ATLANTIC SALMON TRUST

ENHANCEMENT OF SPRING SALMON

Proceedings of a One-day Conference held in the Rooms of the Linnean Society of London

26 January 1996

Edited by Derek Mills

The Atlantic Salmon Trust
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Contents

INTRODUCTION

D H Mills

Institute of Ecology and Resource Management, University of Edinburgh
Darwin Building, Mayfield Road, Edinburgh

An attendance of approximately 150 delegates from all parts of the British Isles, Canada and Norway indicated the growing concern over the general demise of our valuable stocks of spring salmon.

The undoubted success of this well-attended conference was in part due to its being preceded by a half-day workshop on the same subject the day previously. Attendance at this workshop was limited to those scientists and managers directly involved in research into or management of spring salmon. The intensity of debate and exchange of ideas at this workshop was most valuable. It was also useful preparation for the extensive discussion which emanated from a much wider audience stimulated both by the speakers' papers and a number of questions laid before the delegates at the outset. These seven questions are now set out below to both help the reader through these proceedings and stimulate his or her own thoughts on the subject.

1. Are we right to define early-running salmon as a mixture of winter and spring-running MSW fish plus 1SW (grilse) running in the early summer?
2. Has there been a general decline in spring fish numbers, or has it been confined to certain parts of their range?
3. How reliable is the evidence for cyclical changes in the abundance of early-running salmon, given that early-running salmon are available to the fishery for a large part of the season?
4. Do early-running fish home to specific parts of river systems, especially cool upper catchments where juvenile growth rates are lower than those of juveniles occupying areas where faster growth is possible? Is there any evidence for their interbreeding with late-running fish?
5. What evidence is there that early-running is an inherited characteristic and to what extent is it linked with development rate in the sea and fresh water?

6. Do changes in the abundance of early-running salmon reflect changes in the dynamics of maturation, in total marine mortality rates or in the distribution of mortality rates between sea age classes and/or stocks?
7. What provisions can we make, in the present state of knowledge, to enhance early-running stocks through quota buy-outs, catch and release, bag limits, extended close seasons in spring, kelt reconditioning, stocking with eggs/juveniles from early-running parents and habitat manipulation?

These questions are fully addressed in the following papers and Dr Shelton's detailed "summing up".

THE DECLINE OF SPRING SALMON

A F Youngson

SOAEFD Marine Laboratory, Victoria Road, Aberdeen

Introduction

Spring-running salmon typically return to the larger rivers in the central and southern parts of the species' range in Atlantic Europe. They return six months or more before spawning. In some places, they join small numbers of fish that have run the rivers even earlier, during the late autumn and winter, as much as a year before spawning. Members of this class are designated winter-running salmon. Together, both winter- and spring-running salmon form the basis of the spring fisheries and, from this point of view, they are treated as a single group in compiling the catch data on which most of our knowledge of the abundance of early-running salmon depends.

Traditionally - and somewhat arbitrarily - the spring fisheries are defined as terminating at the end of April. However, in dealing specifically with rod catches a later date appears appropriate. From an operational point of view (and by the calendar alone), the spring rod fisheries can be considered to give way to the summer ones about the end of May. Before this time, 1SW fish (grilse) are essentially absent from rivers and no possibility exists of their forming a substantial part of the spring catch. Thus, all the salmon that are caught in spring can be regarded as 2SW or older sea-age fish. Formerly, 3SW fish comprised a notable portion of the spring rod catch in some rivers (see Hutton's account of the Wye in the early years of this century). Fish like these are now rare or uncommon. Currently, therefore, the sea-age class composition of the spring catch is relatively simple: the great majority of early-running salmon are 2SW fish.

Spring Catches

Since the late 1970s and particularly since the late 1980s, there have been marked trends everywhere towards lower catches of early-running salmon. Much of the reduction in the commercial catch can probably be attributed to reduced fishing effort. In the case of the rods, however, catches have fallen in the absence of reductions in effort, suggesting that the number of early-running salmon present in rivers has declined. Whether this is a new or sinister development is rather in doubt. It appears from long-term catch records that changes in the relative abundance of early-running salmon have occurred in the past and that the same fisheries have later reverted to what appeared to be their original condition (Summers, 1993, 1995; Anon, 1994). However, the causes underlying past changes may have differed from time to time. So, although the longest historical records available indicate the range of possible variation, they need not hold the key to understanding current changes or to predicting what may happen in the future. In these respects, close focus on more recent events in the historical series is likely to be most informative.

There is another factor that must be considered. New high-seas fisheries have operated within the last 30 years before they were reduced or eliminated by means of quotas and buy-outs. The Greenland fishery, particularly, is known to have exploited potential 2SW fish destined for European rivers. Shearer (1992) estimated the effect of the Greenland fishery to be substantial on some of the spring fisheries. The Greenland fishery last exceeded 1,000 tonnes in 1982 and it has not exceeded 100 tonnes since a buy-out was first instituted in 1993.

In general, catch records are the only source of information that may be used to consider present-day fisheries in any sort cf historical context. However, systematic, standardised records of the British fisheries were not compiled before a statutory requirement to record and report catches was introduced in 1952. The data that have been gathered annually since then from the rod fisheries are a powerful source of information. The recent part of the record can be taken to describe current trends: the earlier part can be used as a basis for comparison. Even then, evaluating catch data is attended by difficulties, the most obvious being that formal estimates of the fishing effort required to make the reported catches are not available. As a general rule, therefore, changes in abundance cannot be inferred from catch data with confidence.

Most interpretations of catch data have used a different approach, focussing on the relative abundance of the sea-age classes in the annual catch. The recent report on run-timing by the Salmon Advisory Committee (Anon, 1994), for example, relied heavily on this approach. Scrutinising grilse: salmon ratios appears to obviate the uncertainty associated with having to treat catch figures as measures of absolute abundance. However, measures of relative abundance are particularly prone to misinterpretation. Variation in grilse: salmon ratios may result equally from changes in the absolute abundance of grilse, changes in the absolute abundance of salmon or from simultaneous changes in the absolute abundance of both groups.

It is an implicit assumption of many analyses of grilse: salmon ratios that uniform rates of marine mortality prevail. Annual or periodic variation in the ratio is therefore attributed to changes in the tendency of individual fish to return to rivers as grilse or as 2SW salmon. Likewise, variation in the size of the spring catch is attributed to changes in the sea-age composition of the returning fish on the grounds that, unlike salmon, grilse cannot contribute to the spring fishery because of their inherently later run-timing. However, when this hypothesis is tested for the case of the spring fishery of the Aberdeenshire Dee, where a fuller data set is available, it cannot be sustained.

Reciprocation Between the Spring Salmon and Grilse Classes

The Aberdeenshire Dee is perhaps the archetypal spring-fishing river: the major portion of the large annual catch is of 2SW salmon and most are captured between February and May. The Dee is also unusual in that a fish-trap is installed on the Girnock Burn, one of its spawning tributaries. This facility was commissioned in 1966 and has since produced a long time-series of data. Tagging studies have demonstrated that about 50% of the adults that enter the Girnock Burn have homed there and, since the methods used provide under-estimates, true rates of homing can be regarded as being rather greater (Youngson *et al.*, 1994). The Girnock Burn is therefore a relatively simple self-contained system that produces smolts and later receives some of the same fish on their return from the sea.

Scale-reading has shown that the adults that have returned to the Girnock Burn recently - as in the past - are either spring-run salmon or early-summer grilse. The annual catch on the Dee has declined markedly because of its heavy reliance on the declining spring fishery. There is no compelling evidence of a compensatory move of catches from spring to summer or autumn. Crucially, at the Girnock Burn, grilse are no more abundant among the spawners now than they were before. The missing spring salmon are not therefore concealed among the grilse.

Rod Catches and Abundance of Early-Running Salmon

In general, catch figures cannot be used as measures of abundance because no figures are available for the effort expended in making the catches. However, in the special case of early-running salmon, the rod catch figures are a valid gauge of abundance. Thus, commercial effort on early-running salmon has decreased: this ought to have increased their abundance in rivers. Rod fishing effort has increased over the years: this will have resulted in increases in the exploitation rate of the fish within the rivers. Against both these trends, however, spring rod catches have decreased (Fig. 1). In these circumstances, lack of information on the absolute value of fishing effort does not confound interpretation of the figures. Rod catches of early-running fish - considered over an appropriate time scale - are a valid measure of underlying declines in abundance and they under-estimate their true extent. Moreover, the declining trends in catches (and therefore abundance) show considerable coherence among rivers (Youngson, 1995), suggesting that the same adverse factors are at play and that they operate on a broad geographical scale.

Marine Mortality

Since the Girnock Burn trap was commissioned, the stream has produced annual smolt runs of near uniform strength. By inference, the current decline in the Dee spring fishery is therefore unlikely to be the result of poor smolt recruitment. Instead, it is probably attributable to increased rates of mortality between the smolt and adult return stages. Marine fishing mortality on all early-running salmon has lessened with reductions in the home-water commercial fisheries and with the suspension of the ocean fisheries. As far as is known, current, high levels of marine mortality are not attributable to other fishery activity. Mortality is probably therefore attributable to non-fishing causes.

Analyses of tagging data for North Esk fish indicate that marine survival rates have tended to decrease since studies were initiated there in the 1960s (Dunkley, 1995). The North Esk fishery is complex and based ultimately on the multiple contributions of smolts derived from separate populations that are reared in and then return to their own areas of the catchment. Smolts are captured and tagged near the head-of-tide. It is not possible to distinguish the contributions of separate populations to the overall catch of smolts. When the adults return, their intended destinations within the catchment are not known. The estimates of marine mortality derived from the tagging programme are therefore average levels for the entire North Esk stock. It may be that the special difficulties being experienced by the spring fisheries are caused by differences in marine mortality rate among different components of the stock.

Moreover, when catches for the separate months of the spring season are examined in the set of British rivers considered in Figure 1, differences in the patterns of decline are detected among months. Recent reductions in the spring catch appear to have been more severe in the early months of the spring fishery than in the later ones. Again, these effects are consistently evident among the rivers (Table 1).

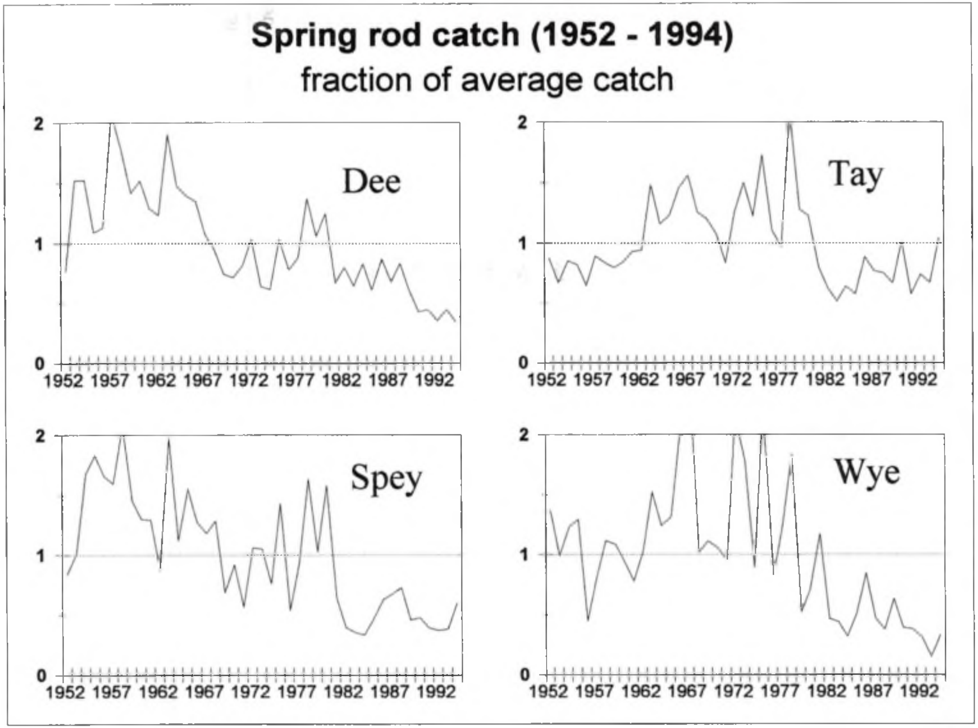

Figure 1. Spring catches (Jan - May) for four of the major British rod fisheries (1952 - 1994). Annual catches are expressed as a fraction of the long-term average.

Figure 1 Spring catches (January-May) for four of the major British rod fisheries (1952-1994). Annual catches are expressed as a fraction of the long-term average.

Table 1 Rod catches of salmon for each spring month in the Rivers Dee, Tay, Spey and Wye. (Values are expressed as fractions of the corresponding long-term average 1952-94, figure and further averaged by decade.)

	Rod catch (as fraction of 1952-1994 average)			
	February	March	April	May
Dee				
1960s	1.1	1.4	1.3	1.4
1970s	1.2	0.9	0.7	0.8
1980s	0.8	0.8	0.8	0.8
1990s	0.4	0.5	0.6	0.6
Tay				
1960s	1.4	1.2	1.1	1.1
1970s	1.3	1.4	1.3	1.2
1980s	0.6	0.7	0.8	0.8
1990s	0.4	0.5	1.0	1.4
Spey				
1960s	1.3	1.4	1.2	1.2
1970s	1.4	1.0	0.9	1.0
1980s	0.7	0.6	0.6	0.6
1990s	0.2	0.3	0.4	0.6
Wye				
1960s	1.4	1.6	1.4	1.2
1970s	1.7	1.3	1.2	1.4
1980s	0.5	0.3	0.6	0.8
1990s	0.1	0.1	0.3	0.5

There is no evidence for a displacement of early spring catches of 2SW salmon to the later spring months: all the monthly catches have declined. Therefore, in the same way that declining spring catches must be taken to reflect reduced abundance caused by increased marine mortality, it can be considered that the monthly components of the spring catch have suffered differential increases in marine mortality rate. This suggests that either the monthly components of the spring catch are not uniformly affected by the same marine conditions or that during some part of their marine migration they are distributed non-randomly in a heterogeneous environment. In either case, genetic differences among seasonal components of the stock are indicated. Indeed, given the evidence for genetic (Stahl, 1987; Verspoor, 1988; Jordan *et al.*, 1992) and behavioural (Hawkins and Smith, 1986; Laughton, 1991) structuring within rivers, the existence of analogous differences in the marine phase of life would not be surprising. Indeed, parallels for this exist widely among populations of other migratory species of which more is known (Berthold, 1992).

Salmon Populations

Homing tends to isolate breeding population of salmon in different catchments and in different parts of single catchments. Patterns of homing are broadly parallelled by what is known of patterns of genetic population structure (Verspoor, 1995): genetic differences exist among the breeding populations of different rivers and lesser differences can be discerned among populations within single rivers.

These findings are based mainly on studies of a class of adaptively neutral genes. Individual fish (and the groups to which they belong) that bear different forms and different combinations of these neutral genes are not particularly expected to display differences of physiology or behaviour. There are other classes of genes, however, that have profound effects on these characters but their study is not technically advanced. The crucial questions therefore remain to be answered. Do genetic differences underpin the variety of life-styles observed among the seasonal components of the fisheries?, and particularly, do early-running fish differ genetically from other classes of fish?

Hansen and Jonsson (1992) have demonstrated that genetic differences in run-timing distinguish the populations of the Imsa and Figga rivers in Norway. Wild fish from both rivers return to the Norwegian coast in summer but Figga fish return earlier than Imsa fish. This distinction appears to be genetic since the difference in return timing was maintained in experimental groups of fish reared together in a hatchery before being released into the sea as smolts.

The Imsa and Figga salmon populations inhabit small rivers in separate catchments located in the same region of southwest Norway. Is it possible that similar differences in run-timing distinguish local populations inhabiting different parts of large river catchments? Radio tagging studies suggest that it is. Laughton's work on the Spey, for example, has shown that at spawning time the position of fish within the catchment is related to their time of river entry. Early-running entrants home to those parts of the catchment that are more distant from the sea: later entrants spawn nearer to the sea.

Distinguishing the Effects of Run-Timing and Sea-Age at Maturity

Both these studies illustrate another crucially important point. Similar patterns of run-timing are separately evident within the two principal sea-age classes. Grilse develop the same patterns as 2SW fish - but later and over a shorter part of the season. In some respects, therefore, early-running grilse are analogous to early-running salmon. Furthermore, early-running grilse and early-running salmon spawn in the same geographical locations (eg the Girnock Burn) and studies of pair formation have demonstrated conclusively that they interbreed (J B Taggart, pers comm). From a genetic point of view, it must therefore be supposed that early-running salmon and early-running grilse are essentially the same.

This indicates that the effects of sea-age and the effect of population structure on return-timing ought to be distinguished in attempting to understand changes in the seasonal composition of mixed-stock fisheries (including rod fisheries) that exploit both grilse and 2SW fish. More broadly considered, run-timing within age-groups and sea-age at maturity may be found to be independent qualities that are separately responsive to genetic and environmental effects. The development of new approaches, supported by further experimental work, will be required to evaluate these possibilities and the collection of additional categories of information from the fisheries may be required.

New Approaches

Two approaches can be envisaged to testing for genetic population effects in existing data sets. First, average smolt age distinguishes the members of upper (colder) and lower (warmer) populations within catchments. Second, fish homing to the different populations are distinguished by their run-timing. Smolt-age data derived from reading adults' scales and/or river entry dates (inferred from dates of capture) might be used in attempting to distinguish population contributions to the catch. Both approaches require that catch data is considered over shorter rather than aggregated time intervals and both require that classification is within sea-age groups.

Within a population-based framework like this, a separate approach to testing for environmental effects on the sea-age structure of catches can be envisaged. The sexes differ in their tendency to mature as grilse or as 2SW salmon: overall, more males than females become grilse (Menzies, 1931). Environmentally induced variation in the sea-age structure of catches should be evident in parallel changes in the sex composition of the separate sea-age classes. In particular, any environmentally-driven tendency towards increased grilsing should involve an increase in the ratio of females to males among the grilse class. In general, the information necessary to examine changes in this way is not collected at present. However, non-destructive blood sampling for determination of sex by hormone analysis might be considered as a adjunct to present data collection. It may even prove possible to obtain retrospective information on sex from archival samples of scales, by developing a molecular genetic approach to sex determination, along the lines explored by Devlin *et al.* (1991) for chinook salmon.

