REPORT

on

WATER RESOURCE DEVELOPMENT IN EAST DEVON

River Axe Fish Study - Evaluation of Fish Movements in the Estuary

by

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1. INTRODUCTION

The option under consideration is the abstraction of up to 25 Ml/d (0.289 m^3/s) of surface water from the R. Axe near the tidal limit, leaving an assumed minimum residual flow of 0.625 m^3/s which would result in a reduction in freshwater flow to the estuary and the sea and which might affect fish migration through the estuary. Salmon (**Salmo salar** L.) and seatrout (**Salmo trutta** L.) are present in the river and traverse the estuary, seawards as smolts, and landwards as returning adult fish and, being the most common, are the main species at risk. Eel (**Anguilla anguilla** L.), sea lamprey (**Petromyzon marinus** L.) and, rarely, Twaite shad (**Alosa fallax** Lacepède) also migrate through the estuary, and flounder (**Platichthys flesus** L.) and mullet (**Mugil** sp.) enter tidal waters from the sea; neither these, nor brown trout (**Salmo trutta** L.), roach (**Rutilus rutilus** L.) and dace (**Leuciscus leuciscus** L.), which have been caught near the tidal limit (Champion & Swain, 1974), will be considered further in this report.

The nature of the movement of salmonid fish in the estuary has not been observed directly but must be infered from observations elsewhere and from data on catches in the R. Axe - by commercial seine netting at the mouth of the estuary, rod fishermen on the river and also the experimental trap operated by the Ministry of Agriculture, Fisheries and Food (MAFF) for several years (1960-1976) near the tidal limit and about 3 km from the sea. The potential impact of the proposed abstraction on fish movements in the estuary will, therefore, be assessed by relating these catches to river flow and other relevant factors.

2. DATA-BASE

2.1. Catches of salmon and seatrout

Monthly catches of adult salmon and seatrout both on rod and line and in nets in the R. Axe and other neighbouring rivers have been supplied by the South West Water Authority (SWWA) from the statutory returns for the years 1956-1984. Annual data on salmon, giving the number of licenced nets and rods, have been obtained from MAFF. Annual catches of salmon and seatrout for the additional years 1948-1955 have also been provided by MAFF.

Annual trap catches have been given for adult salmon for the period 1960-1964 and for seatrout for 1961-1964 (Allan, 1966). Annual trap catches of salmon for the years 1959-1968 and estimates of the stock of salmon and of commercial and angling rates of exploitation for 1963-1968 have also been published (Swain & Champion, 1970). Monthly distributions of salmon trap catches are available for 1964 together with half-hourly data on salmon and seatrout over several days in August, 1962, November, 1964 and July, 1967 (Swain & Champion, 1968). Further data on trap catches have been obtained from monthly News Letters issued by MAFF which include monthly totals of salmon for the years 1960-1976, and for both large and small seatrout (less than 40 cm) or whitling for the years 1960-1966, and for only total numbers of seatrout for 1967-1969; after May, 1969 there is only intermittent reference to the number of seatrout seen.

Monthly total of smolts caught are given in the News Letter for the years 1960-1976 and weekly totals of the number of salmon smolts trapped in the period 1960-1969 have been provided by A. Swain & A. S. Champion (personal communication). The relation between salmon smolt escapement for the years 1961-1968 and the corresponding estimated return of adults has been described by Champion (1973).

2.2. River flow

Data on daily mean flow in the R. Axe at Whitford have been supplied by SWWA for the period 6 November, 1964 to 17 July, 1985.

Annual distributions of water level at the trap have been given for the years 1960-1964, together with the corresponding river flows in 1964 (Allan, 1966) whilst monthly distributions of river flow have been provided for 1964, together with half-hourly observations of flow over several days in August, 1962, November, 1964 and July, 1967 (Swain & Champion, 1968). Further data on monthly average water levels have been provided for the period January, 1962 to July, 1972 by MAFF (E. C. E. Potter, personal communication) and for the period February, 1972 to December, 1976 from the News Letter which also gives maximum levels for the years 1964-1976 though not minima.

2.3. Water quality

Data on water quality in the R. Axe at Whitford Bridge have been provided by SWWA for the period 1974-1985 in the form of 3- or 4-year running means and various percentiles. Additional monthly data on water temperature in the river at Colyford have been provided as monthly means for the period January, 1962 to July, 1972 and for maximum and minimum values for the period August, 1961 to December, 1976 by MAFF (E. C. E. Potter, personal communication). Monthly maximum and minimum temperatures are also provided in the News Letter for 1962-1976.

