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SOUTH WEST WATER

ENVIRONMENTAL SURVEY, MATHEMATICAL MODELLING AND LONG-TERM MONITORING OF THE TAW/TORRIDGE ESTUARINE REGION

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SALMONID FISH STUDY

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EXECUTIVE SUMMARY

An appraisal has been made of limited data on the rivers Taw and Torridge, supplied by SWWA and SWR, in order to assess the status of stocks of salmonid fish and the suitability of the estuaries to allow the passage of salmonid migrants.

For salmon, the total stocks in the rivers Taw and Torridge are relatively low and probably increasing, or remaining steady, whilst those of grilse are rising or remaining steady, and those of 2-SW and 3-SW fish are falling or remaining steady.

This situation is likely to be attributable to long-term cycles in abundance that are common to other stocks of salmon and linked to climatic changes, particularly the temperature of oceanic waters at the feeding grounds.

For seatrout, the stocks are relatively low, especially in the river Torridge, and are probably steady or falling in the river Taw and falling in the river Torridge.

This difference between the two rivers, as well as the falling trends in both rivers, appear to be linked to adverse river water quality in general, insufficient information having been made available to enable an analysis of the possible role of specific water quality characteristics.

The estuarine waters of the rivers Taw and Torridge are quite suitable for the passage of migratory salmonid fish.

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SALMONID FISH STUDY

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1. INTRODUCTION

1.1. Terms of reference

The general terms of reference of the present study are:

1) to describe the present trends in the composition and abundance of salmon and seatrout stocks in the Rivers Taw and Torridge in relation to likely causative factors and

2) to assess the suitability of coastal and estuarial waters of the Rivers Taw and Torridge for the upstream and downstream migratory movements of salmonid fish.

1.2. Limitations

1.2.1. Salmonid stocks

First, it should be pointed out that no direct measurements of the abundance and composition of the stock of salmonid fish are available for either river, there being no counting facilities installed for either upstream or downstream migrants. Therefore, in trying to estimate population numbers and trends, reliance has to be put on indirect measurements, including fish catch statistics, surveys of redds and direct sampling of populations of parr and smolts, all of which approaches are subject to uncertainty.

The number of rod licences, for example, is not available for the rivers Taw and Torridge and, in any case, catch returns for these rivers are probably incomplete and may also be variable, as is certainly true for the area of the South West Water Authority (SWWA) as a whole. Analysis of data on returns for the years 1980-1987 shows significant decreases from 57 to 38% for seasonal licences ($P = 0.01$), from 56 to 46% for weekly licences ($P = 0.05$) and from 63 to 46% for concessionary season licences; there are also indications of downward trends in concessionary weekly licence returns from 73% (in 1982) to 46%, and in day licence returns from 46 to 39% (51 to 35% for concessionary licences) although none of these latter is statistically significant. The trends outside this short period are unknown. An additional limitation is that nil returns (i.e. failures to report any catch, which have been required since 1963, and reports of no catch) are, apparently, confidential for these rivers. In any case, the fishing effort is also unknown, even for netting for which the number of fishing licences is recorded. Much of the stock of fish may enter the river outside the fishing seasons, and there is also an additional unknown quantity of fish taken illegally.

Furthermore, surveys of all kinds (chemical and biological) are bound to be restricted spatially and temporally and are, therefore, subject to sampling error over time and between sampling areas, as well as within them.

Secondly, in trying to account for the estimated stock abundance and composition in terms of various environmental and other factors, the finding of statistically significant correlations does not necessarily imply the presence of causal relationships.

1.2.2. Migratory movements

The caviats mentioned in relation to the estimation of salmonid stocks also apply to the assessment of the suitability of the rivers and coastal waters for migration. However, relevant data are also available for use from other rivers in the UK and elsewhere.

2. DATA-BASE

Data on fish and environmental factors in the rivers Taw and Torridge have been supplied by the SWWA and its successor, the National Rivers Authority, South West Region (SWR). Other sources are acknowledged in the text.

3. METHODS OF DATA ANALYSIS

Trends in catches of fish, river flow and water quality with time, and the relationships between catches and other factors have been evaluated using standard statistical methods, generally either linear and polynomial regression, as mentioned in the text.

4. RESULTS

4.1 Long-term annual catch statistics

The longest time-span of data on catches of salmon and seatrout in the rivers Taw and Torridge is from the statutory annual returns which have been summarised by the Ministry of Agriculture, Fisheries and Food (MAFF)(1961) up to the year 1959, and has been extended to 1988 for the present analysis using comparable data supplied by SWWA. For net-caught fish it begins as a continuous record from 1928 for salmon and from 1929 for seatrout, but there is a gap in the results over the years 1947-1950. For rod-caught fish it is continuous from 1930, but also includes figures for the years 1887 and (for seatrout only) the year 1886. The results are summarised in Figs. 1-4 for salmon and Figs. 4-8 for seatrout, high-order polynomial curves having been fitted to describe the general variation in catch with time.

4.1.1. Salmon

The results for net-caught salmon (Fig. 1) show a general decline from the year 1928, although there appear to be two long-term oscillations over a period of about 30 years, as well as considerable scatter in the data; the latter is probably attributable largely to shorter-term oscillations, the Durbin-Watson ratio indicating a first-order positive auto-correlation.

Catches on rod and line (Fig. 2) are only a fraction (0.14 on average) of those in nets and, whilst they show no significant general decline with time, they do exhibit some long-term oscillations, again over a period of about 30 years, although not exactly synchronised with those of the net catches. Nevertheless, annual rod catches are generally significantly positively correlated with net catches ($P = 0.01$) and, although there is considerable scatter in the results (Fig. 3), the distribution of residual variances is not significantly different from normal ($P = 0.05$); rod and net catches have, therefore, been combined in Fig. 4 in an attempt to describe the long-term trends in catch. A general decline over the whole period is evident, together with some recovery during the middle years and a sharper decline more recently.

It should be noted, however, that there has been a gradual reduction in the number of net licences from a total of 36 in the year 1980 to 14 in 1987, following a Net Limitation Order of 1981. At that time, too, there were also restrictions placed on the length of net of minimum mesh size and on the area available for netting, as well as the prohibition of the use of spinners for angling. These changes probably resulted in catches since 1980 being lower than might otherwise have been the case. Indeed, when the data for 1980-1988 are expressed as catch per licence, no significant trend is apparent in that period.

4.1.1.1. Comparison with other rivers

The annual statutory returns for other rivers (MAFF, 1961) also show long-term trends and oscillations, as well as considerable scatter from year to year. The records for some of these rivers for the years between the 1860's and the 1920's are much more complete than are those for the rivers Taw and Torridge and demonstrate that the long-term oscillations are present throughout the period; those, for example, for net and rod catches in the river Avon, Hampshire, (Wessex Water Authority, 1986) and for nets operated by the Aberdeen Harbour Board (Martin & Mitchell, 1985), occur at 20- to 30-year intervals. This suggests that the long-term oscillations are natural phenomena common to salmon in widely separated areas.

For the period 1940-1980 there is some indication of a coincidence in peak catches in nets and fixed engines in the 1960's in the rivers Eden, Lune, Ribble and Dee - all in the north-west part of England and Wales - although long-term trends are upward in the first two and downward in the latter two. In other rivers, however - the Dart, Teign and Exe, all in the area of SWR - any such coincidence is not obvious, whilst the long-term trends are again either upward, for the first two, or downward, for the latter (see the graphs plotted by Wessex Water Authority, 1986). Downward trends since the early 1970's have also been recorded in Scotland as a whole (National Water Council, 1982) and elsewhere e.g. in France (Prouzet, personal communication).

The shorter-term oscillations of 5 or 10 years, or so, appear to be largely natural phenomena, since they have been reported elsewhere (e.g. Huntsman, 1937; Gee & Milner, 1980; Wessex Water Authority, 1986) and are predictable on theoretical grounds from simple predator/prey or survival/ mortality relationships (e.g. Ricker, 1954; Gee & Milner, 1980). Even the apparently random variations in stock would be predictable from purely deterministic processes controlling population density (e.g. May, 1989).

Thus, the annual returns of salmon catches in the rivers Taw and Torridge, combined, limited as they are, do not indicate anything particularly unusual in terms of short-term variations, but the long-term downward trend, although found in some other rivers, is certainly not universal. Indeed, the net catches in the river Taw and Torridge are negatively correlated with those of Englnd and Wales as a whole for the period 1953-1983.

4.1.1.2. Comparison within the area of SWR

Net catches of salmon for the area of SWR as a whole, excluding those for the rivers Taw and Torridge, are plotted with trend lines for the years 1952-1987 in Fig. 9 and corresponding data for the rivers Taw and Torridge are replotted in Fig. 10 (from Fig. 1) for easy comparison. Similar graphs for rod catches are plotted in Fig. 11 and (from Fig. 2) Fig. 12, respectively.

Whilst net catches show no significant trend for the area of SWR as a whole, excluding the rivers Taw and Torridge (Fig. 9), they do show a significant ($P = 0.01$) downward trend for the rivers Taw and Torridge, amounting to about 0.8% per year (Fig. 10). This trend is still apparent

(P = 0.01) even with the exclusion of catches from 1981 onwards (when the netting effort was reduced), still amounting to a reduction of about 0.7% per year.

The annual catch of salmon on rod and line also shows a downward trend for the rivers Taw and Torridge combined and for the combined catch in all other rivers in the area of SWR; the effect is, however, greatest and most significant for the Taw and Torridge (1.03% per year, and P = 0.01, respectively, compared with 0.65% per year and P = 0.05 for the rest of the area of SWR).

The rod catches for salmon are given for the rivers Taw and Torridge, separately in Figs. 13 and 14, together with significant linear trend lines (P = 0.01); the annual rate of reduction in catch is only about 0.09% for the river Taw, which is lower than for the rest of the area of SWR, but is much greater (1.14%) for the river Torridge. Polynomial curves fitted to these data (Figs. 15 and 16) indicate a levelling off of rod catches over the last decade or so.

4.1.1.3. Conclusions

Annual catches of salmon in the rivers Taw and Torridge, in common with other rivers, show marked oscillations over the last 50 years but, unlike the general trend for the rest of the area of SWR and for the whole of England and Wales, they have shown a marked decline over the last 30 years, especially in the rod catch, particularly in the river Torridge.

4.1.2. Seatrout

The annual catches of seatrout are graphed in Figs. 5-8. Those in nets (Fig. 5) show a marked increase in the 1950's with some indication of a recent decline since about 1983; this decline, however, is not evident if the data for 1981-1988 are eliminated which suggests that it may be partly attributable to reduced netting effort during that period. Indeed, when the latter data are expressed as catch per licence, no significant trend is apparent in that period. For the years 1950-1985, net catches are positively correlated with net catches in England and Wales as a whole (P = 0.01), which also show a general increase with time.

Catches on rod and line for the rivers Taw and Torridge combined (Fig. 6) also show an upward trend in the 1950's, but are soon followed by a fairly marked steady decline from the mid-1960's. This decline is in marked contrast to the results with nets. There is also a slight upward trend from about 1984; this latter increase may also be partly the result of reduced netting, although an upward trend is still indicated when the data for 1981-1988 are eliminated.

Although the rod and net catches do not coincide during the latter third of the period, they are generally positively correlated (Fig. 7), albeit with a considerable scatter. They have, therefore, been combined in Fig. 8 in an attempt to describe the long-term trend in catch. In general, numbers rise from very low values in the early 1930's to a peak in the 1960's, falling thereafter to about half the maximum by the present day, discounting any effect of reduced fishing effort since 1981.

4.1.2.1. Comparison within the area of SWR

Net catches of seatrout for the area of SWR as a whole, excluding those for the rivers Taw and Torridge, are plotted for the years 1953-1987 in Fig. 17, and corresponding data for the rivers Taw and Torridge combined are replotted in Fig. 18 (from Fig. 5) for easy comparison. Similar graphs for rod catches are plotted in Fig. 19 and (from Fig. 6) Fig. 20, respectively.

Net catches for the area of SWR as a whole, excluding the rivers Taw and Torridge show an increase at the beginning of the period and a decrease at the end, with two peaks in between (Fig. 17). Those for the rivers Taw and Torridge combined also show an overall increase and then a decrease, but with only one broad peak (Fig. 18).

The annual catch of seatrout on rod and line for the area of SWR, excluding the rivers Taw and Torridge shows a distribution similar to that of the nets (Fig. 19), and a similar picture applies to the rivers Taw and Torridge combined (Fig. 20), although catches in both rivers, and especially in the Torridge, tend to fall to lower relative values during the last decade or so (Figs. 21 and 22).

4.1.2.2. Conclusions

Thus annual catches of seatrout, whilst exhibiting long- and short-term fluctuations, show considerable similarity between the rivers Taw and Torridge and also between these and other rivers in the rest of the area of SWR, although rod catches in the Taw, and especially in the Torridge, tend to be relatively lower than elsewhere in the area.

4.1.3. Comparison of rod catches in the rivers Taw and Torridge

The similarity in the shape of the trend lines for rod catches of salmon in the rivers Taw and Torridge (Figs. 15 and 16) and the similarity in shape also found in those for rod catches of seatrout for these two rivers, although different from those of salmon (Figs. 21 and 22), indicate that the same factors are operating on a given species in both rivers, albeit to a greater degree in the river Torridge. This is so whether the factors are connected with the availability of fish or with their catchability.

The degree to which these factors are operating can be expressed, independently of the generally declining number of fish caught, by calculating the catch in the the river Torridge as a proportion of that in the river Taw. The result in Figs. 23 and 24 for salmon and seatrout, respectively, shows how rod catches of salmon in the river Torridge have been depressed more than those of seatrout.

It can be noted that these proportions have fallen to values well below the corresponding values for both the catchment areas (0.8) and the average annual daily mean flow of the rivers (0.85, for the period 1963-1988).

4.1.4. Weights of fish

Limited data have been provided by SWR on the weights of fish caught. They are restricted to annual weight and number of fish caught in nets in each river in the area of SWR for the years 1974-1987. Data for rod-caught fish are even more retricted; they are available for the river Taw, only in 1983-1987, for the river Torridge, only in 1984-1987 and for the whole area, only in 1985-1987. Monthly numbers and weights of fish have not been provided for net catches or rod catches, except for the river Taw in 1985. Obviously, this paucity of information on weights severely limits the conclusions that can be drawn on the nature and extent of trends in the fish stocks.

Over the 13-year period the annual mean weight of net-caught salmon was 8.65 lb (3.9 kg) in the rivers Taw and Torridge, which was consistently slightly higher than that (7.85 lb; 3.56 kg) in the the whole area of SWR. There were no obvious trends with time in either case; this is, perhaps, not surprising in view of the known variability in average fish weights and the relatively short length of records.

The annual mean weight of salmon caught on rod and line averaged 9.12 lb (4.14 kg) in the river Taw (for 1983-1987) and 8.66 lb (3.93 kg) in the river Torridge (for 1984-1987), compared with 7.38 lb (3.35 kg) for the area as a whole. Thus they were also generally somewhat heavier than those of net-caught fish.

For seatrout, the corresponding figures were 2.78 lb (1.26 kg) and 2.75 lb (1.25 kg), respectively. Again there were no obvious trends with time. However, Hamilton (1979) analyses the weight distribution for two years, 1972 and 1979. In 1972, 19% of the catch weighed 1 lb or less, whereas in 1979, 40% were in this category. It is likely that these fish were whitling - fish that had migrated to sea as smolts in the year of capture.

The annual mean weights of seatrout caught on rod and line averaged 1.59 lb and 1.58 lb (0.72 kg) for the rivers Taw and Torridge, respectively, compared with 1.4 lb (0.64 kg) for the whole area. Again, Hamilton (1979) found that about 60% of the catch weighed 1 lb or less in 1972, a much higher proportion than that found for net-caught fish.

Thus the salmon caught on rod and line in the rivers Taw and Torridge were generally slightly heavier, whilst the trout were generally slightly lighter, than those caught in nets. The fish were also somewhat larger than those caught elsewhere in the area of SWR.

Monthly records of catches of salmon in the river Taw in 1985 showed no marked trend in weight with place of capture along the length of the river or with time of year, except that fish caught in July tended to be smaller (average 7.6 lb; 3.45 kg) than those caught during the rest of the season (9.6 lb; 4.35 kg). This is to be expected since fish that have spent one winter at sea (1-SW fish, or 'grilse') are likely to predominate during July, a high proportion (0.52) having been caught in nets in this month during the period 1965-1979 (Hamilton, 1979).

For the years 1974-1980, there are data for net-caught fish in the rivers Taw and Torridge for both the proportion of grilse based upon scale sample and weight distribution analysis (Hamilton, 1979) and total annual weight. The relation between the two is significant (P = 0.01) so that, assuming that it would apply for the period 1974-1987, it might be concluded that there had been no trend in the proportion of grilse in the catch over this period; it would have averaged 0.52. However, grilse weights may not have remained constant; on the contrary, they may have increased as they have been found to do (from about 2 kg to 3 kg) between 1952 and 1972 in the catches of the Aberdeen Harbour Board (Martin & Mitchell, 1985).

4.1.5. Salmon of known sea-age

Data are available for numbers of net-caught salmon of particular sea-age determined from scale samples for the years 1965-1972 and from scale samples and weight distribution analysis for the years 1972-1979. (No data are available for later years or for rod-caught fish). During this period the total catch of salmon in nets, whilst being extremely variable, showed no marked trend (approximately the middle part of Fig. 1). This part of the record is replotted in Fig. 25 for easy comparison with the corresponding records for grilse (Fig. 26), 2-SW fish (Fig. 27) and 3-SW fish (Fig. 28).

Catches of grilse show a significant increase (P = 0.05), whilst those of 2-SW and 3-SW fish both decrease (P = 0.01), although the latter were present in relatively low numbers.

Thus, when there was no particular trend in total catch in nets, an increasing abundance of grilse was roughly balanced by a decreasing number of 2-SW fish.

4.1.6. The effect of oceanic water temperature

It has been shown (Martin & Mitchell, 1985) that the proportion of multi-SW salmon in the catch in nets operated by the Aberdeen Harbour Board from 1877 to 1972 increased significantly, from about 0.3 in 1952 to 0.8, with increase in sub-arctic temperature over a small range of about 2 deg C (measured at Grimsey Island, N. Iceland). Over the whole period, numbers of salmon increased with increase in temperature whilst numbers of grilse decreased.

Annual measurements of sea temperature in N. Iceland waters (66°N, 18°W) are available for the period 1952-1985 at 50 m (Malmberg, 1985); they are plotted for the period 1952-1980 in Fig. 29 and, although extremely variable, show relatively high values in the presence of high salinity Atlantic water up to 1962, and relatively low temperatures with the intrusion of low salinity Polar water since then.

The total catch of salmon in nets in the rivers Taw and Torridge over this period is re-plotted in Fig 30 from part of Fig. 1. The broad similarity to the graph of temperature is obvious and a significant positive correlation is found (Fig. 31) between catch and temperature ($P = 0.01$); the correlation is smaller (0.41) and less significant ($P = 0.05$) when catch is related to temperature in the year previous to the catch, and is slightly larger (0.56) and more significant ($P = 0.01$) when it is related to temperature two years previously (Fig. 32).

The data on the estimated number and proportion of salmon of known sea-age in net catches in 1965-1979 (Hamilton, 1979) were also regressed against Icelandic sea temperature: for grilse, in the year before catch; for 2-SW fish, averaged for two years previously; and for 3-SW fish, averaged for 3 years previously. However, no significant results were found; this may be because the record started after the major reduction in ocean temperature, or because other factors of over-riding importance were operating.

4.1.6.1. Freshwater flow

Another factor which has been examined is the freshwater flow in the rivers. The variance in catch about the polynomial regression in Fig. 30 was regressed against the total flow during the netting period (April to August); however, no significant relationship was found.

4.1.6.2. Conclusions

It appears, therefore, that although there is still a considerable amount of unaccounted variation in annual net catches of salmon in the rivers Taw and Torridge, the general trends, like those described by Martin and Mitchell (1985), are related to ocean temperature. This factor, however, does not account for the general difference in annual rod catches of salmon between the rivers Taw and Torridge, nor the trends in seatrout catches and the differemce in rod catches of seatrout between the two rivers.

4.2. Long-term monthly catch statistics

The long-term trends in annual catches reflect the trends within the fishing seasons; these may differ between different times of the year and also be affected by environmental factors. In seeking to describe temporal trends, therefore, account has to be taken of such factors, when possible, although synchronous data may be limited to relatively short periods. In general, the approach has been to use multiple linear regression analysis.

4.2.1. Net catches

The results for monthly catches of salmon and seatrout in nets are summarised in Tables 1 and 2.

4.2.1.1. Salmon

Catches of salmon have been related to year of capture, the combined monthly mean daily flow of the rivers Taw and Torridge and water temperature off N. Iceland, as mentioned in Section 4.1.6 (Table 1).

For the months of May and June, catches decreased significantly with time, but in August they increased; this is consonant with a high proportion of multi-SW fish being present in the early months and with grilse predominating in the summer, the numbers of which have decreased and increased, respectively, with time, as set out in Section 4.1.5.

Catch is negatively correlated with river flow in July, the month when river flows were lowest during this period of analysis (average monthly mean daily value of 9.86 m^3/s; range, 1.2-44.5 m^3/s). Presumably, this is because low flows tended to hold fish up in the estuary and increased the time they were at risk from netting. The effect appears to be progressive through the season, as indicated by the correlation coefficients plotted in Fig. 33. The same effect has be found in the river Axe, Devon (Alabaster, 1986).

Oceanic temperature is significantly positively related to catches in May which is consistent with the relation between muti-SW fish and temperature found by Martin & Mitchell (1985). Again, the effect is progressive through the season, as illustrated by the correlation coefficients plotted in Fig. 34.

The analysis has been pursued for grilse, 2-SW salmon and 3-SW salmon separately (Table 2) using the data of Hamilton (1979). The result reinforces the conclusion that grilse catches have increased, especially in August, whilst those of multi-SW fish have decreased. It sheds no further light on the effect of flow and sea temperature, although the correlation coefficients indicate differences between grilse and multi-SW fish for these two factors, as shown in Figs. 35 and 36, respectively. Catches of multi-SW salmon do not appear to be affected by flow (Fig. 35) and the correlation with temperature tends to be positive with grilse and negative with salmon as well as tending to increase in the negative direction during the season with all fish.

4.2.1.2. **Seatrout**

The results with seatrout are summarised in Table 1. Catches increased in April and May over the period. They do not appear to be related to flow, which is in accord with observations elswhere that the entry of seatrout into freshwater from estuaries is less affected by freshwater flow than that of salmon - e.g. in the river Coquet (Alabaster, 1970) and the river Axe, Devon (Alabaster, 1986; 1987; 1989a).

The lack of a correlation with Icelandic temperatures is to be expected since the fish do not appear to migrate in that direction, although there are doubtless correlations between the meterological conditions in that region and those in South-west England.