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CHANGES IN SPRING SALMON ABUNDANCE IN SCOTLAND WITH PARTICULAR REFERENCE TO THE RIVER NORTH ESK

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Introduction

Much has been written and spoken about the decline in the numbers of early-running Atlantic salmon (*Salmo salar* L.) returning to Scottish rivers in recent years. There have been calls for changes in annual close times, the introduction of catch and release policies and voluntary cessation of fishing. A number of these measures have been introduced.

In order to investigate whether real changes in stock abundance have occurred, it is necessary to have access to information describing the status of salmon population abundance over an extended period of years. Unfortunately, no such comprehensive data exist for Scottish salmon populations with the exception of that of the North Esk. Even there, data are only available for the period from 1981 to present.

Nevertheless, this paper presents an attempt to describe changes that have occurred in Scottish spring salmon abundance since the early 1950s.

Materials and Methods

The only data applying to the whole of Scotland which are available are the Scottish national salmon catch statistics. Each year since 1952, the Scottish Office has collected data on salmon and sea trout catches under the terms of the Salmon and Freshwater Fisheries (Protection) (Scotland) Act 1951. About 2,000 questionnaires are sent out annually to owners and occupiers of salmon fisheries in Scotland requesting details of the numbers and weights of salmon, grilse and sea trout caught each month by each of the permitted fishing methods. A return rate of more than 95% of the forms issued is achieved each year.

Atlantic salmon return to Scottish rivers throughout the year. However, the numbers returning are not evenly distributed between months; there are distinct peaks in activity at different times of the year. This has been identified and described historically by fishermen by reference to different "runs" of fish, Spring salmon, Summer salmon, grilse and so on.

The salmon catch statistics published annually by the Scottish Office are split to reflect these categories of fish. Spring salmon are taken to be those recorded as caught between January and the end of April each year. The reason for using the end of April as the dividing line is that analysis of scales removed from salmon caught at net and coble fisheries around Scotland indicated that the majority of the fish caught in May had widely-spaced growth bands at the edge of their scales rather than the closely-spaced bands that are characteristic of spring salmon. This split may not fit so readily to rod caught salmon as some spring salmon are undoubtedly caught in rivers after the end of April; indeed, it is known that some spring salmon become catchable by rod and line very late in the season when they become active again as spawning time approaches. Nevertheless, for the purposes of this paper, the catch data examined were split as in the published statistics.

Catch data from salmon fisheries in the North Esk Salmon Fishery District were examined. These included net and coble catches taken in the period 1925 to 1995, kindly provided by Messrs Jos. Johnston and Sons Ltd of Montrose, as well as the rod and line and fixed engine catches reported to the Scottish Office during the period 1952 to 1994.

In making their catch returns, net and coble fishermen are asked to provide maximum and minimum numbers of men and crews employed each month while fixed engine fishermen are asked to report the maximum and minimum numbers of men and traps employed each month. These indices of fishing effort were examined to determine whether any changes in catch levels were merely reflections of changes in fishing activity. For the purposes of this exercise, indices of effort were calculated as:

$$(\max+\min)/2$$

for each of crews and traps. Because of the difficulties in interpreting data relating to some fixed nets in the Solway, effort data from that region were excluded. No fishing effort data have been collected for the rod and line fishery.

The numbers of fish entering the North Esk each day have been monitored since 1981. In 1980, a purpose-built fish counter was constructed at Logie on the North Esk (Brown, 1981). Investigations into the reliability of the resistivity method of counting fish led to the development of a microprocessor-based fish counter. Nevertheless, the results obtained between 1981 and 1984 are regarded as reliable because of the intensive monitoring and surveillance work undertaken to verify the counts recorded.

Results

The all-methods catch of salmon taken before 30 April each year in Scotland has fallen from over 100,000 *per annum* in the early 1950s to less than 8,000 in 1993 and 1994 (Fig. 1). Rod and line catches of spring salmon peaked at 26,539 fish in 1957 but have since declined to 5,785 in 1993 and 6,203 in 1994 (Fig. 2), although there was a brief recovery in the period 1977 to 1981. In the net and coble fishery, spring salmon catches declined from a peak of 59,998 fish in 1954 to 672 in 1991 and, although they recovered slightly, catches were still low at 724 in 1994 (Fig. 2). This represents a decline by a factor of more than 50 from start to finish of the time series. The early part of the time series was characterised by wide fluctuations in catches between years. The greatest catch of spring salmon by fixed engines was recorded in 1952 (45,895 fish) and, although wide inter-annual fluctuations were recorded in the 1950s and 1960s, the pattern of catches has been a steady decline, reaching a low of 605 fish in 1989 and 645 fish in 1994 (Fig. 2). This represents a decline from start to finish of the time series by a factor of about 70.

Fishing effort in both the net and coble and fixed engine fisheries throughout Scotland has also declined since 1952 (Fig. 3). In the early 1950s, the average number of crew months recorded for the net and coble fishery for the months of February, March and April was over 250, compared with 23 in 1994, a decline by a factor of over 10. In the fixed engine fishery, an average number of trap months of over 1500 (excluding Solway fixed engines) was recorded for the period February, March and April in the early 1950s. By 1994, the number of trap months had decreased by a factor of nearly 30 to 54 trap months.

The recorded catch statistics for the North Esk Salmon Fishery District since 1952 (Fig. 4) show a gradual increase in spring salmon catches in the rod and line fishery but declines in both the net and coble and fixed engine fisheries. Figure 5 shows the annual rod and line spring salmon catches expressed as percentage differences from the 1952-1994 mean. Catches remained below the long-term mean until 1976 but, with exceptions in 1979 and 1981-1984, have remained at or above average since, the highest catch being recorded in 1986. The 1994 reported catch was the fourth highest on record. Between 1952 and 1994, rod and line spring catches have increased by a factor of 21.

At the start of the time series, the majority of spring salmon caught were taken in the fixed engine fishery. However, there was a rapid decline and after 1962, catches generally remained below the 1952-1994 average (Fig. 6). Catches by fixed engines have declined by a factor of 18 between 1952 and 1994.

Figure 1

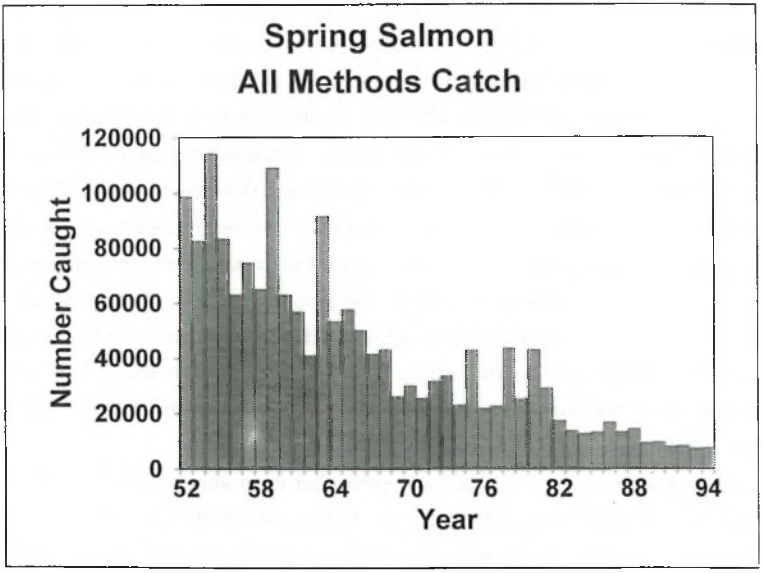

Figure 2

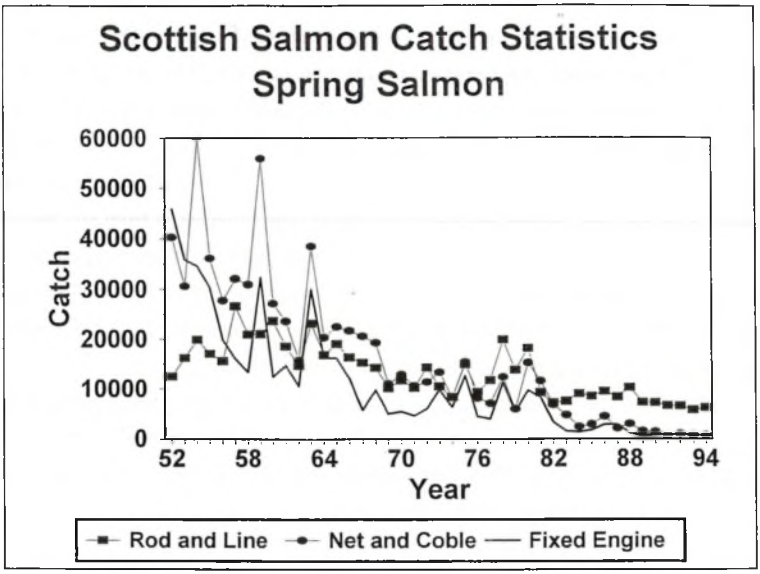

Figure 3

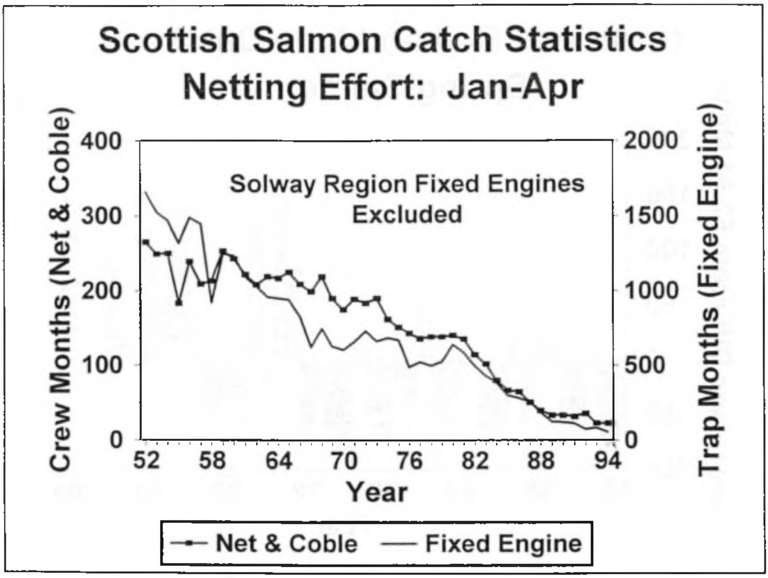

Figure 4

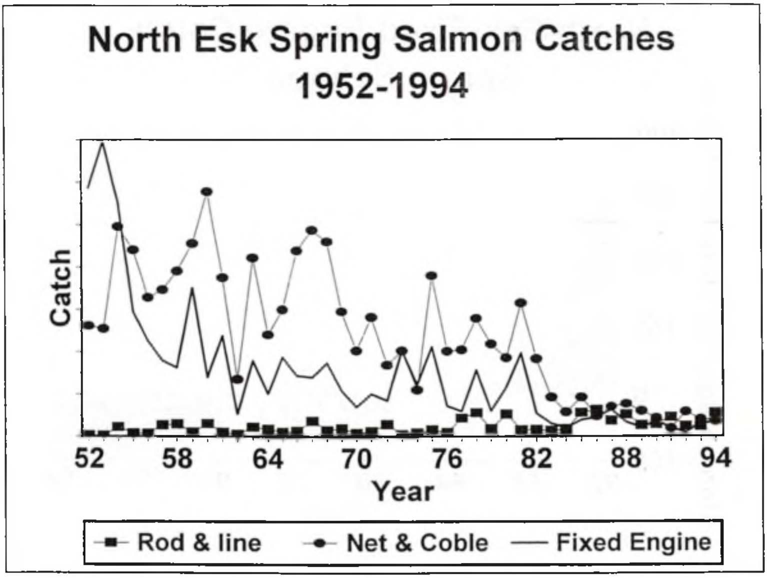

Figure 5

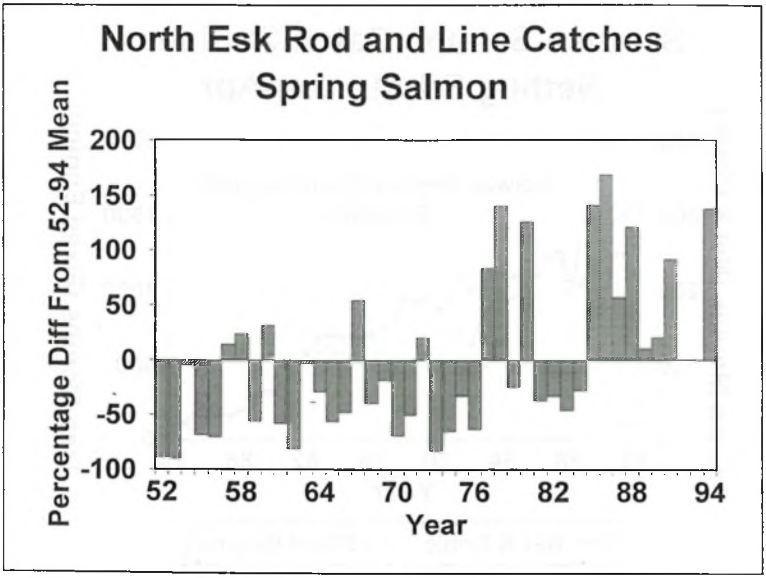

Figure 6

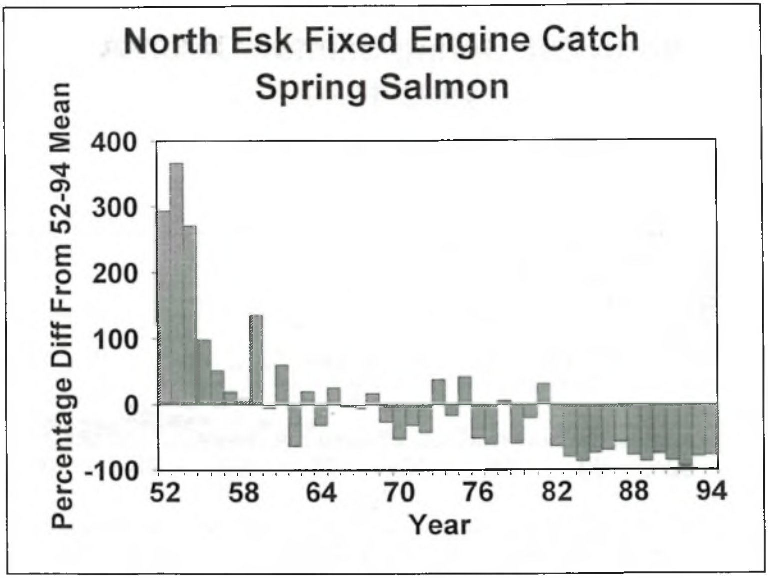

Figure 7

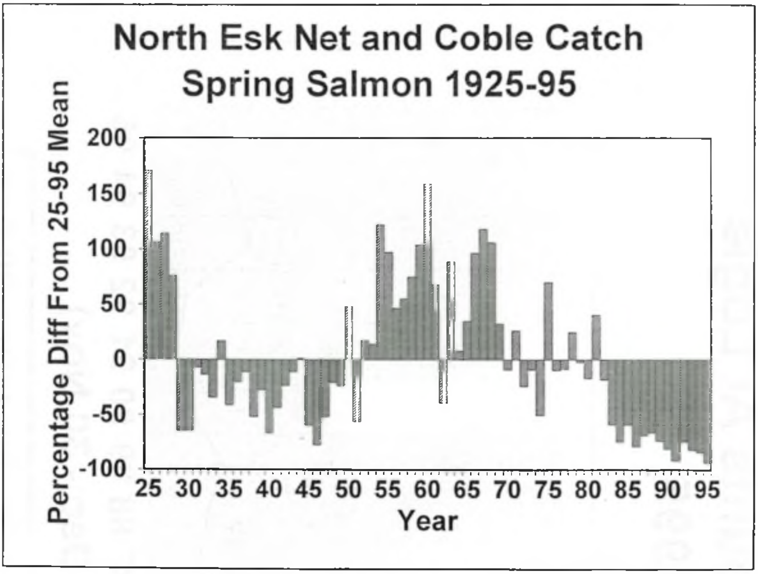

Figure 8

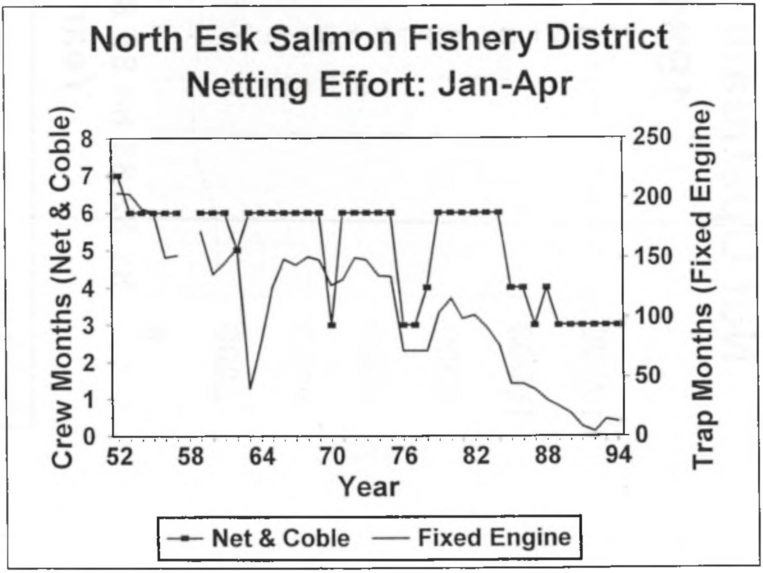

Figure 9

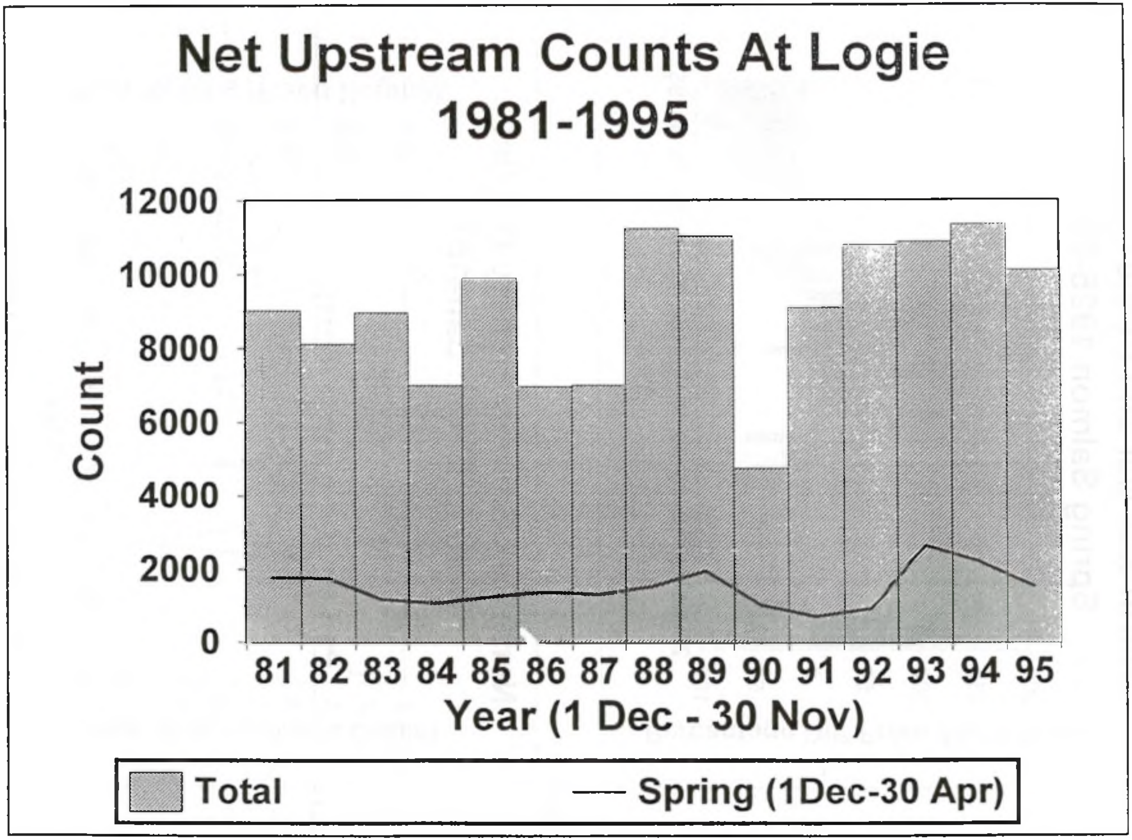
Net Upstream Counts At Logie
1981-1995
12000
10000
8000
6000
4000
2000
0
Count
81 82 83 84 85 86 87 88 89 90 91 92 93 94 95
Year (1 Dec - 30 Nov)
Total
Spring (1Dec-30 Apr)