3. METHOD OF DATA ANALYSIS

Trends in catches, river flow and water quality with time have been evaluated by either linear or polynomial regression over the periods 1951-1984, 1964-1985 and 1974-1985 respectively. The relationship between catches and other factors has been assessed by linear multiple regression analysis over much shorter periods, dictated by the availability of data on flow and water quality during the early years and the relatively short period of operation of the MAFF trap.

4. RESULTS AND CONCLUSIONS

4.1 Distribution of catches of fish and water level

Upstream migrants

Relatively few salmon were trapped in the R. Axe, the ratio of the annual catch to those of large seatrout and whitling for the data summarised in Table 1 being 1:3.8:7.7, the numbers being 237:892:1817.

Table 1. Percentage distribution of average annual trap catch of fish in the R. Axe and mean and minimum monthly water level (inches).

Period	Salmon 1960-1976	Large seatrout 1962-1966	Whitling	Mean level 1962-1976	Min. level
Jan.	0.4	0.1	0.2	11.5	0.2
Feb.	0.8	0.4	0.1	9.7	0.4
March	2.0	1.3	0.4	7.7	0.8
April	4.9	8.7	0.2	5.7	0.5
May	10.7	18.5	0.3	4.6	2.0
June	12.8	17.2	5.1	2.7	0.0
July	9.8	12.8	35.1	1.5	0.0
August	14.1	7.0	28.5	1.8	0.0
Sept.	9.2	5.2	11.2	2.8	0.0*
Oct.	11.8	13.1	10.5	4.7	0.0*
Nov.	18.7	13.4	7.1	8.0	1.8
Dec.	4.8	2.3	1.3	7.8	4.4

* below zero on the depth gauge

Table 1 shows that most of the salmon and large seatrout were each trapped as two main runs in the period, May to November, while whitling were caught mostly from July to October, as also described by Potter (1985). Mean monthly water levels reached a minimum in July and a maximum in January, but mimimum monthly water levels of zero or less on the gauge occurred from June to October. Thus a substantial proportion of the fish was at risk from low water levels.

The average annual rod catch corresponding to the data in Table 1 (February-September up to 1970; February-October after 1970) amounted to 7% of the trap catch for salmon and 3.4% of that for seatrout, i.e. 17 and 19 fish, respectively. The corresponding figures for net catches are 17% and 0.7%, repectively, i.e. 41 salmon and 18 seatrout.

Smolts

The majority (77.8%) of the salmon smolts which were trapped in the period 1960-1969 (excluding 1963 when escapement was likely to have occurred) were caught in April, 20% being caught in May and only 2.2% in March. Although low minimum flows have been recorded in April (Table 1), no relationship was found between monthly numbers trapped and mean or maximum flow. There was, however, a significant positive correlation with average water temperature in February for those caught in March, accounting for 0.87 of the variance (P = less than 0.001), and a negative correlation with catch in April for those caught in May, accounting for

0.87 of the variance ($P = 0.05$-0.001). The median date of migration also appears to increase with decrease in water temperature in February, rather than being related to flow. Nevertheless, it is clear from the News Letter that large numbers of fish descend with the floods.

Seatrout smolts in the R. Axe also migrate mainly in April although their migration extends for about twice as long as that of salmon (Potter, 1985)

4.2. Net and rod catches of salmon and seatrout

Annual

There have been substantial, statistically significant, reductions in annual net and rod catches of both salmon and seatrout over the period 1956-1984, although the proportion of seatrout has tended to increase over the same period. At the same time the number of rod licences has declined but the catch per licence has also fallen during the period. With seatrout, however, over the period 1964-1972, there is also an increase in the number per licence with reduction in the number of licences. Similar reductions in catch have been found in other rivers in the area of SWWA and elsewhere in the UK and do not appear to be especially related to low river flow in summer. Such long-term changes, as well as the normal seasonal variation in catch, are taken into account when attempting to relate catches to environmental factors, including river flow.

Monthly

Multiple regression analysis of monthly catches on monthly flow, and on year, shows significant reductions in number with time for salmon in May, June and July, and for seatrout in July, August and September; a relationship (also a reduction in number) with flow is shown only for net catches of salmon in June, the applicable period being the years 1964-1979. The regression equation is:

$$y = 147.4 - 1.8\ x_1 - 4.4\ x_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where y = monthly net catch

x_1 = year expressed as 10's and

x_2 = monthly mean daily river flow expressed as m^3/s.