4.2.2. **Rod catches**

The results for monthly catches of salmon and seatrout on rod and line are summarised in Tables 3 and 4.

4.2.2.1. **Salmon**

The results for rod-caught salmon (Table 3) show significant negative correlations with year only in August in the river Taw, but also in March and June in the river Torridge.

In both rivers, however, there are significant positive correlations with river flow for many months, as has been found by the author for rod catches in other rivers, e.g. the Aberdeenshire Don and Dee. This is also consistent with the positive effect of river flow on the movement of fish into freshwater (**loc. cit.** Section 4.2.1.2.), the positive effect of flow on rod catches (Alabaster, 1970) and the negative effect of flow on net catches, as found in the estuary of the Taw and Torridge in July (Table 1).

In August, a relatively small amount of the total variance in rod catch in the river Taw was related to the flow expressed as a fraction of that in the river Torridge. An explanation is not obvious, as there is no evidence of water quality in the Torridge being less favourable to salmon than that of the river Taw (see Section 4.7); water temperature in the river Torridge tends to be somewhat higher than that in the river Taw, but effects of river water temperature on catches have not been demonstrated, although they have been found by the author elsewhere, e,g, in the river Don, Aberdeenshire, and have also been found to affect the movement of salmon into freshwater from the estuary of the river Axe (Alabaster, 1989a).

A further analysis, which included mean monthly river temperature for June to August combined, failed to show any effect of temperature, but gave fairly consistent results in relation to flow for both the rivers Taw and Torridge (Table 4).

4.2.2.2. Seatrout

The results for seatrout (Table 3) show significant negative effects of time on rod catches only in the river Torridge, especially late in the season (July-September). There are also positive correlations with flow for the summer months only.

In May, a substantial amount of the variance in the river Torridge was related to the flow in the river expressed as a proportion of that in the river Taw. This suggests that at times of relatively high flow in the former, more fish might be caught than would otherwise be the case.

A further analysis (Table 4) was carried out with the inclusion of mean monthly river temperature as an additional independent variable, but it failed to show any effect of temperature, although it gave fairly consistent results in relation to flow for the rivers Taw and Torridge.

4.2.3. River flows

Because of the marked effect of river flow on fish catch, particularly the increase in rod catch with increase in river flow, the flow records for the rivers Taw and Torridge have been examined for trends. These are summarised in Table 5. This shows that in both rivers there has been a significant reduction in flow in August, amounting to approximately $0.4m^3/y$ in the river Taw and $0.3m^3/y$ in the river Torridge; there has also been an increase in December. Changes in other months do not show significant linear trends.

4.2.4. Conclusions

Monthly net catches of multi-SW salmon have decreasd with time. This is partly accounted for, in May, in terms of sea temperatures off Iceland. Monthly catches of grilse, on the other hand, have increased, although they were reduced by high freshwater discharge in July.

Monthly rod catches of salmon show a decline in some months, especially in the river Torridge, and also decrease with reduction in river flow. River flow partly accounts for the fall in catch, since it has also declined in August in both rivers; this decline in flow, however, has been similar in both rivers, whereas catches have fallen more in the river Torridge than they have in the river Taw.

Monthly net catches of seatrout have increased, but monthly rod catches have not shown any linear trends.

4.3. Fish stocks in relation to catches

Fish catches can be used as a reliable index of stocks over a period, if they are representative samples, are relatively small in relation to the stock size and are of known efficiency. The question of sample size will be deferred to Section 4.4. In this section, the representativeness of the samples and the efficiency of sampling will be touched upon. Data for the period 1965-1979 are used for comparison because the estimated numbers of grilse, 2-SW fish and 3-SW fish are available (Hamilton, 1979).

The question of catch per unit of netting effort is taken up in Section 4.3.4.

4.3.1.Salmon

4.3.1.1. Net catches

The monthly numbers of salmon of different sea-age have been expressed as a percentage of the total of all ages and then plotted in Fig. 37, excluding 3-SW fish because they comprised only 2.6% of the total. The 2-SW fish (left-hand graph) tended to be caught about 6 weeks earlier than the grilse, whilst the 3-SW fish were caught mainly about a month earlier than the 2-SW fish. The two plotted seasonal distributions are evidently truncated for lack of fishing at the beginning and end of the season, especially that for grilse. This suggests that the numbers of grilse were under-estimated in the net catches and that the upward trend (Fig. 26) may have also been under-estimated. Similarly the numbers of 2-SW fish may also have been under-estimated, although to a lesser degree.

Nevertheless, the near-normal appearance of the distributions within the fishing season, as might be expected of a run of a particular sea-age, suggests that the sample is reasonably representative. Furthermore, it is likely that escapement during fishing times and during the regular weekly closed season, as well as immediately before and after the fishing season, would tend to follow the same general seasonal trend as the catches themselves, although escapement might well be reduced at low river flow.

The representativeness of the net catches has been examinied further by fitting normal distributions to the data for 1965-1979 for salmon of each sea age. This was done by supplying the next missing values and fitting the best distribution iteratively (W. J. Brooker, personal communication). A very good fit (Filliben, 1975) was obtained with 2-SW fish (P = less than 0.005) and with 3-SW fish (P = 0.01-0.005) from which the portion of the run that was captured by the nets could be calculated; it was 0.92 and 0.66 for these two age groups, respectively. The distribution of grilse, however, was markedly asymmetrical because of 4 individuals counted in April out of a total of over 13,000 but, with these eliminated from the analysis, an excellent fit was also obtained (P = less than 0.005), and the proportion captured estimated at 0.94. Thus a high proportion of the runs was captured in this period. Applying this method of estimation to all the data in the period, irrespective of sea age, also gave a good fit and produced an overall estimate of capture of 0.83.

This method of fitting normal distributions has also been used to estimate the proportion captured thoughout the period 1953-1988, for which the purpose, it was divided into 6 equal periods of 6 years each. The figures obtained were: 0.80, 0.88, 0.92, 0.96, 0.72 and 0.86, respectively and thus, whilst they tended to be lowest at the beginning and end of the whole period, probably because of the predominance of 2-SW and 3-SW fish at the beginning and of grilse at the end, they are all reasonably high.

4.3.1.2. Rod catches

The distribution of rod catches of salmon in the rivers Taw and Torridge is shown for each river separately in Fig. 38 - by the dashed and plain lines, respectively. Whilst the percentage distributions within each river are similar, they are markedly different from those of grilse and 2-SW fish in Fig. 37, and that of the total for all ages. This indicates that catches on rods are inversely related to those in nets. This relationship (P = 0.01 for logarithms) could imply that rod catches are reduced by high net catches, but it is more likely that the efficiency of rod fishing is reduced as the number of fish available for capture increases, as has been shown for anglers' total annual catch of salmon in the river Coquet (Alabaster, 1970); see also Section 4.4.

In any event, it appears that, of net and rod catches, the former would be the better measure of stock abundance.

4.3.2. Seatrout

The data for seatrout, corresponding to those in Figs. 37 and 38, are plotted in Figs. 39 and 40 for net and rod catches, respectively. With this species, the pattern of seasonal catch in nets is similar to that for salmon, again suggesting a near-normal distribution. The pattern for catch on rod and line, however, although similar in shape, is displaced about one month later. Rod and net catches are not correlated, even if net catches are taken for the preceeding month, the main reason being the very high rod catches in August. This is presumably because of high catches of whitling, which are returning in the same year in which they migrated seawards as smolts and which are too small to be caught efficiently in the nets. This probably also accounts for the weight of rod-caught fish being lower than that of those in nets (Section 4.1.4)

The number of seatrout caught on rods, expressed as a proportion of the number caught in nets shows no trend, even excluding the data for August, which is in line with the observation in the river Coquet that, in contrast to the situation with salmon, anglers' overall annual efficiency changed very little as numbers of seatrout available for capture increased.

The stock of seatrout would, therefore, probably be better expressed as a combination of net and rod catches, rather than as one or the other.

4.3.3. Conclusions

Considering only rod and net catches as measures of stock, net catches would appear to be the better for salmon, whilst a combination of both would probably be suitable for seatrout.

4.3.4. Catch per unit effort of netting

Since 1980, the netting effort has varied in terms of 1) a reduction in the length of net having a minimum mesh size, 2) restriction on where netting is allowed, 3) the number of licenced nets, which was 36 in 1980 and has ranged irregularly from 14 to 22 since then, 4) the number of endorsees, which has varied from 38 to 206 in the period 1974-1988, whilst the number of endorsees per licence has fallen steadily from about 5 in 1980 to about 3 in 1988, and 5) a 20% extension of the weekend close season. These changes, amongst others, increase the uncertainty in interpreting the catch data in terms of stock.

The data for 1974-1988 have, therfore, been examined to see whether or not the annual catch of salmon per unit effort is constant. Fishing effort has been expressed in two ways - as the number of licenced nets and as the number of endorsees; catch has been expressed as the annual number of fish caught per net and as the annual number of fish caught per endorsee, respectively.

In both cases, the efficiency of netting decreases with increase in effort (P = 0.05), the correlation coefficient being slightly larger for catch per endorsee (0.63) than for catch per net (0.56). The former relationship is utilised later, when considering the interaction between adults and progeny (Sections 4.5.2. & 4.5.3).

4.4. Redd surveys

A summary of total numbers of redds of salmon and seatrout observed in 6 areas of the river Torridge is given by Davies (1986) for the years 1979-1984 inclusive. Additional information was made available for the river Torridge by SWR on maps of the river showing both the areas surveyed and the location of individual redds for the years 1985, 1986 and 1988. Similar maps were also provided for the river Taw for these years and 1987. All areas were not always covered and surveys were not always complete for a given area. Conditions of river height and water turbidity were not always good for making observations, especially in 1985 and 1986. Other observations have been made since 1968, but details have not been provided.

The most complete record is for the river Okement, a tributary of the river Torridge. The count, however, was very variable from year to year and no significant correlations were detectable with year, net catch or river flow, except for a positive correlation between the count of seatrout redds and river flow in November, when the years 1984 and 1986 were eliminated.

The remainder of the data are too few to seek meaningful correlations, except that it is possible to draw some tentative conclusions about rates of exploitation.

4.4.1. Exploitation by rods

The maximum rate of exploitation by rods can be calculated from the number of fish caught on rods and the minimum number of redds observed, if the number of fish associated with each redd is known. For the present calculations, it is assumed that this number is two, as shown by Blezard **et al.**, 1970.

The lowest values of these maxima were found in the river Torridge, those for the years 1985 and 1988 being 0.13 and 0.28, respectively; they related to net catches of salmon of about 1600 and 500, respectively and therefore indicate that the maximum rate of exploitation may fall with increase in number of fish available, as already suggested in Section 4.3.1.

4.5. Juvenile salmonid populations

4.5.1. Surveys of fry and parr

Several surveys have been carried out to estimate the number of juvenile salmon and trout present in the the rivers Taw and Torridge. For those carried out in 1964, 1975 and 1979 in the river Taw, and in 1968, 1975 and 1979 in the river Torridge, Hamilton (1979) gave the mean values for different numbers of salmon and trout for several groups of stations, without identifying them specifically. The surveys of 1983 were summarised by Davies (1985) listing the stations and comparing the results with those of 1979. Reader & Steel (1987) gave details of the survey of the river Torridge made in 1986, including all the stations and also giving the results for non-salmonid fish and mean weights of the fish; they also included comparable data for salmonid fish for 1979 and 1983. A similar report has also been produced for the survey of the river Taw carried out in 1988 (SWWA, 1989a), but only a preliminary assessment is available for a similar survey of the river Torridge in 1988; the number of salmonid fish caught on the first of three samplings is given for each station, together with the numbers caught on each of the three samplings in 1983 and 1986.

Exactly comparable data for the whole period are not, therefore, available, but there is sufficient overlap between sets of consistent data to illustrate the general changes over time. The results, using the maximum number of comparable stations are shown for salmon of 1+ years and more in Figs. 41 and 42, for the rivers Taw and Torridge, respectively, and for trout for these rivers in Figs. 43 and 44, respectively. The last three connected points in Figs. 42 and 44 are calculated from the total number of fish caught in the first sample only, divided by the total area sampled, as given by Reader & Steel (1987), whereas the actual population estimates would be about twice as high, as calculated in Section 4.5.4. The corresponding results for 0+ fish are given in Figs. 45-48; the same caviat applies to the last three points as for the 1+ fish.

On all the graphs, the un-linked points are for seven other rivers in the area of SWWA, as given by Hamilton (1979).

4.5.1.1. **Conclusions**

It is evident that for salmon of all ages in both rivers (Figs. 41, 42, 45 & 46), the numbers of juveniles are below average for the area and, except for 0+ fish in the most recent samples in 1988, have tended to fall over the period, although there was also a general partial recovery in 1983. This conclusion is congruant with the results of net catches already described (Section 4.1.1).

For trout, the numbers of all ages in the river Taw have been about average for the area (Figs. 43 & 47), although they have varied widely from year to year. In the river Torridge, on the other hand, the numbers have been very much below average, especially for the 0+ fish (Fig. 48), whilst for 1+ fish and over, they have declined progressively over the period (Fig. 44). This situation is also congruent with the results of net catches (Section 4.1.2).

4.5.2. Relation between juvenile salmonids and redd counts

There are only a few years' data available when the estimated number of juveniles is matched by corresponding information on redd count. These are limited to the year 1988 in the river Taw, and to 1983 and 1986 in the river Torridge.

There are no significant correlations between the number of juveniles and redd counts in previous years, except for salmon, using the normalised data for 0+ and 1+ fish combined ($P = 0.01$). The level of significance increases slightly when the redd count for the river Taw in 1986 (when observations were incomplete) is eliminated. The equation is:

$$y = 0.1 + 0.64\ x,$$

where y is the density of 0+ and 1+ salmon expressed as a proportion of the mean values of either, and x is the redd count in 100's; it implies an increase of about 60% above average for the maximum observed count of 240 in the river Taw and suggests, not unexpectedly, that the spawning capacity of salmon in these rivers is a limiting factor in the production of juveniles.

The lack of clear evidence for a similar relationship for trout may be the result of non-migratory trout contributing to the population of juveniles.

4.5.3. Relation between juvenile and adult salmonid fish

In the absence of more extensive and reliable data on redd counts, an indication of the size of the spawning population may be given by the net catches, provided that escapement is consistent. Net catches have, therefore, been used to examine the relation between juvenile and adult populations, although there are only a few years' matching data available for either river.

The missing data for the river Torridge in 1988 have been estimated by calculating the overall efficiency of capture from the triple fishings in 1986 and 1987 (Leslie & Davis, 1939) and using the mean of the two to adjust the single catch data for 1988.

The numbers of 0+ and 1+ fish have been regressed against the net catch per licence endorsee, one and two years previously, respectively. Significant positive correlation ($P = 0.05$) was found with 0+ and 1+ salmon in the river Torridge alone and when combined with the river Taw. Replicate regressions were made using, as the dependent variable, the residual variances from the relation between catch per endorsee netsman and number of endorsees (Section 4.3.4.); they were positive, but not statistically significant.

The finding of significant relationships between juvenile populations and net catches reinforces the notion that the latter can be used as a general measure of stock abundance of salmon, albeit with some caution when netting effort is not constant. The converse relationship is to be expected and should be of value in predicting future runs in the short term.

4.5.4. Relation between adult and juvenile salmonid fish

There are only three years (1975, 1979 and 1983) when estimates are available for the numbers of juvenile salmonid fish in both the river Taw and the river Torridge, so enabling further estimates to be made of the potential smolt runs for the two catchments together. This has been done by taking the average number of 1+ parr for both catchments after adjusting for the relative sizes of the two catchment areas. This simple measure of potential salmon smolt production was cross-correlated with: net catch one and two years later; corresponding number caught per endorsee netsman and residual variance about the relation between net catch per endorsee; and number of endorsees (Section 4.3.4.). The highest value (0.99) was obtained with the latter and was positive, but of course it was not statistically significant.

Extra data points have, therefore, been estimated for 1964, 1968 and 1986 from the relationships between salmon populations in the two rivers:

$$y = 0.46 + 0.64 \, x \text{ and}$$
$$x = -0.65 + 1.54 \, y$$

where y is the number of 1+ salmon per 100 m^2 in the river Taw and x is the corresponding number in the river Torridge. (These equations also illustrate the difference between the two rivers).

The number of endorsees is not available for the two earliest years, so the catch per net had to be used as the independent variable. A significant relationship was found between the average number of 1+ salmon and the catch of adults three years later ($P = 0.05$), but not with the catch two years later. This may be because the grilse tend to be aged 2+ as smolts and have a higher rate of return that the 2-SW fish. The equation is:

$$y = 7.64 + 16.5 \, x$$

where y is the annual catch of salmon per net and x is the average number of 1+ salmon per 100 m^2. Other things being equal, this equation would predict catches well above average in 1989 and 1990.

4.5.5. Conclusions

The numbers of juvenile salmon are relatively low in the rivers Taw and Torridge. They are positively related to redd counts, generally reflect the net catches of adults, and are specifically correlated with catches of fish from which they might be derived and to which they might have given rise.

Such results support the use of the commercial net catch to indicate stock abundance as well as the use of estimates of juvenile populations to predict adult returns in the immediate future, making allowance in both cases for any reduction in net catch per unit effort that accompanies an increase in effort.

The numbers of juvenile trout are relatively low only in the river Torridge. Thus they too reflect the general pattern of net catches, but, unlike salmon, they show no clear relation to redd counts.

4.6. River water quality

4.6.1. Biological surveillance

The results of annual surveys of aquatic invertebrate organisms made in the river Torridge in 1978-1983 have been summarised by Newton (1985). Three of the sites examined in 1979, and 15 of those included in 1983, were either identical with, or very close to those for which data on juvenile populations of salmonid fish were summarised by Davies (1985). One of these sites (that had data on both fish and invertebrates) was examined in both years; between the two dates the numbers of salmon and trout of all ages increased, but the biotic scores - Biological Monitoring Working Party (BMWP) score and average score per taxon - both decreased (Table 6).

The data for all 18 site/occasions have been analysed for significant cross-correlations; none was found.

The results for three stations in the upper, middle and lower reaches of the main river Torridge (Kingsley Mill, Beaford Bridge and Rothern Bridge, respectively) are shown in Fig. 49 for the BMWP score, and in Fig. 50 for the average score per taxon. They are both plotted on the same time scale as that used in Figs. 41-48 for juvenile salmonid fish, in order to facilitate comparison.

There is a tendency for the scores to be highest in the upper reaches (the upper curves in Figs. 49 and 50) and for them to fall between 1980 and 1983; this is in contrast to the general increase in the numbers of salmon and 0+ trout over this period.

4.6.2. Chemical sampling

The information that has been made available on water quality in the rivers Taw and Torridge comprises: 1) single annual values for biochemical oxygen demand (BOD), ammonia and dissolved oxygen (DO) for 18 stations on each river for the period 1967-1984 (SWWA, 1985); 2) individual sample data for one station on each river (Chapelton Footbridge on the river Taw and Beam Footbridge on the river Torridge) for the period 1983-1988; 3) individual sample data for 8 stations on the river Torridge for 1974-1989; and 4) daily summaries for one station (Sheepwash) on the river Torridge for March-September, 1988.

Thus, the data are only partially compatible over the whole period and between the two rivers. This makes impossible, a proper comparison between the rivers Taw and Torridge and assessment of trends, as well as restricting the value of the already limited amount of information on juvenile fish populations.

However, the broad differences in water quality between the two rivers can be illustrated, as in Figs. 51 and 52, for the rivers Taw and Torridge, respectively, taking total concentration of ammonia as an example. In each case, the line for the years 1964-1984 is the average trend of maximum annual concentrations for all stations, whilst the line for 1983-1988 is the annual mean daily value.

Concentrations are consistently lower in the river Taw than in the river Torridge, although they show a significant increase between 1967 and 1984 (P = less than 0.001) and again in 1987 (P = 0.01), as shown by the polynomial fit to the points in Fig. 53. In 1967, the maximum BOD was also lower in the river Taw (1.43 mg/l) than in the river Torridge (2.8 mg/l), but rose significantly (P = less than 0.001) to 3 mg/l in 1984.

4.6.2.1. Juvenile salmonids and water quality

Because of the paucity and incompatability of much of the data on water quality, it is not possible to make full use of it to investigate its possible relevance to the status of juvenile salmonid populations; only a few comparable data points can be deduced and these are by no means ideal.

Consistent relationships are not evident between population density and water quality, except within the river Taw, where there is a marked reduction in numbers of 1+ salmon and trout and of 0+ salmon in 1988 compared with values in 1983. The data have been combined, by expressing each as a proportion of the respective mean for the group, and plotted in Fig 54. This is not necessarily to be interpreted as a direct effect of ammonia on fish density, partly because concentrations of ammonia may be correlated with those of other water quality characteristics (they are, indeed, correlated with those of suspended solids) and because, in any case, they are much lower than values expected to have adverse effects upon fish (Alabaster & Lloyd, 1982).

4.6.3. Conclusions

Water quality in the river Torridge tends to be lower than that in the river Taw, which is consistent with there being poorer populations of fish in the former. However, the role of specific water quality characteristics must remain an open question until a more thorough study can be undertaken, given further data on past water quality, together with definitive estimates of juvenile populations in 1988.

4.6.4. Water pollution from farm wastes

Because data on water quality are generally based upon intermittent sampling, they are not necessarily representative of the range of conditions prevailing, especially in the upper reaches of rivers where sampling frequency may be relatively low. These areas are likely to include valuable potential spawning areas for salmonid fish and to be at risk from infrequent pollution incidents, including those from farm wastes.

Reported pollution incidents from farms have been especially important in the area of SWWA, comprising 37% of total reported pollution incidents in 1985 and 30% in 1986, compared with 19 and 17%, respectively for the whole country (Water Authorities Association, 1986; 1987); and most of the incidents (89 & 93% in the two years, respectively) were related to cattle. In the catchment of the River Torridge, there have been large, significant increases in both livestock numbers and stocking density between the years 1952 and 1982; dairy cattle, in particular, increased by 155% (from 13,800 to 35,000) and livestock units per hectare increased by 64% (from 0.95 to 1.55)(Water Authorities Association, 1986).

These incidents are likely to have been responsible, in part, for the relatively poor water quality in the river Taw and, especially, in the river Torridge.

4.7. Estuarine water quality

Daytime surveys of water quality in the Torridge estuary have been carried out by SWWA in May and July, 1972, July and September, 1973, May and July, 1974, July and September, 1979-1981, April to August, 1983 and August and September, 1984. A 24-hour survey was also carried out on 10-11 June, 1985. Details of these surveys have been given by SWWA (1985b), and the complete data for the surveys in 1972 and 1973 have also been made available. These surveys covered both spring and neap tides, as well as wet and dry years.