Figure 7 shows the North Esk net and coble spring salmon catch for the period 1925 to 1995, each year's catch being expressed as the percentage difference from the 1925-1995 mean. Catches remained above average during the period 1925 to 1928 but were generally below average in 1929 to 1951. Catches were mostly above average between 1952 and 1969, peaking in 1959. Between 1970 and 1981, catches fluctuated about the long-term mean but have remained consistently below the mean since then, declining steadily to the catch in 1995, which was the lowest recorded in the time series. For comparison with the data available for the other fishing methods, net and coble catches of spring salmon declined by a factor of 7 between 1952 and 1994.

Figure 8 shows the reported netting effort figures for the North Esk Salmon Fishery District. Both net and coble and fixed engine fishing effort has decreased over the time series. Net and coble effort has decreased from an average of seven crew months in the period February, March and April in 1952 to three crew months for the same period in 1994. In the fixed engine fishery, the average number of trap months for the period February, March and April in 1952 was 204, decreasing by a factor of 17 to 12 for the same period in 1994.

The numbers of fish recorded annually by the fish counter installed on the North Esk at Logie are shown in Figure 9. Superimposed on the annual counts are the counts recorded between 1 December and 30 April each year. Annual counts varied between 4,762 in 1990 and 11,341 in 1994. Spring counts varied about a mean of 1,486 fish, with a range from 718 in 1991 to 2,634 in 1993

Discussion

The only index of the abundance of spring salmon available for Scotland as a whole is the time series of catch data collected by SOAEFD. Catches are affected by factors such as changes in fishing effort and fishing efficiency as well as stock abundance. Unfortunately, no effort data are available for the sport fishery. However, it is widely accepted that, if anything, angling effort has increased over the period since 1952. In addition, the introduction of new technology and materials in the production of fishing tackle in recent years is thought to have made fishing easier for less proficient anglers than was the case in the 1950s. Despite this, rod and line catches of spring salmon have halved since 1952.

The situation is even worse in the net fisheries. Net and coble effort in the spring has decreased by a factor of about 10 since 1952 but catches have declined by a factor of more than 50. Fixed engine catches have declined by a factor of 70 whereas fishing effort has declined by a factor of about 30. When fishing stations are taken out of service, the least successful are usually closed first, although this may have changed in recent years as a result of private initiatives to purchase some netting rights. Nevertheless, the rate of decline in catches is still much greater than the rate of decline in fishing effort. The situation is complicated by the fact that in addition to the decreases in crew and net numbers in the Scottish salmon fishery, the weekly close time was extended by 18 hours in May 1988. The level of fishing effort in an active fishing method such as net and coble is dependent not only upon the number of crews operating but also on the time spent fishing by each crew. In many instances throughout Scotland, although crew numbers have decreased a little or stayed the same, the numbers of hours spent fishing have been reduced markedly.

Important data on early-running multi-sea-winter salmon have been collected from investigations on the Girnock Burn and the River Tummel. However, the only complete river system in Scotland for which reliable stock abundance data are available is the North Esk, and only then for the period since 1981. Spring salmon counts have remained rather stable over the period and although low counts were recorded in 1990-1992 , they recovered in 1993 and 1994. The count recorded in 1995, although lower than in the preceding two years, was still above the 1981-1994 average.

In common with the rest of Scotland, the all-methods spring catches in the North Esk Salmon Fishery District have declined over the period 1952-1994. However, there are some differences between the catch statistics from this District and those from Scotland as a whole. Early season catches, historically by net and coble and recently by angling, may be affected to some extent by the presence of a weir, Morphie Dyke, in the lower reaches of the river. Tracking experiments have shown that fish may be reluctant to move upstream of this weir at low water temperatures. However, this Dyke has been in existence in the river throughout the time series involved and its presence cannot influence the number of fish entering the river. Rod and line catches have increased; although no effort data have been collected, it is clear that angling effort has increased in recent years, especially following fishery management changes in the lower river. Although net catches of spring salmon have declined, they have not decreased at the same rate as elsewhere. Net and coble catches have declined by a factor of 7 in the North Esk District compared with a 50-fold decline in Scotland as a whole. Effort has declined in that the number of crew months recorded has halved, compared with an 10-fold decrease in Scotland as a whole. However, not only has the number of crews decreased in the North Esk but the numbers of hours spent fishing and the location of the fishery has changed. These factors are much more difficult to quantify. In the fixed engine fishery, catches have declined by a factor of 18 compared with one of 70 for Scotland as a whole while effort has declined by a factor of 18 compared with a 30-fold decrease for Scotland as a whole. Rod and line catches are likely to comprise almost entirely North Esk salmon but net and coble and, particularly, fixed engine catches are likely to contain some salmon from other rivers. Nevertheless, the catch and effort data suggest that although spring salmon have undoubtedly declined in the North Esk, the decrease does not seem to be as great as elsewhere in Scotland.

Investigations into the fate of individual smolt cohorts emigrating from the North Esk have shown that smolt production from the North Esk has remained remarkably stable since 1964 at an average of about 175,000 smolts *per annum* (Anon, 1995) and that there has been no systematic significant change in smolt age. It has not been possible to identify the proportion of any smolt cohort derived from spring salmon or from which spring salmon are derived if, as recent research into stock structure suggests, such a separate stock component exists. Thus, whereas smolt production has been maintained, it is not possible to determine whether there has been a reduction in the spring component of the smolt stock.

The salmon disease UDN was first identified in the North Esk in 1967. This disease, which still appears to be present although at a lower incidence than during the late 1960s and 1970s, seemed to affect particularly those fish entering the river during the colder months of the year. Recorded levels of predation by seals on returning salmon are higher in the early months of the season than later in the year (Shearer, 1992). Thus the spring component of the stock may have been particularly affected during the period examined here by factors such as disease and predation.

The survival rate of North Esk salmon smolts returning as adults to Scottish home waters, summed over all sea age classes, has almost halved since the 1960s. Catches of grilse and summer salmon have not declined as much as catches of spring salmon. Part of the decline in spring salmon is due to the reduction in the numbers of three-sea-winter salmon returning in recent years but the numbers of two-sea-winter "Springers" have also declined. Summer salmon, most of which have also spent two winters at sea before returning, do not appear to have suffered the same level of post-smolt mortality as the "Springers" even though they have spent a longer time at sea before their return.

This begs the question as to why the mortality rates should be different for these two groups of salmon. Perhaps they utilise different parts of the marine habitat during their time at sea. Perhaps the fish destined to return as spring salmon have encountered environmental conditions which have changed for the worse in recent years or they may have been exposed to greater levels of fishing mortality or predation than the other stock components. Perhaps the distribution of potential spring salmon in the sea is such that they are more likely to be killed as by-catches in fisheries for herring, mackerel or capelin. Perhaps there have been changes in the freshwater environment affecting juvenile smolts the results of which are only manifested when the smolts go to sea. To answer these questions, we require much more detailed information about the distribution, abundance and biology of salmon in the sea than is currently available.

Catches taken in the high seas fisheries have almost certainly had the effect of reducing the numbers of multi-sea-winter fish returning to Scottish waters and have probably accelerated the rate of decline in home water catches but are unlikely to have been the root cause of the problem. The decline in catches of spring salmon in Scottish fisheries appears to have already started when catch records were first collected in 1952. A fishery for salmon existed at West Greenland in the early 1900s but catches there did not exceed 100 tonnes until 1961. By 1964, catches had reached 1,539 tonnes (Shearer, 1992) and had risen to 2,689 tonnes by 1971. International agreements led to the phasing out of fishing by non-Greenlandic vessels during 1972-1975 but the catch remained at about 2,000 tonnes until 1976 when a Total Allowable Catch (TAC) of 1,190 tonnes was set. Since then, catches have been regulated downwards, a TAC of 77 tonnes being set, and taken, for 1995. In many of the most recent years, catches have not reached the TAC. The fishery at the Faroe Islands was started following successful experimental cruises in the late 1960s and catches remained at a low level, 20-40 tonnes, until the late 1970s. In 1981, however, a catch of 1,025 tonnes was recorded. Since 1982, catches have been regulated by international agreement and, as in the Greenland fishery, in recent years the catch taken did not reach the TAC. The TAC agreed for 1995 was 470 tonnes. Private initiatives to buy-out the quotas in the high seas fisheries in recent years have further reduced the catches taken.

The North Atlantic Salmon Working Group of the International Council for the Exploration of the Sea concluded that the expected increases in returns to home waters as a result of the suspensions of the high seas fisheries at Greenland and the Faroe Islands would be well within the observed range of catch variation, and thus it was unlikely that a statistically significant increase in returns could be demonstrated even after many years (Anon, 1995). Nevertheless, it is self-evident that any reduction in post-smolt mortality will result in more fish returning. If fishing mortality in the high-seas fisheries is highest on early-running multi-sea-winter salmon, the increased returns following the cessation of fishing may be more important than the mere numbers suggest.

Acknowledgments

Grateful thanks are due to Jos. Johnston and Sons Ltd, Montrose, for supplying records of net and coble catches for the period 1925 to 1994. Thanks are also due to Mrs J M A Milne for her help in accessing catch and effort data and to Dr R G J Shelton and Mr R B Williamson OBE for their helpful comments on an early draft of this paper.

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A REVIEW OF FACTORS AFFECTING THE ABUNDANCE AND CATCH OF SPRING SALMON FROM THE RIVER WYE AND PROPOSALS FOR STOCK MAINTENANCE AND ENHANCEMENT

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Introduction

The River Wye has long been recognised as the premier salmon river in England and Wales, not only in terms of the number of salmon caught by anglers, around 12% of the total for England and Wales, but also for the high proportion of large salmon within the catch.

Over the past 20 years or so there has been a decline in the number of large salmon caught in the River Wye before June, a phenomenon that is not unique to the Wye but has also been observed throughout the North Atlantic range of the salmon.

This paper examines the main catchment related factors implicated in the decline of spring salmon in the Wye and the measures taken to conserve remaining stocks.

Current Status of Spring Stocks

When catch statistics were first collected from Wye fishery owners early this century, rod catches were relatively low (2,000) and about half the total catch was reported by nets. Catches by both methods increased steadily until the early 1920s when they were approximately equal (both at about 4,000) and then followed a similar pattern until about 1940. Within this period rod catches fluctuated widely from year to year, with two distinct peaks when the annual rod catch exceeded 5,000 fish (Fig. 1). After 1940, the level of rod and net catches diverged, with rods taking an increasing proportion of the catch. This pattern continued until the licensed net fishery in the lower Wye closed in 1984.

Rod catches pre-June (Fig. 2) show a similar pattern to total rod catches. Following a period of high catches in the 1960s and 1970s, catches have shown a dramatic decline and recently have been at their lowest level this century.

The temporal distribution of the overall run has changed as a result of a shift in the age composition with trends away from multi-sea-winter (MSW) salmon towards younger fish. Many fish are now caught towards the end of the angling season and there is evidence that a significant proportion of the run, principally grilse, enter the river after the end of the angling season. For example, in 1995 trials with an acoustic fish counter, located just above the tidal limit on the Wye, recorded over 5000 salmon after the end of the angling season (Gough, 1995). Although the total run size is not known this late run was likely to have comprised a significant proportion of the total stock. However, the scale of this late run may have been exacerbated by long low flow periods earlier in the year.

For maximum smolt production, a target salmon egg deposition rate of 390 eggs per 100 m^2 of rearing habitat has been used (NRA, 1994) and this indicates an estimated run size of 15,173 fish of which 60% would be MSW salmon (2SW and older). This run size would yield a predicted rod catch of 3754 salmon (Fig. 1); a level which has been achieved in only 6 of the last 18 years, but was regularly achieved throughout the 1950s, 1960s and early 1970s. Present estimates indicate that current spawning levels are 56% below the target level.

Most 2SW and 3SW salmon are female and compared to grilse produce larger numbers of ova. The decline in older age groups will therefore have a proportionately larger impact on egg deposition rates and may affect the well-being of the overall stock.

The Factors

Habitat

Although spawning activity in the Wye occurs over a large proportion of the available catchment, it is the river above Hay-on-Wye (Fig. 3) which is particularly important.

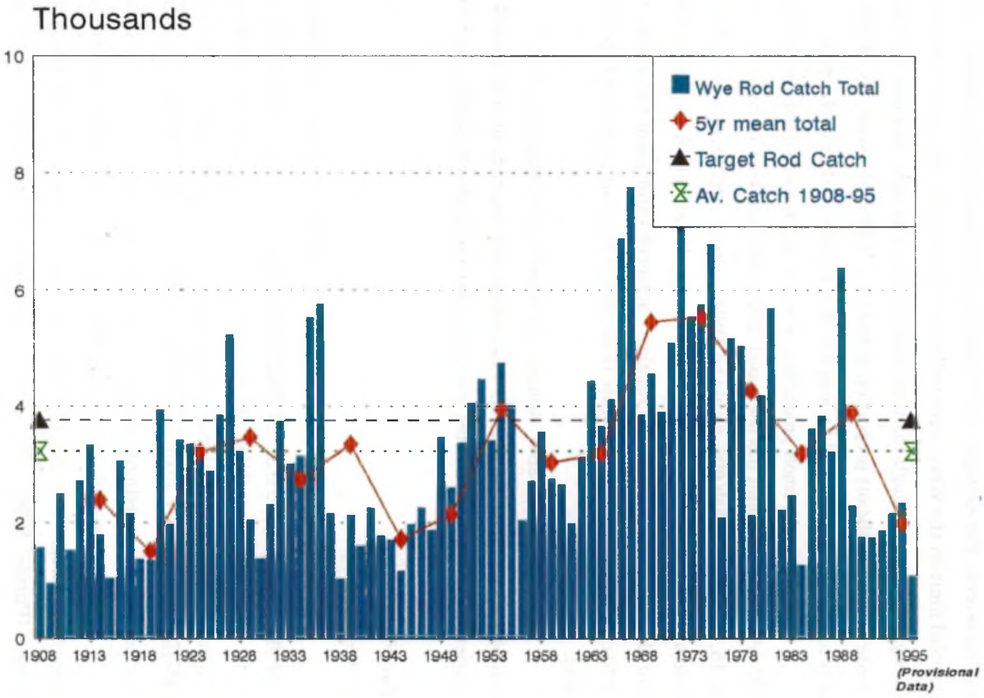
The upper part of the catchment is probably most vulnerable to habitat degradation, whilst being disproportionally important for spawning and juvenile rearing. Habitat deterioration will act against any stock component which specifically selects these areas. It is becoming increasingly apparent that this may be the case for spring salmon.

Radio tracking of early running MSW salmon in the Welsh Dee indicates a trend for those fish to progress upriver towards the upper catchment (Fig. 4) where they presumably spawn (Purvis, 1996). Very early and limited results from a new salmon tracking programme on the Wye indicate that this may also be true there (Purvis, pers comm).

