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Analysis of Atlantic salmon (*Salmo salar*) smolt condition and marine survival; information from two south coast Newfoundland rivers

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[1]La présente série documente les bases scientifiques des évaluations des ressources halieutiques sur la côte atlantique du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

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Abstract

Data from two Atlantic salmon stocks were analysed to examine the influence of smolt condition on subsequent survival to one-sea-winter (1SW) salmon. Survival declined over time at both Northeast Brook, Trepassey, and Conne River, Newfoundland. Condition of smolts varied among years. Timing of the smolt runs appeared to be linked with spring temperatures with late runs generally associated with colder springs. Lower condition was also associated with colder springs and late runs. Years in which sea survival was low were more often associated with years where smolt condition was also low. Results are discussed in relation to the complex physiological processes involved with the timing of the smoltification process.

Résumé

On a analysé des données portant sur deux stocks de saumon de l'Atlantique pour déterminer l'influence de la condition des saumoneaux (smolts) sur la survie subséquente des saumons unibermarins. La survie diminuait avec le temps dans les ruisseaux Northeast et Trepassey ainsi que dans la rivière Conne (Terre-Neuve). La condition des saumoneaux variait selon l'année. La période à laquelle avait lieu les remontées de saumoneaux semblaient dépendre des températures printanières, les remontées tardives étant généralement associées à un printemps plus froid. Une détérioration de la condition des saumoneaux était également associée aux printemps plus froids et aux remontées tardives. Les années de faible survie en mer correspondaient souvent aux années où la condition des saumoneaux était également en baisse. On expose ici les résultats obtenus, en prenant en considération les processus physiologiques complexes associés à la smoltification.

Introduction

Over the past eight years (1984-92), Atlantic salmon (Salmo salar) stocks in eastern Canada have been subjected to various management strategies in an attempt to rebuild depressed stocks. The 1984 Atlantic Salmon Management Plan involved season changes in the commercial fishery and catch restrictions in the recreational fishery, as well as reductions in the numbers of commercial fishermen and amount of licenced commercial gear (O'Connell et al. 1992). In 1990, quotas were introduced for the first time in the Newfoundland commercial salmon fishery. This was followed by further quota reductions in 1991 and a complete moratorium on the commercial fishery for insular Newfoundland in 1992. With commercial landings averaging about 900 $t \bullet y^{-1}$ for the period 1984-89, and a 1992 commercial harvest of only 152 t (O'Connell et al. 1993), this represents an overall reduction in commercial landings by over 80% since the 1984-89 period.

In conjunction with the commercial salmon moratorium, a moratorium was also placed on the northern cod fishery affecting Salmon Fishing Areas (SFAs) 1-9 beginning in early July of 1992. This measure should have eliminated any by-catch of salmon in cod fishing gear.

One expected impact of the above management measures was an increase in survival of salmon returning to rivers to spawn. For some rivers, this has not been the case. Returns of salmon to some rivers in 1992 and 1993 were either similar to, or lower than returns recorded in premoratorium years (Dempson and O'Connell 1993; O'Connell et. al. 1994). This is contrary to what was expected given the extreme reductions in fishing mortality that have occurred. With the effective termination of virtually all legal sources of marine exploitation on salmon, decreased returns may be a result of increased natural mortality on some stocks.

Complex physiological processes are involved in the smolting of salmon (Hoar 1976; Wedemeyer et al. 1980; Sigholt and Finstad 1990). These processes act to synchronize the timing of seaward smolt runs to a 'window' whereby conditions at sea are suitable for survival and growth (Power 1981; Power et al. 1987; Hansen and Jonsson 1989; Staurnes et al. 1993). This paper provides a summary of smolt to 1SW survival rates for two south coast Newfoundland rivers. We also examine temporal variation in smolt run timing and condition in relation to local freshwater environmental factors and how this may have subsequently influenced the observed patterns of smolt survival.

Methods

Counts of smolts and returning adult salmon are available for Northeast Brook, Trepassey (SFA 9) (46°46'N; 53°21'W) since 1986 and 1984, respectively. Counts of returning adult salmon and surveys of outward migrating smolts from Conne River (SFA 11) (47°54'N; 55°41'W) are available since 1986 and 1987, respectively (Dempson and Stansbury 1991; Dempson 1992). Northeast Brook is a third order river with a basin area of 21.2 km^2 while Conne River is a sixth order river with a drainage area of 602 km^2. Numbers of returning small salmon at Northeast Brook have ranged from 49 to 158 ($\overline{x}$ = 92, 1984-93) and at Conne River from 2411 to 10155 ($\overline{x}$ = 5508, 1986-93). At both locations, biological characteristic data (length, weight, age, sex) are collected on smolts throughout the run. Returning adult salmon are sampled at Conne River. At Northeast Brook, biological samples of adult fish are obtained from sampling kelts in the following spring.

Analyses of smolt 'condition' were carried out following the general methods of Patterson (1992) and Cone (1989, 1990) and are fully described by Winters and Wheeler (1994). A general linear model was used to examine the response of fish weight, standardized to a common length, to various factors as:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + b \bullet Z_{ijk} + \epsilon_{ijk}$$

where,

Y_{ijk} is the response variable, smolt weight,
α_i and β_j are class variables year and river, respectively,
$(\alpha\beta)_{ij}$ is the interaction term,
Z_{ijk} is the covariate fork length, and
ϵ_{ijk} is the error term associated with individual observations.

The model was used to calculate adjusted mean smolt weights by year and river standardized to the covariate. Analyses were done using SAS General Linear Models procedures (SAS Institute Inc., North Carolina). Analyses followed the sequential procedure described by Winters et al. (1993) and Winters and Wheeler (1994). Initially, analyses were used to determine the appropriate model, i.e., common slope (b) or multiple slope (b_{ij}), for comparisons of form within a stock (river) and then between the two stocks. Intercept differences (μ) were tested based on class variable effects if a common slope model was appropriate. Interaction effects were examined and the final model used to calculate adjusted mean smolt weights standardized to mean length to account for class-variable effects. Weight and length variables were transformed to natural logarithms. Sample size and range in sampling dates are provided in Table 1. Sampling generally occurred over the duration of the smolt run.

Indices of environmental conditions associated with each river were obtained from Environment Canada, Atmospheric and Environment Service. Data were compiled separately for the Bay d'Espoir (Conne River) area and the southern Avalon peninsula area at St. Shotts (Northeast Brook), for the period April-June, 1986-93 (1987 for Conne River). Mean monthly temperatures for January, February and March in each year for each location were below 0 °C. Consequently, temperatures for April and May only were used in examining the association of air temperature with smolt condition and smolt migration timing. This is the period of time immediately prior to and at the beginning of the smolt runs. The temperature index was calculated as the mean temperature from April 1 - May 15 and generally coincided with the overall 25th percentile of the smolt run at each river.

Results

Sea survival

For both Northeast Brook, Trepassey ($r = -0.709$, $P = 0.075$) and Conne River ($r = -0.933$, $P = 0.007$) sea survival has decreased over time (Fig. 1), with the lowest values recorded in 1991 (year of smolt migration), the first year in which one-sea-winter (1SW) adult salmon returns coincided with the commercial salmon and northern cod moratoria. Although data are limited, the two rivers do show some correspondence. Survival declined from 1986-87 to 1988-89, followed by the lowest value in 1991 and then a small increase in 1992. The smolt run at Conne River has been relatively stable with a coefficient of variation (CV) of 12% ($\bar{x} = 67080$, 1987-93). Similarly, the CV for the smolt run at Northeast Brook, Trepassesy, was 16% ($\bar{x} = 1653$, 1986-93). The numbers of returning 1SW salmon have declined although smolt production, for the most part, has generally been maintained.