Data have also been made available from the more recent surveys of the Taw and Torridge estuary carried out by Wimpol Ltd.; these have been in the form of Preliminary Copies of the First Annual Report, May, 1989. This has been supplemented by a print-out of concentrations of un-ionised ammonia, calculated from the water temperature, pH value and salinity, using equations, as referenced in Alabaster **et al.**, (1983); the tabulation covered the surveys in February, May, August and October, 1988, and also included DO.

The data from these surveys are compared in this Section with the relevant water quality requirements of migratory salmonid fish (e.g. Alabaster & Lloyd, 1982; European Inland Fisheries Advisory Commission, 1983; 1984a; 1984b), the most important water quality characteristics being DO and ammonia, taking account of other relevant factors, including temperature, pH and salinity. Other water quality characteristics, including heavy metals and pesticides are also considered.

No relevant survey data have been provided for coastal waters near the mouth of the Taw and Torridge estuary, but if the quality of the river discharge to the sea were satisfactory, then it would be reasonable to expect that it would still be satisfactory when diluted by the coastal waters of the Bristol Channel, since these also support other substantial runs of migratory salmonid fish to some of the other rivers that discharge into them.

4.7.1. Dissolved oxygen

In order to allow the unimpeded upstream movement of migratory salmonid fish through an estuary, the minimum concentration of DO should probably be as high as 5 mg/l at summer water temperatures of 18-22°C, especially if the distance to be covered at that concentration would involve swimming for more than an hour or so, or for further than several kilometres (Alabaster & Lloyd, 1982; Alabaster, 1988; 1989b). However, there is evidence that in exceptional years fish would proceed even at a value as low as 3 mg/l, although anything lower than this would probably block migration altogether; in the estuary of the river Thames, for example, migration proceeded when the median DO was as low as 3.5 mg/l over a distance of 1 km and as low as 3.7 mg/l over a distance of 10 km (Alabaster & Gough, 1986), although more recent data indicate that the rate of migration is probably reduced at these concentrations (Alabaster & Gough, in preparation).

The minimum DO for the survival of salmon smolts is no higher than 3 mg/l in fresh water and slightly lower in saline water (Alabaster, **et al.**, 1979a) and there is evidence that smolts are likely to make a successful passage through a deoxygenated zone in an estuary if the concentrations do not fall below this value for more than 10% of the time over a distance of about 10 km (Curran & Henderson, 1988).

The minimum DO found by SWWA along the length of the Torridge estuary during daylight hours was generally high, being 9.4 mg/l on average for all surveys. The lowest minimum daytime value recorded was 4.7 mg/l on 26 September, 1984 at one site, Bank End, where the average over the whole day was 7.19 mg/l (S.D., 0.96 mg/l), and this at a time when the average over the whole estuary was 7.25 mg/l (S.D., 1.75 mg/l). It should be noted that 1984 was a year of unusually low freshwater flow and high air temperature. The minimum DO recorded over 24 hours in June, 1985 was 8.3 mg/l.

The minimum DO found by Wimpol Ltd. in the Taw and Torridge estuary in 1988 was 6.95 mg/l at station 5 at High Water on a Spring tide on 31 July; details of this and the lowest concentrations on the other three surveys (all in the Torridge estury and all also at High Water) are shown in Table 7.

4.7.1.1. **Conclusions**

It must be concluded that the DO observed in the Taw and Torridge estuary was not low enough to have interfered with the normal upstream migration of salmonid fish or to have adversely affected their seaward migration in the spring.

4.7.2. **Ammonia**

Ammonia is lethal to salmon at a concentration of un-ionised ammonia of 0.08 to 0.2 mg N/l, depending, particularly, upon the DO and salinity (Alabaster **et al.**, 1979b; Alabaster **et al.**, 1983). The sensitivity of other salmonid fish that have been tested is silmilar to that of salmon.

Concentrations of un-ionised ammonia were calculable from the pH, temperature and salinity of the water for the surveys of the Torridge estuary carried out by SWWA in 1980, 1981 and 1984. The maxima were generally very low, being usually less than 0.1 of the predicted lethal values. This is true of the surveys carried out in May, 1972, July and September, 1973, September, 1980 and of the four surveys carried out in 1984. In the surveys of July, 1972 and 1981, however, isolated relatively high values were found, equivalent to 0.13 and 0.85 of the lethal concentration.

Although the absence of data on pH, temperature and salinity for the surveys in 1974 and 1982 preclude the calculation of un-ionised ammonia for these dates, the concentrations of total ammonia were of the same order of magnitude as those of the other surveys and thus it is likely that the concentrations un-ionised ammonia were also of the same order of magnitude, i.e. not potentially lethal.

For the surveys carried out by Wimpol Ltd. in the Taw and Torridge estuary, the maximum concentrations of un-ionised ammonia were also less than 0.1 of the lethal values, as shown in Table 7.

4.7.2.1. Conclusions

It is concluded, therefore, that concentrations of ammonia in the Taw and Torridge estuary have been well below values harmful to salmonid fish.

4.7.3. Other water quality characteristics

There were no data on direct measurements of heavy metals in the Torridge estuary for the surveys carried out by SWWA, but analyses of the crude sewage from Bideford carried out in August and September, 1984 showed concentrations of the same order of magnitude as those of sewage from Exeter. Maximum concentrations were such that, when diluted in the estuary, they would have been reduced to values well below those that were lethal to salmonid fish or likely to interfere with their upstream migration (Alabaster & Lloyd, 1982).

For the surveys carried out by Wimpol Ltd. in the Taw and Torridge estuary, details are given of the concentrations of heavy metals and other toxicants, including nitrite and pesticides. All of these were at concentrations well below potentially lethal values.

4.7.4. Conclusions

There is no evidence, from surveys carried out between 1972 and 1988, that the quality of the estuarine water of the rivers Taw and Torridge has been such as to have been harmful to the survival and passage of salmonid fish.

5. SUMMARY AND CONCLUSIONS

5.1. Objectives

An appraisal has been made of data on the rivers Taw and Torridge, supplied by SWWA and SWR, in order to assess the status of stocks of salmonid fish and the suitability of the estuaries to allow the passage of salmonid migrants.

5.2. Restriction on supply of data

The appraisal has been hampered by the failure of SWWA and SWR to provide all the data that were available to them, and requested of them. This has also led to the incompatibility of some of the data that were provided.

5.3. Specific conclusions

Nevertheless, it is concluded that:

1. Annual catches of salmon in the rivers Taw and Torridge, in common with other rivers, show marked oscillations over the last 50 years but, unlike the general trend for the rest of the area of SWR and for the whole of England and Wales, they have shown a marked decline over the last 30 years, especially in the rod catch, and particularly in the river Torridge.

2. Annual catches of seatrout, whilst exhibiting long- and short-term fluctuations, show considerable similarity between the rivers Taw and Torridge and also between these and other rivers in the rest of the area of SWR, although rod catches in the river Taw, and especially those in the river Torridge, tend to be relatively lower than elsewhere in the area.

3. When there was no particular trend in total annual catch in nets between 1965 to 1979, an increasing abundance of grilse was roughly balanced by a decreasing number of 2-SW fish.

4. Although there is still a considerable amount of unaccounted variation in annual net catches of salmon in the rivers Taw and Torridge, the general trends, like those described by Martin and Mitchell (1985), are related to ocean temperature. This factor, however, does not account for the general difference in annual rod catches of salmon between the rivers Taw and Torridge, nor the trends in seatrout catches and the difference in rod catches of seatrout between the two rivers.

5. Monthly net catches of multi-SW salmon have decreasd with time. This is partly accounted for, in May, in terms of sea temperatures off Iceland. Monthly catches of grilse, on the other hand, have increased, although they were reduced by high freshwater discharge in July.

6. Monthly rod catches of salmon show a decline in some months, especially in the river Torridge, and also decrease with reduction in river flow. River flow partly accounts for the fall in catch with time, since it has also declined in August in both rivers; this decline in flow, however, has been similar in both rivers, whereas catches have fallen more in the river Torridge than they have in the river Taw.

7. Monthly net catches of seatrout have increased, but monthly rod catches have not shown any linear trends.

8. Considering only rod and net catches as measures of stock, net catches would appear to be the better for salmon, whilst a combination of both would probably be suitable for seatrout.

9. For salmon of all ages in both rivers, the numbers of juveniles are below average for the area and, except for 0+ fish in the most recent samples in 1988, have tended to fall over the period, although there was also a general partial recovery in 1983. This conclusion is congruant with the results of net catches.

10. For trout, the numbers of all ages in the river Taw have been about average for the area, although they have varied widely from year to year. In the river Torridge, on the other hand, the numbers have been very much below average, especially for the 0+ fish, whilst for 1+ fish and over, they have declined progressively over the period. This situation is also in accord with the results of net catches.

11. The numbers of juvenile salmon are positively related to redd counts, and generally reflect the net catches of adults, being specifically correlated with catches of fish from which they might have been derived. They are also specifically correlated with catches to which they might have given rise. Such results support the use of the commercial net catch to indicate stock abundance as well as the use of estimates of juvenile populations to predict adult returns in the immediate future, making allowance in both cases for any reduction in net catch per unit effort that accompanies an increase in effort.

12. The numbers of juvenile trout also reflect the general pattern of net catches, but, unlike salmon, they show no clear relation to redd counts.

13. Water quality in the river Torridge tends to be lower than that in the river Taw, which is consistent with there being poorer populations of fish in the former. However, the role of specific water quality characteristics must remain an open question until a more thorough study can be undertaken, given further data on past water quality, together with definitive estimates of juvenile populations in 1988.

14. Pollution incidents from farm wastes are likely to have been responsible, in part, for the relatively poor water quality in the river Taw and also, especially, in the river Torridge.

15. There is no evidence, from surveys carried out between 1972 and 1988, that the quality of the estuarine water of the rivers Taw and Torridge has been such as to have been harmful to the survival and passage of salmonid fish.

5.4. General conclusions

5.4.1. Fish Stock

For salmon, the total stocks in the rivers Taw and Torridge are relativley low and probably increasing, or remaining steady, whilst those of grilse are probably rising or remaining steady, and those of 2-SW and 3-SW fish, falling or remaining steady.

This situation is likely to be attributable to long-term cycles in abundance that are common to other stocks of salmon and linked to climatic changes, particularly the temperature of oceanic waters at the feeding grounds.

For seatrout, the stocks are relatively low, especially in the river Torridge, and are probably steady or falling in the river Taw and falling in the river Torridge.

This difference between the two rivers, as well as the trends, appears to be linked to adverse river water quality in general, insufficient information having been made available to enable an analysis of the possible role of specific water quality characteristics.

5.4.2. Fish migration

The estuarine waters of the rivers Taw and Torridge are quite suitable for the passage of migratory salmonid fish.

6. REFERENCES

Alabaster, J. S. (1970) River flow and upstream movement and catch of migratory salmonids. **J. Fish Biol.** 2:1-13.

Alabaster, J. S. (1986) River Axe Fish Study - Evaluation of Fish Movements in the Estuary. Report to Mander, Raikes & Marshall. July, 1986. 14pp.

Alabaster, J. S. (1987) River Axe Fish Study - Supplementary Report. Report to Mander, Raikes & Marshall. June, 1987. 4pp.

Alabaster, J. S. (1988) The dissolved oxygen requirements of upstream migrant Chinook salmon (**Oncorhynchus tshawytscha**) in the lower Willamette River, Oregon. **J. Fish Biol.**, 32: 635-636.

Alabaster, J. S. (1989a) River Axe Fish Study - Stage 2. Environmental Assessment for River Abstraction. Report to Mander, Raikes & Marshall. April, 1989. 16pp.

Alabaster, J. S. (1989b) The dissolved oxygen and temperature requirements of King Salmon **Oncorhynchus tshawytscha** in the San Joaquin Delta, California. **J. Fish. Biol.**, **34**: 331-332.

Alabaster, J. S. & Gough, P.J. (1986) The dissolved oxygen and temperature requirements of Atlantic salmon **Salmo salar** L. in the Thames estuary. **J. Fish Biol.**, **29**: 613-621.

Alabaster, J. S., Shurben, D. G. & Mallett, M. J. (1979a) The survival of smolts of salmon **Salmo salar** L. at low concentrations of dissolved oxygen. WRC LR 909, 16pp.

Alabaster, J. S., Shurben, D. G. & Knowles, G. (1979b) The effect of dissolved oxygen and salinity on the toxicity of ammonia to smolts of salmon, **Salmo salar** L. WRC LR 1027, 15pp.

Alabaster, J. S., Shurben, D. G. & Mallett, M. J. (1983) The acute lethal toxicity of mixtures of cyanide and ammonia to smolts of salmon, **Salmo salar** L. at low concentrations of dissolved oxygen. **J. Fish Biol.**, **22**: 215-222.

Alabaster, J. S. & Lloyd, R.(1982). **Water Quality Criteria for Freshwater Fish.** Second Edition. Butterworths for FAO, 367pp.

Blezard, N., Crann, H. H., Iremonger, D. J. & Jackson, E. (1970) Conservation of the environment by river regulation. Assn. Rivers Authorities' Conference, Chester, 1970. 46pp.

Curran, J. C. & Henderson, A. R. (1988) The oxygen requirements of a polluted estuary for the establishment of a migratory salmon, **Salmo salar L.**, population. **J. Fish Biol.** 33 (Supplement A): 63-69.

Davies, C. V. M. (1985) Report of surveys and other data: river Torridge estuary; fisheries and recreation. Proof of Evidence, Public Inquiry, Bideford Fine Screening Plant, 17 September, 1985.

Durbin, J. & Watson, G. S. (1951) Testing for serial correlation in least squares regression II. **Biometrika 38**:159-178.

European Inland Fisheries Advisory Commission (1983) Water Quality Criteria for European Freshwater Fish. Report on chromium and freshwater fish. EIFAC Technical Paper No. 43. FAO, Rome. 31pp.

European Inland Fisheries Advisory Commission (1984a) Water Quality Criteria for European Freshwater Fish. Report on nickel and freshwater fish. EIFAC Tecnical Paper No. 45. FAO, Rome. 20pp.

European Inland Fisheries Advisory Commission (1984b) Water Quality Criteria for European Freshwater Fish. Report on nitrite and freshwater fish. EIFAC Technical Paper No. 46. FAO, Rome. 19pp.

Filliben, J. J. (1975) The probability plot correlation coefficient test. **Technometrics 17** (1):111-116.

Gee, A. S. & Milner, N. J. (1980) Analysis of 70 year statistics for Atlantic salmon (**Salmo salar**) in the river Wye and implications for management of stocks. **J. Anim. Ecol. 17**:41-57.

Hamilton, R. M. (1979) Proof of Evidence. Public Inquiry, Net Limitation Order, Rivers Taw and Torridge.

Huntsman, A. G. (1937) The cause of periodic scarcity in Atlantic salmon. **Trans. Roy. Soc. Can., Section V:17-27.**

Leslie, P. H. & Davis, D. H. S. (1939) An attempt to determine the absolute number of rats on a given area. **J. Anim. Ecol.** 8: 94-113.

Malmberg, S-A. (1985) The water masses between Iceland and Greenland. **Rit. Fiskideildar** 9:127-140.

Martin, J. H. A. & Mitchell, K. A. (1985) Influence of sea temperatures upon the number of grilse and multi-sea-winter Atlantic salmon **(Salmo salar)** caught in the vicinity of the river Dee (Aberdeenshire). **Can. J. Fish. Aquat. Sci.,** 42:1513-1521.

May, R. (1989) The chaotic rhythms of life. **New Scientist.** 18 Nov. 1989:37-41.

Ministry of Agriculture, Fisheries & Food (1961) Report of Committee on Salmon & Freshwater Fisheries. Cmnd 1350. London, H.M.S.O. 151pp.

National Water Council (1982) Fisheries statistics, 1982. National Water Council, London. Dec. 1982. 12pp.

Newton, M. R. N. (1985) Biological survey of the Torridge catchment. September/October, 1983. SSE/ENV/85/18. South West Water Authority, July, 1985. 18pp.

Ricker, W. E. (1954) Stock and recruitment. **J. Fish. Res. Bd.** Canad., **11**:559-623.

South West Water Authority (1985) A review of the river quality objectives for the rivers Taw and Torridge. SSE/ENV/85/11. March, 1985. 37pp.

Smith, L. S. **et al.**(1971). Response of teleost fish to environmental stress. **Wat. Pollut. Control Res. Ser., Wash.,** (18050 EBK 02/71).

Water Authorities Association (1986) Water Pollution from Farm Wastes, 1985, England & Wales. Water Authorities Association, July, 1986. 24pp.

Water Authorities Association (1987) Water Pollution from Farm Wastes, 1986, England & Wales. Water Authorities Association, August, 1987. 28pp.

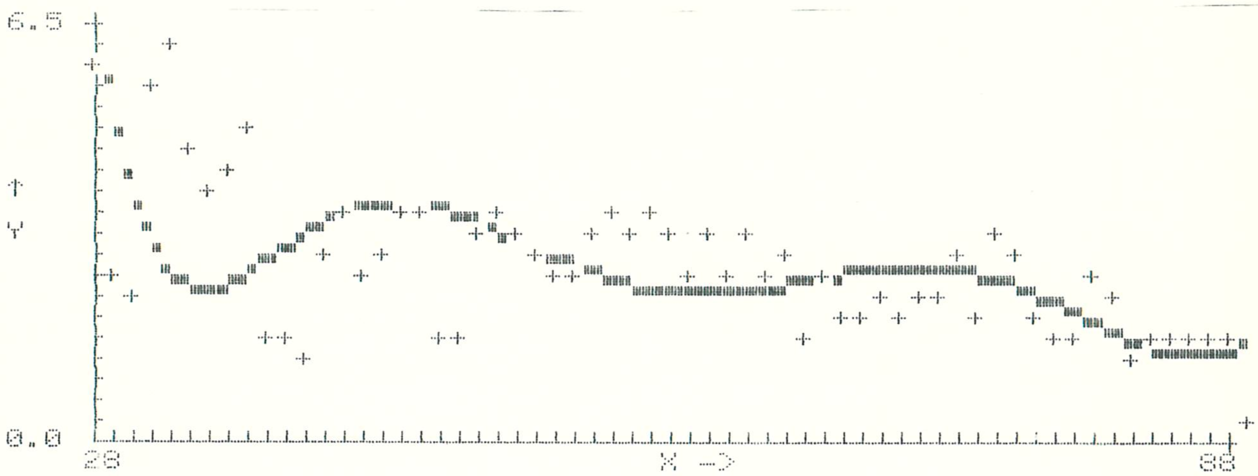
Wessex Water Authority (1986) Investigation into the alleged decline of migratory salmonids. Final Report. Wessex Water Authority, 40pp.

Table 1. Multiple regression analysis of monthly catches of fish in nets against time, monthly mean daily river flow (m^3/s) and water temperature (°C)off N. Iceland for the years 1962-1980.
Months in which none of the constants is significant are excluded. The proportion of the variance that is accounted for is given in parenthesis.

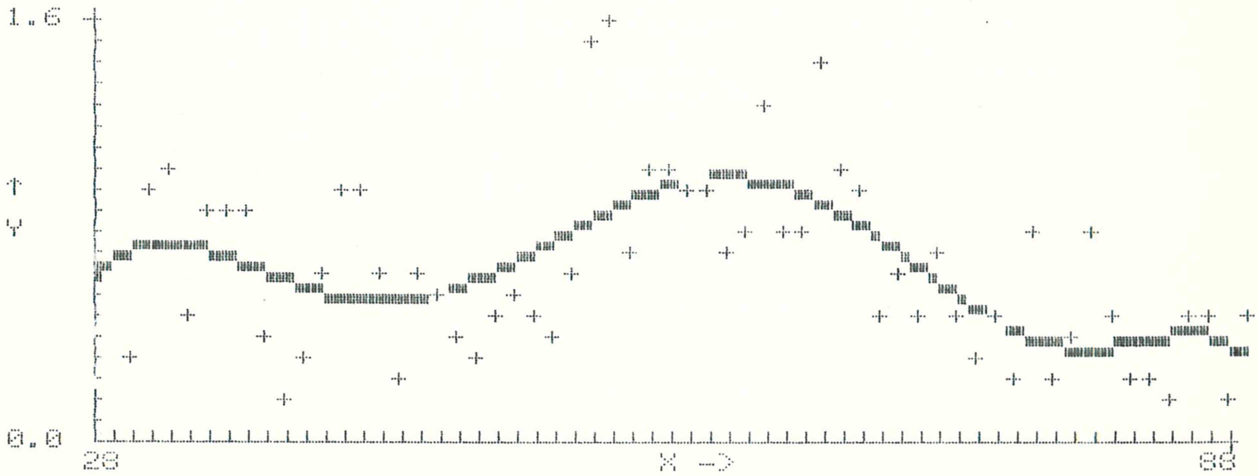
MONTH	a(intercept)	b(year)	c(flow)	d(temperature)
		C O N S T A N T		
S A L M O N				
May	1969	-23.2**(0.38)	N.S	53.7**(0.31)
June	1901	-20.3* (0.31)	N.S	N.S.
July	801	N.S	-10.5(0.23)*	N.S.
Aug.	-863	17.9**(0.34)	N.S	N.S
S E A T R O U T				
April	-1467	25.9* (0.23)	N.S.	N.S.
May	2206	43.7* (0.23)	N.S	N.S.

***, P = less than 0.001; **, P = 0.01-0.001; *, P = 0.05-0.01;
N.S. = not significant

X 110



95 Fig. 1. Annual catch of **salmon in nets** in the rivers Taw and Torridge, 1928-1988.
Y = catch in 1000's; X = year in current century in 10's.



56 Fig. 2. Annual catch of **salmon on rod and line** in the rivers Taw and Torridge, 1928-1988.
Y = catch in 1000's; X = year in current century in 10's.

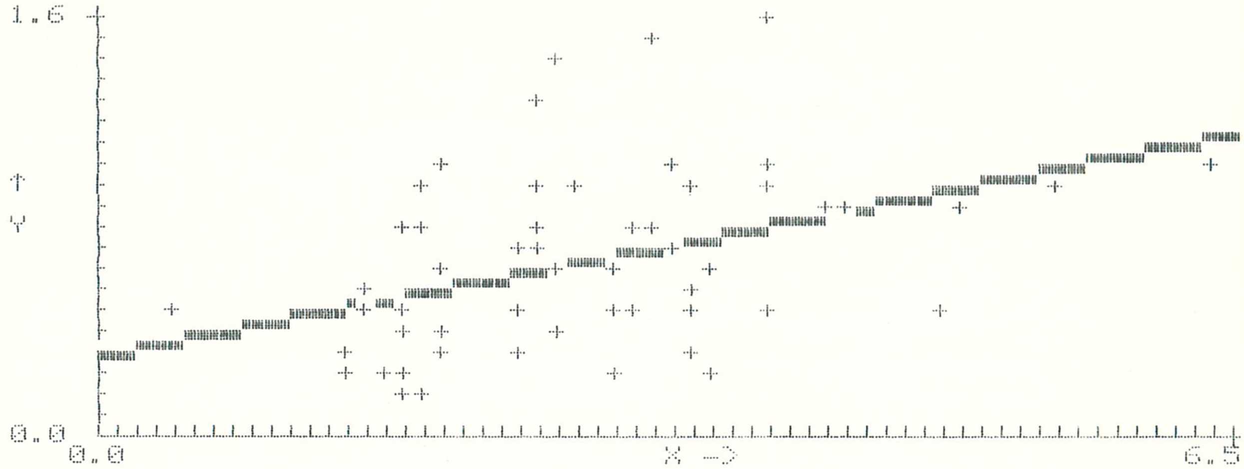


Fig. 3. Relation between annual catch of **salmon on rod and line and in nets** in the rivers Taw and Torridge, 1930-1988.
Y = catch on rod and line in 1000's; X = catch in nets in 1000's.