In the case of the Wye, there has been a localised deterioration in water quality and also, but to a much lesser extent, habitat quality within the upper catchment upstream of Builth Wells (Fig. 3). Since the 1960s and early 1970s a proportion of the available spawning and rearing habitat, which is reported to have been intensively used historically, has been

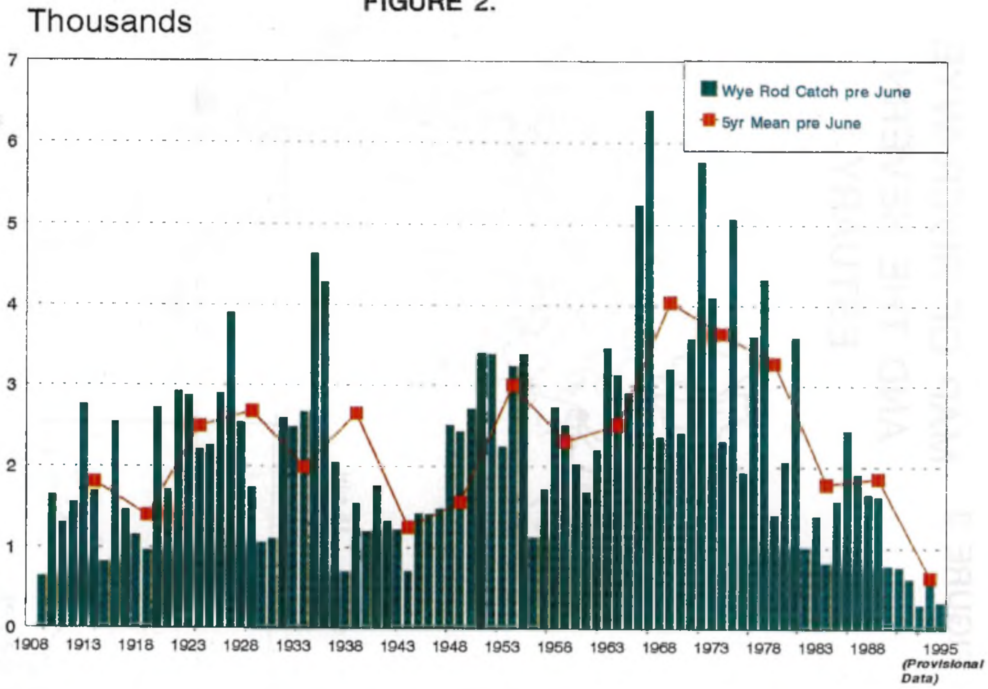
Wye Owner Return Catches 1908-95

FIGURE 1.



Wye Owner Return Catches 1908-95
Pre-June Salmon Catch Distribution

FIGURE 2.



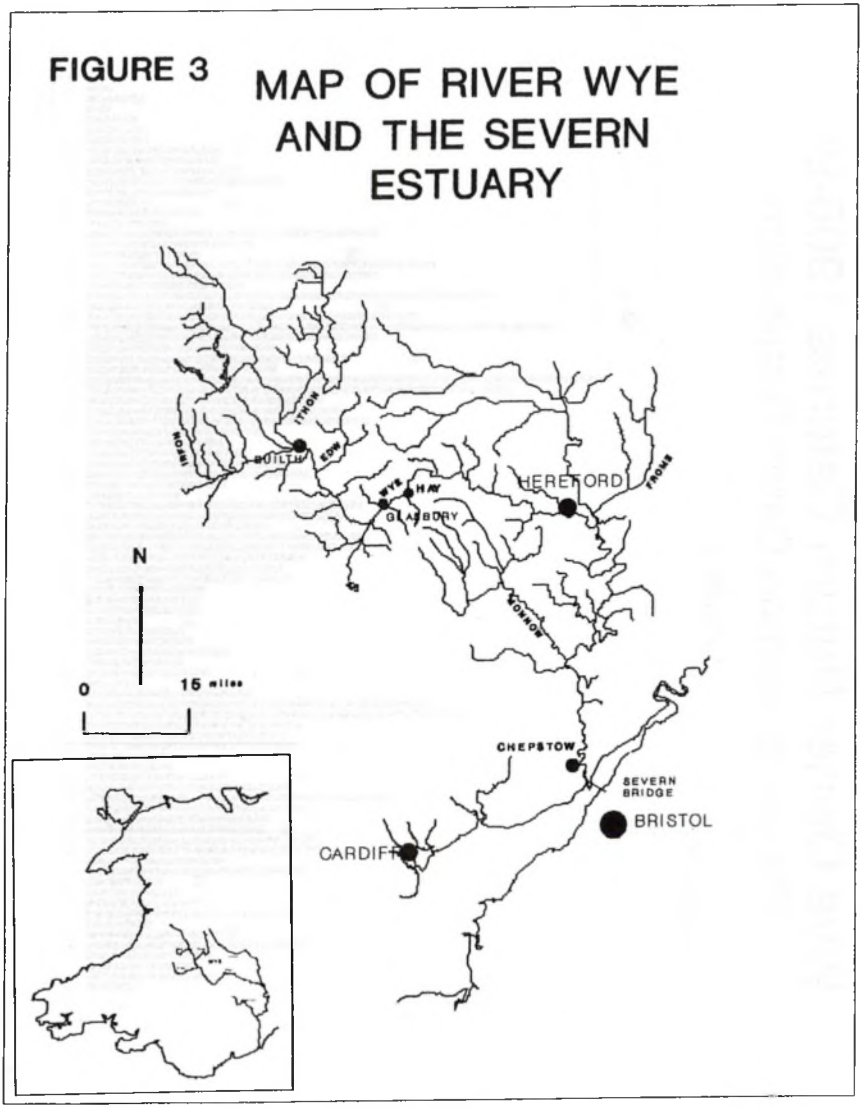
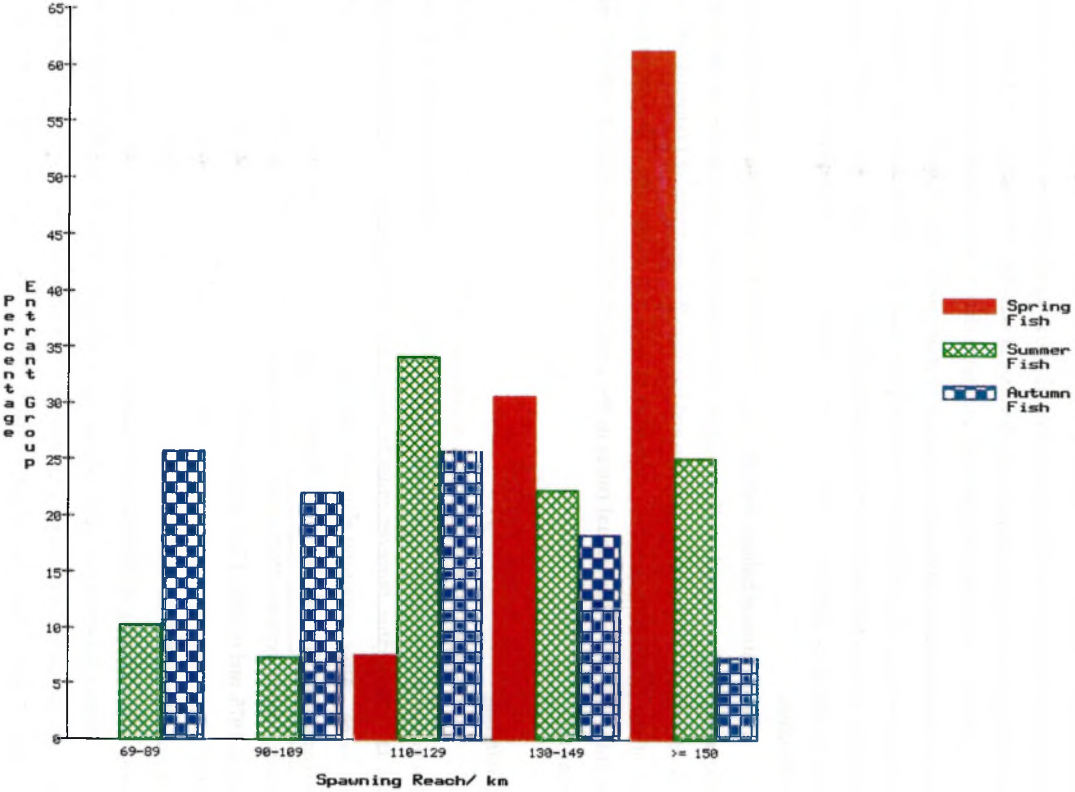


Figure 3 Map of River Wye and the Severn Estuary

Figure 4 **Upstream Spawning Distance by Entrant Group, salmon, R Dee.**



affected by the impact of acidification. The deterioration, and in some cases total loss of production capability, is indicated by biological assessment and fisheries surveys (Fig. 5) together with water quality monitoring. At least 18 km of the main river upstream of Llangurig and in the River Irfon, a substantial tributary of the Wye, and other tributary habitat is considered to be unproductive because of acidification (Betts *et al.*, 1994).

Impacts on the physical habitat are largely due to blockage of potential spawning stream and concomitant habitat deterioration, to inadequate riparian bank management (eg grazing, erosion), to deterioration in spawning gravel quality due to excessive mobility and impaction, and in a few instances to unconsented gravel extraction. The scale of impact of these problems is unknown. However, it is unlikely to be as significant as that due to acidification.

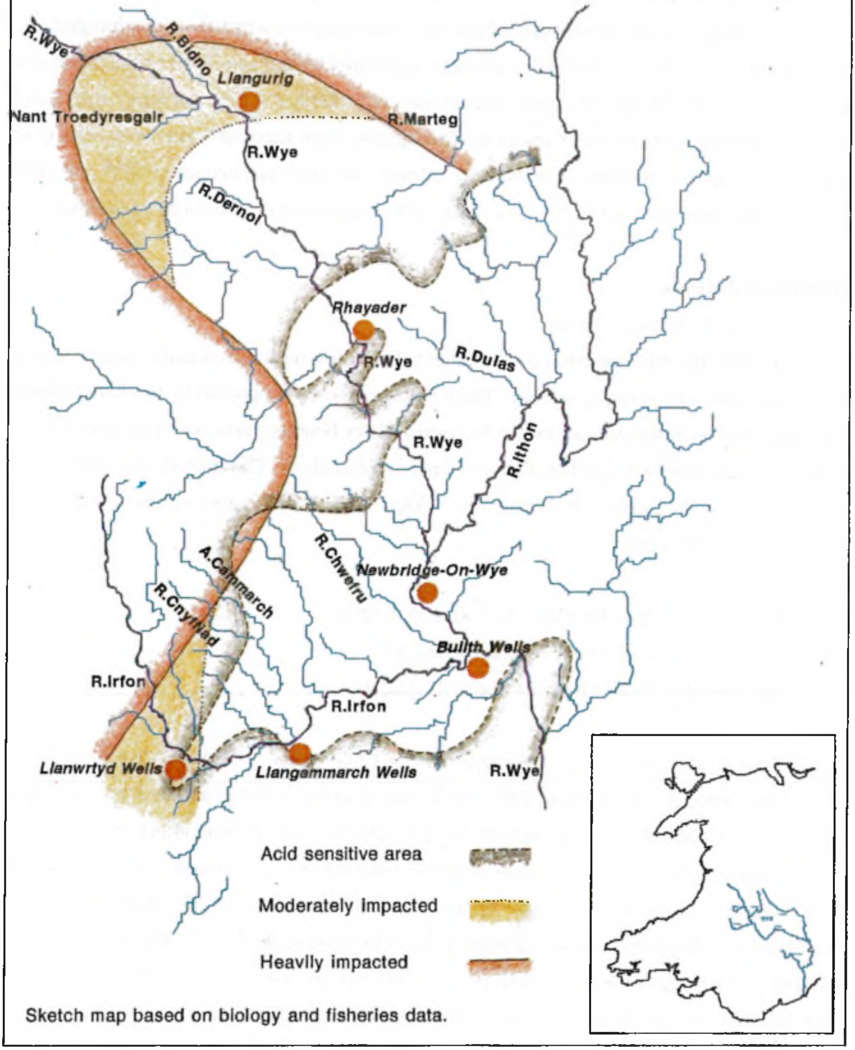
A combination of habitat degradation and loss together with factors influencing access to the upper catchment, such as flow, may be acting specifically against the spring running stock component. In the case of the Irfon and the main Wye upstream of Llangurig, 18% and 31% of the catchments are now incapable of salmonid production. The consequential possible reduction of the annual run is in the order of 1,000 fish, many of which could be spring fish.

Exploitation

The long term average rod catch of salmon (1908-1994) is 3,211, and this figure has been equalled or exceeded continually by the 5 year average catch over the past 40 years (Fig. 1). Against this, however, must be considered the fishing effort expended to achieve this catch. After remaining relatively constant between 1913 and 1945, effort steadily increased from 200 rods (although this was almost certainly an under-estimate due to the general licence system: effort at this time was probably closer to 400 rods) to nearly 1,400 rods in 1975, and in 1982, 1529 season licences were sold. The latter figures do not include either short-term or general licences, and so are under-estimates of the true angling pressure. After 1982 the method of issuing rod licences changed, and the number of season licence holders fishing on the Wye is not known. It is, however, unlikely to have decreased.

Whilst the overall catch of salmon has remained relatively constant over this time, the catch per licence has shown a gradual decline from about 10 in 1940 to 4 in 1975 (Gee and Milner, 1980). This figure masks the pattern for specific age groups within the run. The catch per licence of 4SW salmon was never high, but showed a decline in this period to very low levels. That for 3SW salmon similarly declined from values of around 5 in 1940 to values

Figure 5. The extent of acidification in the Upper Wye catchment



Sketch map based on biology and fisheries data.

between 1 and 2 in the mid 1970s. In contrast to this are the patterns for 2SW and 1SW fish; no trend is observed for the former, whereas a slight increasing trend is apparent for the latter. These patterns appear to be continuing to the present day.

Assuming that the catchability of salmon in each group has remained unchanged, the reduced catch of 4SW and 3SW salmon can be explained by the increased exploitation of a diminishing stock. In fact the great improvements in fishing tackle together with more intensive fishing and greater demand for fishing may have increased the vulnerability of these fish to capture. In contrast to the older salmon, the catch per licence of 2SW and 1SW fish has not decreased, and in the case of the 1SW component may even have increased.

Possible Solutions

Controlling Rod and Net Catches

In 1995, the NRA introduced amendments to rod fishing Byelaws aimed at conserving the remaining stocks of spring salmon. These measures were supported by the Wye Salmon Fisheries Owners Association as well as by Local Fishery Groups, however there was a great deal of opposition from individual fishery owners and anglers. The amendments to fishing methods within the season (26 January to 17 October and 25 October on lower and upper river respectively) were:

- Fly fishing only until 1 May and after 31 August
- Spinning allowed from 1 May to 31 August
- Bait fishing allowed from 1 June to 31 August.

Since these measures were introduced in 1995, there is only one year of data to assess their impact. In addition, 1995 was a poor year for salmon catches with prolonged periods of low river flows reducing entry of fish into the river, fishing effort and catches.

Salmon from the Wye, together with fish from other South Wales rivers, are known from tagging studies to be caught by nets and fixed engines in the Severn Estuary. Amendments to Byelaws to delay the start of the net fishing season until 16 May (previously 1 March and 1 April for drift nets and putchers respectively) were also introduced in 1995. This measure has eliminated the catch of spring salmon in this fishery.

In addition, Sea Fisheries Byelaws were introduced in 1992 and eliminated the illegal fishery in the Severn Estuary, where drift netsmen were fishing for salmon under the guise of fishing for sea fish. These measures are likely to have had a beneficial effect on the number of salmon returning to home rivers entering the Severn Estuary.

The provisional 1995 rod catch for the Wye is 1081 salmon (Fig. 1) which is only 55% of the average for the previous 5 years (1950 fish). The provisional pre-May catch for 1995 was 66 fish, compared to an average of 273 for the period 1990 to 1994 (Figs 6 and 7). In 1995 the proportion of fish caught by spinning remained relatively constant compared to the previous 5 years (43 to 46%), the proportion caught using baits fell (from 33% to 21%) whilst the proportion caught by fly fishing increased (from 17% to 35%). Catches in June, (when bait fishing was allowed), represented 43% (473 fish) of the catch in 1995, compared to 17% (338 fish) in the previous 5 years. This increase could be the result of much increased angling effort during this month and the capture of some vulnerable fish which in previous years may have been caught earlier in the year.

Similar Byelaw restrictions have also been put into place on the River Usk in south Wales and River Dee in north Wales to protect spring salmon. On the Dee the status of salmon stocks has been monitored by the means of a head of tide trap (Davidson *et al*, 1995). Trap catches over the last three years (1992-94) indicate that the run at this time is entirely composed of MSW salmon comprising 2SW fish, 3SW fish and previous spawners. On average, 94% of the total run of 3SW salmon (54 fish) entered the Dee before the end of May compared to 29% of 2SW fish (total run 1343 fish) and 10% of previous spawners (total run 151 fish). It is apparent from these data that 3SW fish now form a remnant population which even in recent years has declined from a run of 88 in 1992 to only 23 in 1994. Following the introduction of the Byelaw restrictions, angling exploitation estimates for MSW salmon entering pre-June 1995 indicate that, with the exception of May fish, most entrant groups experienced a marked reduction in exploitation compared to the average rates observed for 1992-94. This reduction would be equivalent to a 29% fall in the catch of MSW spring fish, representing a saving of 35 fish or 8% of the spring run, with 3SW fish experiencing the greatest saving at 16% of the spring run. There was no evidence of increased late-season exploitation of fish escaping capture earlier in the year.

On the River Usk the impact of the Byelaw changes appears to be similar to the Wye with reduced angling effort and catches before June followed by a significant increase in effort when spinning and bait fishing were allowed in June. Data from the resistivity fish counter on the Usk, located upstream of some significant rod fisheries, indicate increased runs of salmon pre-June in 1995 (813) compared to the average for the previous 3 years

FIGURE 6.