Smolt condition

The analysis of the weight-length relationship for Conne River indicated that slopes were not significant implying no year effect on slopes. At Northeast Brook, slopes were significant although a comparison with the common slope model indicated that the reduction in the residual (error) mean square was negligible (< 2%). In a combined analysis with class variable river included in the model, slopes again were not significant thus a common slope model was adequate to examine comparisons of condition across river and year class variables. In the common slope model, the main effects, river and year, were both significant as was the interaction between river and year (Table 2). Adjusted mean smolt weight (condition) was kept separate for each river - year comparison. Smolt condition was lowest at Conne River in 1990-92 and in 1990-91 for Northeast Brook (Fig. 2). At both rivers, condition increased in 1993 over the previous year. The highest condition values were in 1988-89 at Conne River and 1987 and 1993 at Northeast Brook.

Smolt run timing and environmental conditions

Smolt run timing varied at both rivers (Fig. 3). Median date has differed by up to 14 days at Conne River with dates progressively later in recent years. At Northeast Brook, the median date has differed by as much as 26 days with considerably more variation in the run timing in comparison with Conne River (Fig. 3).

At both rivers, there was a rather consistent decline in the temperature index since 1986 (1987 for Conne River) (Fig. 4). Colder spring temperatures appear to have contributed to a delayed smolt run (median date) at Conne River in comparison with earlier years when spring temperatures were warmer (Fig. 5). At Northeast Brook, two of the earlier smolt run years coincided with warmer springs. In cooler or colder years, run timing was about two weeks later but also more variable (Fig. 5). In 1992, the median date was not unusually late, but the run slowed down considerably with the 75th percentile of the run occurring after the middle of June (Fig. 3). In contrast, the 1993 smolt migration left the river over a short period of time (Fig. 3).

Smolt condition and environmental conditions

Warmer spring temperatures were associated with higher smolt condition values at both rivers (Fig. 6). In colder years, smolt condition was generally lower although at Northeast Brook this was not consistently so. In 1993, for example, a higher smolt condition was estimated in a year where temperatures were intermediate (Fig. 6).

As established above primarily for Conne River, smolt run timing was generally associated with spring temperature conditions (Fig. 5) and to a degree, so was smolt condition (Fig. 6). It follows then that condition of smolts would also display some correspondence with run time. For both rivers, condition was lower during the years when the median date of smolt run was later (Fig. 7).

Sea survival and smolt condition

Although data are limited, there is some suggestion that marine survival may have been partly associated with the condition of smolts migrating to sea (Fig. 8). Years in which smolt condition was low resulted in a low sea survival at Conne River (Fig. 8). Higher survival occurred in years when condition was typically better. At Northeast Brook, the lowest sea survival also coincided with lowest smolt condition, while high survival occurred at both moderate and high values of condition (Fig. 8). However, there was more variability associated with sea survival at intermediate smolt condition at Northeast Brook.

Figure 9 illustrates the standardized smolt condition and sea survival for both rivers. It is noted that had this 'relationship' ($r^2 = 0.32$, $P = 0.044$) been used in establishing an appropriate value for sea survival over the 1992-93 period, then the forecast of 1SW salmon returning to Conne River would have been closer to the estimated total number of fish that did return. While a forecast was not provided at Northeast Brook, had one been developed based on the above relationship, then the number of returning adults would have matched the forecast remarkably well.

Based on calculated condition of smolts migrating in 1993, the 'relationship' suggests survivals of 5.25 ± 1.23% for Northeast Brook, and 6.68 ± 1.61% for Conne River.

Discussion

A summary of the main results in this study indicates the following:

- sea survival has declined at both Northeast Brook and Conne River over time;
- condition of smolts varied among years, and has been the lowest during the early 1990's;
- an index of freshwater environmental conditions during the spring when smolts were initiating their migration has shown a rather consistent decline to colder temperatures over the past 7-8 years;
- timing of the smolt run appeared to some degree to be linked with spring temperatures, with late runs normally during colder springs;
- lower smolt condition was associated with colder springs and late runs;
- years in which sea survival was low were more often associated with years where smolt condition was also low.

Reasons for the decline in survival, particularly for salmon returning as 1SW fish in 1992 when both a salmon and cod fishery moratorium was in place, are not entirely clear. It has been reported that marine environmental conditions in the spring and early summer of 1991 were among the most severe on record (Baird et al. 1992; Drinkwater 1992; Narayanan et al. 1992). For surface waters (0 - 30 m), at least, this appears to be the case. One possibility is that smolt survival may have been directly or indirectly related to the conditions experienced during the early period at sea. Direct effects could include encountering lethal water temperatures, for example. Indirect impacts could include a synergistic effect of water temperature and salinity tolerance, or a delayed production cycle affecting the feeding opportunities of smolts. In either case, the 'condition' of smolts migrating to sea could be important.

Low sea water temperature has been cited as a factor influencing survival of Atlantic salmon. Sigholt and Finstad (1990) found that in cultured Norwegian salmon, low temperature contributed to osmoregulatory failure and poor survival of smolts transferred from freshwater to sea water. Mortality was most pronounced at temperatures below 6°C. Lega et al. (1992) also found that low sea temperatures affect water balance in salmon resulting in a decrease in body moisture content and an increase in plasma osmolarity. The most dramatic changes occurred at temperatures below 4°C (Lega et al. 1992). Other studies have reported that low temperature or rapid change in salinity alone may not impact on survival; however, when these factors interact, decreased survival in Atlantic salmon and rainbow trout (Oncorhynchus mykiss) occurs (Byrne et al. 1972; Finstad et al. 1988; Bakke et al. 1991). Lethal freezing temperatures for Atlantic salmon, in the presence of ice, are known to be about -0.76°C (Fletcher et al. 1988). At temperatures above this, some studies have now shown cold water, in general, can also contribute to reduced survival.

There is a suite of complex physiological processes which are involved in the smoltification of salmon (Hoar 1976; Wedemeyer et al. 1980; Bjornsson et al. 1989; Sigholt and Finstad 1990). Among other factors, smolts are reported to experience a decrease in condition prior to smoltification along with a reduction in total body lipid content with the latter believed to reflect metabolic changes accompanying smolting (Wedemeyer et al. 1980). Bjornsson et al. (1989), in a study of the influence of growth hormone on the smoltification process, concluded that growth hormone by itself is not the primary stimulus associated with a decrease in the condition of smolts. Rather, there is probably a combined influence of growth and thyroid hormones which act on various physiological processes to affect smolt condition (Bjornsson et al. 1989). It was also concluded that temperature is an important environmental cue that can influence growth hormone levels. Changing environmental cues alter the various physiological processes resulting in an incomplete parr-smolt transformation (Bjornsson et al. 1989).

Staurnes et al. (1993) reported higher survival rates for hatchery salmon released during specific time periods in the spring when smolts experienced their highest seawater tolerance. No connection, however, was established between smolt condition and subsequent survival although both condition of smolts and survival decreased over time throughout the spring. Their results were in agreement with Virtanen et al. (1991) who found that physiological criteria are more appropriate than morphological criteria in evaluating smolt quality and subsequent success or survival at sea. Similarly, condition factor was not found to be related to adult survival in anadromous cutthroat trout, Oncorhynchus clarki (Tipping and Blankenship 1993). In the latter two studies, cultured fish rather than wild fish were used. Results from the above studies are in contrast with those of the present study and thus lend caution to extrapolating current results, based on limited data, to forecasts of subsequent adult returns based on smolt condition. However, other studies have demonstrated an association between smolt size (length or weight) and sea survival. High mortality at sea was associated with smaller smolt size in both steelhead trout (Oncorhynchus mykiss) (Ward and Slaney 1988) and in brown trout (Salmo trutta) (Elliott 1993).

