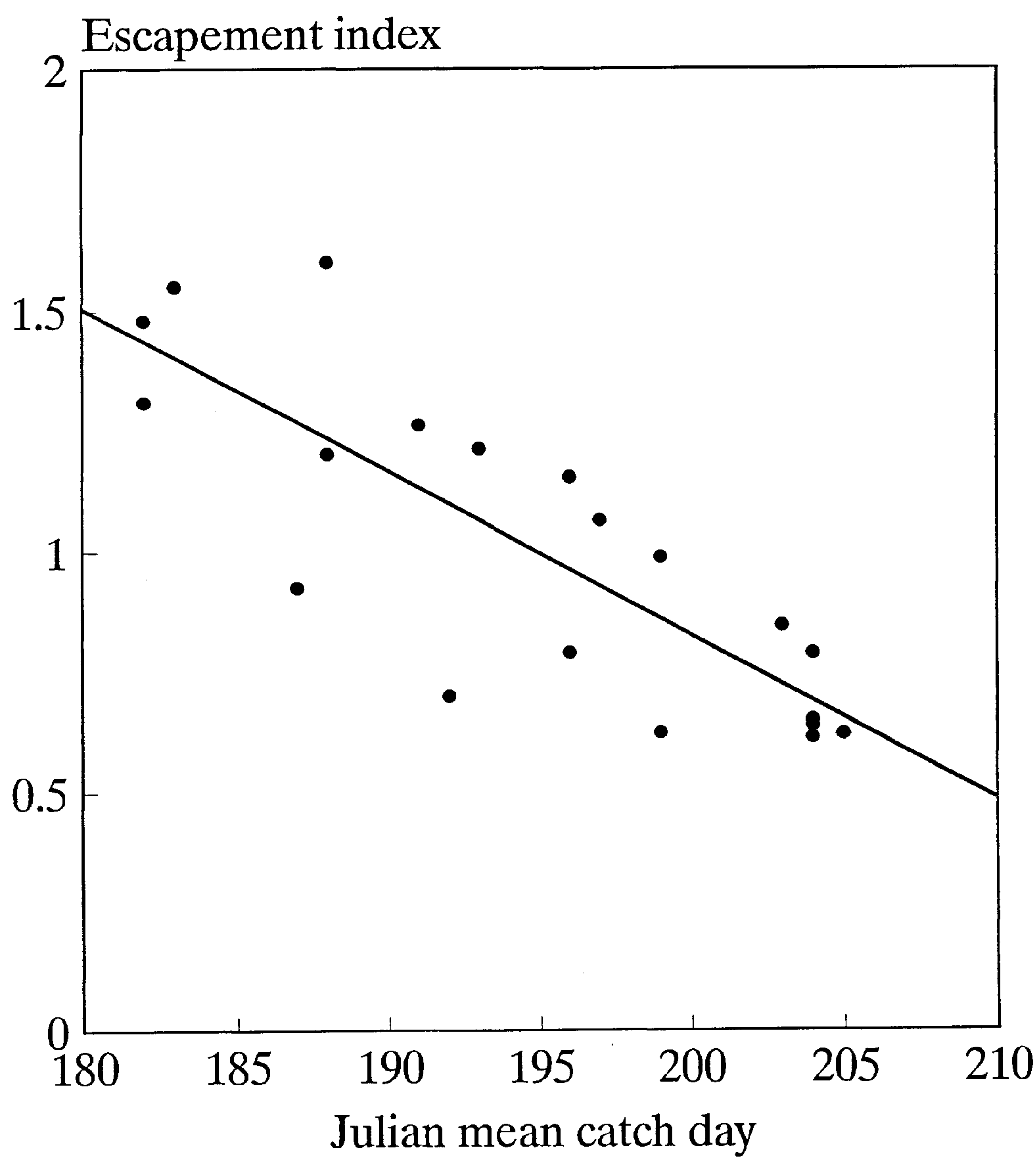


Figure 5a. Mean annual coastal catch date (LÅI-run) for 1957-92. The bars show mean April seawater temperature along the Trelleborg-Sassnitz ferry route from 1974 to 1992.