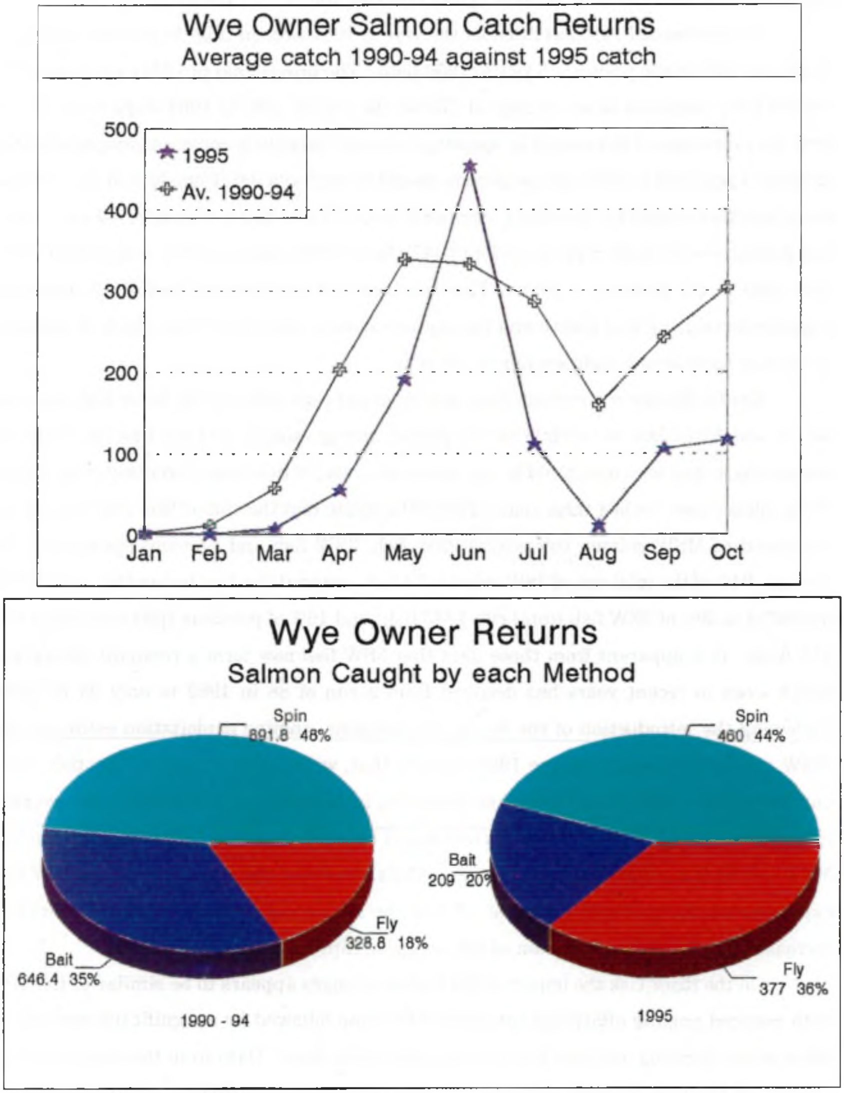
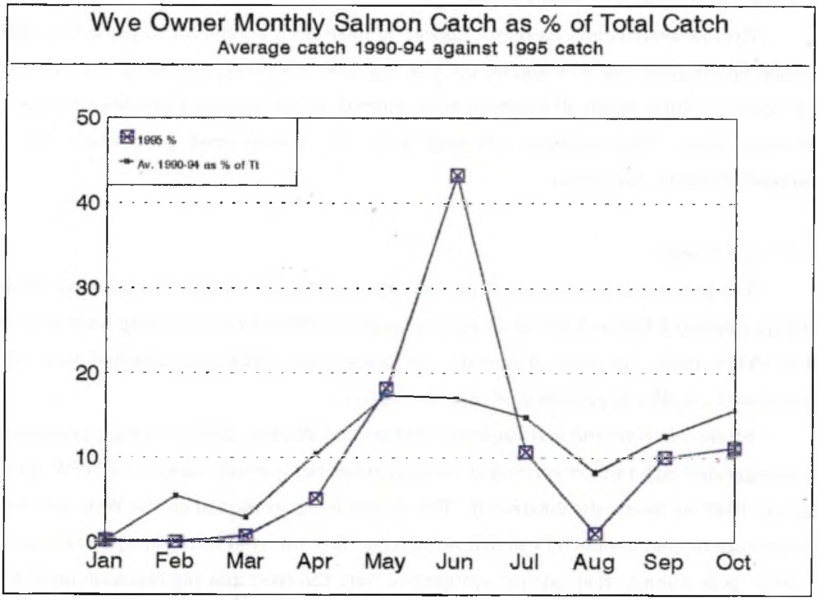
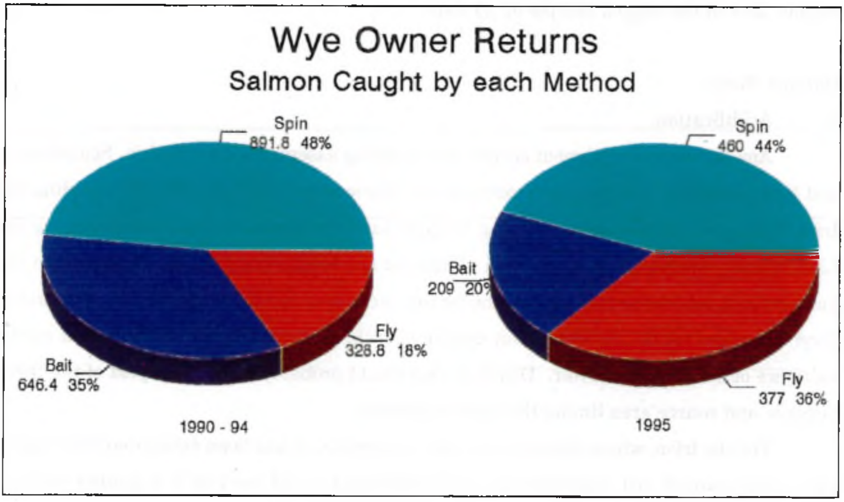

Wye Owner Salmon Catch Returns
Average catch 1990-94 against 1995 catch
500
400
300
200
100
0
1995
Av. 1990-94
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Wye Owner Returns
Salmon Caught by each Method
Spin
891.8 48%
Bait
646.4 35%
Fly
328.8 18%
1990 - 94
Spin
460 44%
Bait
209 20%
Fly
377 36%
1995

FIGURE 7.


Wye Owner Monthly Salmon Catch as % of Total Catch
Average catch 1990-94 against 1995 catch
1995 %
Av. 1990-94 as % of Tt
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct


Wye Owner Returns
Salmon Caught by each Method
Spin
891.8 48%
Bait
646.4 35%
Fly
326.8 18%
1990 - 94
Spin
460 44%
Bait
209 20%
Fly
377 36%
1995

(695). This may be related to reduced fishing effort by nets (season delayed until 16 May) and rods (fly fishing only until 1 June).

Byelaw restrictions therefore appear to have been successful in protecting MSW salmon pre-June on the Wye and on the Usk and Dee. However, increased angling effort, principally in June, when all methods were allowed, led to increased catches compared to previous years. This situation will need to be closely monitored, particularly the age composition of the June catch.

Catch and Release

The practice of catch and release is continuing to grow within England and Wales, with an estimated 10% and 14% of all salmon caught in 1993 and 1994 having been returned alive (NRA, 1995). In order to promote the practice, the NRA has published and widely distributed a leaflet to provide guidance for anglers.

Studies in Scotland and England (Walker and Walker, 1991; Fewings, pers comm) have suggested high rates of survival of released grilse, however the survival of MSW salmon has not been so clearly demonstrated. This is now being examined on the Wye and initial results suggest that around 60% of fish released in May survived until the spawning period (Purvis, pers comm). Rod catches, emigration from the river and tag loss accounted for a further 20% of the tagged sample of 21 fish.

Habitat Works

i) Acidification

Amelioration of catchment acidification is being assessed widely within Scandinavia and North America, and has been examined for three river systems in Wales including the Irfon. Options available include liming of upper catchment water supply reservoirs (eg the Llyn Brianne scheme on the River Tywi - Rogers *et al.*, 1995), direct dosing of rivers and the liming of hydrological source areas. The former technique has proven to be effective on the Twyi (Weatherly *et al.*, in press), but uptake elsewhere would clearly be dependent on the existence of a suitable reservoir. Direct dosing would probably be the cheapest of the three options, and source area liming the most expensive.

For the Irfon, where there is no upland reservoir, it has been estimated that source area liming would cost approximately £740,000, and would need to be repeated perhaps every five years (Merrett, 1992). Even if such treatment was permitted on conservation grounds, it is not considered that it would be cost-beneficial.

ii) Physical habitat

Assessment and improvement of physical habitat is now being undertaken in a collaborative effort by the Wye Salmon Fisheries Owner Association and the NRA. To date, access and physical habitat has been improved on 13 upper catchment tributaries affecting about 100 km of potential spawning habitat. On a further five sites where gravel compaction or siltation had been identified, scarification work has been carried out to improve the physical quality of the spawning habitat. Monitoring of most sites will be carried out later this year to determine the immediate results of the works and longer term stability.

Line Breeding

A further option to address a specific decline in abundance of a salmon stock component is the line breeding and stocking of juveniles derived from selected parents. It is evident however, that there are risks and practical difficulties which must be addressed if such an approach is to become a realistic proposal. These are discussed in Gough *et al.* (1992) where they were presented as a series of points, all of which should be resolved before embarkation on a MSW salmon line breeding programme should be considered :

Component of line breeding programme	Action taken to resolve uncertainty	Conclusion
Genetic feasibility	Assessment of current knowledge on spring salmon genetics (Rogan *et al.*, 1993)	Line-breeding is feasible, but must be carefully monitored.
Broodstock capture	Assessment of angling as source of fish	Capture of fish in sufficient numbers and quality is feasible.
Broodstock retention	Comparison of rod and electrofished broodstock plus long-term holding trials carried out	Rod-caught fish show best survival and prospects for long-term programmes.
Kelt reconditioning	Initial trials undertaken to investigate feeding responses, methods and patterns of maturation	Techniques feasible. First year maturation not assured. NRA site unsuitable.
Hatchery procedures	Review of procedures	Follow best-practice guidelines (eg NASCO).
Monitoring	Programme designed	Monitoring required to examine performance of stocked fry and adult yields.

The importance of a step-wise approach to such a programme is clear, as each component must be resolved and any adverse implications understood before a trial should be expanded in scale.

The Wye Salmon Fisheries Owners Association have acquired a new site for trials which, in collaboration with the NRA, will operate to examine in more detail relevant factors.

Information Needs

Stock Quantification and Escapement Against Spawning Target

One emphasis of the National Strategy for the management of salmon fisheries in England and Wales, shortly to be published by the NRA, will be the production of Salmon Action Plans addressing the specific needs of principal salmon fisheries (NRA, 1996). An important part of such a plan will be the requirement to set spawning targets and monitor performance and so there is a need to acquire accurate and reliable information on the size of the salmon stock and the rates at which the stock components are exploited.

Data on the abundance of salmon in most of the key salmon rivers in England and Wales is currently restricted to rod catch statistics. Although such data is very valuable, they are not necessarily indicative of the true stock size, and do not account for components of the run which may ascend rivers in the angling close-season, or when conditions are not conductive to successful angling. In some rivers good data are available from resistivity counters or traps, however these are a minority as the facilities are usually only financially realistic when an appropriate in-river structure already exists.

Hydroacoustic counters are a new option for riverine salmon stock enumeration in the UK. The techniques have been under development for Pacific salmon in North America since the 1960s (Gaudet, 1990), and their application is now being assessed by the NRA for Atlantic salmon on the River Wye.

Modern hydroacoustic techniques have the potential to accurately and cost-effectively count fish migrating past a fixed point at various flows. The technique has the ability to discriminate upstream and downstream migrants and fish of selected size categories, and therefore provide fundamental information required for effective management (Gough, 1995).

The acoustic equipment is relatively expensive, however overall, for rivers where no suitable structure for either of the other options exists, the acoustic option is substantially cheaper than resistivity counters or traps.

Figure 8

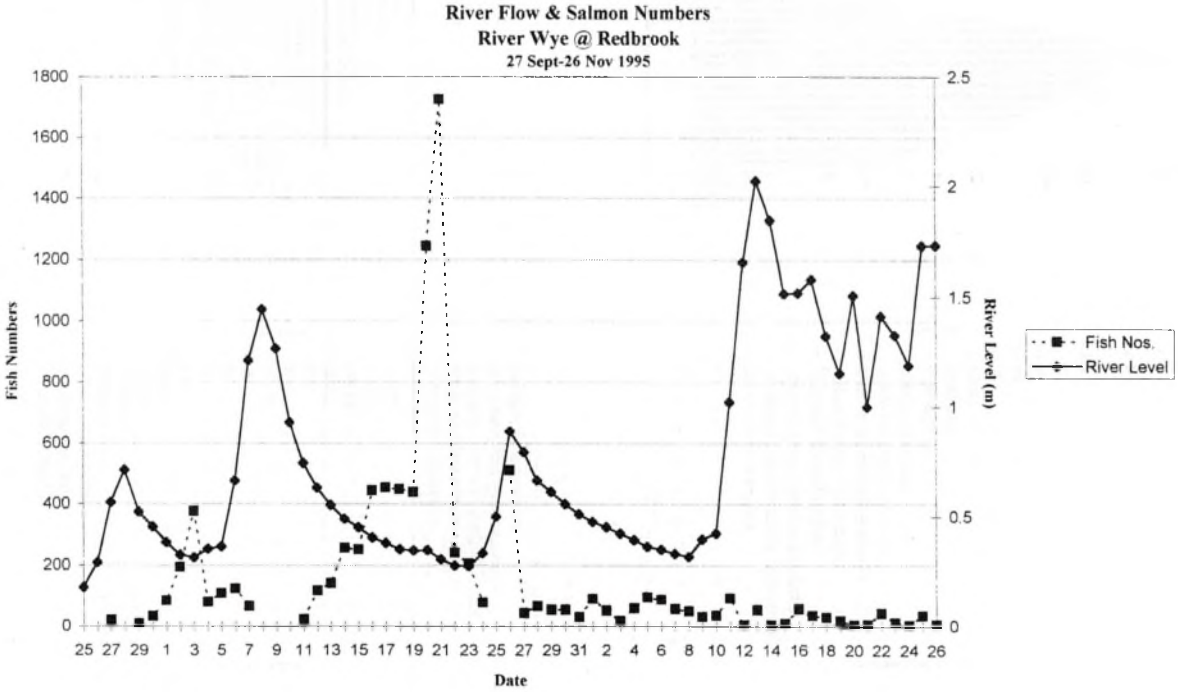
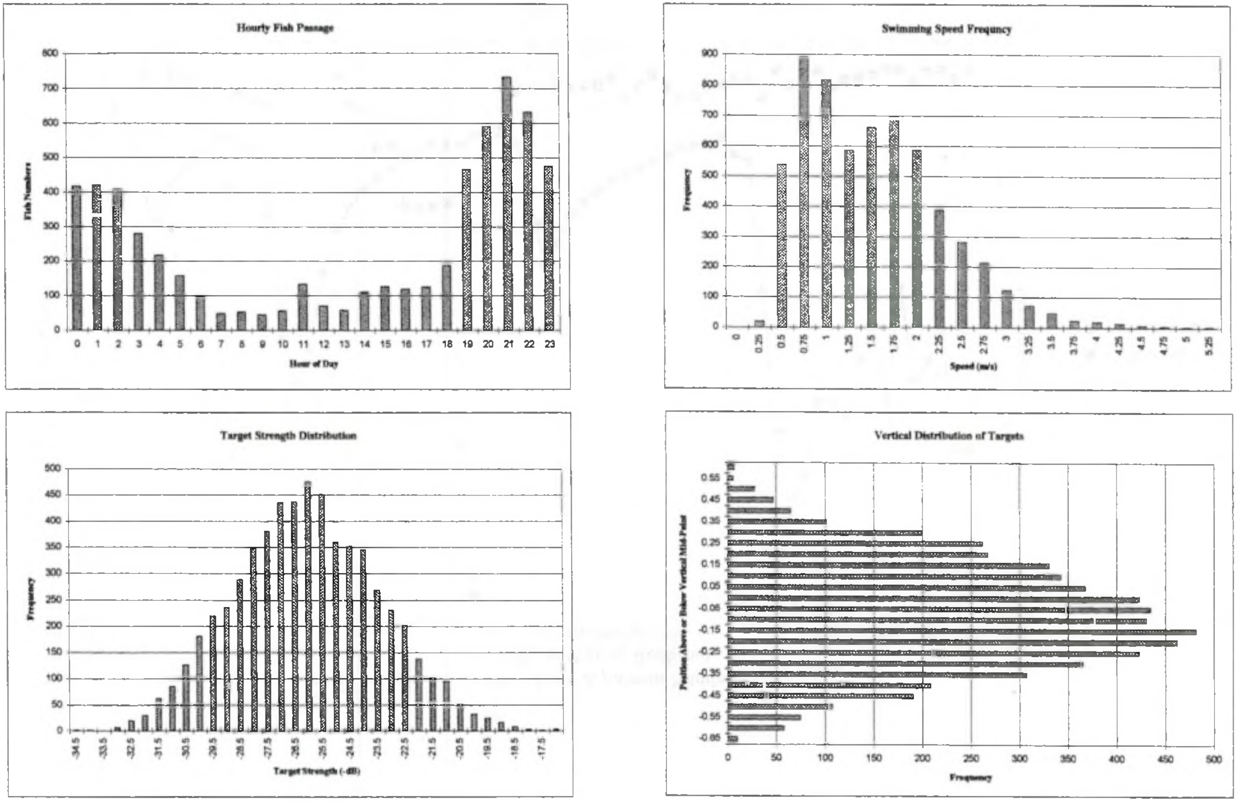

River Flow & Salmon Numbers
River Wye @ Redbrook
27 Sept-26 Nov 1995
Fish Numbers
0
200
400
600
800
1000
1200
1400
1600
1800
River Level (m)
0
0.5
1
1.5
2
2.5
Date
25 27 29 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 2 4 6 8 10 12 14 16 18 20 22 24 26
Fish Nos.
River Level

Figure 9

River Wye Hydroacoustic Data
27 September - 26 November 1995



Initial results from the Wye deployment indicate the sampling potential of the technology, yielding data which is needed for stock management purposes (Fig. 8). The unobtrusive nature of the sampling means that much behavioural data are also collected. These observations, for example, on diurnal patterns of movement, and swimming speed and depth (Fig. 9) are probably the first to be gained for salmon which have not been trapped, tagged or constrained in some way. The data are therefore descriptions of completely natural salmon behaviour. The acoustic size of the fish, which is directly related to physical size, is also obtained allowing the size distribution of the sampled population to be assessed.

Quantitative and behavioural data such as this will be of significant value with respect to assessment of schemes such as river regulation and abstractions.

Within-Catchment Origin of MSW and Spring Salmon.

In order to determine whether, as seems likely, discrete stock components arise from different within-catchment origins, two areas of investigation are being pursued.

Firstly, MSW salmon are being radio-tagged and followed throughout the catchment to determine chosen spawning destination and in-river survival to spawning. In the first year of study, initial observations on both have been made.

Secondly, in order to more reliably determine the origin of stock components, a genetic population survey is now being considered as part of a national R&D programme. The objective of this would be to allocate stock components of each sea age and run timing trait to geographical origin, and thus to identify particularly important sub-catchments for future protection and rehabilitation. The data would enhance stock management generally and provide a more rational basis for any stocking programme.

The views expressed in this report are those of the authors and not necessarily those of the National Rivers Authority.

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DECLINES OF SCOTTISH SPRING SALMON AND THERMAL HABITAT IN THE NORTHWEST ATLANTIC. HOW ARE THEY RELATED?