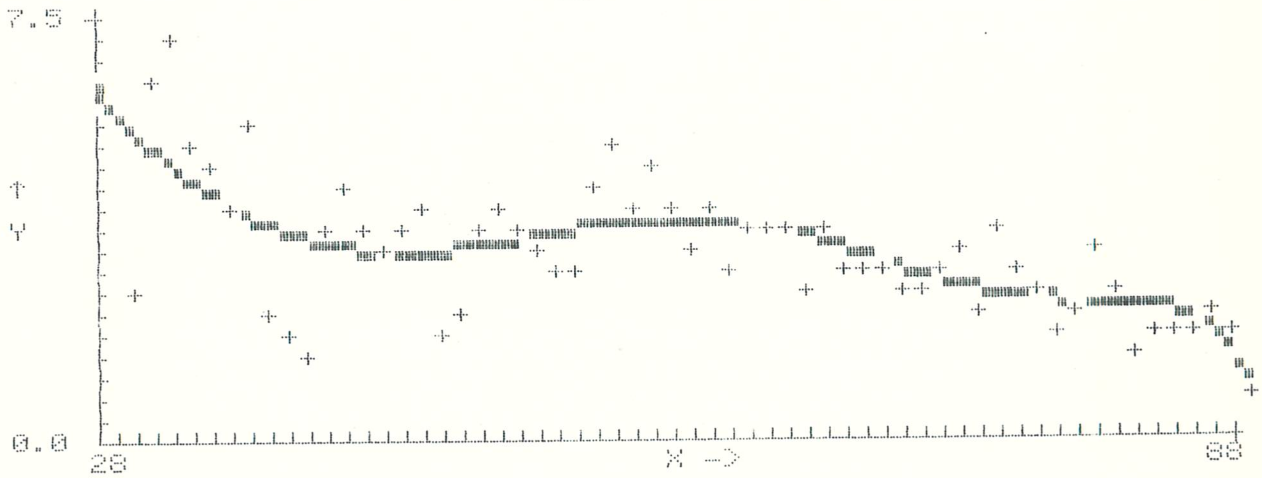


Fig. 4. Annual catch of **salmon in nets and on rod and line** in the rivers Taw and Torridge, 1930-1988.
Y = catch in 1000's; X = year in current century in 10's.

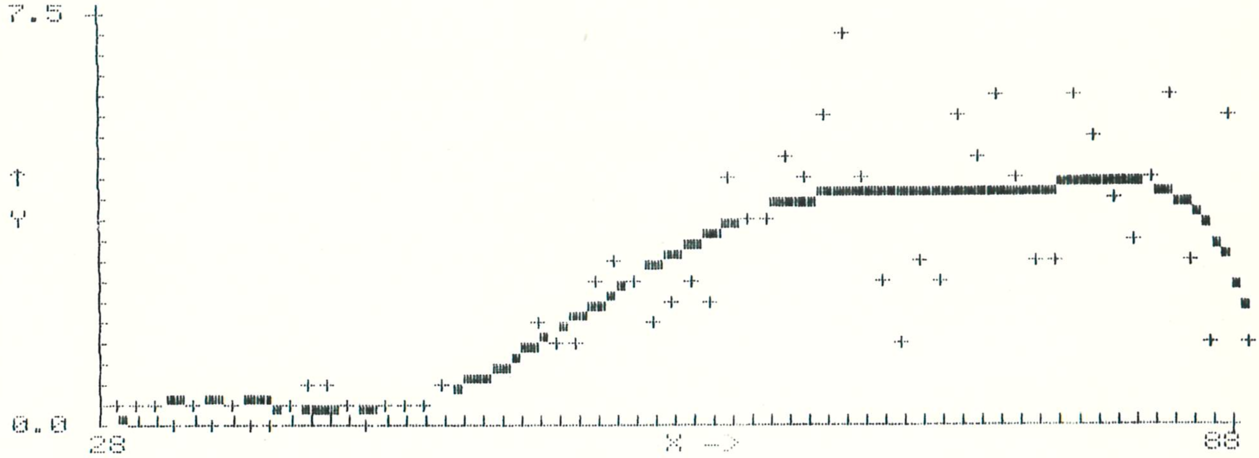


Fig. 5. Annual catch of **seatrout in nets** in the rivers Taw and Torridge, 1929-1988.
Y = catch in 1000's; X = year in current century in 10's.

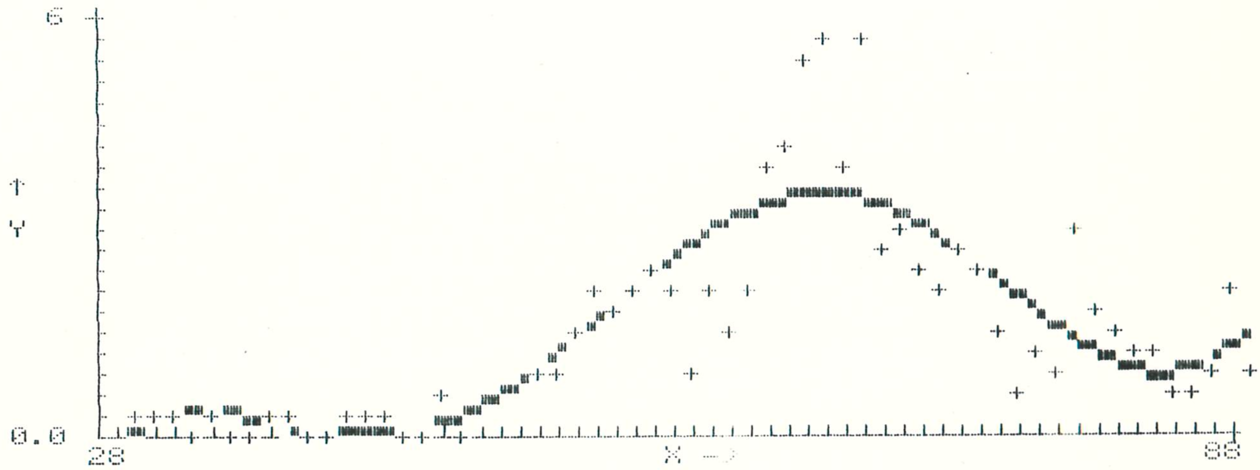


Fig. 6. Annual catch of **seatrout on rod and line** in the rivers Taw and Torridge, 1930-1988.
Y = catch in 1000's; X = year in current century in 10's.

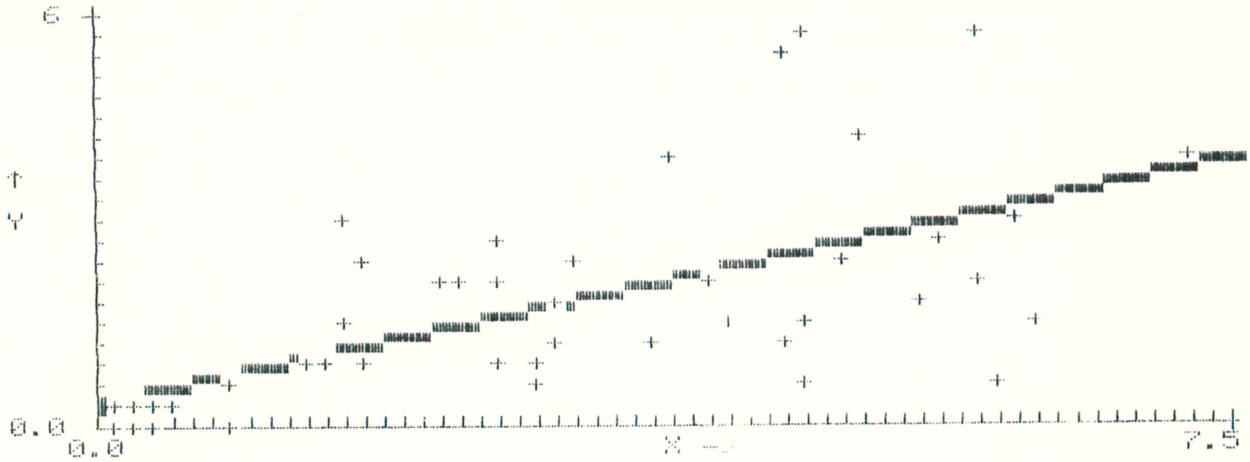


Fig. 7. Relation between annual catch of **seatrout on rod and line and in nets** in the rivers Taw and Torridge, 1930-1988.
Y = catch on rod and line in 1000's; X = catch in nets in 1000's.

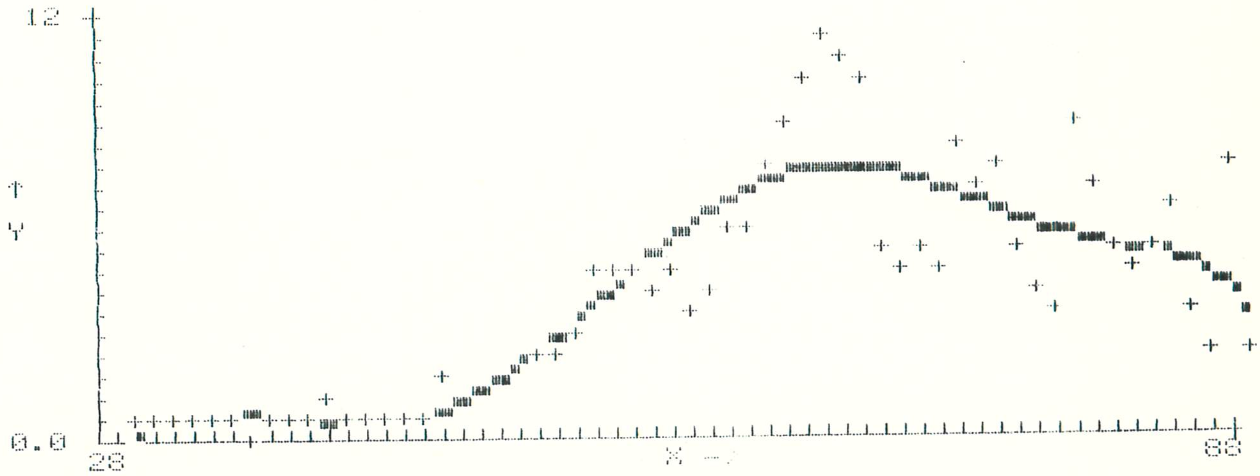


Fig. 8. Annual catch of **seatrout in nets and on rod and line** in the rivers Taw and Torridge, 1930-1988.
Y = catch in 1000's; X = year in current century in 10's.

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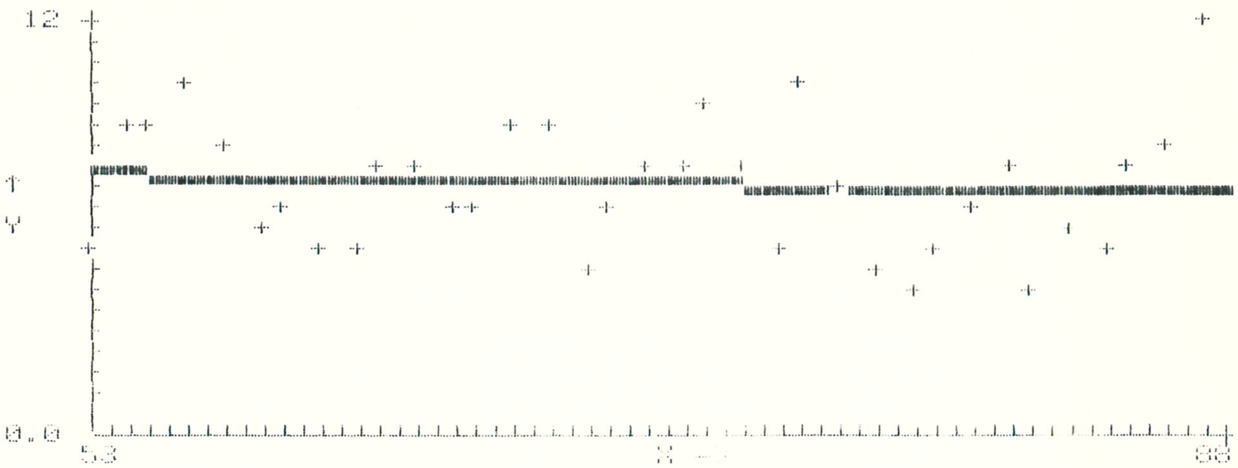

Fig. 9. Annual catch of **salmon in nets** in rivers in SWR except for the rivers Taw and Torridge, 1953-1987.
Y = catch in 1000's; X = year in current century in 10's.

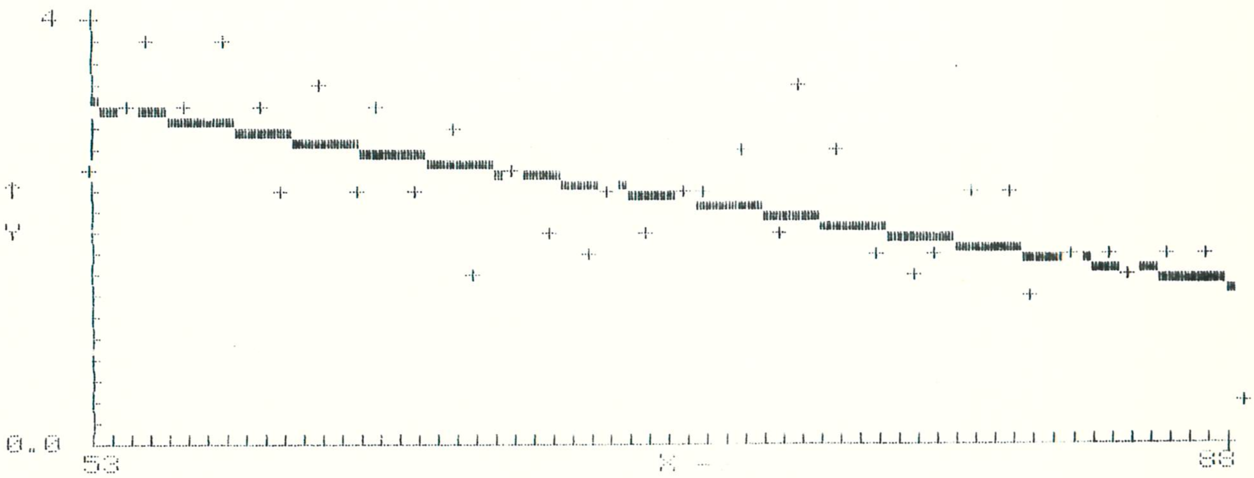

Fig. 10. Annual catch of **salmon in nets** in the rivers Taw and Torridge, 1953-1988.
Y = catch in 1000's; X = year in current century in 10's.

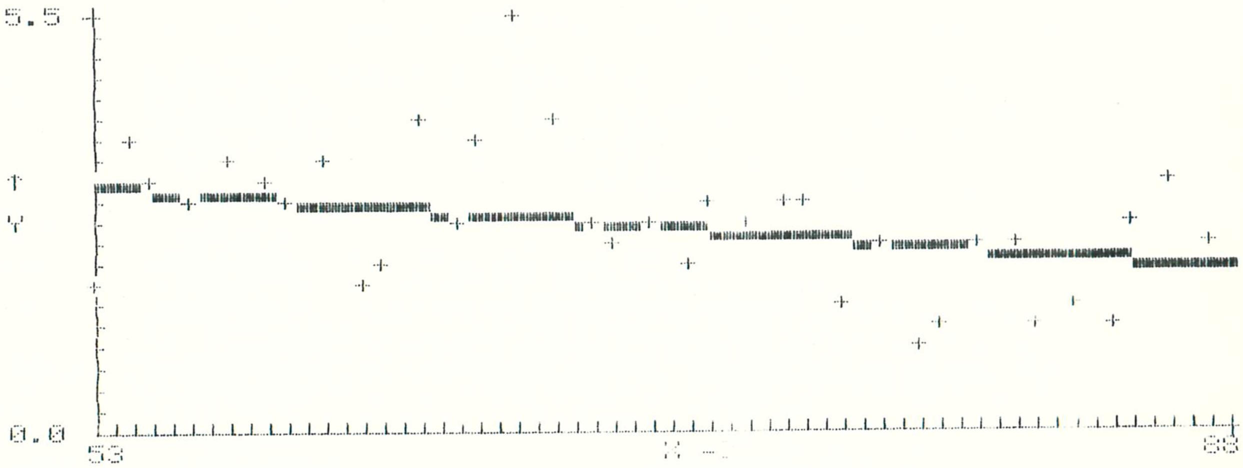

Fig. 11. Annual catch of **salmon on rods** in rivers in SWR except for the rivers Taw and Torridge, 1953-1987.
Y = catch in 1000's; X = year in current century in 10's.

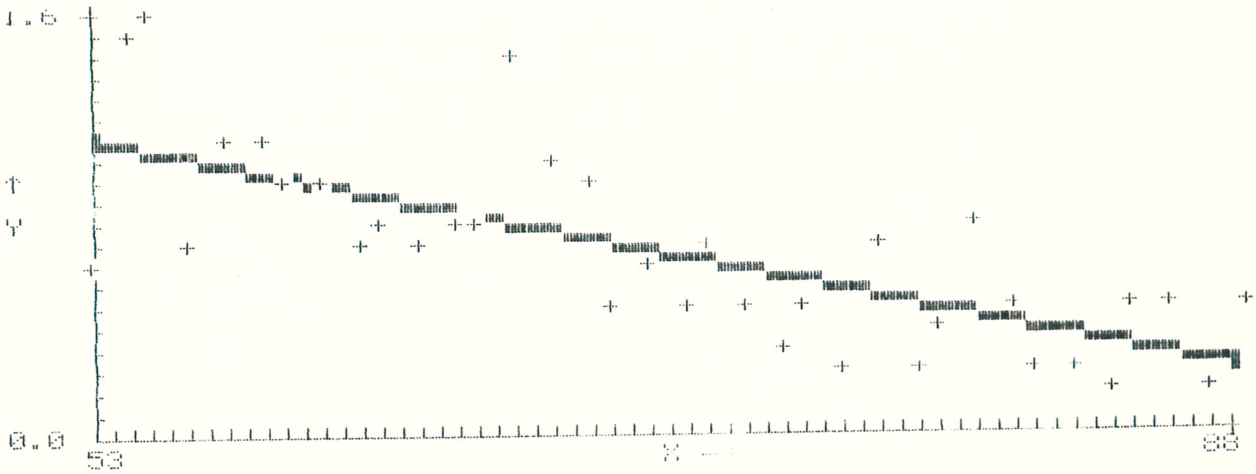

Fig. 12. Annual catch of **salmon on rods** in the rivers Taw and Torridge, 1953-1988.
Y = catch in 1000's; X = year in current century in 10's.

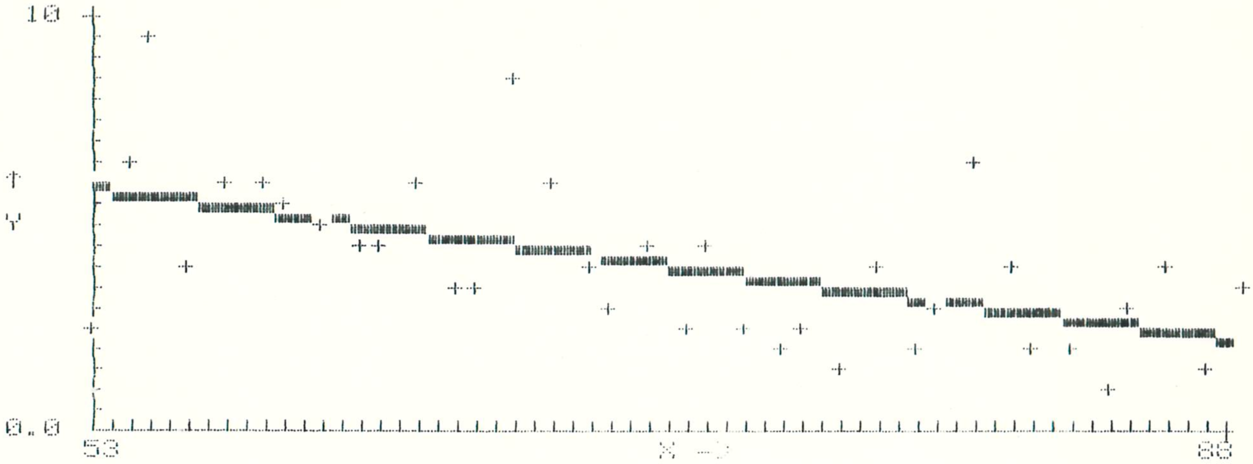

Fig. 13. Annual catch of **salmon on rods** in river Taw, 1953-1987.
Y = catch in 100's; X = year in current century in 10's.

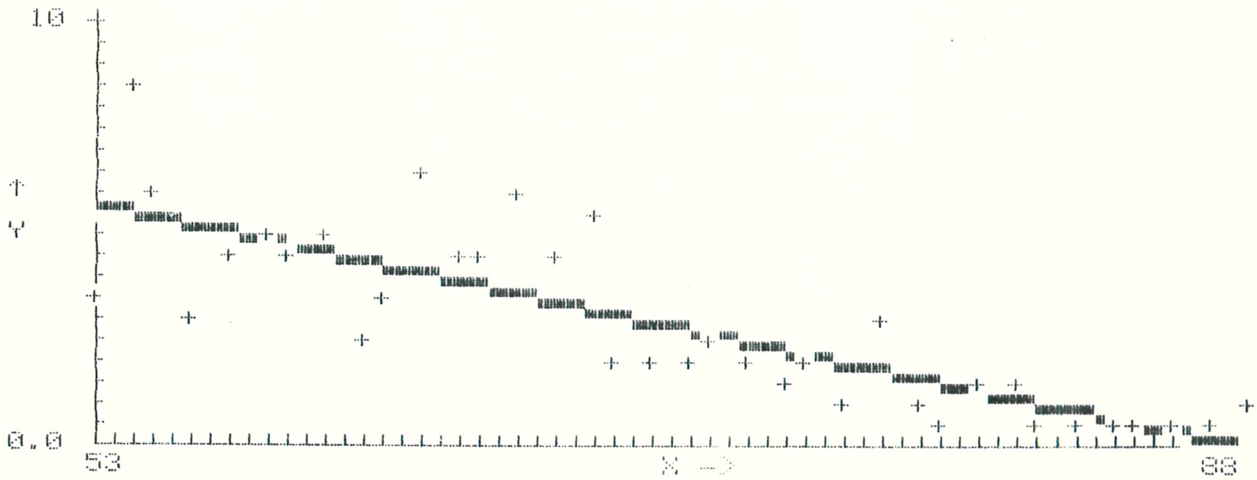

Fig. 14. Annual catch of **salmon on rods** in the river Torridge, 1953-1988.
Y = catch in 100's; X = year in current century in 10's.