The constants for x_1 and x_2 account for 0.46 and 0.20 of the variance, respectively, and for each, $P = 0.05$-0.01. During the period the flow ranged from 0.8 to 4.5 m^3/s, thus being close to the assumed minimum residual flow of 0.625 m^3/s to be left after the proposed abstraction at the maximum rate of 0.289 m^3/s. The impact on net catches of a reduction in flow of 0.3 m^3/s from 0.9 to 0.6 m^3/s, taking the year 1970 as an example, would be to increase the catch of salmon from about 18 fish to only 19. Since net catches are now even lower than hitherto the potential impact of such a change in flow on them would seem to be negligible.

Presumably, the increase in net catch is brought about through delaying the passage of fish past the fishing station so that, in addition to any extra fish caught by the nets, there would be a reduction in the rate of entry of fish to the estuary.

However, the lack of significant increases in rod catches with increase in flow is in sharp contrast to the situation in other rivers, such as the Aberdeenshire Dee and Don, the Taw and Torridge and the Dart, where a positive relationship has been found; this is probably partly attributable to the relatively small numbers of fish caught in the R. Axe, a high proportion being caught downstream of the trap, for example during 1963-1968 (Swain & Champion, 1970), and also to there being a variable number of licenced rods which, in the case of seatrout (during 1964-1972) was inversely related to catches.

4.3. Monthly trap catches of salmon

Flow alone

The data on monthly salmon catches in the R. Axe in 1964 at different daily flows and the percentage availability of such flows each month, presented by Swain & Champion (1968), have been re-examined to calculate the median monthly flows utilised by salmon and the median monthly flows available. These are listed in Table 2.

Table 2. Median monthly daily flow in the R. Axe (m^3/s) derived from Swain & Champion (1968)

Month	Flow available	Flow utilised by salmon at the trap
February	3.4	16.8
March	5.5	16.8
April	5.1	8.4
May	4.1	7.8
June	2.1	6.4
July	1.2	1.6
August	1.1	1.6
September	1.0	-
October	0.8	4.3
November	1.4	4.3
December	2.5	10.2

This shows that salmon were trapped (i.e. moving out of the estuary into fresh water) at daily river flows that, consistently through the year, were higher than those generally available. Similar results have also been found for salmon trapped at the head of the tide on the R. Coquet, except for November and December (Alabaster, 1970). However, the data do not allow the effect of flow to be assessed quantitatively.

Water temperature

Synchronous data for monthly trap catches and river flow (mean water level) and mean water temperature for the years 1962-1965, have been analysed using multiple regression, excluding months when catches were probably underestimated because the trap had to be lowered. The data for two adjacent months were combined in the analysis to improve the chance of obtaining statistically sigificant results but without success, except in the case of salmon trapped in July and August (necessarily restricted to the years 1962-1964), where P = 0.05-0.01. The regression equation is:

$$y = -41.1 + 60.1 x \qquad (2)$$

where y = monthly trap catch of salmon, and

x = mean monthly water level at Colyford expressed in inches. The proportion of the variance accounted for is 0.69, and the standard errors are large (20.4 for the regression coefficient and 26 for the estimate of y).

From the regression equation the level at which the catch would be zero is calculated as about 0.68 inches and would increase by about 60 fish for each inch increase in level. A calibration curve derived from levels and flows given for 1964 by Allan (1966) shows that the two corresponding flows would amount to about 1 and 0.5 m^3/s respectively, the equation being:

$$y = 0.6 + 0.53\ x \qquad (3)$$

where y = daily flow in m^3/s, and
x = water level in inches.

From this equation the level at which the catch would be zero (0.68 inches) corresponds to a flow of precisely 0.95 m^3/s and, since an increase in level of one inch (which is correlated with an increase of 60 in the number of salmon trapped) corresponds to an increase in flow of precisely 0.53 m^3/s, an increase in flow of 0.3 m^3/s would be associated with an increase of about 34 fish. Figures of the same order are obtained from calibrations based either on the data in Table 2, or on those on levels given by MAFF for 1964 and 1965 measured at the trap, together with corresponding flows measured by the SWWA at Whitford. They are listed in Table 3 together with those derived from Allan (1966) but, in view of the much larger scatter of points about the calibration curve, are probably the least reliable; those measured at the trap would certainly have been affected by tidal height, especially on spring tides, and by the method of operating the trap. A further calibration using data to 1972 also shows considerable variability.