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Introduction

Downturns in rod catches of Scottish spring salmon (springers) which began in the 1970s have continued into the 1990s with a marked increase in the rate of decline (Youngson, 1995). Recently, declines in catches and the stocks that produce them have been observed for many salmon stocks on both sides of the Atlantic (Anon, 1995a). In particular, concerns expressed for the health of North American stocks producing 2SW salmon (Anon, 1995a, b) have led to recommendations to close the mixed stock fisheries in Greenland and North America (Anon, 1995a). Because declines have been widespread over several geographic regions, authors have hypothesized that the cause lies with the ocean life of salmon (Reddin and Friedland, 1993; Friedland *et al.*, 1993), a period about which we know little. The ocean life has been likened to a black box into which salmon enter but from which many do not return. Analysis of remote sensing data from earth observation satellites has started to open up the black box and, as knowledge from this source improves in quality and distribution, it will become more valuable and useful (Friedland and Reddin, 1993; Reddin *et al.*, 1993; Anon, 1993, 1994, 1995a).

At first glance, it would seem ridiculous to look to North American salmon stocks and the marine environment of the northwest Atlantic as possible sources of explanation(s) for the downturn in spring salmon in Scotland and elsewhere in Europe. However, salmon are known to move widely throughout their ocean environment and Scottish salmon are no exception. For instance, European and North American salmon are known to share the feeding areas off west Greenland (Parrish and Horsted, 1980). More specifically, tagging studies have shown that potential Scottish spring salmon are found at west Greenland (Møller Jensen, 1980a, b; Swain, 1980), in the Labrador Sea (Reddin and Lear, 1990) and possibly along the coast of Labrador as far south as the island of Newfoundland (Reddin *et* *al.*, 1984). Furthermore, tagging studies have provided no evidence that the Scottish springers are present in the area north of the Faroes Islands in the northeast Atlantic (Shearer, 1992). So, other than for the stage of entry into the sea as post-smolts, it would seem more appropriate to look farther from home rather than closer for explanations of what may be happening to Scottish spring salmon. In particular, the northwest Atlantic would seem entirely relevant to the life of Scottish spring salmon in the sea.

In this paper, we evaluate the relationship between spring salmon abundance in Scotland using rod catches as an index of abundance, estimates of pre-fishery abundance of the 1SW cohort of North American salmon that are destined to return as 2SW spawners, European salmon caught at west Greenland, abundance estimates for several stocks in Newfoundland and Labrador, and an index of salmon habitat in the northwest Atlantic Ocean.

Methods

Recruitment variability in anadromous salmonids can be partitioned separately into those effects arising from their life in fresh water and in the sea. The task of tracking the events controlling survivorship of Atlantic salmon becomes more complex after post-smolts leave fresh water and enter the marine environment. With other marine fish species the task is one of characterising the fate of large numbers of larval fish in a relatively small area whereas with salmon we are faced with the task of characterising the fate of small numbers of fish over a wide area consisting of a major part of the north Atlantic (Friedland *et al.*, 1993). Previous studies have shown that salmon stocks originating over wide geographic areas tend to have synchronous survival rates and that the winter period may be the critical stage for post-smolt survival (Scarnecchia, 1984a; Reddin and Shearer, 1987; Ritter, 1989). More recent analyses by Reddin and Friedland (1993) and Friedland *et al.* (1993) have confirmed the importance of the winter period to overall survival. In order to explain what is causing declines in Scottish and Welsh spring salmon catches, several hypotheses will be tested:

- relationships between various abundance indices of salmon including spring salmon and several northwest Atlantic salmon stocks;
- relationships between indices of abundance of Atlantic salmon and environmental factors; and,

- relationships between spring salmon, European salmon abundance at Greenland, growth, and environmental factors.

Sources of Data on Catch and Abundance

The rod catch data (1970-93) for Scottish rivers and the Wye, Wales comes from Youngson (1995) and with the exception of the Wye were updated to include 1994 catches (D A Dunkley, pers comm). Specifically, spring rod catches for the Dee, Tay, Spey, Tweed, Helmsdale, Deveron, and Ness rivers in Scotland were used. The definition of spring salmon is that of Youngson (1995) denoting fish that are available for capture by rod fisheries in the winter and spring months of January to May. Biologically a spring fish is one without new-season growth on the edge of its scales but as scale samples are rarely available to match with catch statistics, springers are differentiated in this paper from other river entrants based solely on date of capture. The rod catch data for spring salmon are particularly useful for analysis as they probably provide a better index of abundance than the statistics of the net fisheries where total, and especially early season, fishing effort has declined markedly (Youngson, 1995). The terminology used to describe other stages of salmon life history is that of Allan and Ritter (1977).

In order to test for synchronicity amongst salmon stocks in the northwest Atlantic, abundance estimates for several salmon stocks from Newfoundland and Labrador were included as part of the analysis. In Newfoundland and Labrador, rod catches and commercial catches have been divided into small and large salmon based on weight (Ash and O'Connell, 1987). Estimates of abundance of small salmon for the Gander River stock, 1970-94 were developed from angling catch statistics and counting fence information by O'Connell *et al.* (1995a). Gander River small salmon are mainly 1SW in age and were used as a validity check. The salmon population of Gander River, being predominantly grilse, should not be related to stocks that mainly produce MSW salmon. Also used in the analysis were estimates of total production of 2SW salmon from Labrador and Bay St George stock complexes, 1970-94. Both of these areas historically produced high proportions of MSW salmon and have documented declines in recent years (Anon, 1995a, b; O'Connell *et al.*, 1995a, b; D Reddin, unpublished data).

Estimation of Pre-fishery Abundance of Two-sea Winter Salmon

The calculations of pre-fishery abundance of two-sea winter (2SW) salmon have been explained in detail (Anon.1993, 1994 and 1995a) and will not be repeated herein. Estimates of the total number of two sea-winter salmon (termed pre-fishery abundance by ICES because numbers have been estimated prior to the fishery at west Greenland) originating in North American rivers have been made using a technique that reconstructs salmon runs based on counts at enumeration facilities and catch statistics (Anon, 1995a). The pre-fishery abundance estimator for a given year reconstructs the population of 2SW returns by summing 2SW returns in the following year, 2SW salmon catches in Canada, and catches in year I from fisheries on non-maturing 1SW salmon in Canada and Greenland. An assumed natural mortality rate [M] of 0.01 per month is used to adjust the back-calculated numbers between the salmon fisheries on the 1SW and 2SW salmon (10 months) and between the fishery on 2SW salmon and returns to the rivers (1 month). This estimated pre-fishery abundance represents the extant population and does not take into account the fraction of the population that may be present in any given fishery.

Derivation of the Thermal Habitat Index for Salmon in the Northwest Atlantic

A relative index of the area suitable for salmon overwintering in the marine environment of the northwest Atlantic, termed thermal habitat, was derived from sea surface temperature (SST) data obtained from the National Meteorological Centre of the National Ocean and Atmospheric Administration and previously published catch rates for salmon from research vessels fishing in the northwest Atlantic (Anon, 1995a; Reddin *et al.*, 1993). The SST data consisted of two data sets of monthly mean SSTs. The first data set labelled *in situ* consisted of SST data that extended up to 61°N latitude from 1970-81. It was derived from sea surface temperatures recorded in situ by ships of opportunity, buoys, and sea-ice limits. The second data set labelled "optimally interpreted (OI)" data extended from 1982-95. The OI data consisted of monthly SST values on a 1" grid and were derived by optimally interpolating SSTs from the *in situ* data described above, earth observation satellites (AVHRR) and sea ice cover data (Reynolds and Marsico, 1993; Reynolds and Smith, 1994; Reynolds *et al.*, 1994). The SST data obtained from satellite imagery has been shown to be highly accurate when compared with known measurements (Reynolds *et al.*, 1994).

The index of overwintering habitat termed thermal habitat has been fully described in Reddin *et al.* (1993) and Anon (1995a). It was developed by computing a weighted sum of sub-area squares within the region specified in Figure 1. The area used to determine

Figure 1. The area in the Labrador Sea used for determination of suitable overwintering salmon habitat.

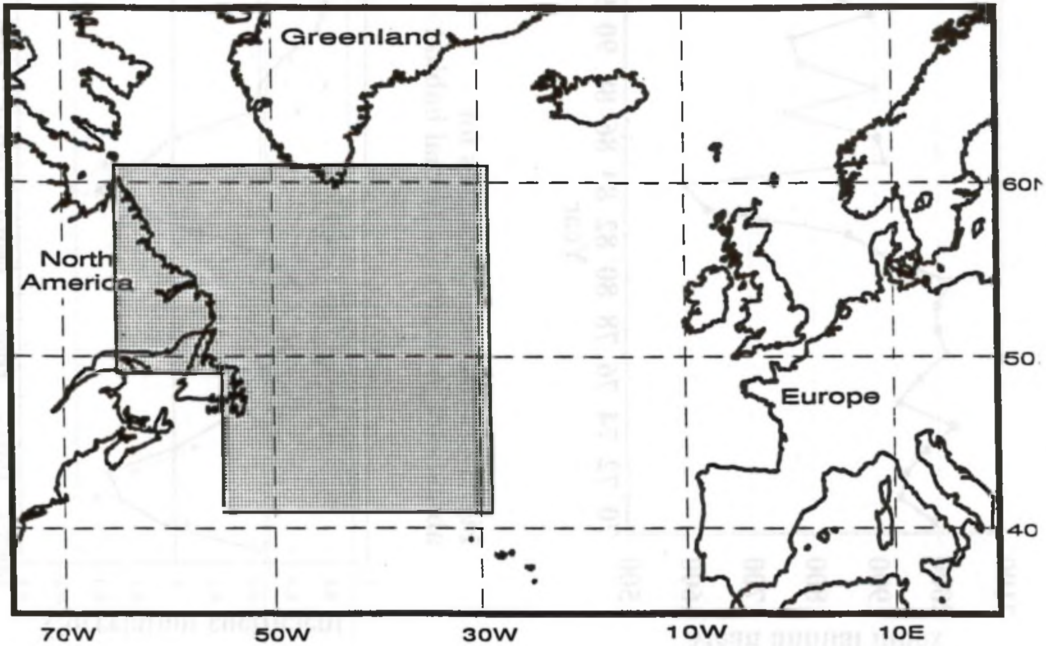


Fig. 2 Annual thermal habitat for salmon in the northwest Atlantic.

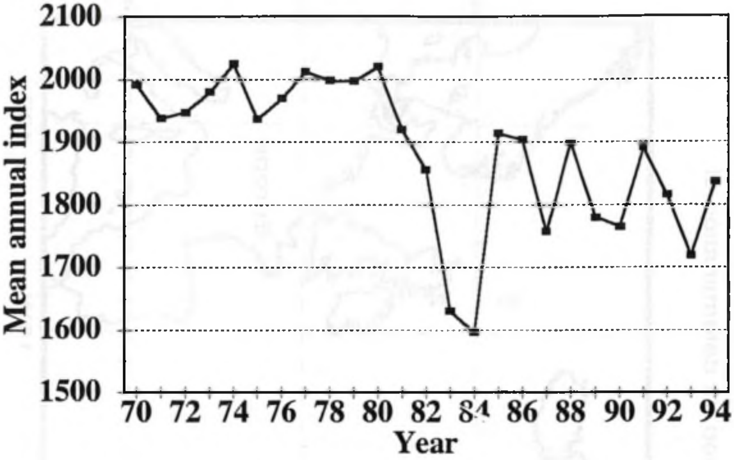
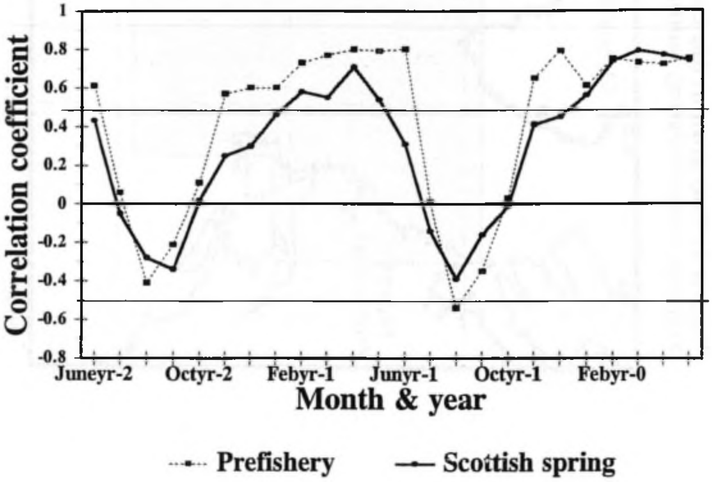


Fig. 3 Correlation summaries for abundance indices and thermal habitat



available salmon habitat encompassed the northwest Atlantic north of 41°N latitude and west of 29°W longitude and includes the Davis Strait, Labrador Sea, Irminger Sea, and the Grand Bank of Newfoundland. Analyses of the relationship between salmon catch rates obtained from a variety of research vessel surveys in the northwest Atlantic Ocean (Møller Jensen and Lear, 1980; Reddin, 1985; Reddin and Shearer, 1987; Reddin and Short, 1991) and SST showed that the relationship between salmon and SST is non-linear. Furthermore, salmon were found at sea in water with SSTs between 3 and 13°C with the peak in abundance occurring at around 7 to 8.5 °C. The significant non-linear relationship for SSTs and salmon catch rates suggested that salmon modify their movements at sea at least in part depending on SST. This relationship also suggested that habitat area in the northwest Atlantic should be weighted to catch rate and SSTs. Consequently, weighting factors were derived from these mean catch rates. A relative index of the area suitable for salmon termed thermal habitat was calculated by weighting the area at each temperature group by the catch rate for the same temperature group from the research vessels.

Influence of Greenland Catches, Growth Factors, and Thermal Habitat

Results of tagging studies have indicated that Scottish spring salmon are caught in the fishery at Greenland more so than in the Norwegian Sea (Youngson, 1995). Recent findings have shown European salmon to be declining at Greenland in terms of mean weight and numbers (Anon, 1993). Analysis of variance was used to model four of the many factors that could be linked to decreases in spring salmon in Scotland, viz mean weight of European salmon and numbers caught at Greenland, thermal habitat, and pre-fishery abundance. The mean weight of salmon used and numbers of European salmon caught are from Anon (1993).

Statistical Analyses

All statistics were calculated using SAS procedures CORR, GENERAL LINEAR MODELS, and REG (SAS Institute Inc, 1988). All correlations were done using Spearman Rank Correlations to avoid problems of assumption of normally distributed data. Of course, correlations do not indicate a cause and effect relationship but only show that the two data sets are varying in the same way. It may be that the significant correlations are due solely to chance alone and are thus spurious. Alternately, it may be that there is a third variable that is causally related and correlation with it generates the relationship. Where possible the number of significant correlations was compared to what would be expected by chance alone.

Results

Relationships Between the Various Abundance Indices

The various spring rod catches and other indices of abundance are highly interrelated (Table 1). The only exception was for the Gander River salmon which was only significantly correlated to pre-fishery abundance. This implies a high degree of synchronicity among stocks suggesting a common cause(s). When tested for annual trends, all stocks showed significant declines in catches (Table 1).

Table 1 The relationships between various indices of stock abundance using Spearman correlations. The number in the table is the Spearman correlation coefficient and the underline signifies significance at less than 1%.

	Pre-fishery abundance	Scottish spring	Wye spring	Dee spring	Bay St George	Gander small	Labrador 2SW
Year	-0.83	-0.65	-0.59	-0.58	-0.79	-0.86	-0.88
Pre-fishery	-						
Scottish	0.59	-					
Wye	0.60		-				
Dee	0.65	0.82	0.41	-			
BSG	0.78	0.60	0.58	0.54	-		
Gander	0.70	0.22	0.21	0.32	0.43	-	
Labrador	0.97	0.58	0.58	0.67	0.76	0.78	-

Relationships Between Thermal Habitat and Salmon Abundance

The availability of thermal habitat for salmon in the northwest Atlantic as shown by the annual mean is highly variable with peaks in habitat occurring in the 1970s, lows occurring in the mid-80s and then increases in the late 80s and 90s to levels below those of the 70s (Fig. 2). In the years since 1982, thermal habitat was more variable than during the 1970-82 period. The lowest value in the period of 1970-94 occurred in 1984, the second lowest in 1983 and the third in 1993. Also, during the period 1970-82 the annual habitat index of 23,627 was higher than the annual habitat index of 21,508 during the period of 1983-94 (F = 29.7, P<0.0001). Several authors have noted the good correlation between salmon habitat at sea and the abundance of salmon in the North Atlantic (Scarnecchia, 1984a, b; Reddin, 1988a; Reddin and Friedland, 1993; and Friedland *et al.*, 1993).

Further relationships were examined between thermal habitat and salmon abundance using pre-fishery abundance, Scottish and Welsh spring catches, and abundance estimates from salmon in Labrador, Bay St George, and Gander River. The pattern of the relationships between the monthly thermal habitat indices, pre-fishery abundance, and Scottish spring salmon catches shows close similarity (Fig. 3). There are significant correlations between thermal habitat and pre-fishery abundance occurring in the spring of the year they went to sea, from November to June of the post-smolt stage, and then for November to May of the return year to freshwater. For Scottish spring catches a similar pattern exists, although significant relationships were found only in February to May of the first winter at sea and then November to May of the final year at sea (Fig. 3). The observed pattern for thermal habitat and pre-fishery abundance is easy to understand since these salmon are known to spend much of their time in the northwest Atlantic. For Scottish spring salmon, the months and locations of residence in the northwest Atlantic are not completely known. However, tagged salmon from the Dee and other Scottish rivers have been caught at West Greenland, in the Labrador Sea, and along coastal Labrador from the summer and fall of their second sea year (Reddin *et al.*, 1984). Consequently, further analyses examined the relationships between thermal habitat and Scottish spring catches in the first sea winter.

Table 2 Correlations of monthly rod catches of spring salmon with thermal habitat indices of the preceding year. All correlations were positive. Upper case letters indicate significance at less than 1% and lower case at less than 5%.

