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# The environmental requirements of adult Atlantic salmon (*Salmo salar* L.) during their upstream migration in the Northwest Miramichi River, New Brunswick, 1963-1967.

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Abstract: Statistical examination of data on counts of salmon and environmental factors in the Northwest Miramichi River have shown strong correlations between the rate of upstream migration and river flow, water temperature and predicted toxicity. These relationships indicate a cessation of migration in a given year at 1) maximum and mean temperatures as low as 28.2 and 22.6°C for daily values and 25.0 and 21.6°C for weekly averages, and 2) daily concentrations of copper and zinc combined equivalent to 0.77 of the threshold LC 50 value in a particular year, and weekly average concentrations equivalent to 0.78 to 1.28 of the LC 50 over a 5-year period.

## I. INTRODUCTION

The environmental requirements of adult Atlantic salmon *Salmo salar L.* have not been well described, although field data exist on the numbers of fish passing upstream through fish-counting installations, together with data on water quality and flow. The main problem in trying to relate numbers to environmental factors is in avoiding bias caused by an unequal distribution of fish during a run, low numbers of fish occurring at the beginning and end and high numbers in the middle. A suitable approach involving probit analysis has now been applied to data from the Northwest Miramichi River, New Brunswick.

## II. DATA-BASE AND METHODS

Detailed information has been tabulated on the number of fish passed daily through a counting fence 7 miles upstream of the head of the tide on the Northwest Miramichi River from 1963 to 1967 (Henderson, Saunders & Kerswill, 1965; Schofield, 1967; 1968), together with daily readings of water temperature (at 0800 h and 1700 h, which are close to the times of minimum and maximum values, respectively), river discharge and water quality, including concentrations of dissolved copper and zinc (Sprague & Carson, 1964; 1965; 1966; 1967; & 1968).

The total daily count of grilse (salmon that have spent only one year at sea before returning to the river as adults) passing upstream during June to August varied between 1030 and 3900 and appeared to be distributed approximately normally over these months. They were, therefore, expressed as a cumulative percentage over this period for each year and then further transformed to units of standard deviation (probability) so that the increment each day - i.e. the rate of migration - could be expressed as standard deviation per day. Whilst this method eliminates the bias otherwise caused by high numbers during the middle of the run, it puts considerable weight on very low numbers of fish caught at the very beginning and end of the run. For this reason some analyses were repeated eliminating these extreme points. These measurements of the fish counts were used as the dependent variable in linear multiple regression analyses, whilst the daily flow, maximum and minumum water temperature, and concentration of copper and zinc, were used as independent variables. A similar calculation was made on weekly counts and also the concentrations of copper and zinc were expressed as fractions of their incipient lethal levels (threshold LC 50 values) of 48 and 500 ug $l^{-1}$, respectively (Sprague, 1963), and summed. A second distinct peak in the count of grilse occured in the autumn, but was ignored in the present analysis.

In 1967 a total of 1017 seatrout was counted between 5 June and 14 August and was also included in the analyses.

## III. RESULTS

The results are summarised in Tables I to V. Significant positive correlations of daily rate of migration were found with river flow in 1964 and 1966 and negative correlations found with minimum temperature in 1963 and 1965 (Table I). The regressions with maximum temperature are less significant and account for less of the variance than those with minimum values, but have been calculated for 1963 and 1965 excluding minimum temperature, since maximum and minimum temperatures are highly correlated and likely to be mutually exclusive. Results for weekly rates of migration (Table II) are somewhat similar to those for daily rates, except that more of the variance is accounted for, though at a lower level of significance, and temperature is a significant factor only in 1963.