Table 3. River Axe mean monthly flows corresponding to specific effects of water level on trap catches of salmon in July and August, as predicted by Equations (2) and (3).

Source of calibration data	Period	Flow for zero catch (m^3/s)	Change in catch for a change in flow of 0.3m^3/s
Allan (1966)	1964	0.96	34
Table 1	1964	1.21	40
MAFF & SWWA	1964-1965	1.08	19

The average catch for months when the trap was not out of action due to floods was 26 for July (1960-1964) and 66 for August (1962-1964), so that the reduction in catch with a reduction in flow of 0.3 m^3/s, as predicted by Equations (2) and (3), represents a substantial proportion of the totals.

Year

A further analysis has been carried out for the period 1962-1972 with the inclusion of year as one of the independent variables. No statistically significant results were obtained, except for the combined data of

August and September, where P = 0.05-0.01. The regression equation is:

$$y = 296.0 - 4.3 x_1 + 14.6 x_2 \qquad (4)$$

where y = monthly trap catch of salmon,
x_1 = year expressed in 10's, and
x_2 = monthly mean daily water level expressed in inches.

The proportion of the variance accounted for is 0.14 for year and 0.25 for water level; the standard error of the estimate, as in Equation (2) is large (26.5).

Again using Allan (1966) as a source for flow calibration, Equation (4) shows that, in 1962, an increase in flow of 0.3 m^3/s from 0.6 to 0.9 m^3/s is associated with an increase of about 9 fish from a total of about 32. In later years, however, the impact is greater because of the generally lower catches; in 1969, for example, the increase would again be about 9 fish but from a total of only two.

Mean and maximum water levels (but not minima), and maximum and minumum water temperatures, are available for the years 1964-1976. Multiple regression analysis for this period shows significant reduction in catch with time and mean temperature and increase with maximum water level for some of the months May-June, as summarised in Table 4.

Table 4. Multiple regression analysis of monthly catches of salmon in the Axe trap on year, mean and maximum water level and maximum and minimum water temperature. The proportion of the variance accounted for is shown in parenthesis. *, P = 0.05-0.01; **, P = 0.01-0.001, N.S., not statistically significant.

Month	CONSTANT for year	CONSTANT for max. water level (inches)	CONSTANT for min. water temp. (°C.)
May	N.S.	0.1*(0.45)	-17.1*(0.15)
June	-4.0**(0.63)	N.S.	N.S.
July	N.S.	0.54*(0.54)	N.S.
August	-4.2* (0.53)	N.S.	N.S.

Maximum levels, reflecting floods, are clearly much more relevant than means, but the impact on catches of a change in flow of only 0.3 m^3/s in such values is hardly measurable.

Catch in preceding month

Since there is limited availability of fish to enter the estuary from the sea and to run up into freshwater, catches in a given month are likely to be influenced by those in the preceding month when these are unusually affected by extremes of environmental variables, as has been found in the R. Coquet (Alabaster, 1970). To examine the extent to which this occurred in the R. Axe, and interacted with the correlation between catch and flow, monthly catches were adjusted for seasonal and annual differences before analysis. Catches for each month were first expressed as a proportion of the mean for all corresponding months over the years 1960-1976; these proportions were then corrected for differences in the annual totals for all months, divided by the annual total for the year in question. This made catches in a given month comparable with those in a preceding one and also allowed the data from adjacent months to be combined in the analysis. The multiple regression analysis was carried out for the months of May to October taking catch in the preceding month, maximum water level and maximum water temperature as independent variables. The results are summarised in Table 5.

Table 5. Multiple regression analysis of corrected monthly catches of salmon in the R. Axe (see text) on corrected catch in the preceding month, maximum water level and maximum water temperature. The proportion of the variance accounted for is shown in parenthesis. *, P = 0.05-0.01; **, P = .01-.001; N.S., not statistically significant.

Months	C O N S T A N T for preceding month	for water level (inches)	for water temp. (°C.)
May & June	N.S.	0.18**(0.34)	N.S.
July & August	-0.47**(0.24)	0.01* (0.21)	-0.10* (0.10)
Sept. & Oct.	N.S.	0.03**(0.30)	N.S.