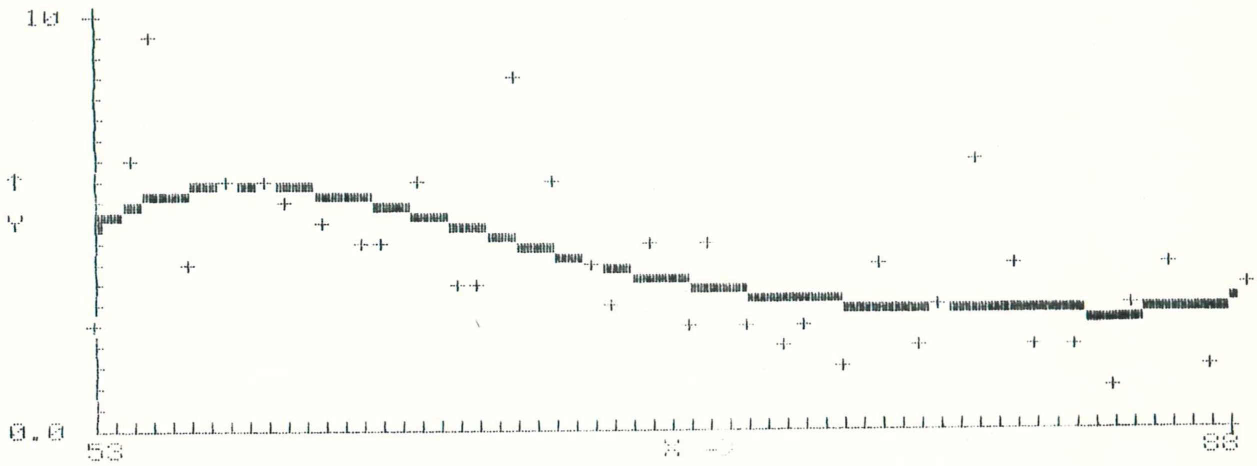

Fig. 15. Annual catch of **salmon on rods** in river Taw, 1953-1987.
(as Fig. 13, but with a fitted polynomial)
Y = catch in 100's; X = year in current century in 10's.

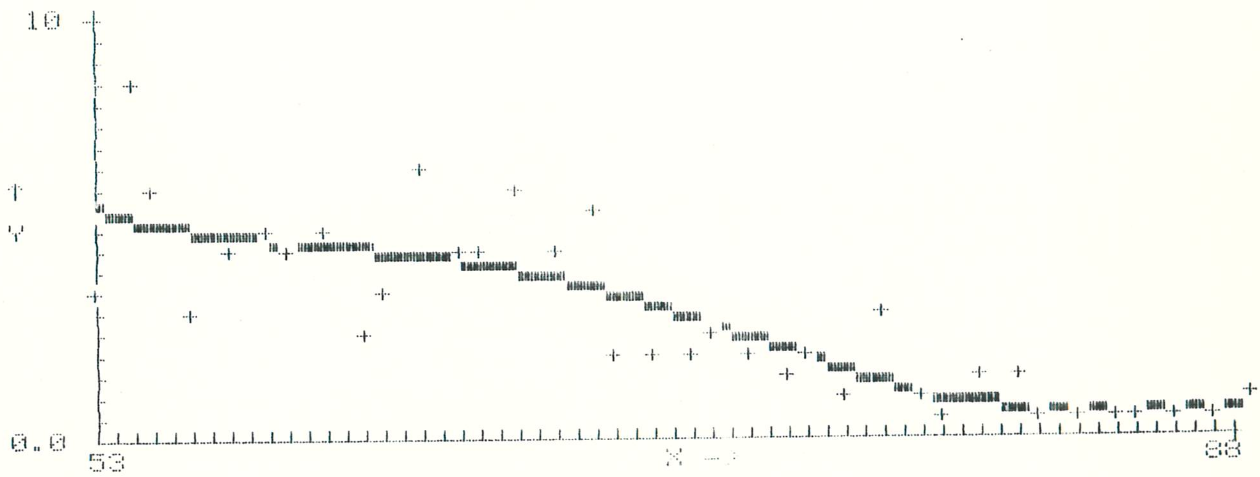

Fig. 16. Annual catch of **salmon on rods** in the river Torridge, 1953-1988.
(as Fig. 14, but with a fitted polynomial)
Y = catch in 100's; X = year in current century in 10's.

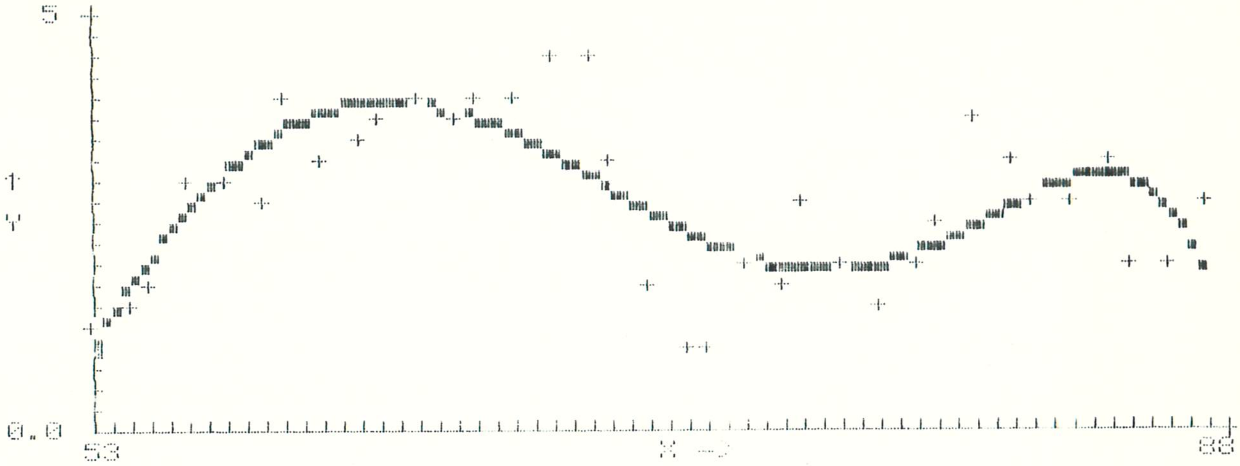

Fig. 17. Annual catch of **seatrout in nets** in rivers in SWR except for the rivers Taw and Torridge, 1953-1987.
Y = catch in 1000's; X = year in current century in 10's.

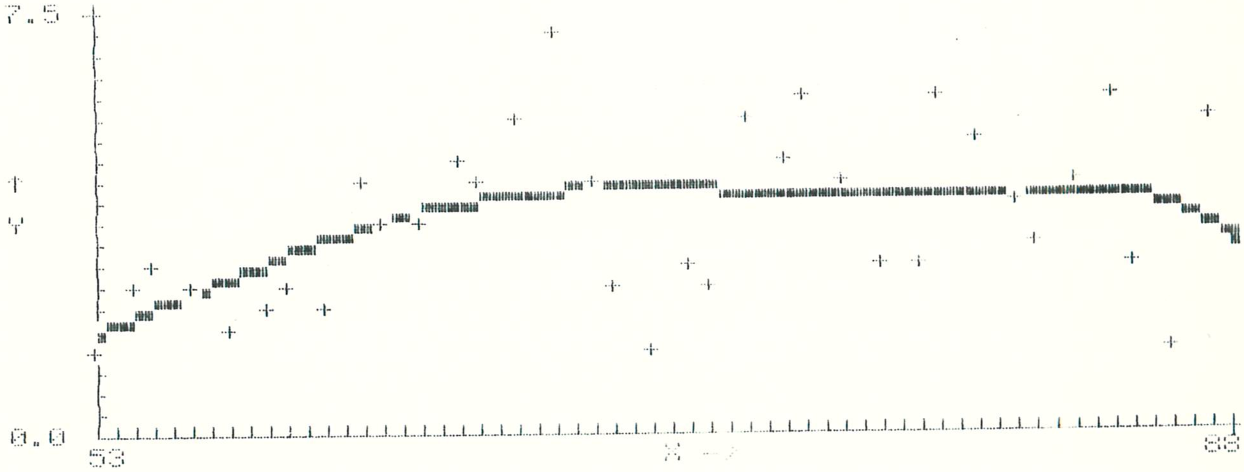

Fig. 18. Annual catch of **seatrout in nets** in the rivers Taw and Torridge, 1953-1988.
Y = catch in 1000's; X = year in current century in 10's.

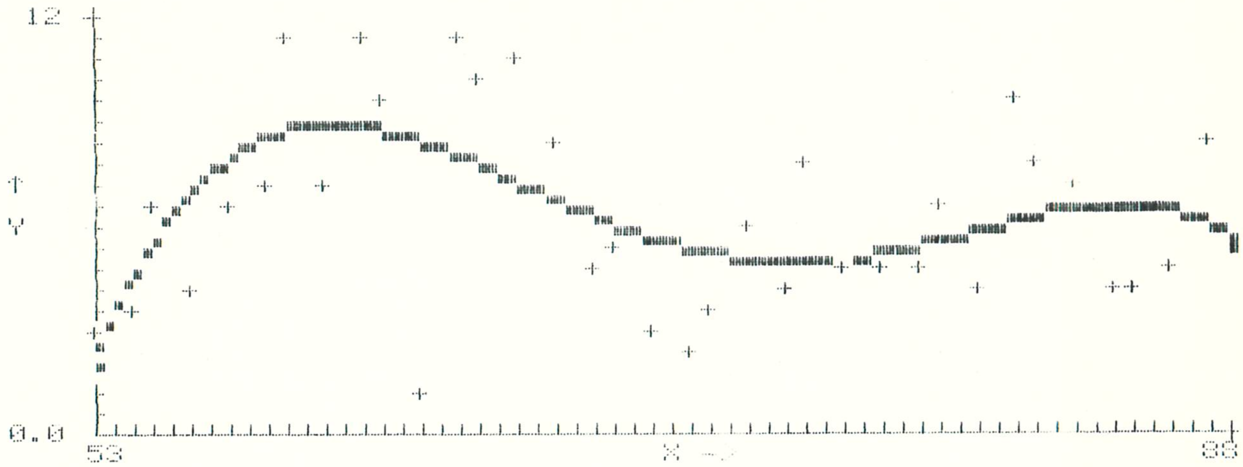

Fig. 19. Annual catch of **seatrout on rods** in rivers in SWR except for the rivers Taw and Torridge, 1953-1987.
Y = catch in 1000's; X = year in current century in 10's.

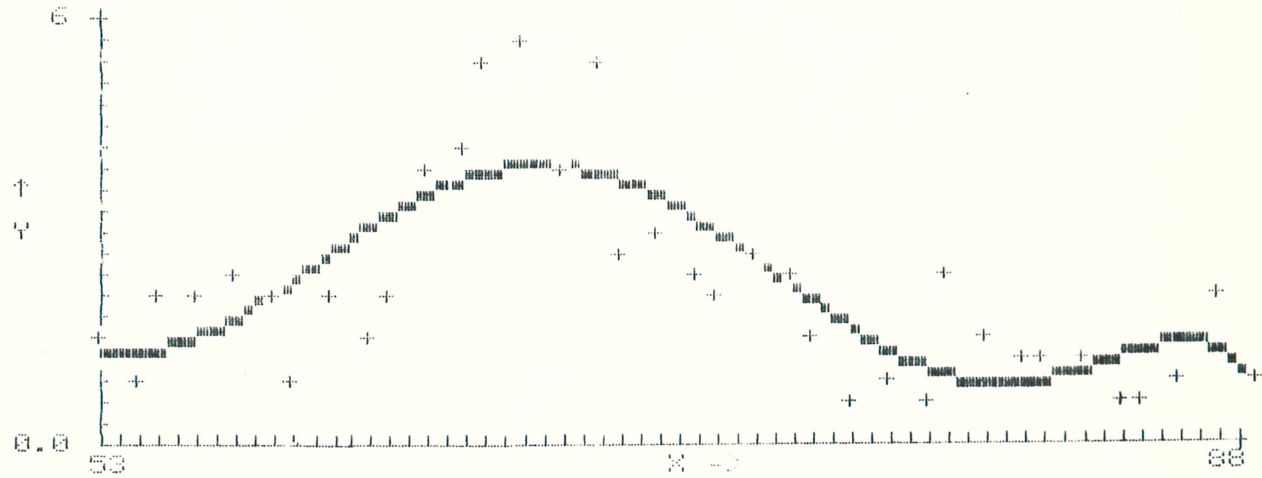

Fig. 20. Annual catch of **seatrout on rods** in the rivers Taw and Torridge, 1953-1988.
Y = catch in 1000's; X = year in current century in 10's.

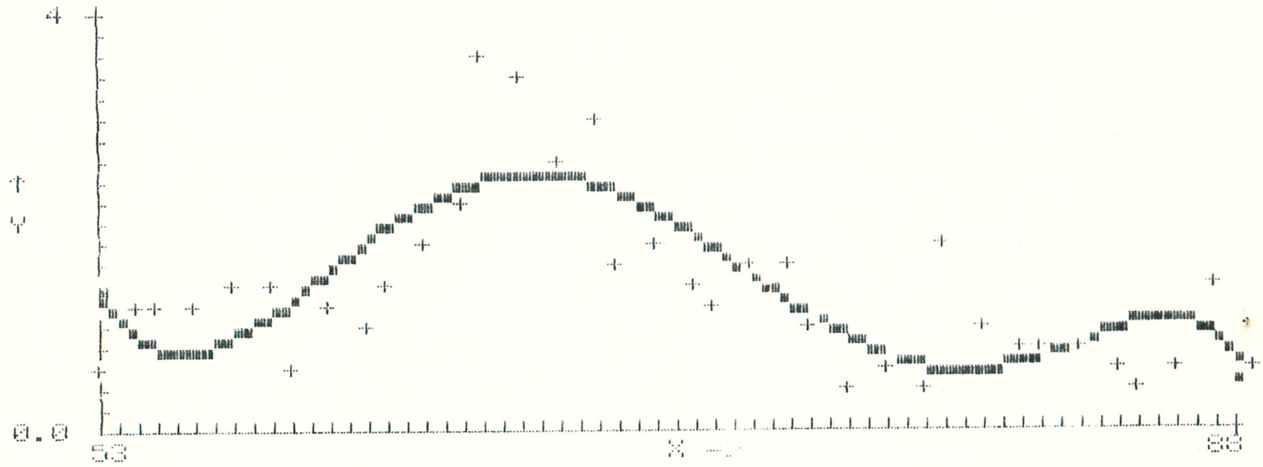

Fig. 21. Annual catch of **seatrout on rods** in river Taw, 1953-1988.
Y = catch in 1000's; X = year in current century in 10's.

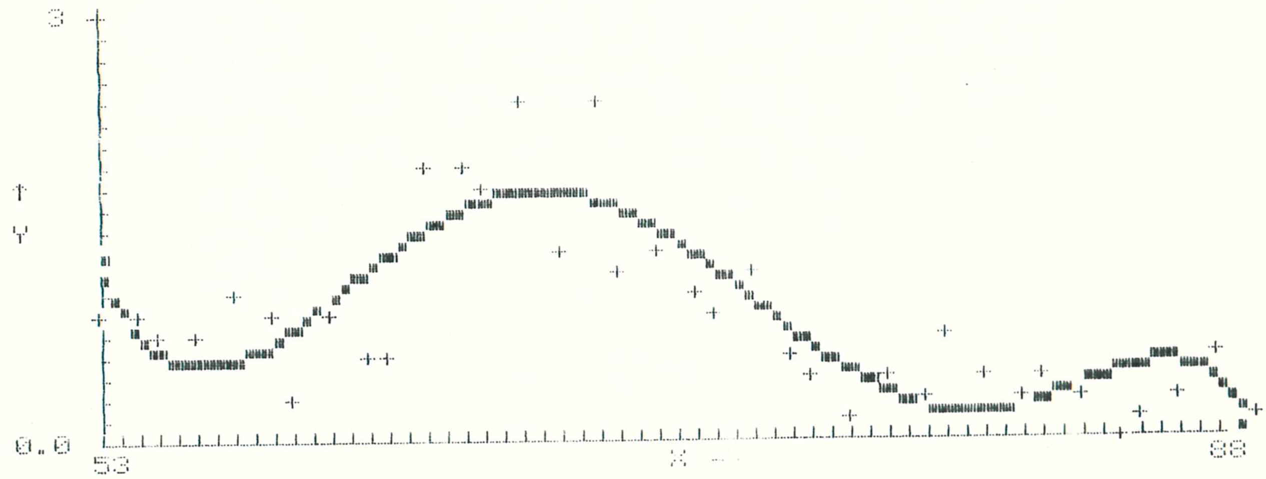

Fig. 22. Annual catch of **seatrout on rods** in the river Torridge, 1953-1988.
Y = catch in 1000's; X = year in current century in 10's.

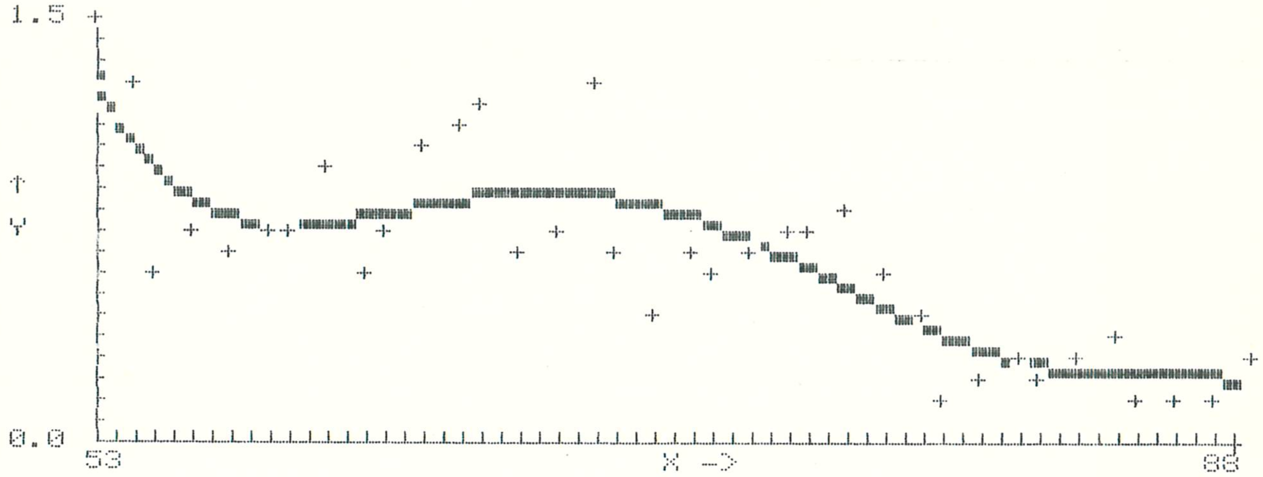

Fig. 23. Annual catch of **salmon on rods** in the river Torridge as a proportion of that in the river Taw, 1953-1988.
Y = proportion; X = year in current century in 10's.

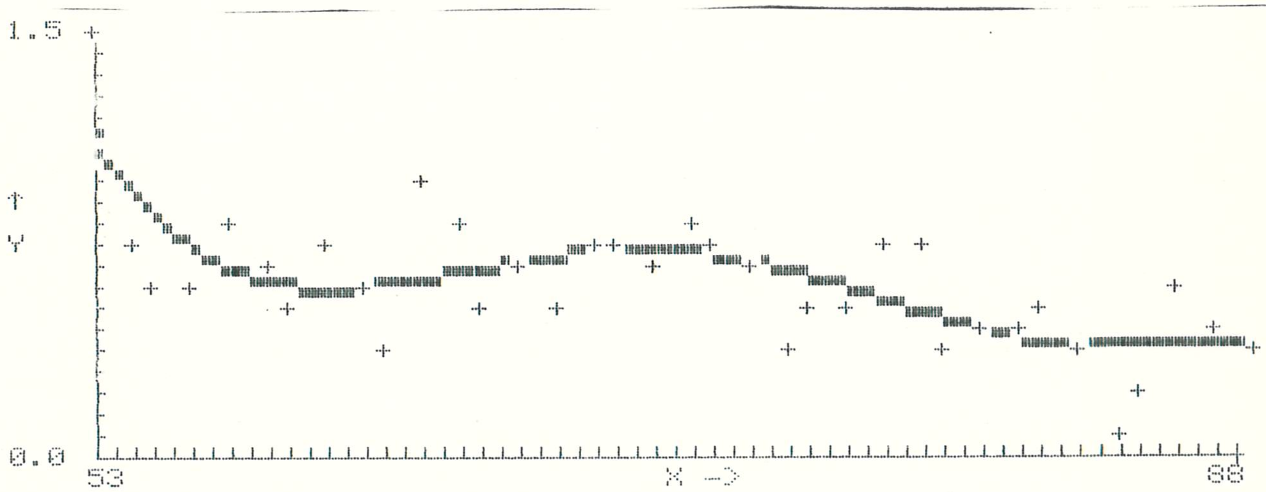

Fig. 24. Annual catch of **seatrout on rods** in the river Torridge as a proportion of that in the river Taw, 1953-1988.
Y = proportion; X = year in current century in 10's.

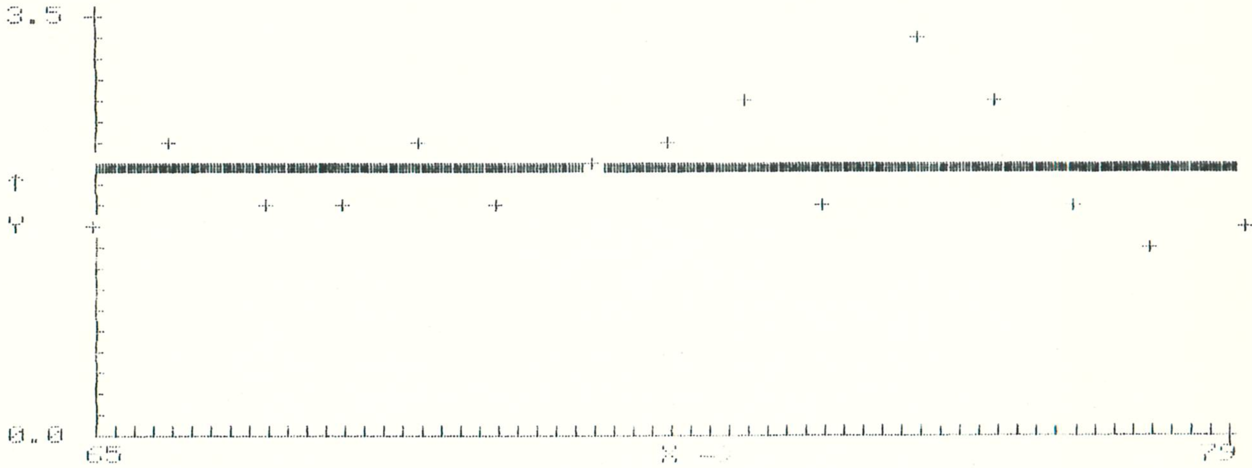

Fig. 25. Annual catch of **salmon in nets** in the rivers Taw and Torridge, 1965-1979.
Y = catch in 1000's; X = year in current century in 10's.