Results observed to date at Conne River and Northeast Brook, Trepassey, would not necessarily imply similar patterns could be expected in other Newfoundland stocks. Differences in timing of smolt migrations, variable climatic conditions and stock specific relationships between temperature or salinity tolerance could all contribute to varying results in different geographic regions. The results, however, may not be just coincidence and additional information from these and other rivers may be instructive in understanding more about possible freshwater factors influencing marine survival.

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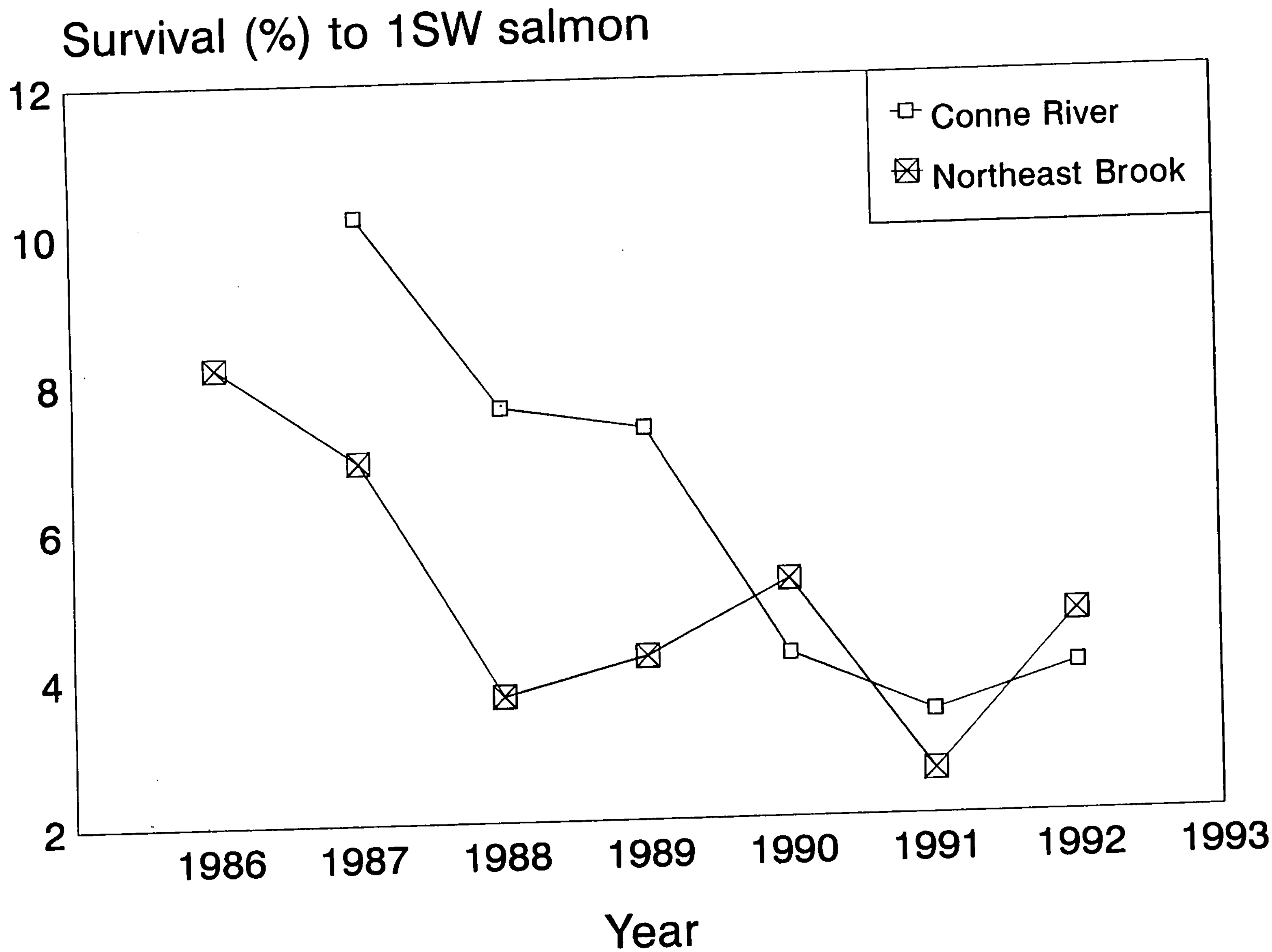
Table 1. Number of specimens and range in sampling dates for Atlantic salmon smolts included in analyses of smolt condition.

	Northeast Brook		Conne River	
Year	N	Sampling date range	N	Sampling date range
1986	55	May 19 - June 18		
1987	71	May 9 - June 15	272	May 1 - June 28
1988	63	May 4 - June 1	333	May 4 - June 4
1989	60	May 13 - June 3	332	May 11 - June 2
1990	60	May 14 - June 6	271	May 11 - June 11
1991	62	May 8 - May 26	248	May 11 - June 11
1992	66	May 5 - June 17	169	May 16 - June 9
1993	60	May 18 - May 23	248	May 16 - June 2

Table 2. Results of analyses of the common slope GLM weight-length regression model for Northeast Brook, Trepassey, Conne River, and the combined analysis with main effects of class variables river and year in the model. Asterisk denotes significance at P < 0.01.

River	Slope	Intercept	r^2	Source of variation	DF	Type III SS	F	P
Conne	2.74**	-10.30**	0.94	Log-length	1	209.01	26535.01	0.0
				Year	6	1.97	41.62	0.0
Northeast Brook	2.63**	-9.79**	0.92	Log-length	1	30.98	5471.30	0.0
				Year	7	0.26	6.59	0.0001
Combined	2.73**	-10.28**	0.93	Log-length	1	239.14	32223.81	0.0
				River	1	1.84	248.50	0.00
				Year	7	0.76	14.65	0.0001
				River*Year	6	0.35	7.79	0.0001



Year is year of smolt migration

Figure 1. Estimates of sea survival from smolt to returning 1SW salmon at Conne River, SFA 11, and Northeast Brook, Trepassey, SFA 9, Newfoundland.