There is a significant reduction in catch in July and August with increase in catch in the respective preceding month, and a similar, but less significant correlation for September and October (P = 0.2-0.05) that would account for 0.11 of the variance; however, the increase in catch with increase in maximum water level is still evident.

4.4. Daily trap catches of salmon during and between spates

The MAFF monthly News Letter comments upon the occurrence of spates, often giving specific dates, together with a separate total for number of salmon passed through the trap. From April to September during the years 1967-1975 there were 45 such documented spates, each lasting for up to 3 days, amounting in total to 0.05 of the whole period and accounting for 0.75 of the total count of fish. This proportion showed a significant (P = 0.01-0.001) increase during the year from a mean of 0.63 in April, through to 0.71 in June, 0.8 in August and 0.98 in December. It showed no relationship to the size of spate, as judged by the difference between the peak flow at the start of the run and the minimum within one week beforehand (which averaged 6.75 m^3/s in size and ranged from 0.7 to 32.2 m^3/s), nor with the minimum itself (average, 1.65; range, 1-4.2 m^3/s).

The majority of fish therefore appear to move on the spates available, whatever their size, although there is a significant proportion during the early months that is passing from the estuary at a much slower rate at other times. This minority may be at risk from a reduction of flow from 0.9 to 0.6 m^3/s, but a more detailed examinination of the daily log would be required to make a further assessment.

4.5. Trap catches of seatrout

Data on the annual distributions of water level and catch of seatrout in the R. Axe at different water levels in 1964, tabulated by Allan (1966) show that, unlike salmon, a substantial proportion of the fish is trapped at flows lower than those generally available (and much lower than those utilised by salmon, as has been found elsewhere, e.g. by Alabaster (1970) in the R. Coquet). The results are summarised in Table 6 using Equation (3) to convert levels to flows.

Table 6. Cumulative percentile distributions of flows available and of flows utilised by salmon and seatrout trapped in 1964 (from Tables 13, 14 & 15 of Allan, 1966)

Percentile	Flow available (m^3/s)	Flow utilised by fish: Salmon	Flow utilised by fish: Seatrout
50	3.0	6.0	2.1*
70	4.1	7.8	3.3
90	6.7	10.9	8.0

* extrapolated value

The lowest range of flows in Allan's tables (0-3.25 m^3/s) accounts for 71% of the catch of seatrout but it is not possible to provide more detailed information at flows close to the dry weather values.

Multiple regression analysis of monthly catches against water level and water temperature for the years 1962-1966, excluding months when escapement of fish was likely to have occurred, failed to show any significant correlation with level, except for large seatrout trapped in June (P = 0.05-0.01); 0.81 of the variance was accounted for. However, a further analysis for this month using the combined number of large and small seatrout, which was available for the period 1962-1968, showed no significant relationships.

Counts of seatrout (as well as those of salmon) during several spates, shown graphically by Swain & Champion (1968), have been summarised in Table 7 and also expressed as proportions of the corresponding totals for the month of the spate.

Table 7. Number of fish trapped during spates (from Figs. 3, 4 & 5 of Swain & Champion (1968)). Proportion of total number trapped in the month is shown in parenthesis.

Dates of spates	no. of spates	Salmon	Large seatrout	Whitling
6-8 Aug., 1962	1	10(0.56)	46(0.51)	120(0.16)
13-18 Nov., 1964	3	116(0.99)	188(0.96)	120(0.76)
23 July, 1967	1	30(0.36)	35(0.08*)	67(0.08*)

* based on combined total of large seatrout and whitling

They support the general conclusions already drawn (Section 4.4) concerning the proportion of salmon counted during spates and also show that, while the proportion of large seatrout is similar to that of salmon, that of whitling is very much smaller.

4.6. Size of smolt run

The annual run of salmon smolts, but not that of seatrout, shows a significant fall over the years 1960-1976. This could explain, in part, the decline in annual number of adult salmon trapped over the same period, for the latter is significantly correlated with the combined annual totals of smolts counted one year, and two years, prior to the adult run (P = 0.01-0.001).

Although the decline in smolt run could, in turn, be partly explained by the decline in adult run, the annual number of smolts being related significantly (P = 0.05-0.01) to the combined annual totals of adults counted two years, and three years, prior to the smolt run, this accounts for only 0.26 of the variance. A multiple correlation, including year as an independent variable, shows that time is also a significant factor (P = 0.05-0.01), accounting for 0.38 of the variance.