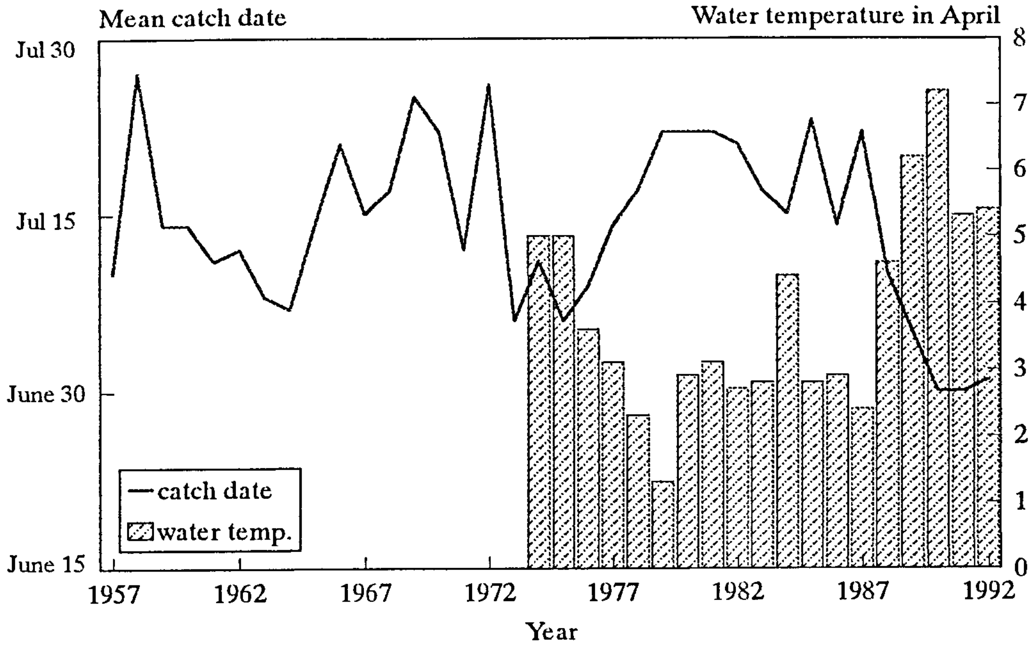


Figure 5b. Scatter plot relating annual April seawater temperatures to mean catch date. The line shows the linear regression.

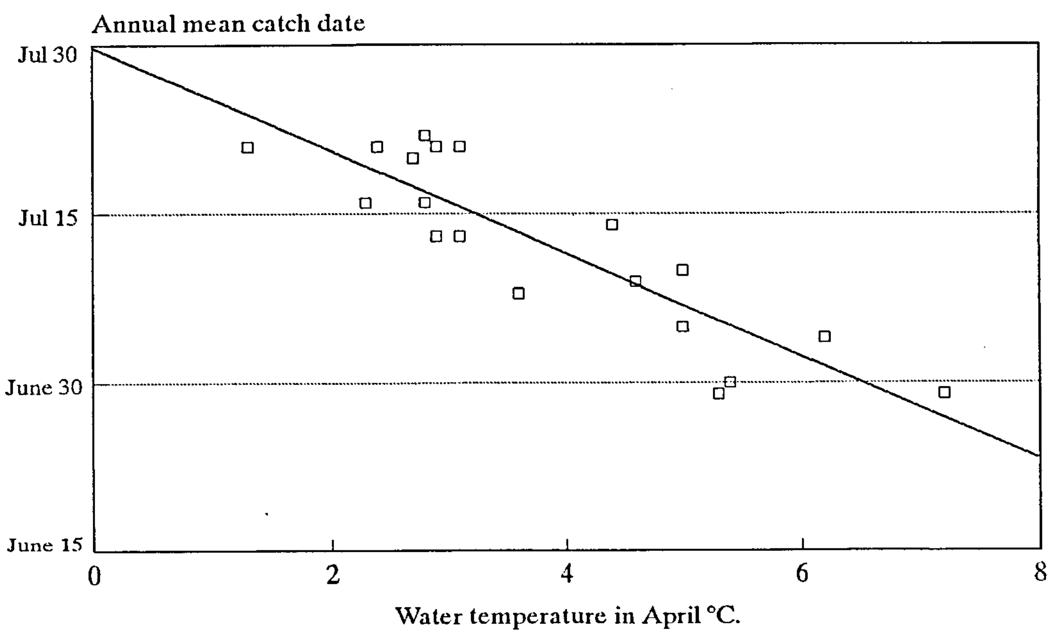


Figure 6. Annual variation in the geographic distribution of the catch of tagged spawners in the Gulf of Bothnia during 1956-92.