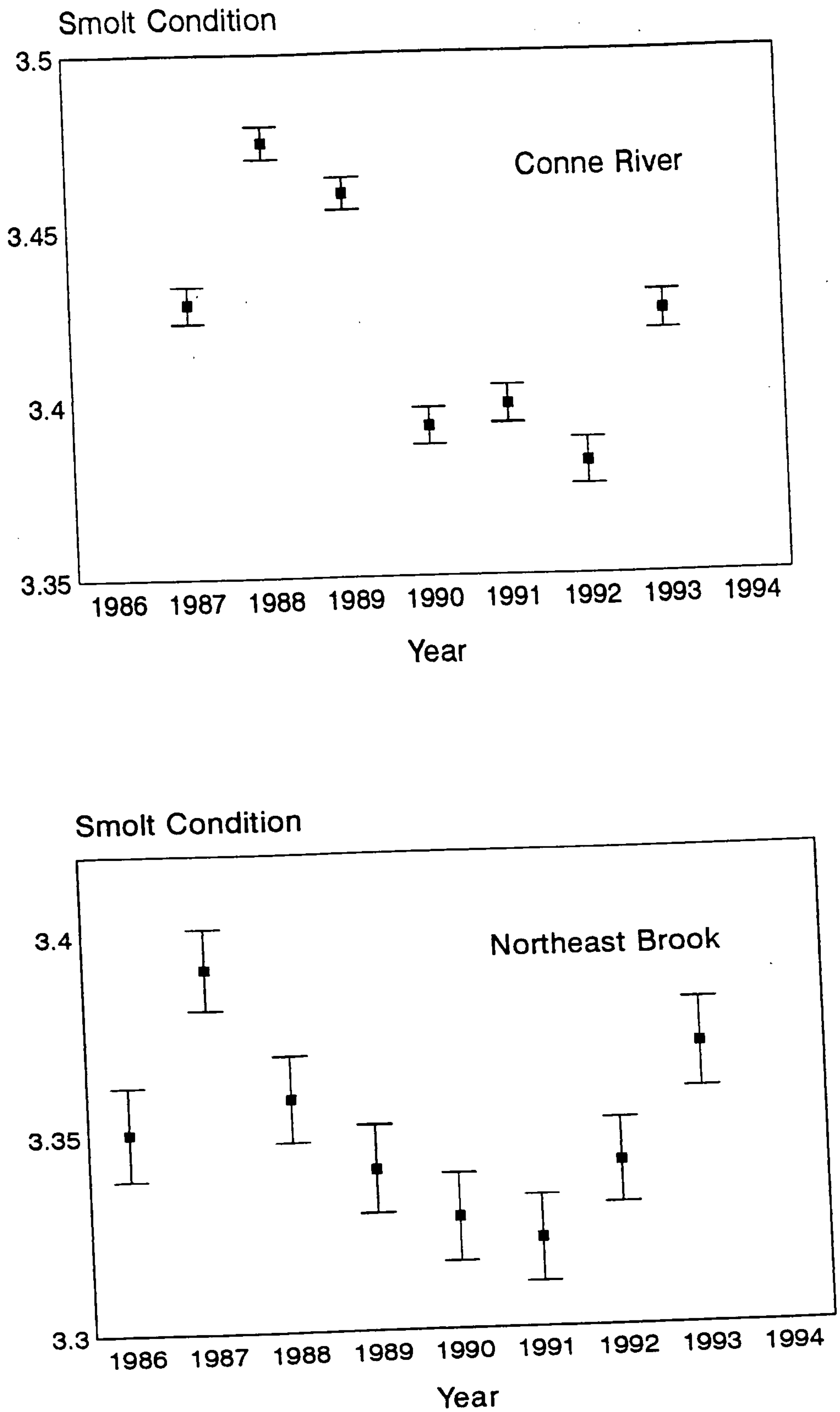
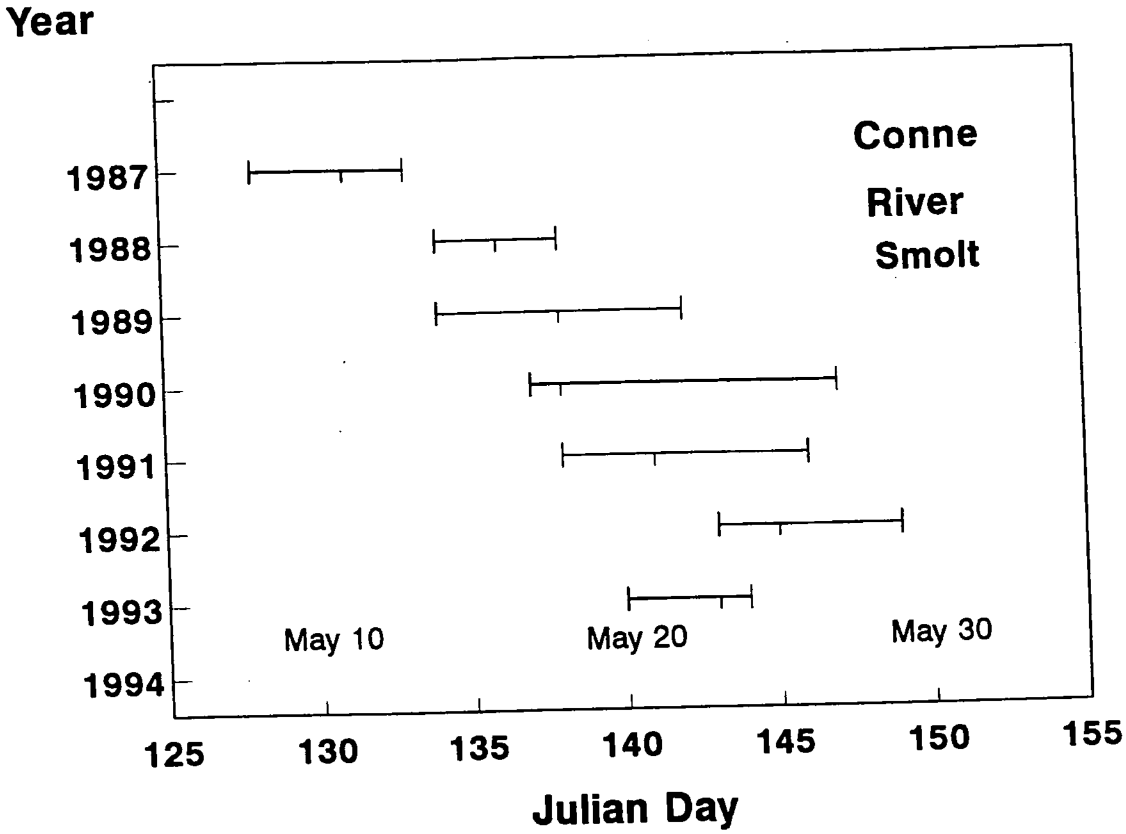
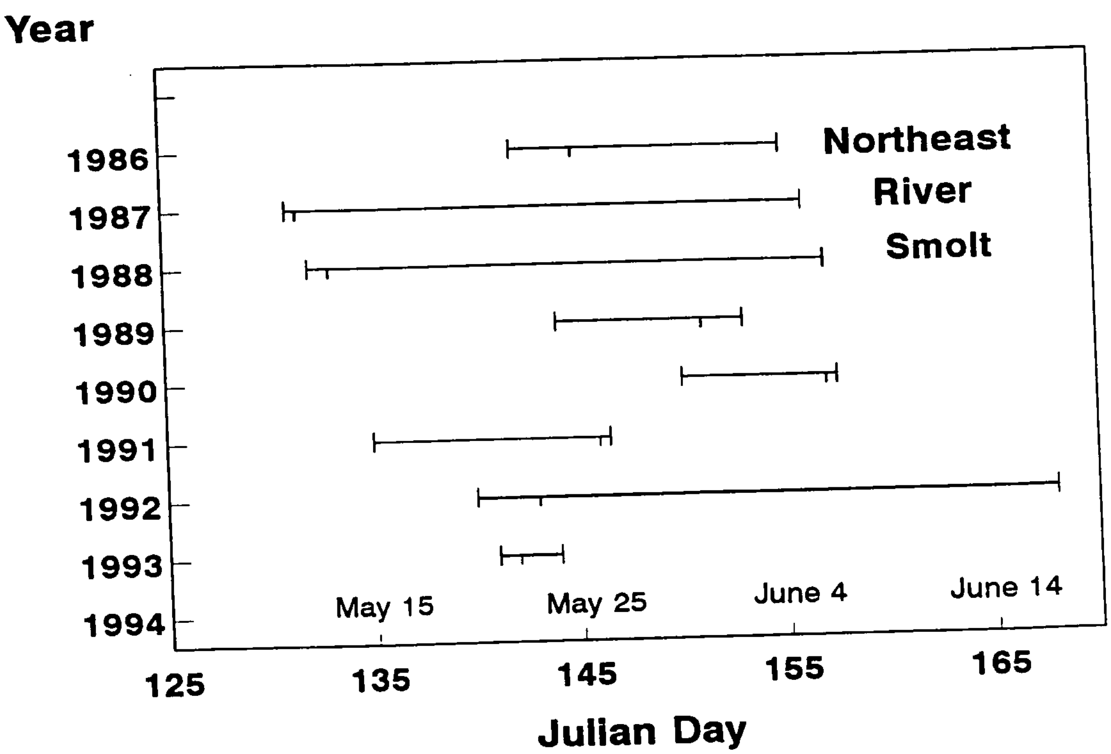


Figure 2. Temporal variation in condition of Atlantic salmon smolts from Conne River and Northeast Brook, Trepassey. Condition is the adjusted mean smolt weight (log scale) standardized to the grand mean length. Vertical bars represent ± one standard error.