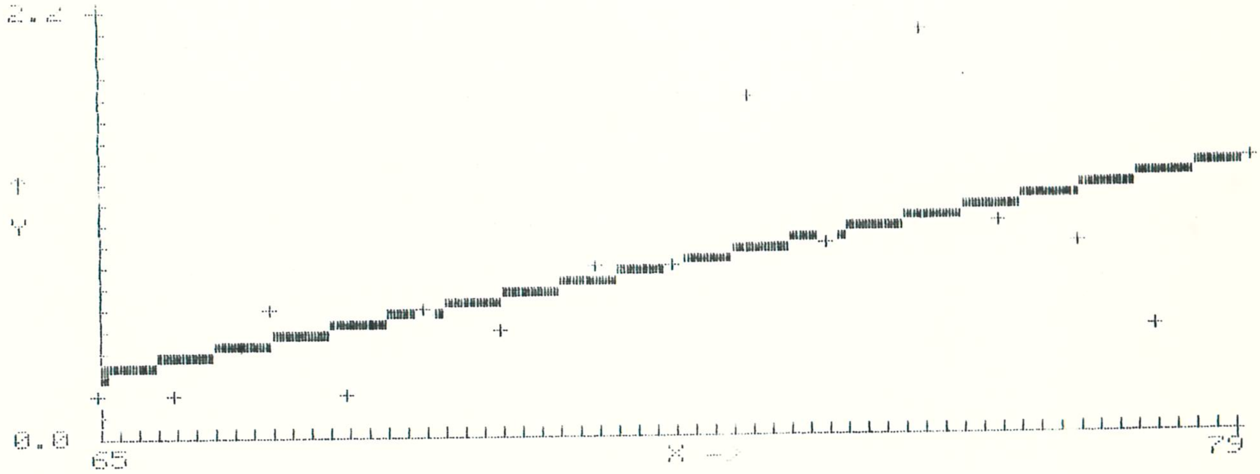

Fig. 26. Annual catch of **grilse in nets** in the rivers Taw and Torridge, 1965-1979.
Y = catch in 1000's; X = year in current century in 10's.

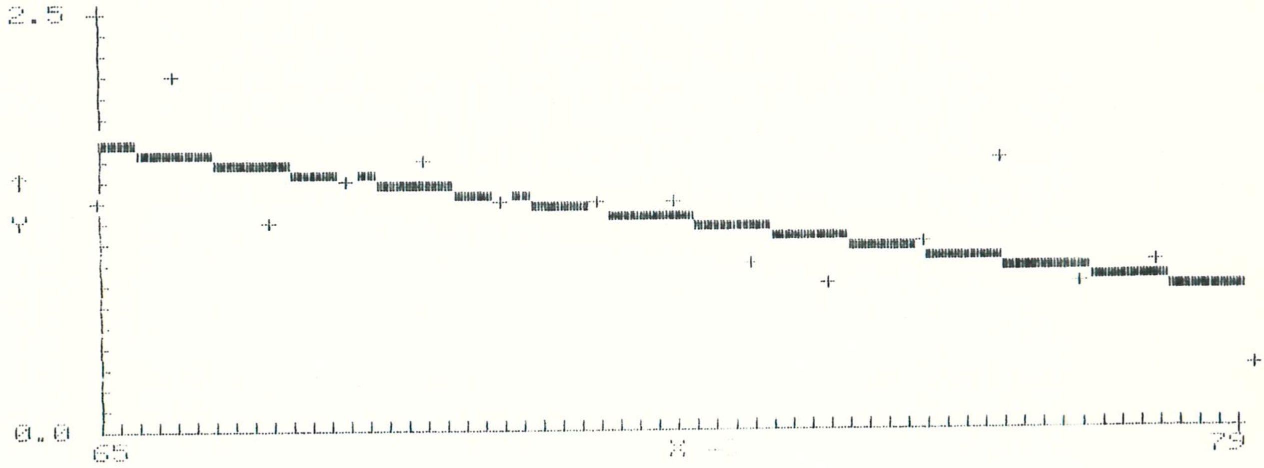

Fig. 27. Annual catch of **2-SW salmon in nets** in the rivers Taw and Torridge, 1965-1979.
Y = catch in 1000's; X = year in current century in 10's.

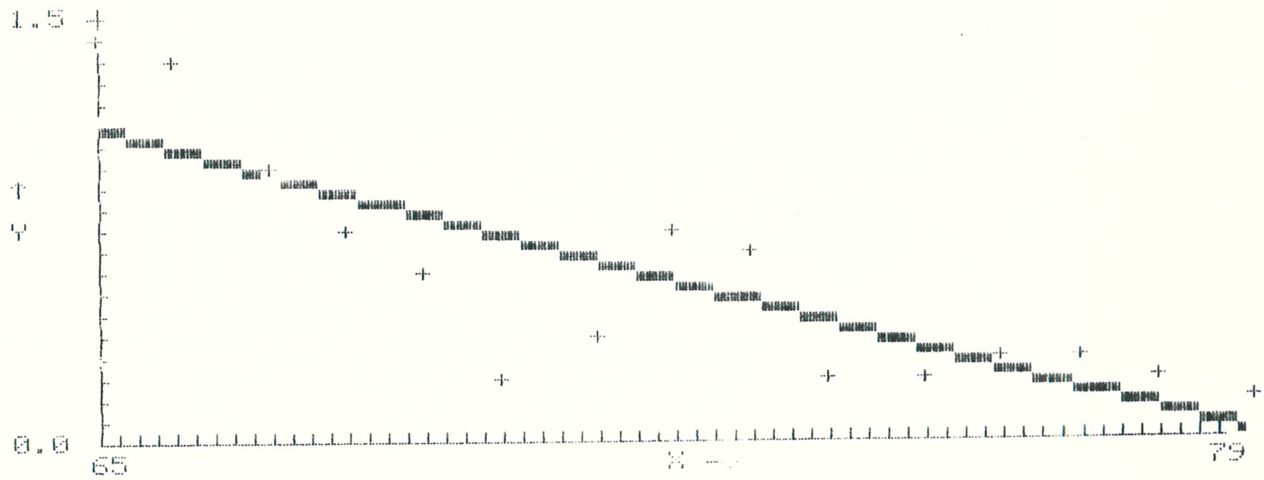

Fig. 28. Annual catch of **3-SW salmon in nets** in the rivers Taw and Torridge, 1965-1979.
Y = catch in 100's; X = year in current century in 10's.

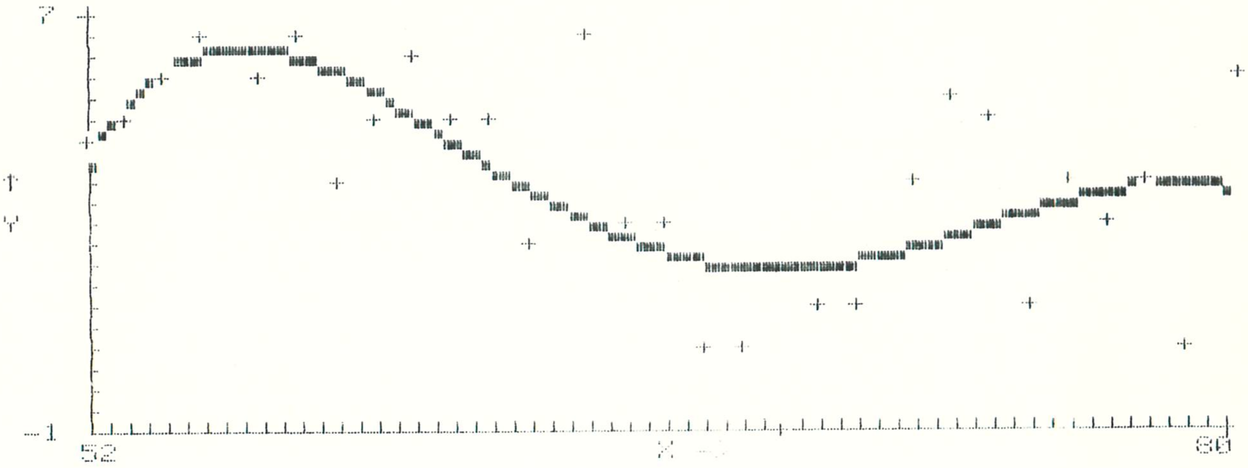

Fig. 29. Annual **sea temperature** in N. Iceland waters (66°N, 18°W) 1952-1980 (from Malmberg, 1985)
Y = temperature in °C; X = year in current century in 10's.

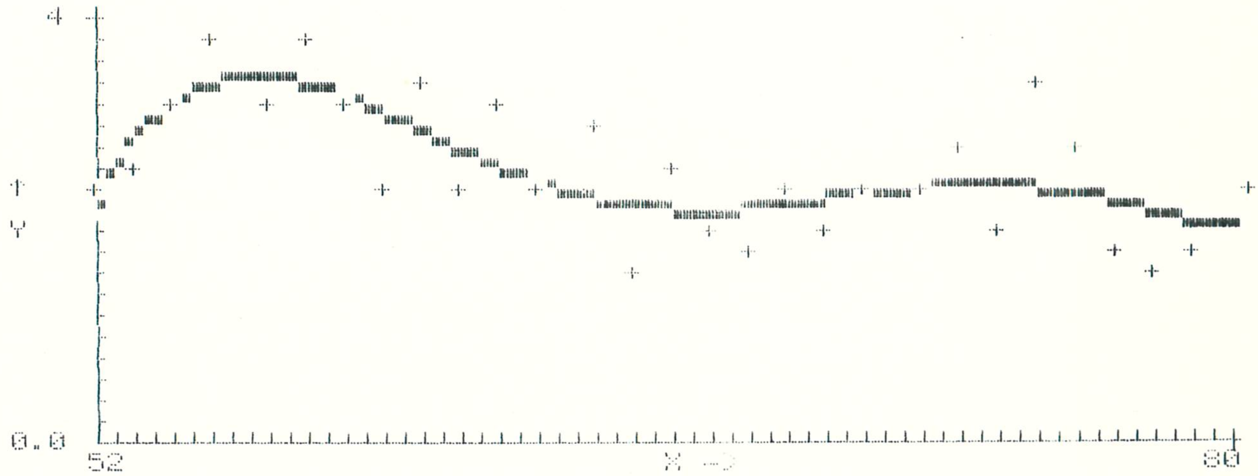

Fig. 30. Annual catch of **salmon in nets** in the rivers Taw and Torridge, 1952-1980.
Y = catch in 1000's; X = year in current century in 10's.

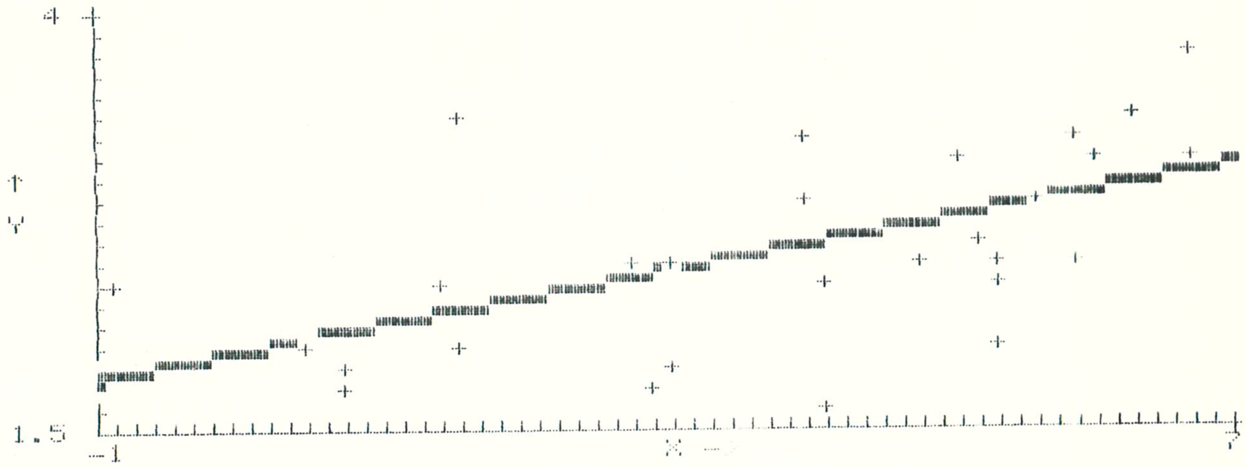

Fig. 31. Relation between annual **catch of salmon in nets** in the rivers Taw and Torridge and **sea temperature** in N. Iceland waters, 1952-1980. Y = catch in 1000's; X = temperature in °C.

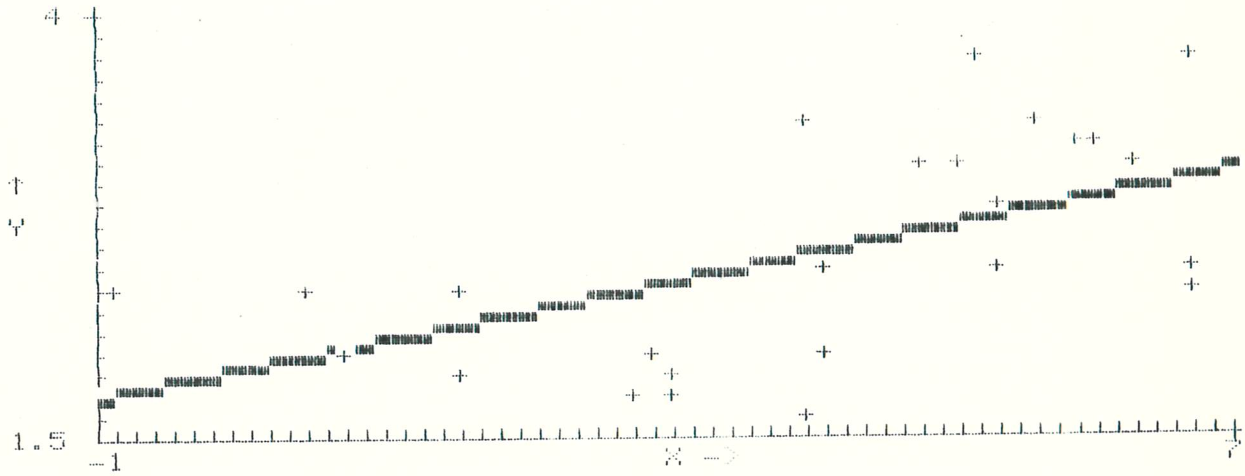

Fig. 32. Relation between annual catch of **salmon in nets** in the rivers Taw and Torridge and **sea temperature** in N. Iceland waters 2 years beforehand, 1952-1980. Y = catch in 1000's; X = temperature in °C.

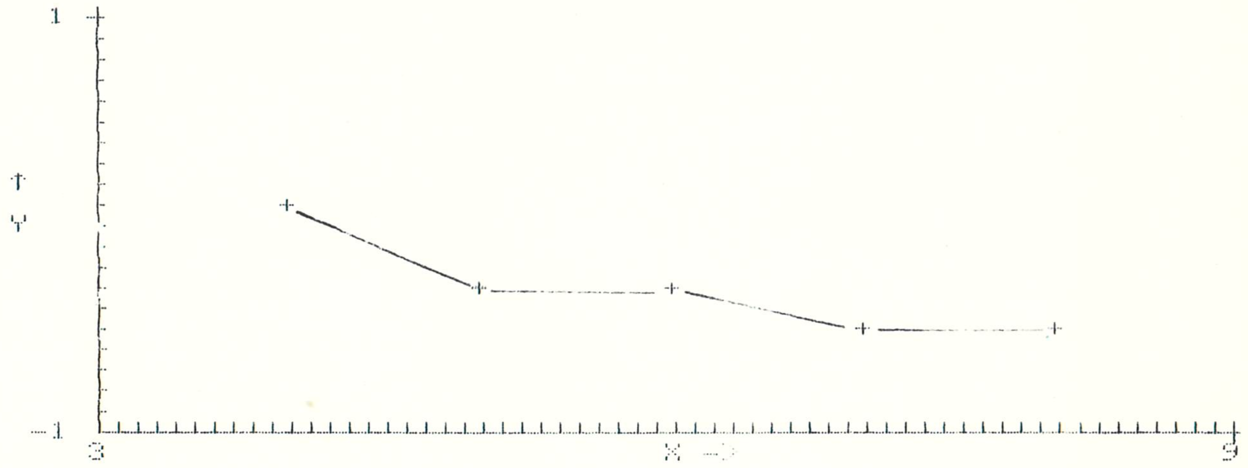

Fig. 33. Correlation coefficients of monthly catch of **salmon in nets** in the estuary of the rivers Taw and Torridge to **freshwater flow**, 1962-1980.
Y = corelation coefficient; X = month of the year.

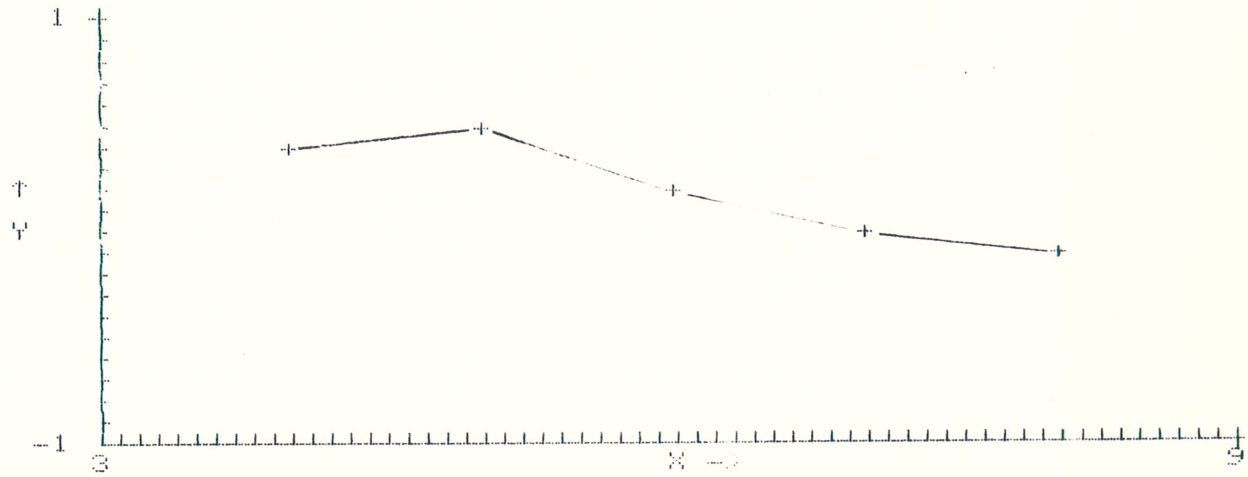

Fig. 34. Correlation coefficients of monthly catch of **salmon in nets** in the estuary of the rivers Taw and Torridge and **Icelandic water temperature** 1962-1980.
Y = correlaation coefficient; X = month of the year.

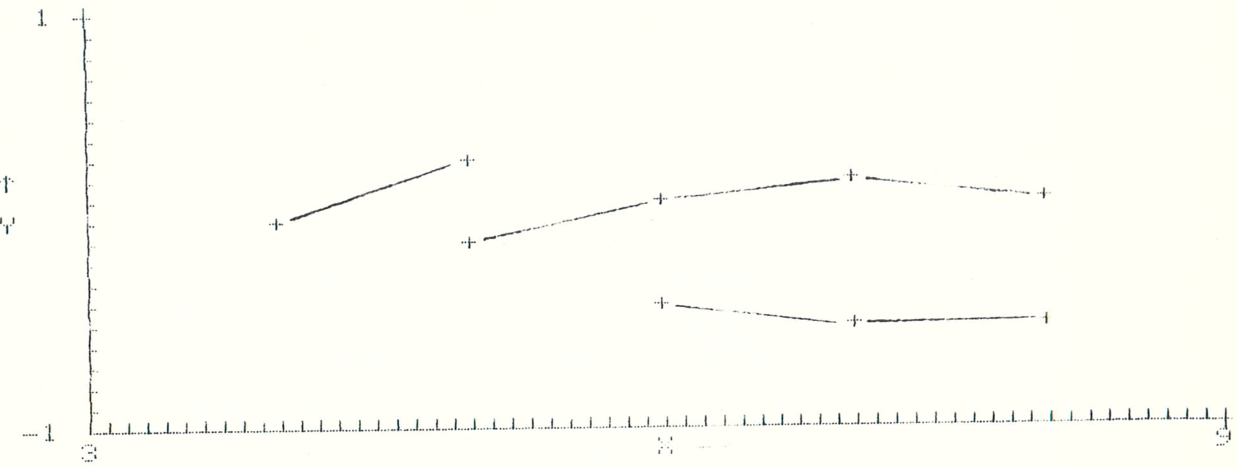

Fig. 35. Correlation coefficients of monthly catch of **salmon in nets** in the estuary of the rivers Taw and Torridge to **freshwater flow**, 1962-1980.
Y = corelation coefficient; X = month of the year.
Lines from left to right: 3-SW fish, 2-SW fish and grilse.