	February catch	March catch	April catch	May catch
Dee	J F M A M	- F M A M	- f - A M	- f - A -
Tay	J F M A M	J F M A M	- - m A -	- - - - -
Spey	J F M A M	J F M A M	J F M A M	- f m a -
Tweed	- f - a -	- - - - -	- - - - -	- f m a m
Wye	j f - a m	J F m a m	j F M A M	j - m A M
Helmsdale	- f - - -	- f - A -	- - - - -	- - - - -
Deveron	j f - a m	j f M A M	- - m a -	- - - a -
Ness	j f - a m	j f M A M	- - - a -	- f m a m

Table 3 The results of analysis of variance to examine factors influencing the Scottish spring salmon catches.

Source	F Value	Pr > F
Greenland European salmon catch	0.11	0.7404
Pre-fishery Abundance	0.24	0.6298
Thermal habitat in April	5.21	0.0386
Mean weight of European salmon	0.04	0.8477

The relationships between thermal habitat and monthly rod catch statistics for several Scottish rivers and the Wye in Wales indicated that out of 160 tested relationships 97 of them or 61% were significant (Table 2). From chance alone, it would be expected that about 8 of the relationships tested would have been significant and the 97 that are significant are highly different than the number that would be expected by chance alone ($P<0.0001$). Of course, the five habitat indices treated in each cell of Table 2 are not independent of one another because environmental conditions tend to persist over long time periods. Because of these auto-correlations, the relationships represented by each cell should not be taken literally; however, the internal consistency of the values in the table suggest that when taken collectively for an individual river or group of rivers there is a strong possibility that the decline in abundance of spring salmon is in some way related to climate in the northwest Atlantic.

Relationships Between Springers and Greenland

The numbers of European salmon caught at Greenland and in the Scottish spring salmon fishery are both declining, although the decline in catches at Greenland has a much steeper slope, partly related to the decrease in catches due to management changes (Anon 1995a) (Fig. 4). If declines in returns of spring salmon were solely related to the Greenland fishery then management changes reducing catches at Greenland should have increased returns to the Scottish spring fishery. Whole weights of North American and European salmon sampled from catches at Greenland are also declining (Fig. 5). The results of ANOVA examining the relationship between Scottish spring catches and catches of European

Fig. 4 Numbers of European salmon at Greenland & Scottish spring salmon.

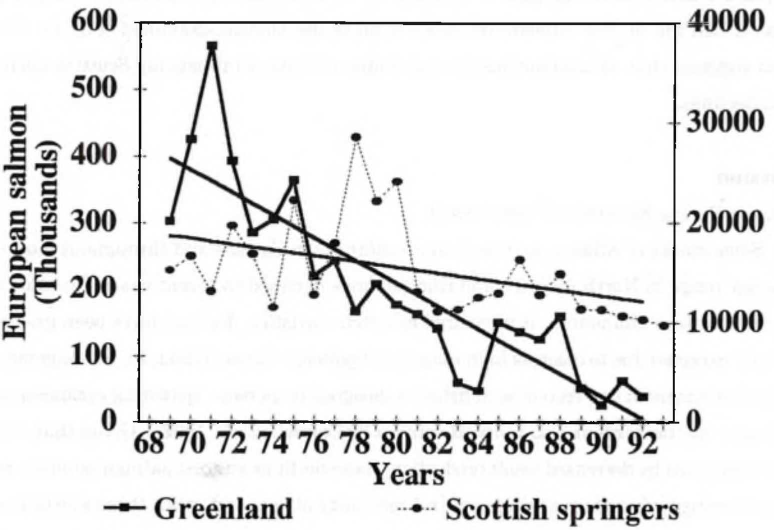
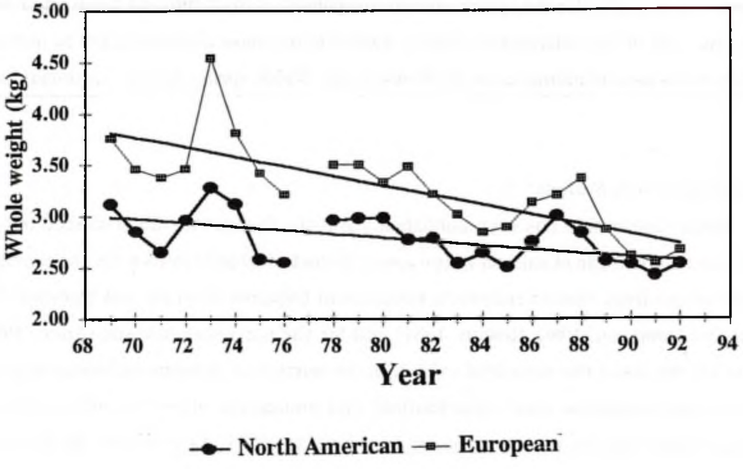


Fig. 5 Whole weights of North American and European salmon at Greenland



origin salmon at Greenland, pre-fishery abundance of North American salmon, the April thermal habitat index, and whole weight of European salmon at Greenland indicated that only April thermal habitat was significant (Table 3). In this case, April thermal habitat was used as it had the highest probability value of all of the months examined (Fig. 3). The analysis suggests that of the four factors tested only climate is influencing Scottish spring salmon declines.

Discussion

Declines in Spring Salmon and Other Stocks

Some stocks of Atlantic salmon (*Salmo salar* L.) in Canada and throughout most of the species' range in North America and Europe, have declined in recent years. In some of these cases, where abundance is measured by catch statistics, declines have been greater than those expected due to changes in management policies (Anon, 1995a, b). Management changes in commercial and recreational fisheries designed to increase spawning escapements should have by their intent also reduced catches (O'Connell *et al.*, 1992). Given that they were not preceded by decreased smolt production, these declines suggest salmon populations are experiencing higher than average natural mortality at sea; and, since these mortalities lack a causal explanation, they are viewed with great concern by salmon resource interests (Nickson, 1991). The declines have been confirmed by counts of salmon at numerous enumeration facilities (Anon, 1993), which have also shown that MSW salmon are declining at a faster rate than are 1SW (1-sea-winter salmon) (Anon, 1995a, b). These declines extend to Europe and in particular the spring salmon component in Scotland and some other rivers in the UK. All of the information that is available on these declines point to increased mortality in the sea, including those for Scottish and Welsh spring salmon as shown in this paper.

Marine Climate and Salmon

Much information has been published about the freshwater life of salmon but very little is known about life of salmon in the sea and most of what is known for the northwest Atlantic comes from studies related to commercial fisheries (Parrish and Horsted, 1980; Reddin and Dempson, 1986; Reddin, 1987) and for the northeast Atlantic (Anon, 1995a). What is known about the sea life of salmon in the northwest Atlantic including migration patterns, food resources, ocean distribution, and abundance of post-smolts, grilse, and multi-sea winter salmon has been summarized by May (1973), Lear (1976), Møller Jensen and Lear (1980), Reddin (1985), Reddin and Shearer (1987), Reddin (1988a, b), Mills (1989), Reddin and Short (1991), and Hislop and Shelton (1993). Various authors have shown that the numbers of salmon returning to fresh water have environmental links (Scarnecchia, 1984a, b; Porter and Ritter, 1984; Meerburg, 1986; Reddin, 1988b; Ritter, 1989; Reddin and Friedland, 1993; Turrell and Shelton, 1993; and Friedland *et al.*, 1993). Other biological characteristics of salmon such as growth and age at maturity have also been linked to variations in the marine environment (Scarnecchia, 1984a, b; Reddin and Shearer, 1987; Ritter, 1989; Reddin and Friedland, 1993; Friedland *et al.*,1993; Turrell and Shelton, 1993; Anon 1993, 1994, 1995a) including changes in sea age (Saunders *et al.*, 1983; Martin and Mitchell, 1985). Yet it still remains that our knowledge of salmon in the sea is dominated not by what we know but by what we do not know (Dempson *et al.*, 1986). Declines in Scottish and Welsh spring salmon have been linked to changes in marine climate in the northwest Atlantic but the lack of a specific cause emphasizes the need for more information on factors influencing salmon in the sea.

Earth observation satellites provide us with an unique opportunity to view conditions for salmon at sea and sea surface temperatures from satellites have been used by Reddin and Friedland (1993) and Friedland *et al.* (1993). Reddin and Friedland (1993) tested various hypotheses of overwintering habitat influencing the productivity of salmon stocks which indicated significant relationships for some stock complexes. The results suggest that there is a relationship between survival and overwintering habitat during the post-smolt stage and second winter at sea that seems to have a significant impact on survival and growth of Atlantic salmon in the northwest Atlantic Ocean. These results are consistent with those for Scottish and Welsh spring salmon shown in this paper and strengthen the overall conclusions of links between sea survival, returning numbers of salmon to fresh water, and thermal habitat.

Recently, there have been several attempts to include environmental effects on recruitment of salmon in stock assessments. Reddin and Shearer (1987) showed how environmental conditions in the Labrador Sea influenced the abundance of salmon at West Greenland and this insight has been used to provide advice to fisheries managers through the North Atlantic Salmon Conservation Organization (Anon, 1995a). Reddin *et al.* (1993) used time series and regression techniques to forecast the abundance of the two-sea winter component of the North American stock complex of Atlantic salmon prior to fisheries in Greenland and North America. These estimates provide the basis for fishery catch allocation in North America and Greenland and two-sea winter escapement in Canada. However, the biological basis for these relationships is to date only speculative and deserves further study.

Research vessel catches summarized by May (1973); Reddin and Shearer (1987); Reddin and Short (1991); Reddin and Friedland (1993) indicated that Atlantic salmon of all sea ages occurred seasonally over most of the northwest Atlantic. Salmon were concentrated throughout the year in the Labrador Sea gyre, in summer and fall off west Greenland, and in the spring near the eastern slope of the Grand Bank of Newfoundland. Post-smolt salmon were also found in abundance in the Labrador Sea in the fall of the year. These areas had in common seasonal sea-surface temperatures between 4 and 10 °C within which range about 80% of the salmon population was found.

Corroborative evidence that salmon change their distribution at sea, according to thermal conditions, can be discerned from the distribution in relation to SST of MSW salmon tagged and released as smolts in the Sand Hill River, Labrador, during 1969-72 (Pratt *et al.*, 1974). Some fish from this stock were captured in the general vicinity of the home river in Labrador as well as along the northeast coast of Newfoundland. However, when plotted with the June 4°C isotherm, the distribution of tag recaptures suggested that some of the annual variability in the locations of the capture of these fish was related to environmental conditions (Reddin and Shearer, 1987). In 1972, for example, MSW fish were recaptured considerably farther south than in either 1971 or 1973. The 4°C isotherm for June extended much farther southward in 1972 than in 1971 or 1973. The colder SSTs in 1972 may have occurred because of a more southerly distribution of sea ice and the concomitant cold water than in 1971 and 1973 (Reddin and Day, 1980). Dunbar and Thomson (1979), Reddin and Shearer (1987), and Ritter (1989) provide evidence that other salmon stocks also distribute themselves at sea in relation to SST.

What is the Mechanism of Mortality at Sea?

A possible mechanism for salmon mortalities at sea has been proposed by Youngson (1995). He drew on information from bird migration studies which showed that climate variations shifted bird migration pathways away from those normally travelled (Berthold, 1993). Bird migrations are highly structured and once out of their recognized migrational areas, mortalities from predation and the inability to locate new food sources increased over what would have normally occurred. It is well known that salmon also change migrational pathways due to shifts in climate, eg, sea temperature and ice in particular. Also, salmon have many known predators at all stages of sea life which could take advantage of any shifts in distribution (Hislop and Shelton, 1993). If similar to birds, they could have difficulties adapting to new food sources when migrational pathways and distributions change, and suffer significant mortality. Additional mortality at any stage in the migrational route will reduce the total number of fish returning later to the spawning grounds (and to fisheries). Any changes in the extent or the quality of the habitat available to migratory species (at any life stage) will affect their fitness and abundance. Since we have documented reductions in thermal habitat available for salmon in the northwest Atlantic and have shown that spring salmon catches are related directly to that habitat, it seems reasonable to conclude that this is a possible reason for the downturn in spring salmon abundance.

What Should Fisheries Managers Do?

Fish stock assessments used to set TACs and future catches have traditionally only included the responses of fish populations to exploitation, assuming constant recruitment independent of environmental effects (Ricker, 1975; Pope, 1972). These types of assessment, perhaps because the specific mechanisms are lacking, have continued up to the present in spite of the knowledge that environment does play an important role in determining recruitment (Lett *et al.*, 1975; Sutcliffe *et al.*, 1976). Recently, the management regime for the fishery at west Greenland has changed from one based on political negotiation to one based on science. Information on marine climate has been incorporated into the assessment process and, along with knowledge of required spawning targets in North America, is used to derive a quota for the Greenland fishery and to make recommendations for fishing in home waters (Anon, 1995a). In North America, relationships between the amount of spawning and subsequent recruits have been identified in some Atlantic salmon populations with recruitment reaching a maximum at an intermediate level of spawning (Anon, 1991). Consequently, management practices for salmon fisheries can maximize recruitment by ensuring that an optimum number of salmon are allowed to spawn. In Canada, targets are set for individual rivers based on conservation goals (Anon, 1991). Salmon managers in Scotland may have to consider something like the Canadian system for rivers with a high spring component if they wish to protect and conserve it for the future. The suggested approach as recommended by Youngson (1995) would be to maintain the spawning stock at as high a level as possible to ensure an adequate number of spawners are available when the declining trends reverse themselves.

It was noted (Anon, 1995a) that the pre-fishery abundance tended to persist in "poor" and "good" states for several years. Moreover, the likelihood of reversing from poor to good in a single year appeared to be about 10%. Since spring salmon rod catches are auto-correlated in the sense that the current year is a predictor of the coming year (Youngson, 1995), this could also apply to spring salmon populations in Scotland and Wales and thus in all probability spring catches may continue to be low for several more years. The further the spawning escapement is below the target egg deposition (or biological level to maintain optimal production), and the longer this situation occurs, even at rates only slightly below that level, the greater the possibility exists of incurring greater risk to future stocks (Anon, 1991).

In summary, we have shown that several spring salmon stocks in Scotland and Wales are declining and the declines are related to the condition of the marine environment (thermal habitat) in the northwest Atlantic during winter to spring of the first year salmon are at sea. Similar trends to those observed in Scottish and Welsh spring salmon populations have also been observed for MSW salmon populations in Bay St George, Newfoundland and Labrador. Marine condition in January to April was significantly correlated with spring rod catches in February to May. Analyses to show the impact of factors related to fishing at Greenland indicated that only marine environmental conditions were important. In other words the success of both the west Greenland and home water spring fisheries depends upon the environmentally determined status of the salmon populations exploited by both fisheries. Thus, when these populations are at a low level, reductions in the west Greenland quota do not lead to obvious increases in the home water spring catch. The benefits which accrue to home water spring fisheries, when the west Greenland fishery is restricted at times of low stock abundance, lie in reduced rates of decline in the availability of salmon to both the anglers and the spawning population.

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ESTIMATED INCREASES IN RETURNS OF SALMON TO HOME WATERS FOLLOWING THE SUSPENSION OF COMMERCIAL SALMON FISHING AT FAROES AND GREENLAND

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Introduction

Two changes in the management of the distant water salmon fisheries at Faroes and West Greenland in recent years have resulted in significant reductions in catches. These are:

- the adoption by the North Atlantic Salmon Conservation Organisation (NASCO) of a scientific model for setting the West Greenland quota; and
- the voluntary agreements by Faroes and Greenlandic fishermen not to fish for salmon in exchange for compensation payments from interested parties.

The scientific model adopted by NASCO for setting the West Greenland quota is based on a method developed by the International Council for the Exploration of the Sea (ICES) (Anon, 1993; Rago *et al.,* 1993a and 1993b; Reddin *et al.*, 1993; Potter, 1995). The key elements to the assessment are the number of non-maturing, one-sea-winter (1SW) North American fish predicted to be alive prior to the start of the fishery and the number of these fish which must be allowed to return to their home rivers to spawn. The difference between these two numbers (with some minor adjustments to take account of natural mortality) provides an estimate of the number of fish that can be caught without reducing the total spawning stock below the target level. The application of this model has therefore been designed to safeguard the spawning escapement.

The compensation arrangements negotiated with the Faroese and Greenlandic fishermen have, on the other hand, been designed to re-allocate the quotas in the distant water fisheries to increase both home water catches and spawning escapement The arrangements developed from an international campaign launched by Mr Orri Vigfusson in 1989, followed by the establishment of the North Atlantic Salmon Fund (NASF). The first agreement was reached with the Faroese fishermen in 1991. Since then only one vessel has operated, fishing under the instruction of the Faroes Fisheries Laboratory. In Greenland, all commercial fishing for salmon within territorial waters was suspended for the years 1993 and 1994 in accordance with an agreement reached with the Organisation of Hunters and Fishermen in Greenland (OHF). In 1995, the NASF failed to reach agreement with the OHF for the continuation of the compensation arrangement. However, the NASCO quota was reduced to 77 tonnes because of continuing low stock abundance estimates.

This paper examines the effects of the compensation agreements on stocks of salmon returning to home waters. The objective has been to provide estimates of the total numbers of extra salmon returning to each country, even where only limited data are available for some of the calculations. It must be emphasised, however, that the paucity of the data means that some of estimates may be fairly imprecise.

Method for Assessing Effects of Management Measures

The following information is required to estimate the effects of the compensation agreements on the numbers of salmon returning to home waters:

- the reduction in the number of fish killed by the fishery;
- the breakdown of the catches by age and by country of origin; and
- the time taken for fish to return to their home rivers and their survival on the homeward migration.

Reduction in number of fish killed

The number of fish saved from the fishery equals the catch that would have been landed if the fishery had operated, minus any catch that was actually taken. The maximum catch that should have been taken by each fishery is limited by the quota, but it cannot be assumed that the full quota would have been taken. The likelihood of the quota being taken may be assessed by considering the abundance of fish and the actual (or potential) fishing effort before and after the change in management.

Fish which are killed as a result of fishing but which are not recorded as catches (non-catch fishing mortality (NCFM)) must also be considered. Some such losses (eg unrecorded local consumption) may have persisted during the suspension of commercial salmon fishing.

Composition of the catches by age and by country of origin

The age composition of the catches in both the Faroes and West Greenland fisheries have been obtained by sampling landings over many years. Additional data have been obtained from the research vessel operating in the Faroes area during the suspension of commercial salmon fishing.