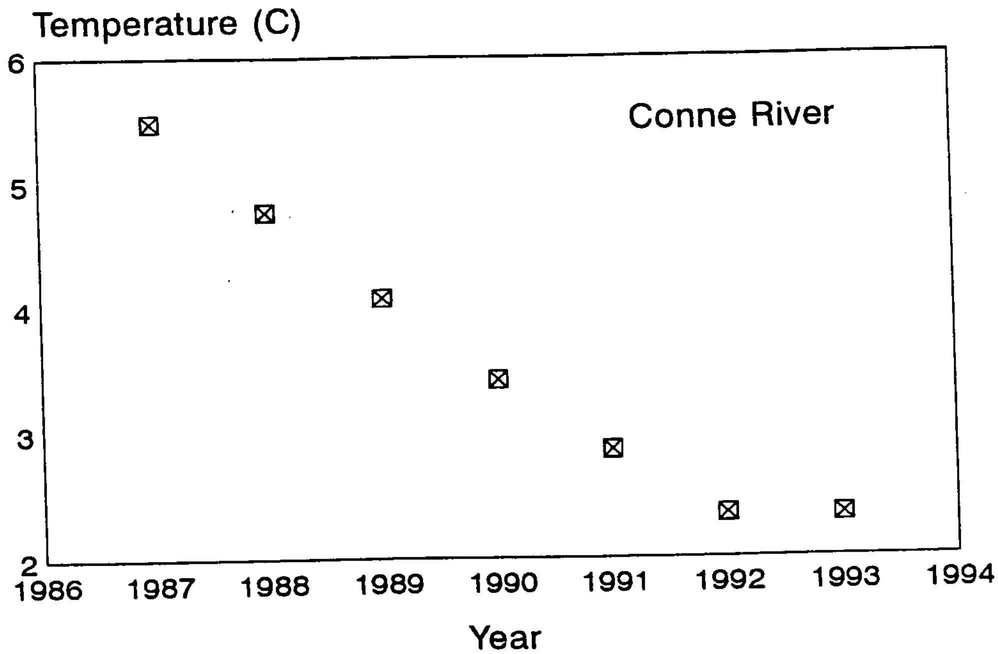




25th, 50th (median), and 75th percentiles of the run

Figure 3. Run timing of Atlantic salmon smolts at Conne River and Northeast Brook, Trepassey. The median point, along with the 25th and 75th percentiles are illustrated.

Temperature Index (April 1-May 15)



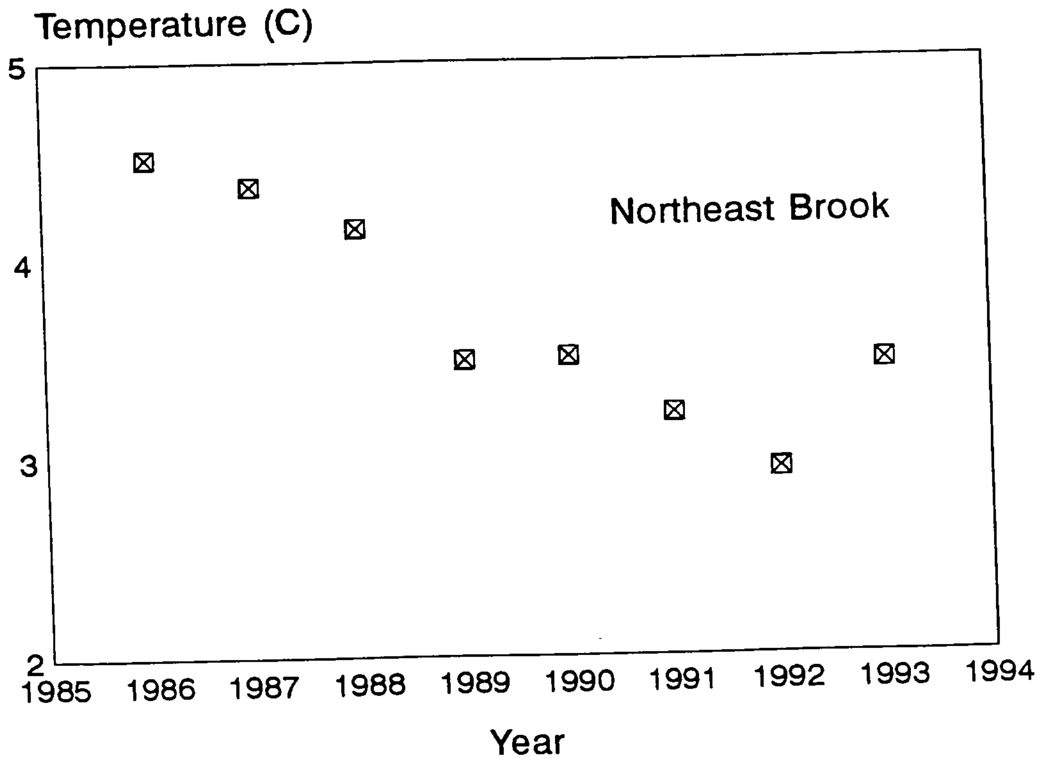
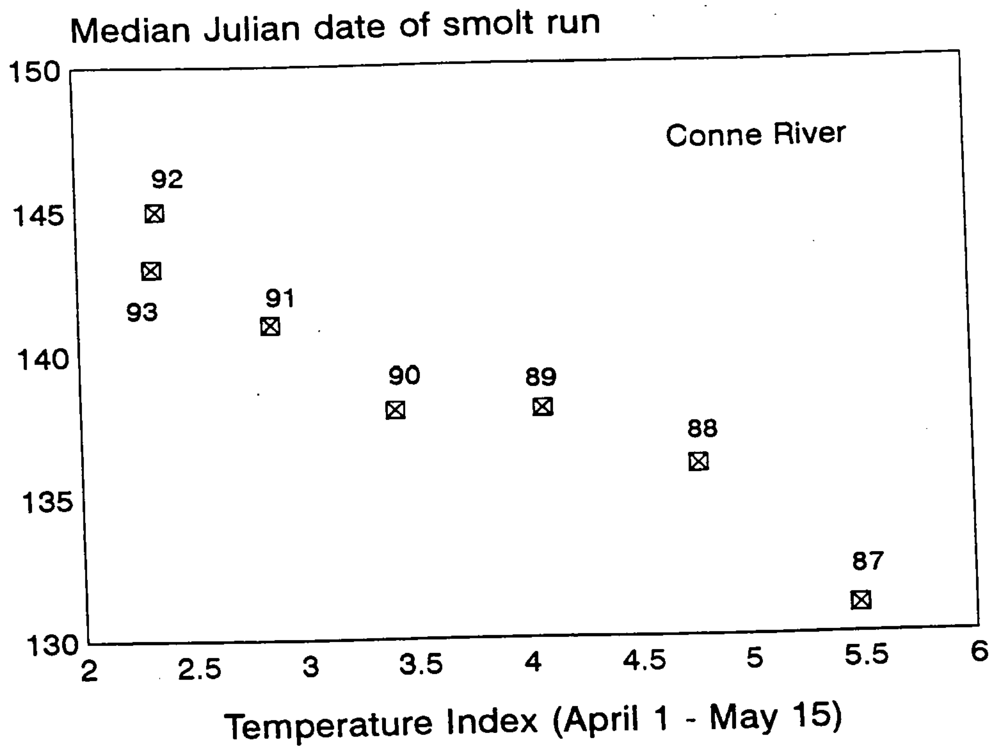


Figure 4. Air temperature index at Conne River and Northeast Brook, Trepassey. The April 1 - May 15 dates generally coincide with the overall 25th percentiles of the smolt run at each river.