There was a significant negative correlation in 1967 of daily rate of migration with dissolved copper and, in 1963-1967, of weekly rate with dissolved zince and (when the first and last daata points were eliminated) dissolved copper (Table III). In the first case, the value equivalent to a zero rate of migration would be 32 ug Cu $l^{-1}$, which is equivalent to 0.66 of the threshold LC 50 value of 48 ug Cu $l^{-1}$ (or toxic unit of copper). During the run the average concentration of zinc was 66 mg $l^{-1}$ which is equivalent to 0.11 of a toxic unit of zinc (600 mg Zn $l^{-1}$), making a total of 0.77 toxic units for copper and zinc together. In the second case, the equation (which includes n effect of weekly average maximum temperature) indicates that, at the average maximum temperature of 21°C for the whole period, the weekly rate of migration would be zero at concentration of zinc of 325 mg Zn $l^{-1}$ (equivalent to 0.54 toxic units). During the whole period the average concentration of copper was 11 ug Cu $l^{-1}$, which is equivalent to 0.22 toxic units, making a total of 0.76 for both metals combined. In the last case, the concentration of copper at which the rate of migration would be zero at the average prevailing flow is 33 ug Cu $l^{-1}$ (0.68 toxic units), whilst the average concentration of zinc over the period was 87 mg Zn $l^{-1}$ (0.15 toxic units), making a total of 0.83 toxic units of copper and zinc combined.

The temperatures at which the rate of migration would be predicted, from the equations, to be zero are shown in Table IV together with the corresponding average observed values and the average sum of the fraction of the toxic units of copper and zinc.

No significant correlations of weekly rate of migration were found with the sum of toxic units of copper and zinc included in the regression analysis, except for the period 1963-1967 when the first and last data points were eliminated. The equation is:

$$R_g = 0.055 + 0.15 F_w - 0.073 T,$$

where $R_g$ is he weekly rate of migration of grilse, $F_w$ is the weekly average daily flow in 1000's $ft^3 s^{-1}$ and T is the weekly average sum of toxic units of copper and zinc. This implies no migration at a sum of toxic units of 1.28.

With seatrout in 1967, daily flow was the only significant factor, the equation being:

$$R_t = 0.057 + 0.172 F_d,$$

where $R_t$ is the daily rate of migration of seatrout in standard deviations per day and $F_d$ is the daily average flow in 1000's ft$^3$ s$_{-1}$.

## IV DISCUSSION

The increase in rate of migration (as defined in this paper) with increase in river flow is congruent with other data on catches of fish in traps at the head of the tide on the River Coquet, Northumberland (Alabaster, 1970) and the river Axe, Devon (Alabaster, 1989), as well as with recent observations of the number of fish passing through an automatic counter in the River Dee, Wales (Alabaster, 1990). Differences in the relationships found in different years probably reflect differences in other envioronmental factors, including temperature and concentration of copper and zinc, even though they are not always found to be significant at less than $P = 0.05$.

There are few other data available with which to compare the present results on the effect of temperature. However, monthly catches of salmon in the trap on the River Axe over the period May to August, 1962-1975 showed that the rate of migration reduced with increase in temperature, and would be expected to have ceased at a monthly mean value of 24.9°C. In the River Dee, the corresponding figure for minimum weekly temperature associated with no count of fish over the period June to August, 1988 and 1989 is 24.9°C at the average flow prevailing at the time. This is similar to the minimum weekly figures for the Northwest Miramichi over the period 1963-1967 in Table IV, but rather higher than the figures for 1963 and 1965, perhaps because concentrations of copper and zinc in the River Dee are likely to have been very much lower than those in the Northwest Miramichi River (Table IV).

The estimated sum of toxic units of copper and zinc of 0.77 to 1.28 associated with complete inhibition of the rate of migration is similar to the results of avoidance experiments with juvenile salmon under laboratory conditions at 18.2°C using mixtures of dissolved copper and zinc in roughy eqi-toxic proportions (Sprague, 1964); 100 per cent avoidance was observed at between 0.6 and 2 toxic units and 50 per cent avoidance at 0.02 units. The result is also consistent in a general sense with an increased percentage of fish that returned downstream through the trap when mining operation started in 1957 compared with the years 1954-1956 (Sprague, Elson & Saunders, 1965); in the present study period, the number of grilse that were counted down in June to August averaged 4% of those counted up in the same months, compared with only 0.7% in 1954-1956.