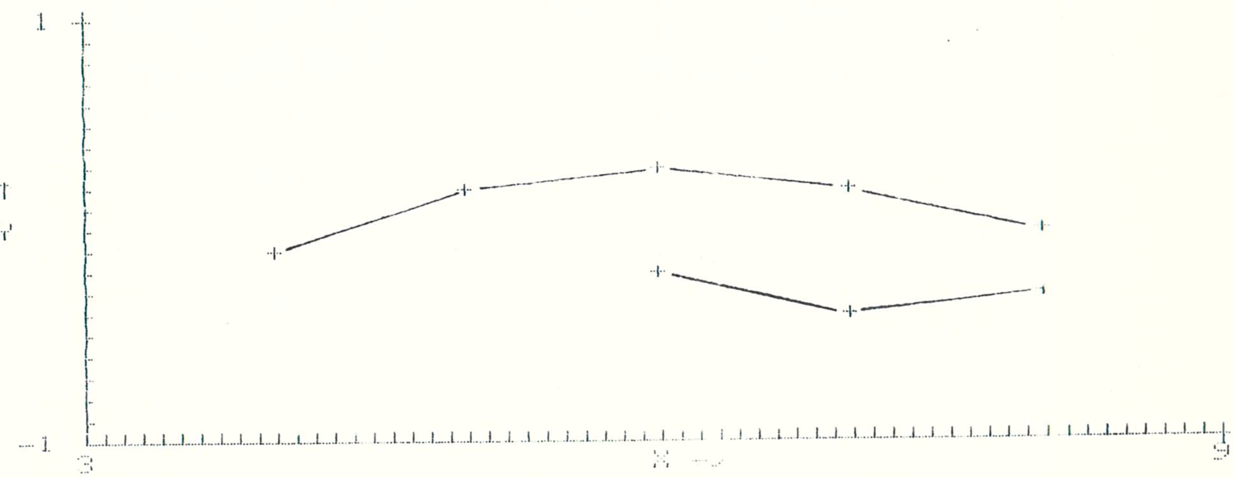

Fig. 36. Correlation coefficients of monthly catch of **salmon in nets** in the estuary of the rivers Taw and Torridge and **Icelandic water temperature** 1962-1980.
Y = correlaation coefficient; X = month of the year.
Upper line, 2-SW and 3-SW fish; lower line, grilse.

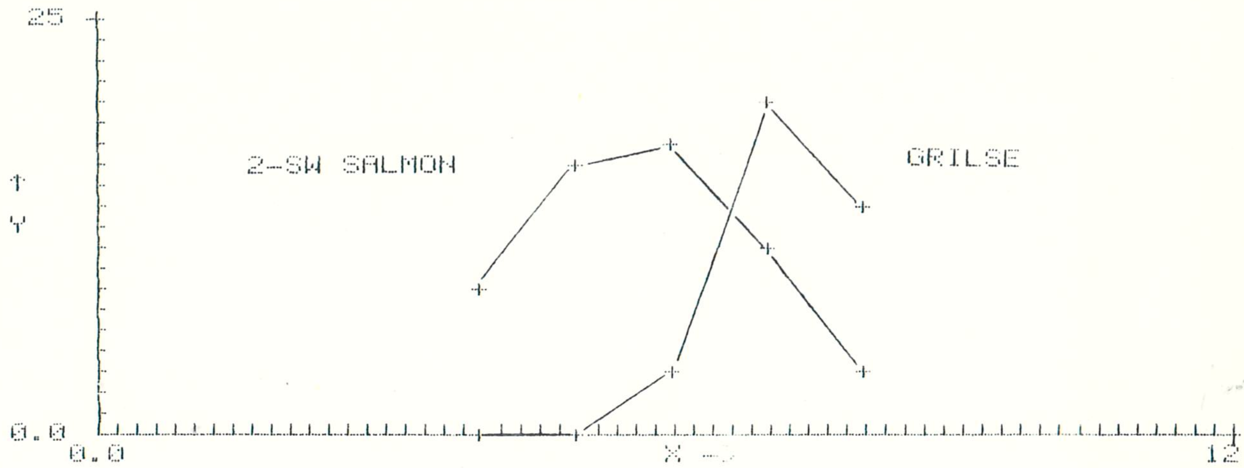

Fig. 37. Monthly percentage distribution of catch of **salmon in nets** in the rivers Taw and Torridge, 1965-1979.
Y = percentage; X = month of the year

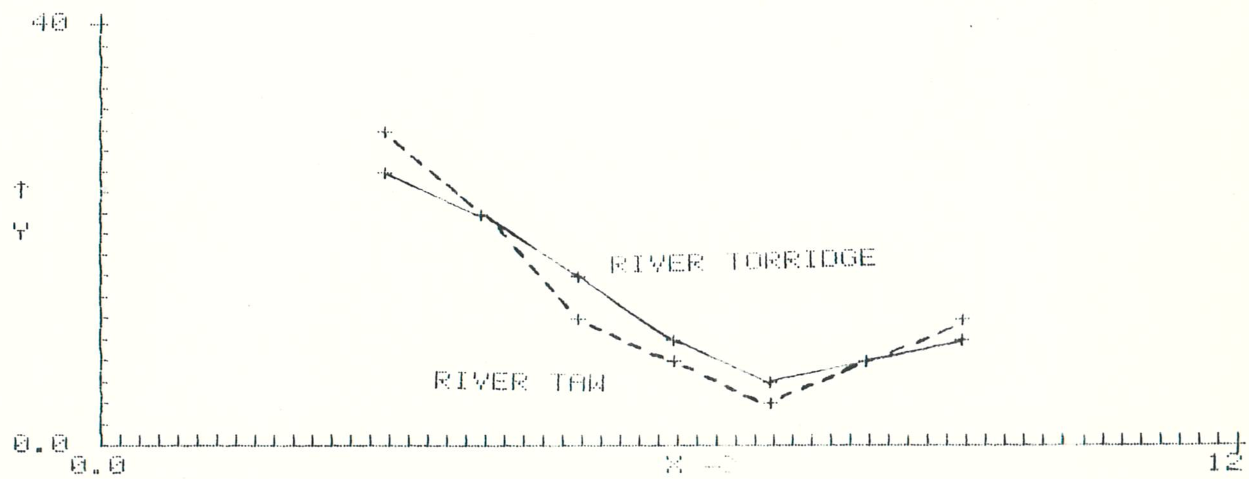

Fig. 38. Monthly percentage distribution of catch of **salmon on rod and line** in the rivers Taw and Torridge, 1965-1979.
Y = percentage; X = month of the year

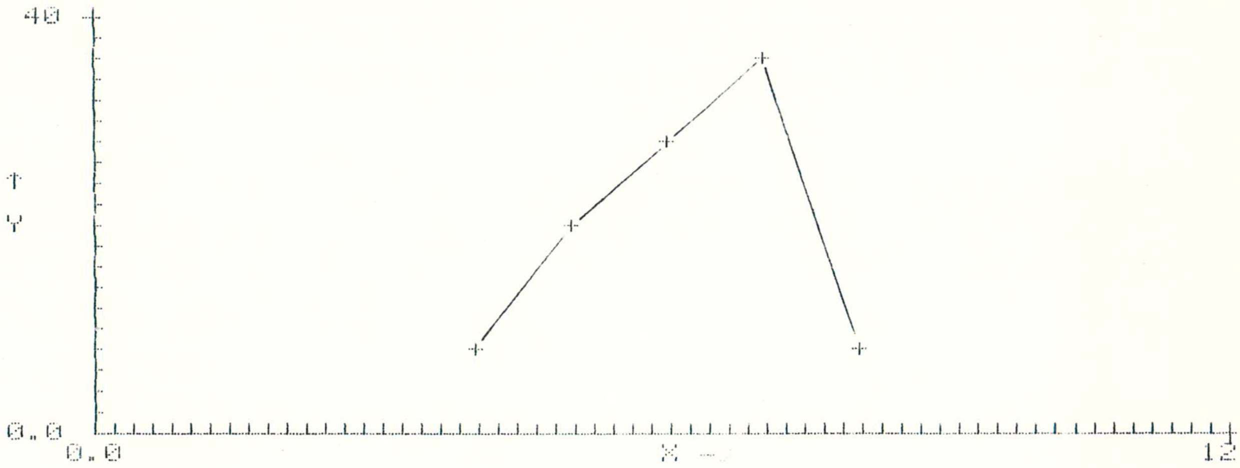

Fig. 39. Monthly percentage distribution of catch of **seatrout in nets** in the rivers Taw and Torridge, 1965-1979.
Y = percentage; X = month of the year

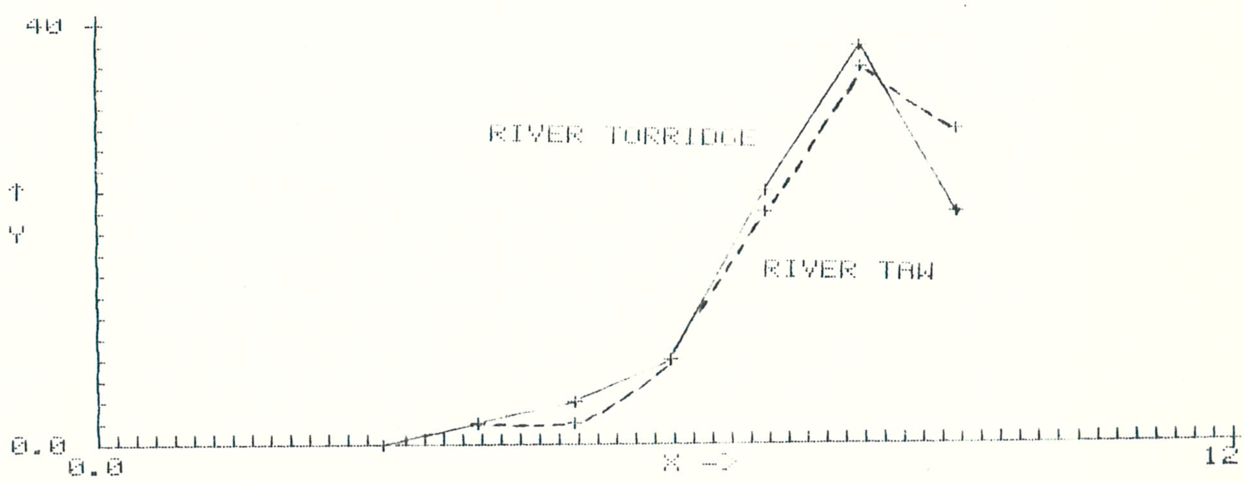

Fig. 40. Monthly percentage distribution of catch of **seatrout on rod and line** in the rivers Taw and Torridge, 1965-1979.
Y = percentage; X = month of the year

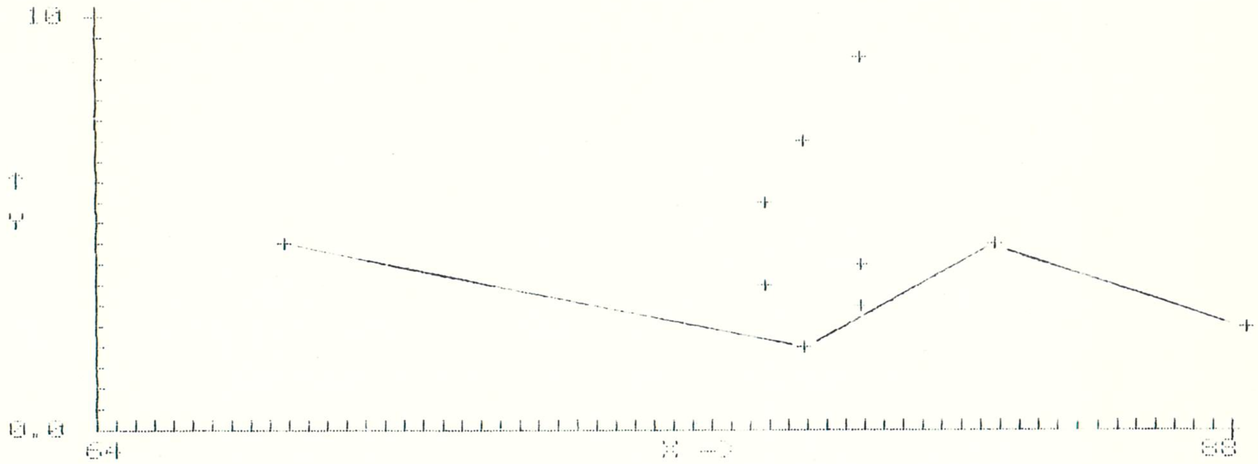

Fig. 41. Mean number of juvenile **salmon (1+ or more)** in the river Taw.
Y = no. per 100 m^2; X = year in current century in 10's.
Free points are for other south-western rivers (see text).

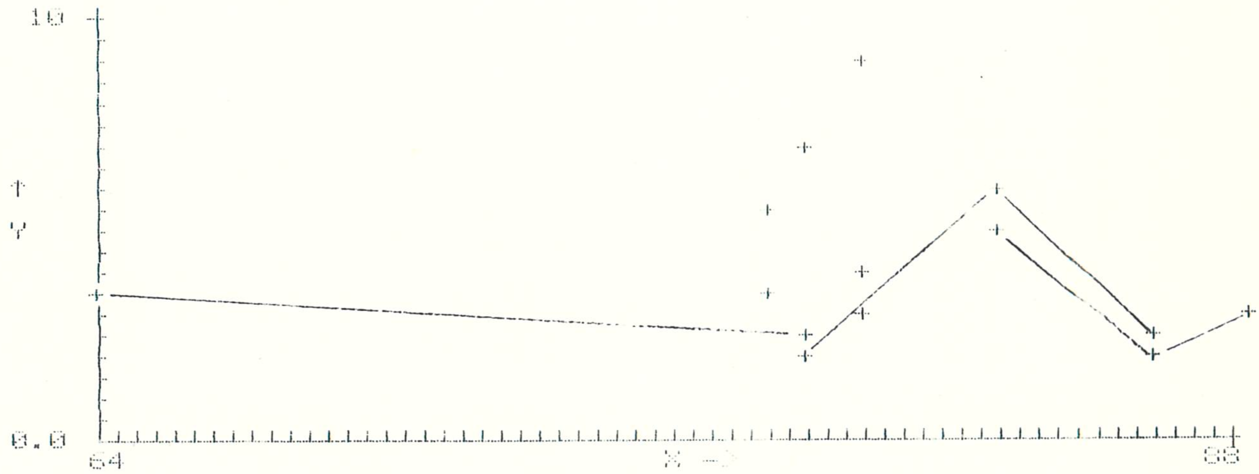

Fig. 42. Mean number of juvenile **salmon (1+ or more)** in the river Torridge
Y = no. per 100 m^2; X = year in current century in 10's.
Free points are for other south-western rivers (see text).

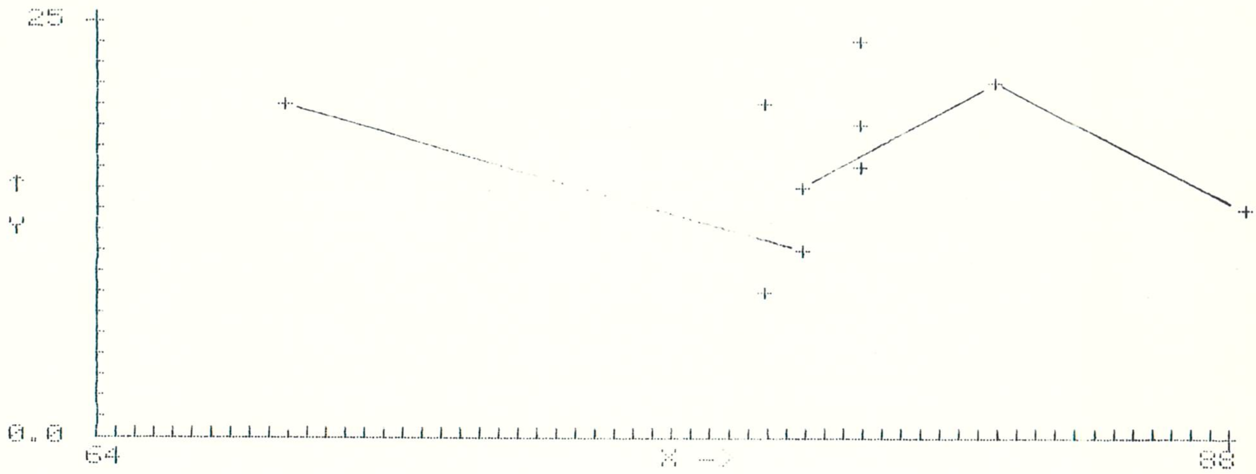

Fig. 43. Mean number of juvenile **trout (1+ or more)** in the river Taw.
Y = no. per 100 m^2; X = year in current century in 10's.
Free points are for other south-western rivers (see text).

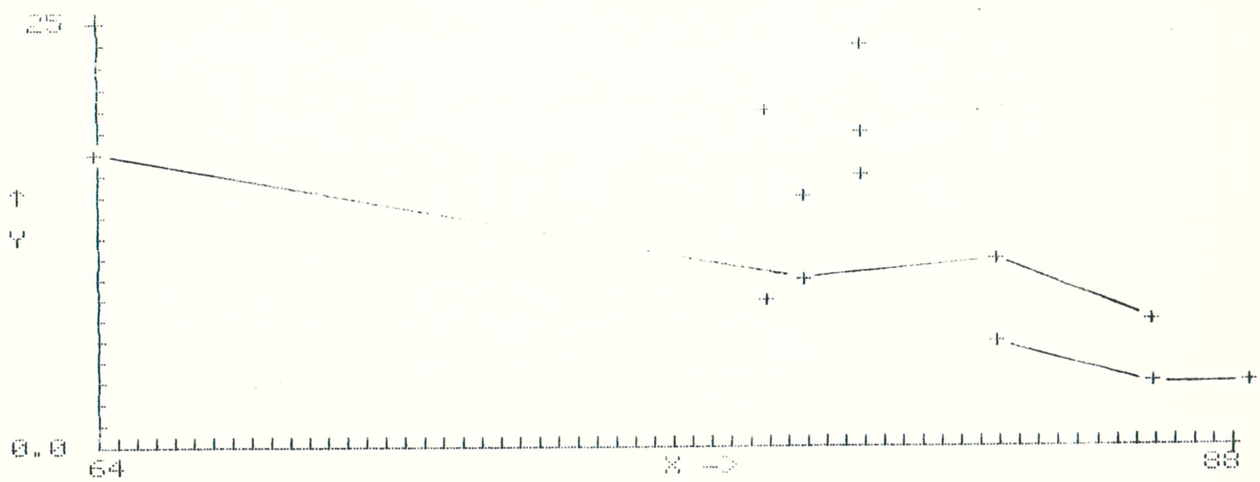

Fig. 44. Mean number of juvenile **trout (1+ or more)** in the River Torridge
Y = no. per 100 m^2; X = year in current century in 10's.
Free points are for other south-western rivers (see text).

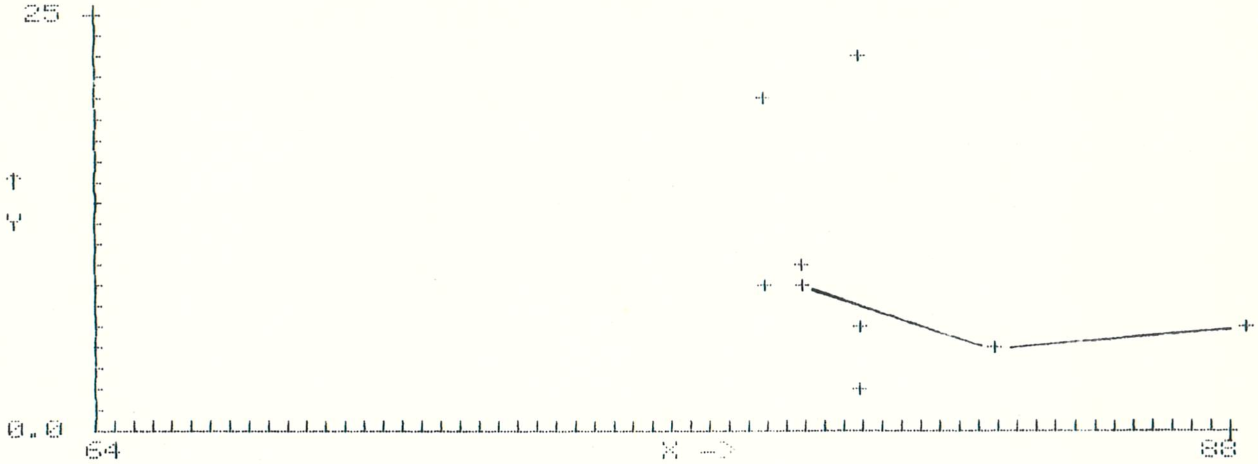

Fig. 45. Mean number of juvenile **salmon (0+)** in the river Taw.
Y = no. per 100 m^2; X = year in current century in 10's.
Free points are for other south-western rivers (see text).

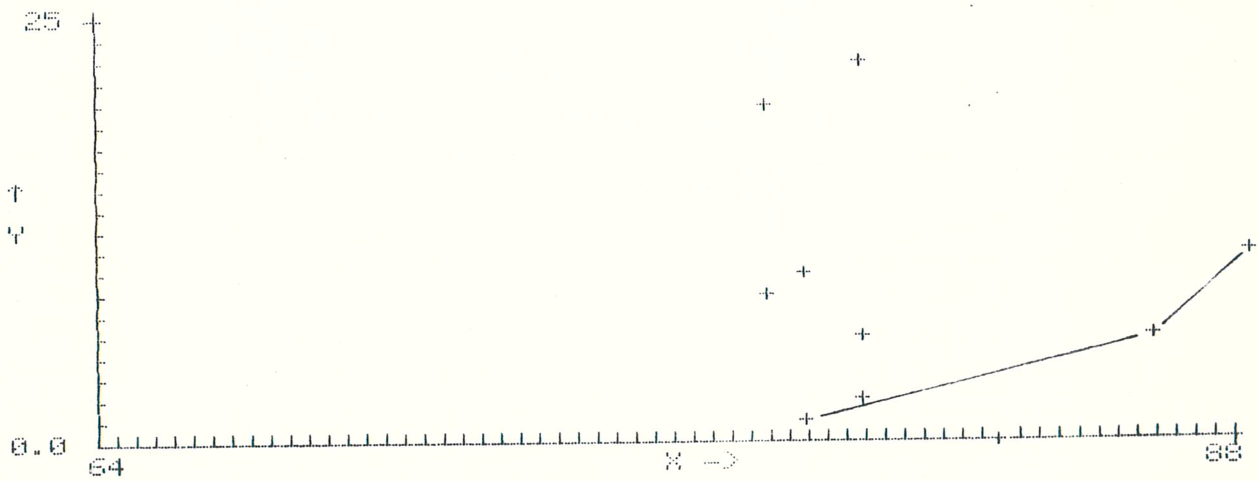

Fig. 46. Mean number of juvenile **salmon (0+)** in the river Torridge
Y = no. per 100 m^2; X = year in current century in 10's.
Free points are for other south-western rivers (see text).