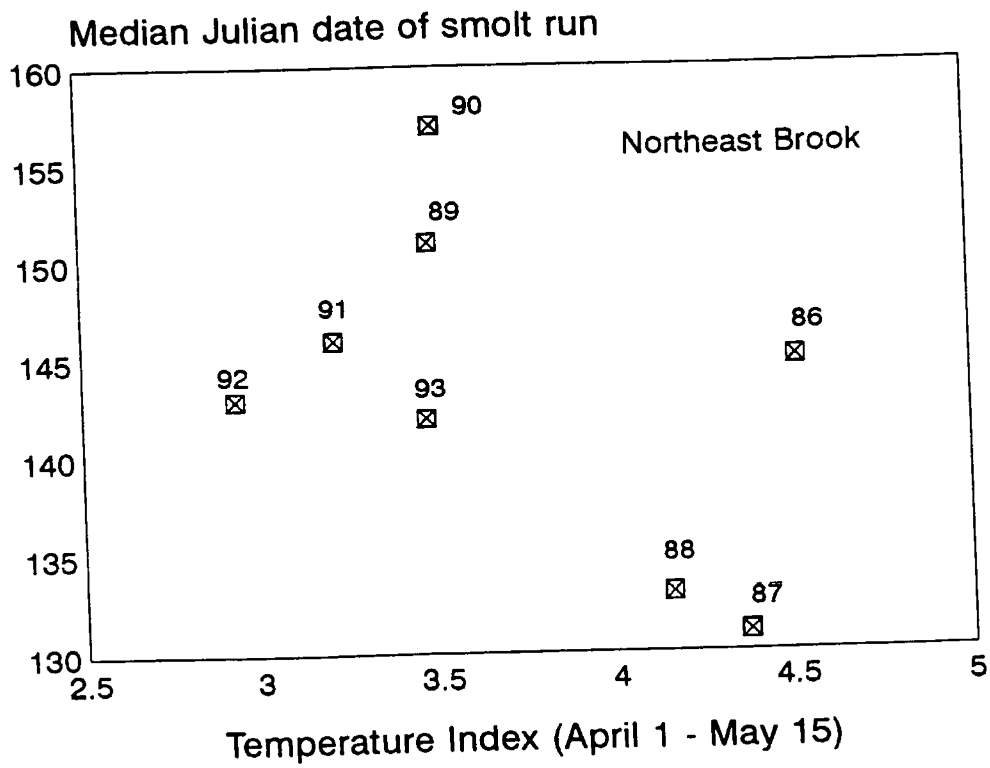
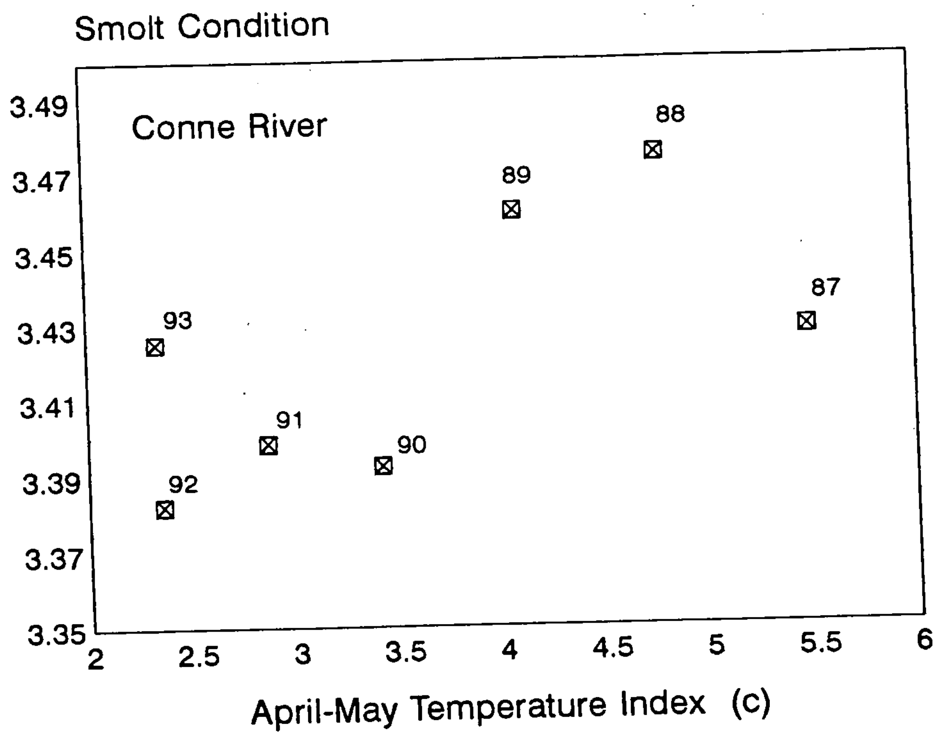


Figure 5. Association between the median run timing date and the spring temperature index at Conne River and Northeast Brook, Trepassey.