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Table I. Summary of linear multiple regression analysis of daily rate of migration of grilse in the Northwest Miramichi River, New Brunswick in which no significant effect of metals is found. **, P = 0.01-0.001; *** P = less that .001; N.S., not significant; N.I., not included. The proportion of the variance that is accounted for ($r^2$) is shown in parenthesis.

| YEAR | CONSTANT | | | |
|---|---|---|---|---|
| | Intercept | Flow ($ft^3s^{-1}$) (1000's) | Min. temp. (°C) | Max. temp. (°C) |
| 1963 | 0.362 | N.S. | 0.016(0.27)*** | N.S. |
| | 0.338 | N.S. | N.I. | 0.012(0.20)*** |
| 1964 | -0.036 | 0.43(0.38)*** | N.S. | N.S. |
| 1965 | 0.276 | N.S. | 0.012(0.23)*** | N.S. |
| | 0.24 | N.S. | N.I. | 0.008(0.13)** |
| 1966 | 0.039 | 0.13(0.12)** | N.S. | N.S. |

Table II. Summary of linear multiple regression analysis of weekly rate of migration of grilse in the Northwest Miramichi River, New Brunswick in which no significant effect of metals is found. *, P = 0.05-0.01; **, P = 0.01-0.001; N.S., not significant; N.I., not included. The proportion of the variance that is accounted for ($r^2$) is shown in parenthesis.

| YEAR | C O N S T A N T | | | |
|---|---|---|---|---|
| | Intercept | Flow ($ft^3 s^{-1}$) (1000's) | Min. temp. (°C) | Max. temp. (°C) |
| 1963 | 0.517 | N.S. | N.S. | 0.02(0.52)** |
| | 0.453 | N.S. | 0.021(0.42)* | N.I. |
| 1964 | -0.008 | 0.33(0.61)** | N.S. | N.S. |
| 1966 | 0.026 | 0.21(0.64)* | N.S. | N.S. |

Table III. Summary of linear multiple regression analysis of rate of migration of grilse in the Northwest Miramichi River, New Brunswick in which significant effects of metals are found. *, P = 0.05-0.01; **, P = 0.01-0.001; *** P = less that .001; N.S., not significant; N.I., not included. The proportion of the variance that is accounted for ($r^2$) is shown in parenthesis.

| CONSTANT | | | | |
|---|---|---|---|---|
| Intercept | Flow ($ft^3 s^{-1}$) (1000's) | Max. temp. (°C) | Copper ($ug\ l^{-1}$) | Zinc ($mg\ l^{-1}$) |
| | | Daily data, 1967 | | |
| 0.374 | N.S. | N.S. | -0.005(0.10)* | N.S. |
| | | Weekly data, 1963-1967 | | |
| 0.391 | N.S. | 0.014(0.27)*** | N.S. | -0.014(0.07)* |
| | | Weekly data, 1963-1967§ | | |
| 0.056 | 0.17(0.16)** | N.S. | 0.003(0.09)* | N.S. |

§ First and last data point each year deleted

Table IV. Average observed water temperatures and sum of toxic units of copper and zinc in the Northwest Miramichi River, during the migration of grilse in June to August, and the tempratures at which the predicted rate of migration would be zero.

| | Average observed values | | | Predicted extinction temp. | |
|---|---|---|---|---|---|
| | Temperature | | Toxic units | | |
| | Maximum (°C) | Minimum (°C) | (Cu + Zn) | Maximum (°C) | Minimum (°C) |
| | | | Daily values | | |
| 1963 | 20.8 | 17.1 | 0.40 | 28.2 | 22.6 |
| 1965 | 20.8 | 17.3 | 0.51 | 30.0 | 23.0 |
| | | | Weekly values | | |
| 1963 | 20.4 | 16.9 | 0.40 | 25.9 | 21.6 |
| 1963-67 | 21.0 | 17.2 | 0.36 | 27.6 | 24.8 |