One relevant time-related factor could be river flow which, when high after spawning time, could wash eggs from the gravel and, when low in summer, could adversely affect the growth and survival of young immature fish in their nursery areas. The mean monthly flow in the river Axe has declined significantly in both July (P = 0.01) and August (P = 0.05), decreasing by 0.08 and 0.06 m^3/s, respectively, each year, over the period 1965-1984. (Somewhat similar results have been found in the rivers Taw, Torridge and Dart). Although the size of the salmon smolt run does not appear to be correlated with these means one year, or two years earlier, it shows a significant (P = 0.05-0.01) decline with the minimum for August two years prior to the run, 0.55 of the variance being accounted for; a reduction 0.3 m^3/s in the minimum flow in August is associated with a reduction of 1577 in the number of salmon smolts i.e. about half the size of the average run, but the standard error of the estimate is large (797). No significant relationships between smolt run and flow have been found for seatrout.

Another relevant factor is summer water temperature, which is relatively high when flows are low. Multiple regression analysis was carried out using annual number of smolts (over the period 1967-1976) on year, and average minimum flow and average maximum water temperature for the combined months of June, July and August, both one year, and two years, prior to the smolt run; it showed significant effects (P = 0.05-0.01) for only salmon smolts with temperature and year, which accounted for 0.31 and 0.43 of the variance, respectively.

The analysis was repeated, substituting for the annual number of smolts, the residuals of the separate regression of either number of smolts on year, or number of smolts on the combined number of adults counted two years, and three years, prior to the smolt run; this still showed temperature as the only significant independent variable, the proportion of the variance accounted for being 0.54 (P = 0.05-0.01) and 0.48 (P = 0.01-0.001), respectively. In both cases the residual (as the dependent variable) is zero at a maximum monthly water temperature of about 21°C. (20.95 and 21.2°C., respectively), based upon a regression of the means of the maximum water temperature on the means of mimimum flow for June, July and August during the years 1965-1976. Such maximum temperatures in the R. Axe are found at a flow of about 1.5 m^3/s and are associated with minima of about 17°C. This is within the range (9-17°C.) reported as preferred by salmon (Mantleman, 1958a, in Alabaster & Lloyd, 1982). Flows of 0.9 and 0.6 m^3/s are associated with maximum temperatures of 23.6 and 25°C., respectively which, in turn, are associated with substantial reductions in the smolt run of about 2000 and 3000, respectively, and mean temperatures of 18 and 18.5°C., respectively, which are outside the preferred range.

4.7. Water quality

Multiple regression analysis of 3- or 4-year running-mean values of concentrations of suspended solids on year and mean flow in the R. Axe at Whitford Bridge for the period 1975-1985, shows a significant increase with year (P = 0.05-0.01); polynomial regression analysis shows concentrations reaching a maximum at about the year 1980 and remaining high from then on. Mean concentrations of biochemical oxygen demand (BOD) also show a peak at about the same time followed by a slight decline. The 95 percentile concentrations of ammonia show a peak slightly earlier at about the year 1978 and a more marked decline since then.

It is likely that such changes in water quality reflect similar changes further upstream and that these have adversely affected migratory fish in their young stages and thus, by reducing the size of the resulting smolt run, contributed to the decline in catches of returning adults.

5. DISCUSSION AND GENERAL CONCLUSIONS

The overall decline in catches of salmon and trout in the R. Axe is somewhat similar to that found in other rivers in the SWWA area. Since the runs of tagged adult salmon in the R. Axe have been closely related to those of the smolts, the decline is likely to have been linked in part to the evident deterioraton in water quality in the river over the last 10 years, although other factors, such as increased exploitation in the sea and a high incidence of disease in the early 1970's, are also likely to have been involved.

The generally poor correlation between either net or rod catches of salmon and trout on the one hand and river flow on the other is probably partly attributable to the relatively small numbers of fish involved and the incompleteness of the returns. The increase in net catch at the mouth of the river associated with a decrease in average daily river flow of 0.3 m^3/s is statistically significant but so small as to be of little consequence, especially as catches are extremely low at present.

The poor correlation usually found between trap catches of salmon and average daily river water level in the R. Axe is probably attributable in part to the poor correlation found between mean water level reported by MAFF at the trap and river flow measured by SWWA further upstream at Whitford, as shown by the scatter about the calibration curves. Even so, the results indicate the general relation between catches of salmon and flow, and show that a substantial reduction in the run in July and August is associated with a reduction in river flow of 0.3 m^3/s.