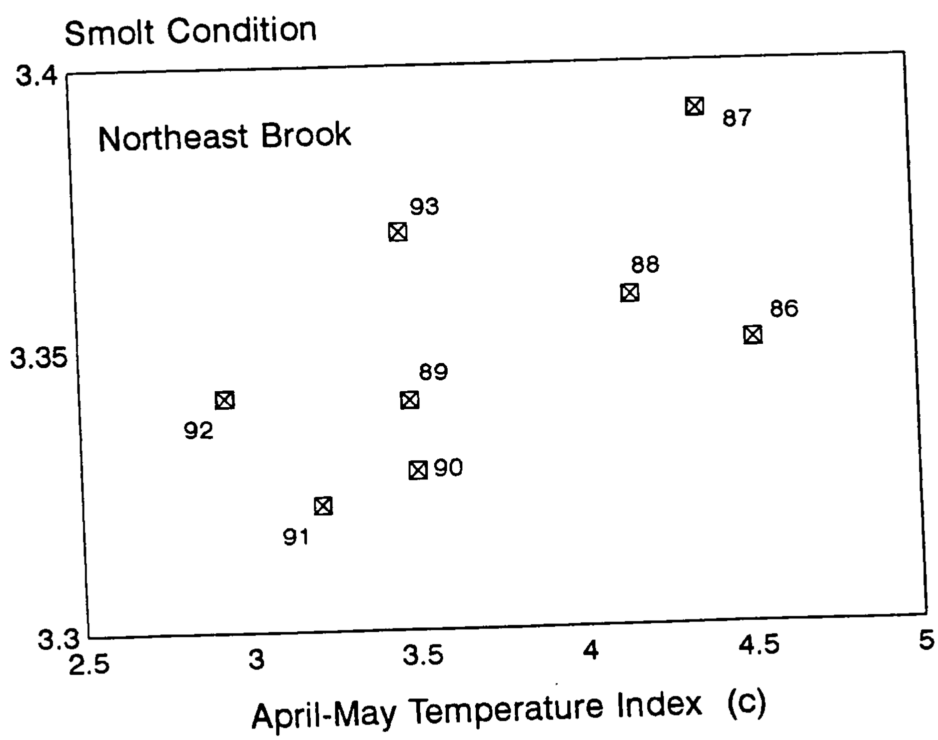
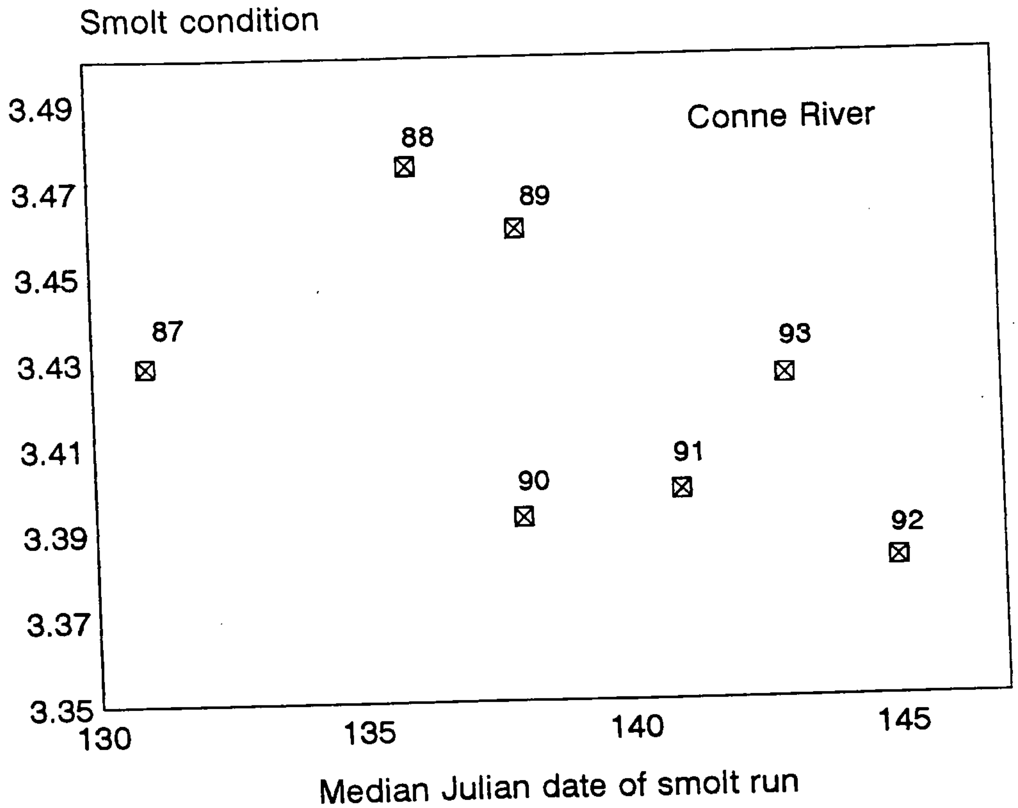


Figure 6. Association between smolt condition and the spring temperature index at Conne River, and Northeast Brook, Trepassey.



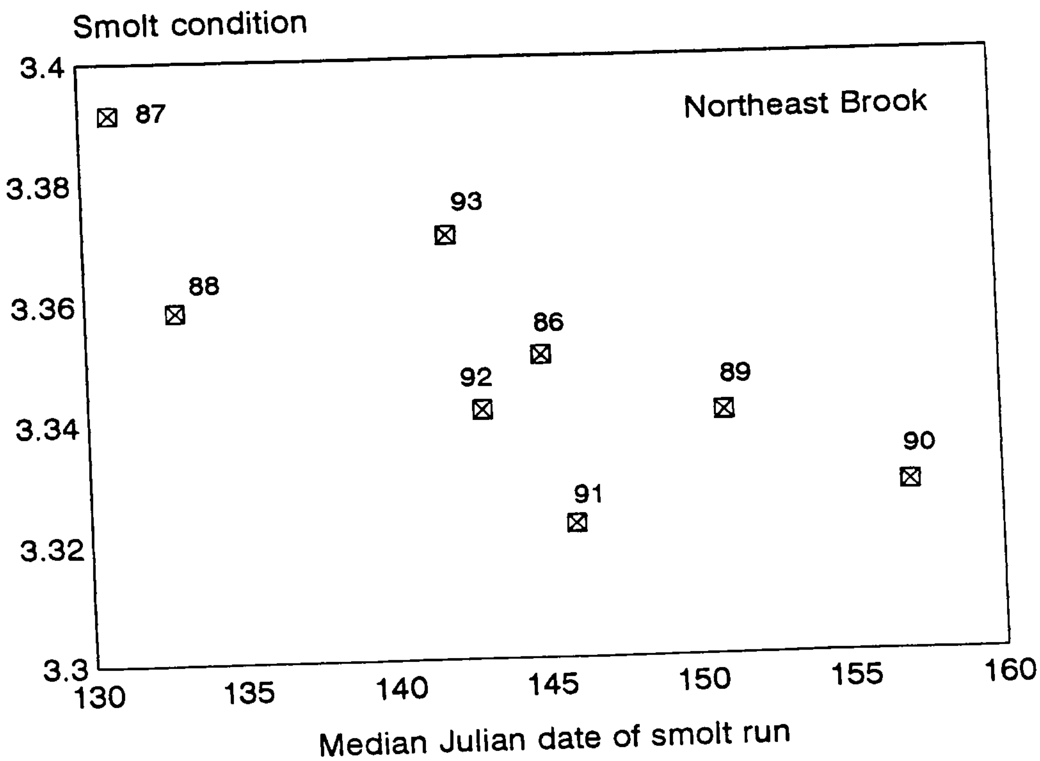
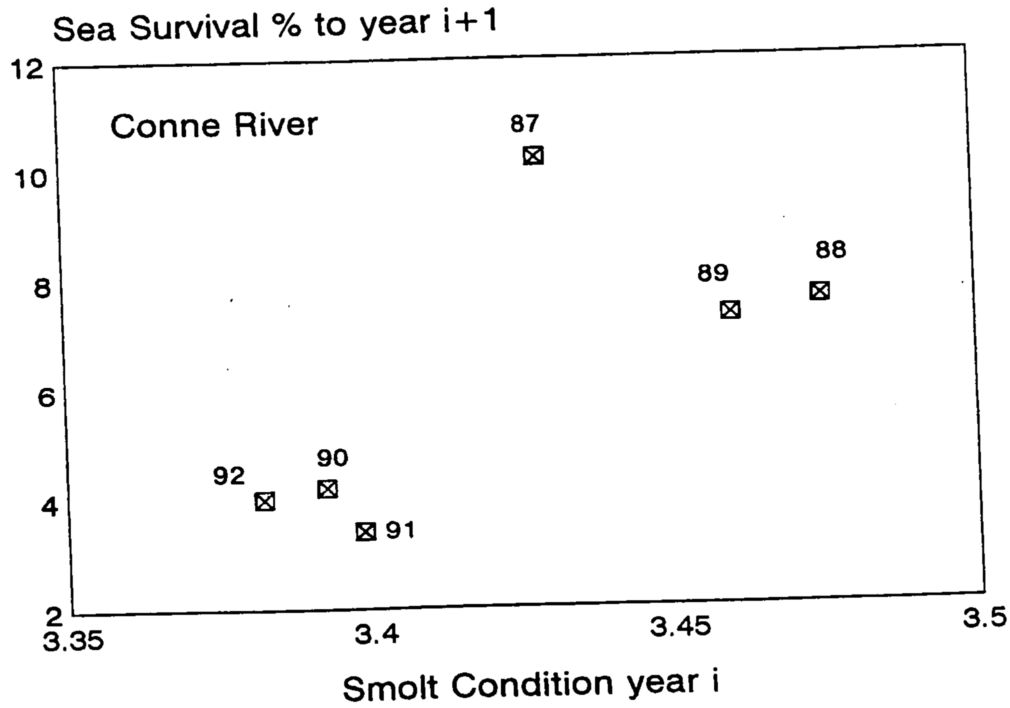
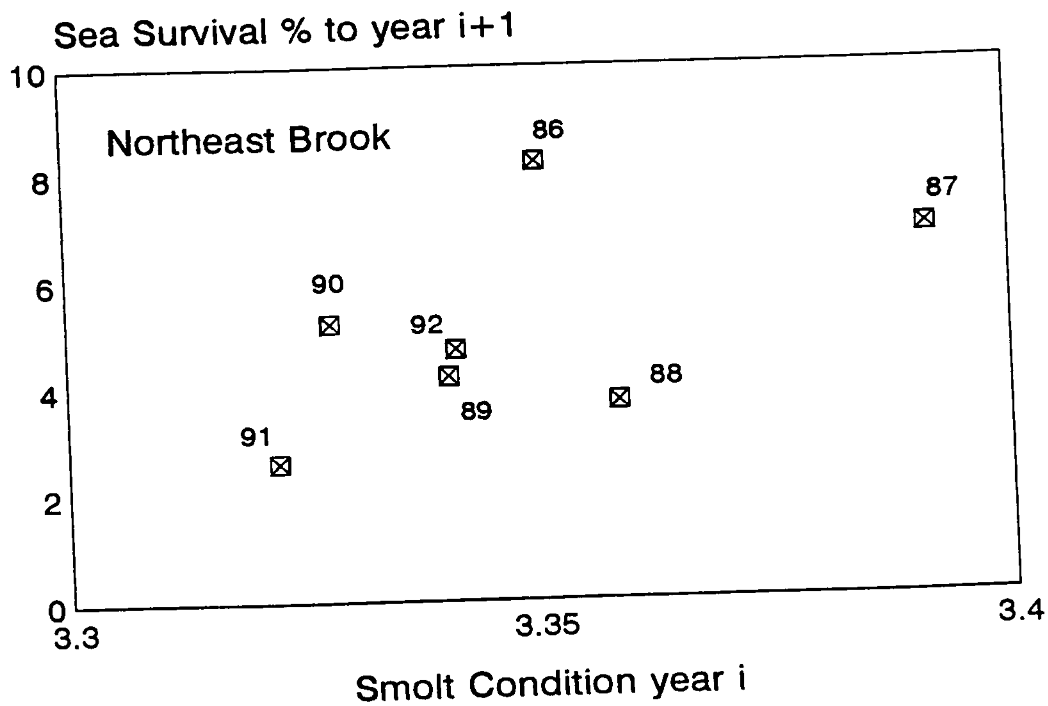