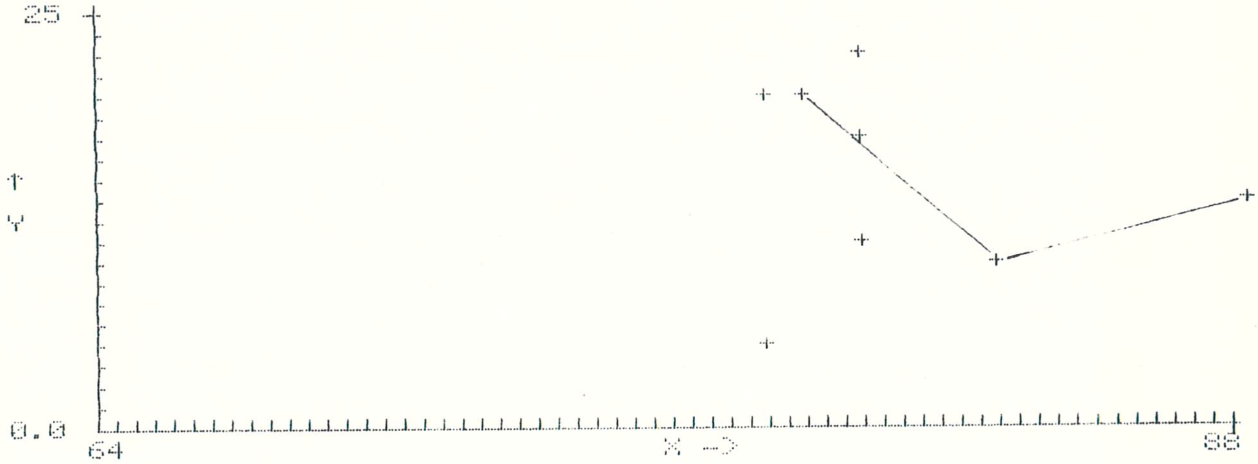

Fig. 47. Mean number of juvenile **trout** (0+) in the river Taw.
Y = no. per 100 m^2; X = year in current century in 10's.
Free points are for other south-western rivers (see text).

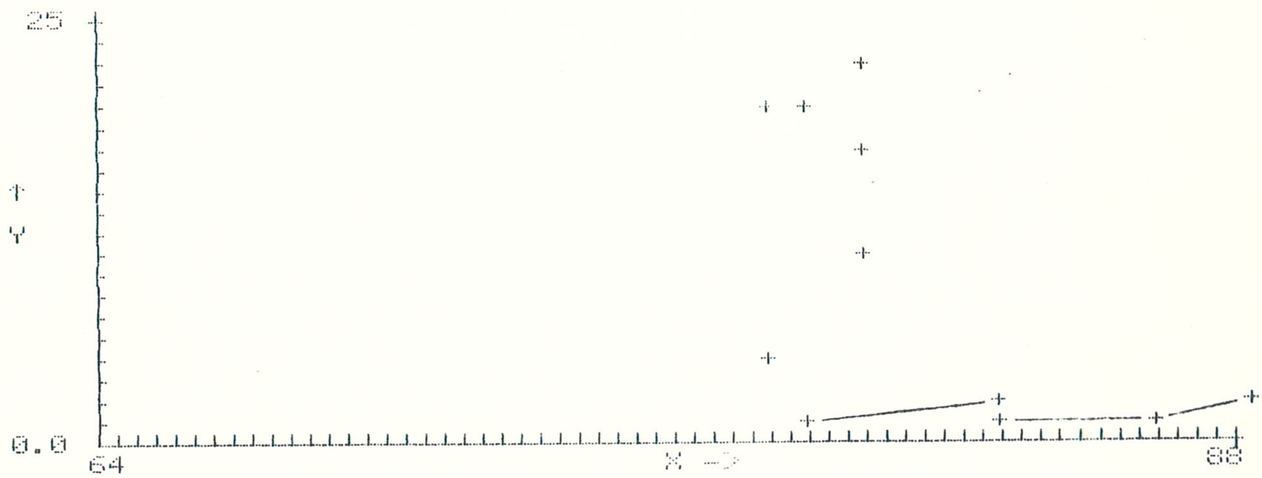

Fig. 48. Mean number of juvenile **trout** (0+) in the river Torridge
Y = no. per 100 m^2; X = year in current century in 10's.
Free points are for other south-western rivers (see text).

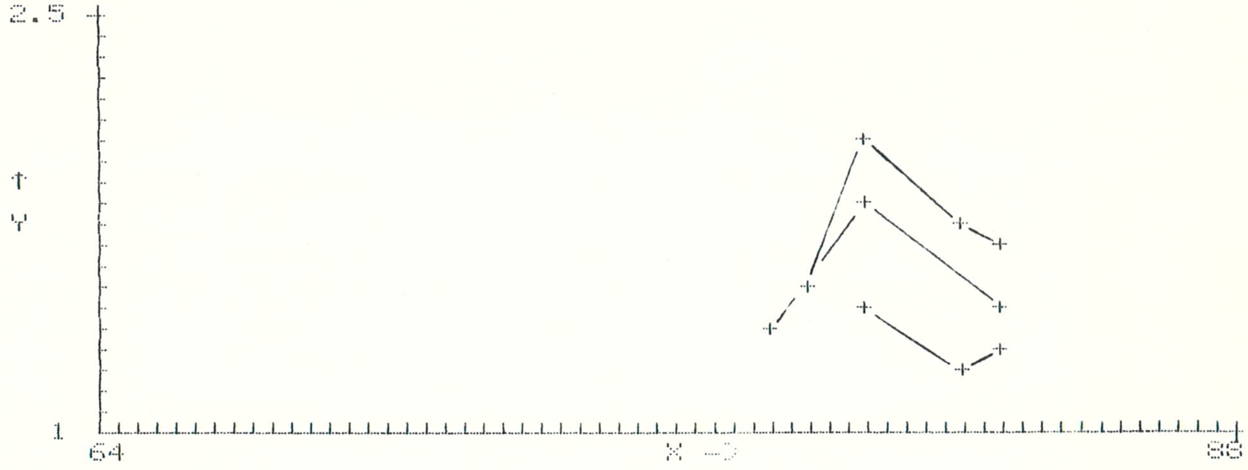

Fig. 49. Biological Monitoring Working Party (BMWP) Score in the river Torridge for stations in the upper, middle and lower reaches.
Y = Biotic score; X = year in current century in 10's.

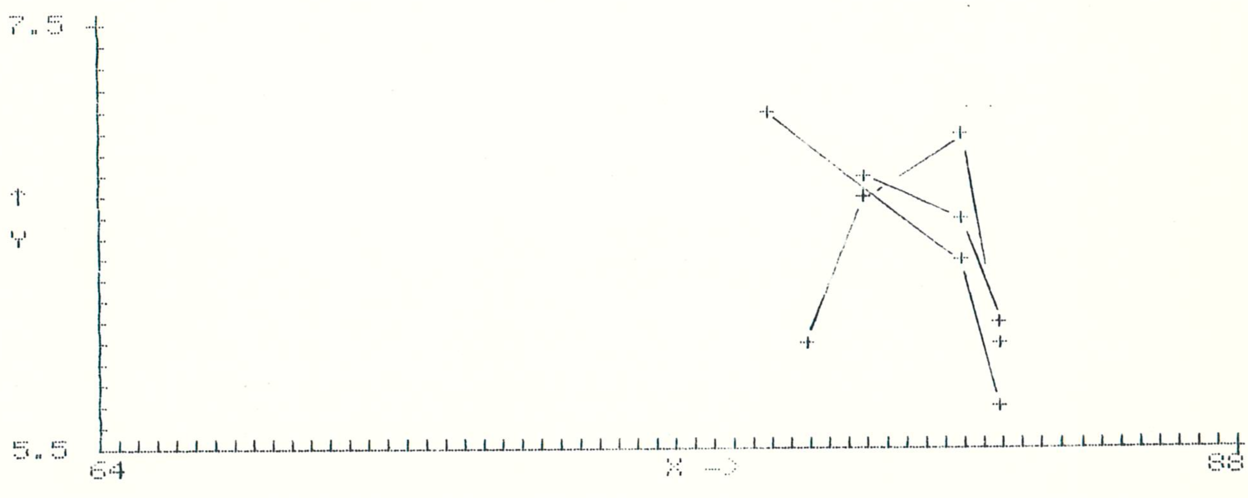

Fig. 50. Average biotic score per taxon in the river Torridge for stations in the upper, middle and lower reaches.
Y = biotic score; X = year in current century in 10's.

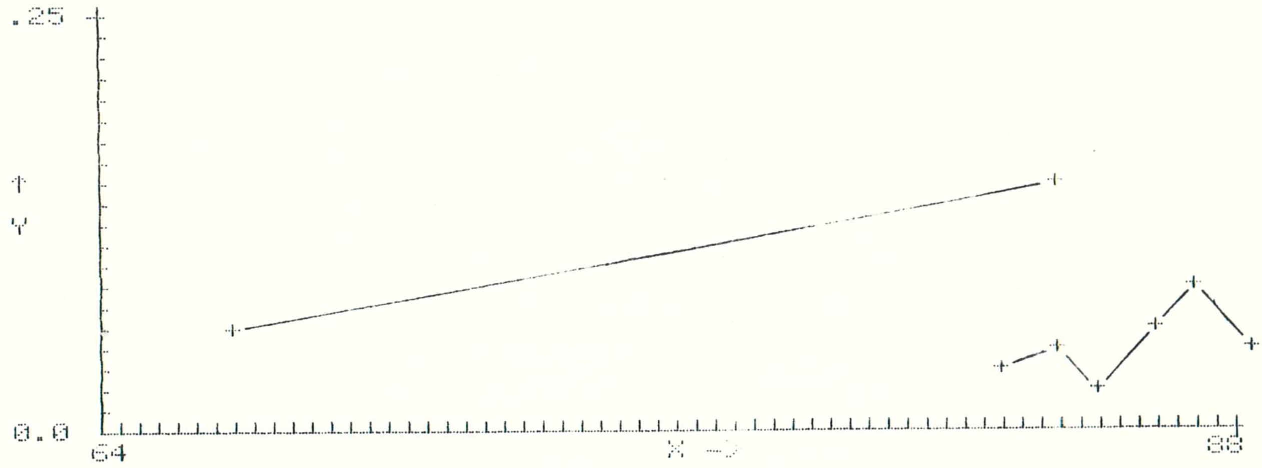

Fig. 51. Concentration of **total ammonia** in the river Taw.
Y = concentration in mg/l; X = year in current century in 10's.
Left-hand line, maxima; right-hand line, means (see text).

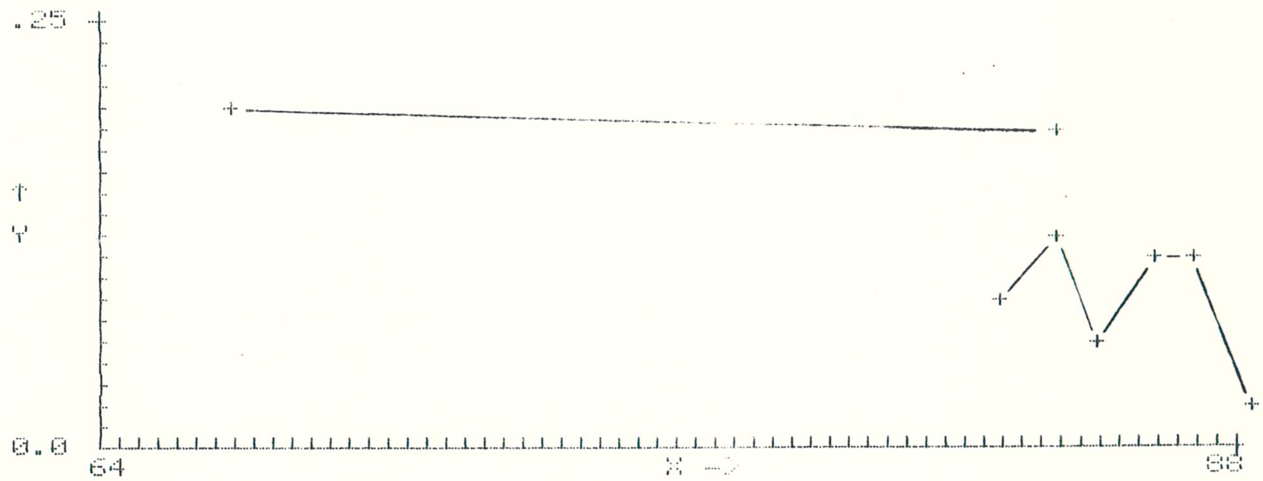

Fig. 52. Concentration of **total ammonia** in the river Torridge
Y = concentration in mg/l; X = year in current century in 10's.
Left-hand line, maxima; right-hand line, means (see text).

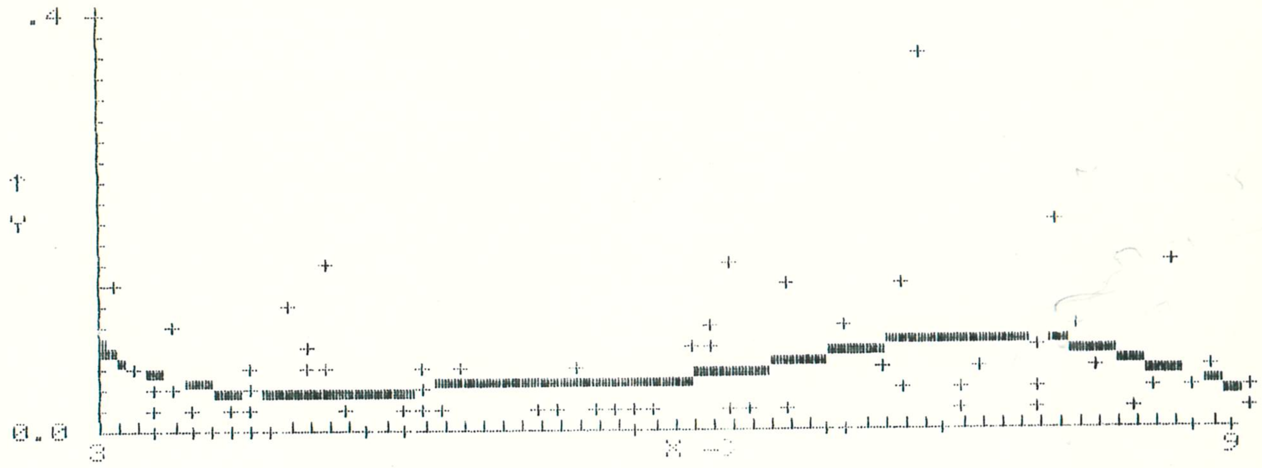

Fig. 53. Concentration of **total ammonia** in the river Taw, 1983-1988.
Y = concentration in mg/l; X = year in 1980's in units.

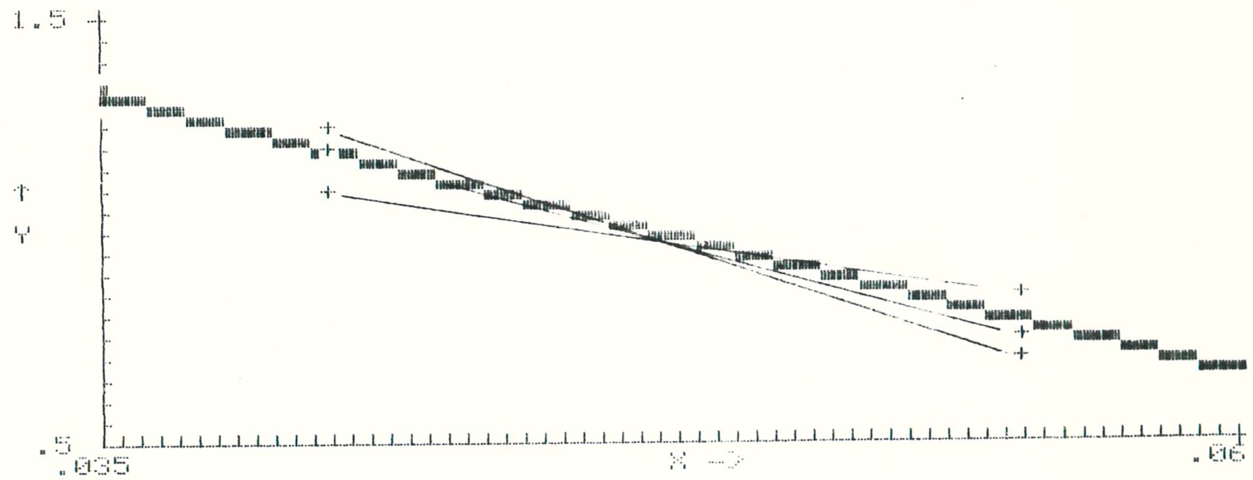

Fig. 54. Relation between juvenile **salmonid populations** (1+ salmon and trout and 0+ trout) and concentration of **total ammonia** in the river Taw.
Y = no. of fish per 100 m^2; X = concentration of ammonia in mg/l.

Table 1. Multiple regression analysis of monthly catches of fish in nets against time, monthly mean daily river flow (m^3/s) and water temperature (°C)off N. Iceland for the years 1962-1980.
Months in which none of the constants is significant are excluded. The proportion of the variance that is accounted for is given in parenthesis.

MONTH	a(intercept)	b(year)	c(flow)	d(temperature)
S A L M O N				
May	1969	-23.2**(0.38)	N.S	53.7**(0.31)
June	1901	-20.3* (0.31)	N.S	N.S.
July	801	N.S	-10.5(0.23)*	N.S.
Aug.	-863	17.9**(0.34)	N.S	N.S
S E A T R O U T				
April	-1467	25.9* (0.23)	N.S.	N.S.
May	2206	43.7* (0.23)	N.S	N.S.

***, P = less than 0.001; **, P = 0.01-0.001; *, P = 0.05-0.01;
N.S. = not significant

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Table 2. Multiple regression analysis of monthly catches of salmon in nets against time, monthly mean daily river flow (m^3/s) and water temperature (°C) off N. Iceland for the years 1965-1979.
Months in which none of the constants is significant are excluded. The proportion of the variance that is accounted for is given in parenthesis. Combined catches for June-August are expressed as proportions of monthly means.

MONTH	a(intercept)	b(year)	c(flow)	d(temperature)
		CONSTANT		
GRILSE				
Aug.	-2306	36.50** (0.57)	N.S	N.S.
June-Aug.	4.5	0.08***(0.26)	N.S	N.S.
2-SW SALMON				
June	2202	-25.20** (0.45)	N.S.	N.S.
July	1570	-19.30* (0.36)	N.S.	N.S.
Aug.	620	-7.40* (0.36)	N.S	N.S.
June- Aug.	6.3	0.07***(0.38)	N.S	N.S.
3-SW SALMON				
April	239	-3.8***(0.65)	N.S.	N.S.
May	179	-2.2* (0.30)	N.S.	N.S.

***, P = less than 0.001; **, P = 0.01-0.001; *, P = 0.05-0.01;
N.S. = not significant

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Table 3. Multiple regression analysis of monthly catches of fish on rods against time, monthly mean daily river flow (m^3/s) and flow in river Torridge/flow in river Taw for the years 1969-1984.
Months in which none of the constants is significant are excluded. The proportion of the variance that is accounted for is given in parenthesis.

MONTH	a(intercept)	b(year)	c(flow)	d(flow in R. Torridge/ flow in R. Taw)
SALMON				
RIVER TAW				
April	17.31	N.S.	5.0* (0.27)	N.S.
June	-3.1	N.S.	4.9***(0.98)	N.S.
July	0.4	N.S.	4.4* (0.42)	N.S.
Aug.	75.5	-1.1***(0.53)	1.8* (0.15)	16.4*(0.11)
Sept.	12.8	0.7* (0.31)	N.S.	N.S.
RIVER TORRIDGE				
March	254.5	-2.8* (0.37)	N.S.	N.S.
April	2.1	N.S.	3.9* (0.36)	N.S.
June	107.6	-1.4* (0.06)	4.4***(0.83)	N.S.
July	3.0	N.S.	2.1* (0.32)	N.S.
Aug.	77.5	-1.0** (0.14)	2.8***(0.73)	N.S.
Sept.	11.9	N.S.	0.8* (0.32)	N.S.
SEA TROUT				
RIVER TAW				
June	36.2	N.S.	8.1** (0.46)	N.S.
July	165.1	N.S.	25.6* (0.27)	N.S.
Aug.	70.1	N.S.	75.2***(0.83)	N.S.
RIVER TORRIDGE				
April	71.2	-0.8* (0.33)	N.S.	N.S.
May	-32.3	N.S.	N.S.	74.5*(0.29)
June	21.0	N.S.	8.0***(0.62)	N.S.
July	1147.4	-12.9* (0.38)	N.S.	N.S.
Aug.	1957.5	-24.3** (0.20)	46.7***(0.63)	N.S.
Sept.	1087.2	-12.2***(0.56)	N.S.	N.S.

***, P = less than 0.001; **, P = 0.01-0.001; *, P = 0.05-0.01;
N.S. = not significant

Table 4. Multiple regression analysis of monthly catches of fish on rods against time, monthly mean daily river flow (m^3/s) and monthly mean water temperature (°C) for the months of June, July and August combined for the years 1974-1984.

CONSTANT			
a(intercept)	b(year)	c(flow)	d(temperature)
SALMON			
RIVER TAW			
-3.9	N.S.	6.6***(0.77)	N.S.
RIVER TORRIDGE			
41.5	-0.54*(0.05)	2.7***(0.64)	N.S.
SEA TROUT			
RIVER TAW			
80.5	N.S.	37.7** (0.31)	N.S.
RIVER TORRIDGE			
51.3	N.S.	20.8** (0.29)	N.S.

***, P = less than 0.001; **, P = 0.01-0.001; *, P = 0.05-0.01;
N.S. = not significant

Table 5. Correlation coefficients of mean monthly river flow against year for the years 1969-1983.

	River Taw	River Torridge
January	0.15	0.21
February	-0.21	-0.18
March	0.27	0.32
April	-0.07	-0.23
May	0.11	0.11
June	-0.26	-0.23
July	-0.09	-0.36
August	-0.50*(0.25)	-0.51*(0.26)
September	-0.14	-0.08
October	0.44	0.54*(0.29)
November	0.03	0.14
December	0.53*(0.28)	0.52*(0.27)

*, P = 0.05-0.01; others not significant.

Table 6. Fish populations and invertebrate diversity in the upper, middle and lower reaches of the river Torridge

Year	Number of fish per 100 m^2				Biotic Score	
	Salmon 0+	Salmon 1+	Trout 0+	Trout 1+	BMWP	Average/taxon
1979	0	2.2	7.8	26.7	171	6.1
1983	2.2	10.6	36.6	42.0	110	5.2

Table 7. Minimum concentrations of dissolved oxygen and maximum concentrations of un-ionised ammonia in the Taw and Torridge estuary, during surveys in February, May, July/August and October, 1988 (Wimpole Ltd., 1989)

Date	Concentration (mg/l)	River	Station (code)	Tide	Depth (m)
		Dissolved Oxygen			
16 Feb.	8.8	Torridge	(BW)	High, Spring	5.9
8 May	7.2	Torridge	(D)	High, Neap	3.6
31 July	7.0	Taw	(5)	High, Spring	3.8
24 Oct.	7.1	Torridge	(E)	High, Spring	6.6
		Un-ionised Ammonia			
16 Feb.	0.005	Torridge	(AW)	High, Spring	6.3
10 May	0.008	Torridge	(ZS)	High, Neap	10.9
1 August	0.007	Taw	(4N)	Low, Spring	0.4
24 Oct.	0.004	Taw	(5)	High, Spring	4.6