There is an indication from the data of 1964 (Table 3) that the run of salmon ceases at a flow of 0.96 m^3/s. Since the river is about 20 m wide where the trap was located, this amounts to about 0.05 m^3/s per metre width of river; this is close to the values at which migrating salmon elsewhere are reported by Craig-Hine (1985) to be inactive (at 0.03 m^3/s per metre width) and to commence migrating upstream (at 0.08 m^3/s per metre width). However, it is likely that any interuption in the run during the summer months caused by such a low flow, or any reduction caused by a reduction in flow of 0.3 m^3/s, would be compensated for by an increase later in the year; this is because the annual total number of adult fish trapped on their return to the R. Axe has been shown to be related primarily to the escapement of their particular year-class as smolts and also there is evidence for the period June-August, and an indication even up to October, that relatively low catches in one month are balanced by relatively high catches later.

Although virtually all smolts produced between 1964 and 1966 were tagged, a large proportion of the returning fish (0.66 of the salmon and 0.79 of the whitling) was not marked or carrying tags (Potter, 1985) and were probably strays from neighbouring rivers. It is possible that some of these fish, if delayed by low flows in moving upstream in the R. Axe, would be encouraged to find their home streams.

It is likely that the distribution of monthly catches of large sea-trout is also reduced with reduction in river flow, although to a lesser extent than those of salmon, while those of small sea trout (whitling) seem to be hardly affected at all.

The finding of a correlation between catches and environmental variables does not necessarily imply that these are causal relationships, especially where monthly, or even daily, averages are used. Detailed observations of individually tagged fish in estuaries indicate that, while tending to move up and down with the tidal currents, they migrate upstream into freshwater in reponse to an increase in freshwater flow (Le Cren, 1985). A similar response has been observed within freshwater in the R. Fowey (Le Cren, 1985) as well as being indicated by the detailed data given by Swain & Champion (1968) over several days in the R. Axe. It is likely that flow, or change in flow, **per se** is not the only factor involved, but that changes in water odour associated with rainfall and run-off are also important. Observations at the Axe trap would also have been affected by tidal height and hour of the day or night, both of which factors appear to be relevant to the passage of fish from tidal to fresh water. Hesitation of salmon in moving upstream has been observed at tidal doors and road bridges and may also have occurred at the Axe trap, despite the care taken to funnel the water through the upstream-migrant trap when very low flows were experienced; on the other hand, funelling the fish may have made the upstream passage of fish easier than it would otherwise have been and so minimised the problem normally posed by low flows.

Salmon smolt migration into tidal water in the R. Axe is unlikely to be affected by the proposed abstraction because it occurs when flows tend to be relatively high and also no relation between trap catches and flow have been found. Seatrout smolts in the R. Axe migrate at about the same time as salmon smolts, although over a more extended period (Potter, 1985), and thus are also unlikely to be affected by the proposed abstraction.

The size of the salmon smolt run is related to the minimum flow in

June, July and August and could be adversely affected by flows lower than $1.5 m^3/s$; a reduction in flow of $0.3\ m^3/s$ is associated with a reduction of about 1000 smolts, high water temperature probably being the factor most directly concerned. However, the effects would doubtless take place in the nursery areas, whereas the flow measured at Whitford, which had to be used in the analysis, simply reflected flows in the relevant tributaries further upstream. Only if the proposed abstraction took place upstream of the main nursery areas would it be likely that the smolt run would be reduced in size; conversely, augmentation of tributary flows during the summer could be beneficial, depending on the quality and quantity involved.

Some (perhaps one third) of the water to be abstracted at Whitford is to be exported from the catchment, but the rest is to be returned to the estuary itself as sewage effluent. Its impact will depend upon its quality and quantity and has not yet been assessed.

6. SUMMARY

The direct effects of the proposed abstraction of water from the R. Axe at Whitford upon the movements of migratory fish through the estuary are likely to be minimal, any reduction being confined to salmon and large seatrout moving upstream into freshwater during the summer months and being compensated for by an increase in catch at higher flows later in the year.

However, since a substantial proportion of fish have been trapped in the past, not during spates, but at relatively low flows (Section 4.4), more detailed data analysis remains to be carried out to investigate the relation between these catches and river flow; data on daily trap-catches of fish should be abstracted from the original log sheets held by MAFF, concentrating upon the months of June, July and August and, if necessary, more detailed analyses carried out taking into account variation in river flow and catch-rate within 24-hour periods.

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