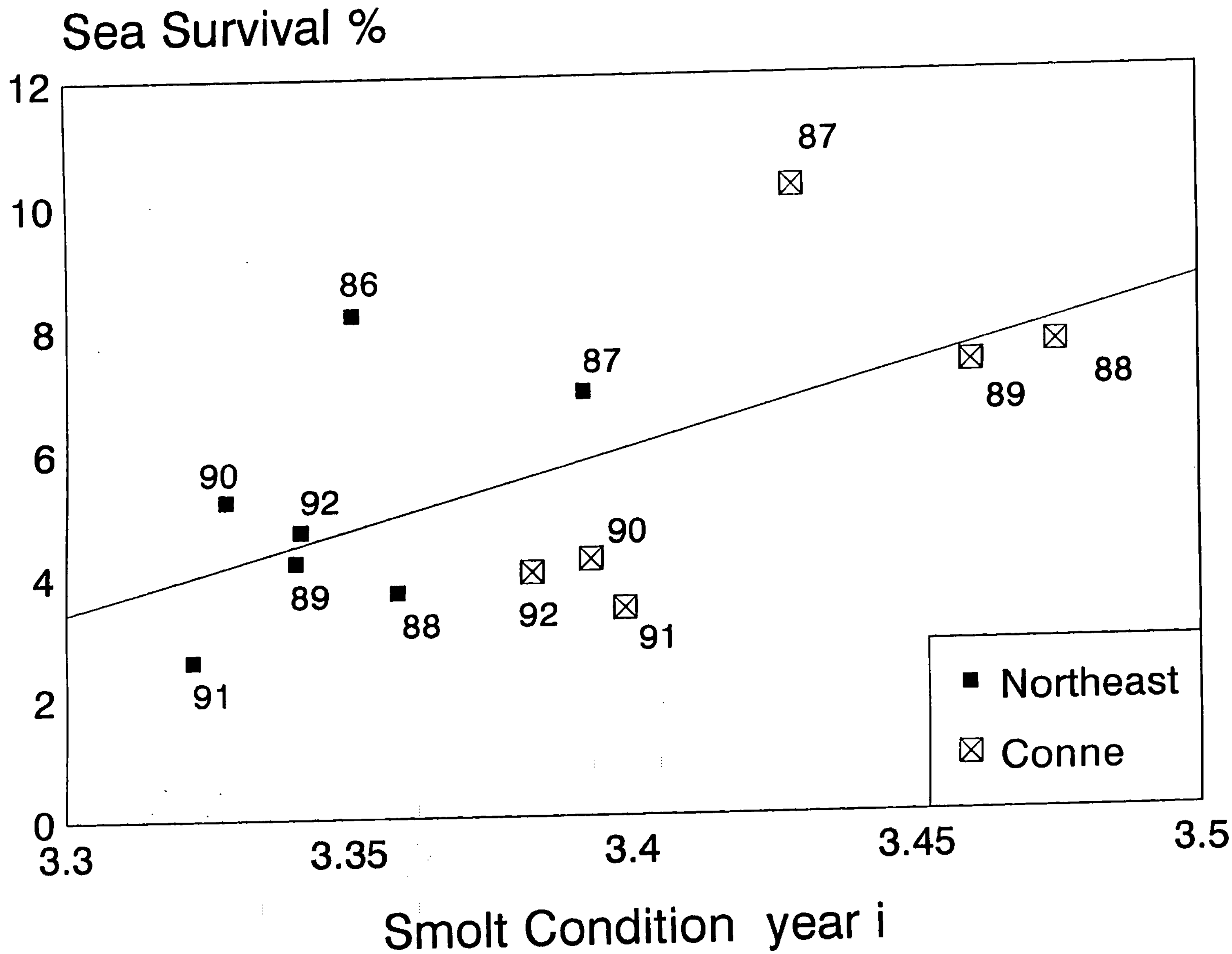
Figure 7. Association between smolt condition and the median run timing date at Conne River, and Northeast Brook, Trepassey.





Year is year of smolt migration
Survival is survival to 1SW salmon

Figure 8. Association between condition of smolts migrating in year i with survival to returning 1SW salmon in year i+1, at Conne River and Northeast Brook, Trepassey.



Survival to 1SW salmon year i+1

Figure 9. Combined relationship between sea survival and smolt condition for Conne River and Northeast Brook, Trepassey.