Various investigations have been conducted into methods to discriminate stocks using features such as scale characteristics (Reddin *et al.*, 1988) or allozyme frequencies (Payne and Cross, 1977). Such methods are routinely used to distinguish fish of North American and European origin caught at West Greenland (eg Anon, 1993), but they do not yet permit salmon from different countries to be distinguished. The only information on the countries of origin of the salmon caught in the two fishery areas has therefore come from tagging studies conducted on adults caught in the fisheries or on smolts leaving freshwater. These investigations have shown that salmon from different areas are very unevenly mixed in the ocean, and that the benefits from the suspension of commercial fishing will not be uniformly distributed between countries. The results of all tagging studies must, however, be treated with caution; not only is it possible for tagged fish to behave differently to untagged individuals, but where the number of recaptures is small the estimates derived from the data will be imprecise.

Adult tagging studies were conducted in the West Greenland and Faroes fisheries in the early 1970s. Salmon have also been tagged in the Faroes area in the 1992/93 and 1993/94 fishing seasons, but only preliminary, incomplete results are available (Anon, 1995).

Smolt tagging studies have been conducted on salmon stocks in many parts of the North Atlantic since the 1960s. Recovery rates for fish tagged as smolts can be used to estimate the contribution of individual stocks to catches in distant water fisheries. These results may also be used to estimate the contribution of the stocks from a whole country. One method for doing this is a modification of the run-reconstruction model (Potter and Dunkley, 1993). The run-reconstruction model uses the numbers of tagged fish of each sea-age class that return to the river to back-calculate the numbers of tagged fish alive at the time of each fishery. This then allows the levels of exploitation in the fisheries to be estimated from the numbers of tag recaptures. The numbers of tagged fish in the model can be scaled up to the size of the national stock and corrections made for known differences in the patterns of exploitation. A preliminary analysis of this kind has been conducted for the majority of North East Atlantic stocks, although the data provided for some countries were very limited; indeed for some countries it was necessary to extrapolate from neighbouring regions (Anon, 1991a). The model is also very sensitive to some of the parameters used and some of these cannot be estimated precisely. It was intended that this analysis should have been improved with data from later years (Anon, 1991b), but this has not been possible because of the suspension of fishing in the Faroes area. As a consequence these results represent the only comprehensive assessment available.

Time before the fish will return to their home rivers

Some of the fish saved from the fishery will be expected to die before they return to home waters. The rate of natural mortality experienced by salmon after their first year in the sea is thought to be about 1% per month (Anon, 1987). Those fish that survive may return to home waters in the season following the fishery, in some cases within a few weeks, or may remain at sea for at least a further year. Information on this behaviour has been obtained from tagging experiments, and in the case of the Faroes fishery, from hormonal studies of the state of maturation of the fish (Anon, 1985). The time taken for the fish to return is taken as the number of months between the median date of the fishery and the median date of the run of the specific sea-age groups in home waters.

Suspension of Commercial Salmon Fishing at Faroes

Background on the Faroes fishery

The long-line fishery in the Faroes area developed in the late 1960s. Catches built up slowly to 40 tonnes in 1977, but subsequently increased much more rapidly, reaching 1,027 tonnes in 1981. Since 1981, catches have been controlled by quotas, which have been negotiated with EC (1981/82 to 1983/84 fishing seasons) and by NASCO (1984-95 calendar years). Since 1988, the quotas have been supplemented by effort restrictions, although in all years the effort actually employed has been less than the maximum allowed. The fishery has involved up to 44 vessels in some years, but by the 1990/91 season (the last season before the suspension of commercial fishing) only 13 vessels obtained licences and only 8 of these actually fished.

The annual quotas for the Faroes fishery for 1987-1995 are shown in Table 1. Although these have been set for calendar years, the fishery has operated from October/November to March/April and most of the biological data collected has been related to this period (referred to as the fishing season). The calculations in this paper are therefore based on catches in each fishing season. In each season between 1987/88 and 1990/91, the catch fell short of the annual quota by a significant margin. The compensation arrangement began in March 1991, and only one vessel has continued to fish, obtaining research data under the direction of the Faroes Fisheries Laboratory.

Reduction in the number of fish killed at Faroes

The quota for the Faroes fishery sets the maximum weight of salmon that may be caught. Thus the weight of fish saved by the compensation arrangement might be considered to be the quota minus the catch in the research fishery (Table 1). However, in the three years prior to the compensation arrangement (1988-1990) the quota was not taken in full. If the fishery had operated in the 1991/92-1993/94 seasons, the quota is only likely to have been taken if there had been: an increase in the availability of salmon in the area; an increase in the number of vessels operating or the amount of gear used; or more favourable fishing conditions permitting increased effort by each vessel.

A crude measure of relative abundance of salmon in the area is provided by the catch per unit of effort (CPUE) (Table 2). This was collected for the whole fishery prior to the 1991/92 season and for the research fishery in the subsequent seasons. Although the CPUE was slightly (4%) lower in the latter period, the difference was not significant, suggesting that there was a similar mean annual abundance of salmon in the area in the two periods. The CPUE varies considerably between months and may be affected by many factors, including weather and competition between vessels. While these factors may have differed between the two periods there is no evidence that they would have resulted in a systematic increase or decrease in CPUE.

Table 1 shows the maximum fishing effort permitted in the Faroes fishery under the NASCO agreements since 1987. The number of boats that have operated has generally been less than the number allowed and has been declining steadily. A mean of 15.3 licences was issued each year between 1988 and 1991 (although the limit at that time was 26), and an average of 10.3 vessels actually fished in the 1988/89 to 1990/91 fishing seasons. The maximum number of vessels allowed to fish during the period of the compensation arrangement (13-15) was therefore about 39% greater than the number that operated previously. However, if the decreasing trend observed in previous years had continued, the number of vessels operating might have been expected to decrease by 25-50%. In view of this range of uncertainty it is assumed that the same number of vessels would have operated in the period 1991/92 to 1993/94 as in the three previous seasons.

Finally there is no evidence that conditions have been any better for fishing since 1991 than in previous years. In fact, as in many previous years, fishing was impossible during January and parts of February between 1992 and 1994 due to poor weather.

Since the stock abundance and the fishing effort are likely to have been similar after 1991 to the three previous years, the mean annual catch for the 1988/89 to 1990/91 seasons (87,484 fish) provides the best estimate of the expected catch in each of the subsequent three seasons. This catch must be raised to take account of discard losses. The expected discard rate of 10.9% (in numbers) is obtained from the proportion of the research vessel catches that were below the minimum landing size of 60 cm (total length) (Anon, 1995), and the mortality rate for these fish which is assumed to be 80% (Anon, 1987). Thus 96,046 fish would have been expected to have been killed in each season.

The mean number of fish killed in the research fishery in each of the last three seasons is estimated from the total catch (including undersized fish which were retained) minus the tagged fish which were released (Anon, 1995). (The tagging mortality is unknown and is therefore ignored.) This gives an annual mean total of 6,022 fish killed in the research fishery. Thus an average of 90,024 fish is estimated to have been saved each year.

Presence of farm escapees in Faroes catch

Recent studies have indicated that, in some years, a substantial proportion of the fish caught in the Faroes fishery has been escapees from fish farms (Hansen *et al.*, 1993). Since 1991, these fish have been estimated to comprise an average of 27% of the fish caught in the area each year (L P Hansen, pers comm). Little is known about the origin of these fish or their behaviour and it is unclear whether they will return to freshwater as readily as the wild fish. However, it may be assumed that they would not be welcome contributors to wild spawning stocks in most rivers and so they are treated separately in this analysis.

Age composition of the Faroes catch

The expected age composition of the wild catch may be estimated from the research vessel sampling conducted in the 1991/92 to 1993/94 seasons. This provides the mean annual data shown in Table 3.

Expected timing of return of fish from Faroes to freshwater

ICES has previously provided a model to assess the effects of the catch at Faroes on stocks returning to home waters (Anon, 1984). On the basis of an analysis of serum hormone levels in fish caught in the fishery, it has been estimated that 78% of the 1SW and two-sea-winter (2SW) fish (and 100% of older fish) in the Faroes area will mature in the same year. It is estimated that 97% of these will survive to reach home waters if they are not caught (assuming a natural mortality rate of 1% per month). The remaining 1SW and 2SW fish are assumed to mature in the following year, with 86% surviving to return to home waters.

Composition of Faroes catch by country of origin

Although adult tagging studies were conducted around the Faroe Islands between 1969 and 1975 (Anon, 1980), much of the fishing since then has taken place further north, and the tagging results are not thought to provide reliable information on the stocks currently exploited by the fishery. Further adult tagging studies have been conducted during the 1992/93 and 1993/94 seasons, but the results are not yet available.

The application of the run-reconstruction model to smolt tagging results has indicated that the level of exploitation of salmon from Norway and Sweden has been very much higher than on fish from UK and Ireland (Anon, 1995). It is also clear that there are marked differences in the patterns of exploitation of 1SW and multi-sea-winter (MSW) fish.

There is evidence from both smolt and adult tagging experiments that some North America salmon have been taken in the Faroes fishery. However, there are insufficient data to estimate this contribution.

Although the analysis of the smolt tagging data described above is based, at least in part, on limited data, it provides the best available estimate of the composition of the catch at Faroes by country of origin. This has therefore been used to estimate the catches of 1SW and MSW salmon from different countries that would have been taken if the commercial fishery had operated since 1991 (Table 4). It must be noted that the use of this approach assumes that the composition of the population has remained stable. In addition, where the estimated proportion of the catch is large (eg for Russia), errors could have significant effects on the estimates for all other countries.

Increase in returns to home waters following suspension of commercial salmon fishing at Faroes

The data described above have been used to estimate the additional numbers of salmon returning to home waters as a result of the suspension of commercial salmon fishing at Faroes (Table 5). This suggests that the greatest proportional increase in returning MSW stocks will have occurred in Northern European countries (ie Sweden, Norway, Finland and Russia), while the greatest numerical contribution will have been made to Norwegian and Russian stocks. Increases in returns of 1SW fish will probably have been more evenly spread between North East Atlantic countries. The large returns to Norway and the relative contributions to countries in Northern and Southern Europe are broadly consistent with the relative sizes of the stocks (indicated by catch data) and the relative levels of exploitation at Faroes (indicated from smolt tagging). However, it is important to re-iterate that the estimates for some countries (eg Russia and Finland) are based upon few tag returns (and extrapolations) and may be inaccurate.

An additional 24,000 farmed fish (on average) are expected to have been saved from the Faroes fishery each year. It is not known whether these fish will have returned to the areas from which they escaped. If so, and assuming the number of escapees is proportional to the production in each country, about 70% of the survivors might be expected to return to Norway and 20% to Scotland.

Suspension of Commercial Salmon Fishing at West Greenland

Background on the West Greenland fishery

The present fishery on the west coast of Greenland began in the early 1960s, and catches increased to a peak of 2,689 t in 1971. Since 1976, the fishery has been controlled by quotas and only Greenlandic vessels have been allowed to take part. The annual quotas have been divided between a 'free component' for which all licensed fishermen can fish and a "small boat component" which is allocated to small boats on a district basis, however there have been no effort restrictions.

The quotas set for the fishery in recent years are shown in Table 6. Since 1993, these have been calculated in accordance with a regulatory measure adopted by NASCO for 1993-1997 which incorporates a formula developed by ICES for providing catch options. The fishermen suspended commercial salmon fishing in 1993 and 1994 in exchange for compensation payments; however, a small subsistence fishery (12 t) was allowed to continue.

Because no sampling took place in the fishery in 1993 and 1994, data obtained from sampling programmes in earlier years have been used for the following analyses.

In 1993, a quota of 213 tonnes was agreed by NASCO for the West Greenland fishery. The predicted pre-fishery abundance of North American non-maturing 1SW fish in this year was 258,000, and the actual abundance was subsequently estimated to be between 100,000 and 201,000 fish. It is reasonable to assume that the 1993 quota could therefore have been taken, because a catch of 237 tonnes was taken in 1992 when the estimated pre-fishery abundance was between 123,000 and 232,000 fish. In 1994, the quota was reduced to 159 tonnes, although the predicted pre-fishery abundance of North American 1SW fish had increased to 280,000. (This reflected the agreement to phase-in the implementation of the scientific model for setting the quota.) Thus it is assumed that the 1994 quota could also have been taken in full.

The total number of fish that would have been caught in the fishery is calculated by dividing the quota by the mean weight of all fish taken in 1990-92 (2.71 kg) (Anon, 1993). This gives an expected catch of 78,598 fish in 1993 and 58,672 in 1994.

The number of saved fish needs to be raised to take account of non-catch fishing mortality. Unrecorded catches in the subsistence fishery continued in 1993 and 1994. However, unseen mortalities resulting from the operation of the drift nets (eg fall-out and haul back losses) should be added to the estimated catch. Estimates of some of these losses were provided by the ICES Working Group on North Atlantic salmon (Anon, 1982). Based upon the mid-points of the ranges given, the additional losses are thought to be of the order of 16% of the total fishing mortality. Thus the total number of fish saved from the fishery by the compensation agreement is estimated to be 93,569 in 1993 and 69,847 in 1994.

Age composition of West Greenland catch and return pattern

All of the salmon saved from the Greenland fishery would be expected to return to home waters as MSW fish if they survived. The majority (~95%) would return as 2SW salmon, the remainder being older fish (~ 4%) and previous spawners (~1%).

The proportion of fish farm escapees found in catches of salmon taken at West Greenland have been negligible (~1%) (Anon, 1994) and so no account of these is taken in this assessment. Fish are assumed to take an average of 11 months to return to home waters (Anon, 1995), and so the survival rate for returning fish is estimated to be about 90% (assuming a natural mortality rate of 1% per month). A total of 83,819 extra salmon are therefore estimated to have returned to home waters in 1994 and 62,569 in 1995.

Composition of West Greenland catch by country of origin

The proportions of the salmon caught at West Greenland that originate from North America and Europe have been estimated using a discriminant analysis of scale characteristics (Reddin *et al.,* 1988; Anon, 1995). The catch has normally been split fairly evenly, although in 1990 the North American proportion was estimated to be 75% and in 1991, 65%. No catch sampling took place in 1993 and 1994, and so the North American proportion was estimated to be 54%, from the trend in the previous years' data (Anon, 1993, 1994). The great majority of the North American stocks will have returned to Canada, and no attempt is made here to separate out the USA stock components.

Two approaches are available for assessing the composition of the European component of the West Greenland catch by country of origin. An adult tagging programme was conducted in the West Greenland fishery in 1972, and 39 tag recoveries were reported from Europe (Table 7). The numbers of recaptures of tagged fish in home water fisheries should be corrected to take account of differences in the exploitation and tag reporting rates in different countries. However, such data are not generally available and it must therefore be assumed that the rates are approximately equal in all areas. The second source of data is the run-reconstruction model analysis discussed in Section 2.2 above. The model provides estimates of the numbers of salmon from each North East Atlantic country caught in the West Greenland fishery (Table 7). It is not possible to say whether the results of the smolt or adult tagging are more reliable, and so average values have been used in the following assessment.

Once again it must be emphasised that many of these estimates are based on small numbers of tag returns and may be very imprecise. The estimates of the numbers of extra fish returning to individual countries should therefore be treated with caution.

Increase in returns to home waters following suspension of commercial salmon fishing at West Greenland

The data described above have been used to estimate the numbers of extra salmon returning to home waters in 1994 and 1995 as a result of the suspension of commercial salmon fishing in the West Greenland fishery in 1993 and 1994 (Table 8). These results suggest that around 45,000 extra fish should have returned to North America in 1994 and 34,000 in 1995. The numbers of extra fish estimated to have returned to Europe are about 39,000 in 1993 and 29,000 in 1994. Over 60% of the European component of the West Greenland catch is estimated to originate from Scotland with the majority of the remainder coming from Ireland, and England and Wales. These results are consistent with recapture rates from smolt tagging experiments conducted in the 1960s and 1970s (Anon, 1980) when adjusted to take account of the relative size of national stocks (inferred from catch records). The mean recovery rates of tagged fish at West Greenland were similar for stocks in Scotland, England and Wales and France; but these were over six times the rates for Swedish stocks and ten times those for Norwegian fish. The results for British stocks were also more than twice those for Irish stocks.

Conclusion

The estimates of the increased numbers of fish returning to home waters as a result of the suspension of commercial salmon fishing at Faroes and West Greenland are based upon a number of assumptions. These relate to the likely level of catches in the fisheries and estimates of various other parameters, such as rates of non-catch fishing mortality, maturation and natural mortality. It is not known how reliable these values are and so it is not possible to give precise confidence limits on the results of the analyses. The estimates will be particularly sensitive to errors in the number of fish expected to have been caught if the fisheries had operated; an error of say 20% in this value will have approximately the same percentage effect on the estimate of the numbers of fish returning. In the case of the Faroes fishery there is considerable uncertainty about the number of salmon that might have been caught, and the error could easily be as large as ±50%. If the West Greenland fishery had operated, the catch (in tonnes) should not have exceeded the quota (the value used to estimate the expected catch), but it could have been less; this would mean that the number of fish saved could have been overestimated. In addition, an error in the mean weight of fish caught at West Greenland will have a direct effect on the estimate of the number of fish saved from this fishery (ie if the mean weight is overestimated by a factor of 1.1 then the number of fish saved will be underestimated by the same factor). Similar errors in other parameters will have a much smaller effect on the estimates; for example a 20% error in the rate of natural mortality will affect the results by about 2%.

Estimates have also been made of the effects of the compensation programmes on returns to individual countries. These estimates are broadly consistent with various data on national stocks available from smolt and adult tag return rates, exploitation rates and catches. However, they are based upon very limited information and there is potential for significant errors; the results should therefore be used with great caution. It should be possible to improve some of these estimates when the results of the adult tagging programme at Faroes are available. The nature of these calculations is such that if the returns to one country are overestimated, then the returns to other countries will be underestimated. All these potential errors must be borne in mind when considering the results.

The estimated overall effect of the suspension of commercial salmon fishing at Faroes and West Greenland on the numbers of 1SW and MSW salmon returning to home waters in the years 1992 to 1995 is shown in Table 9. Nearly 0.4 million extra salmon are estimated to have returned to all countries around the North Atlantic as a result of these arrangements, with around 79,000 returning to North America and about 307,000 to European countries. All those extra fish returning to North America and about 93% of those returning to Europe would have been MSW salmon. The numbers of extra salmon returning each year are estimated to have ranged from about 52,000 in 1992 (all to Europe) to about 146,000 in 1994 (split approximately 70:30 between Europe and North America).

The greatest beneficiary, in numbers of salmon returning, from the total compensation programme appears to have been Norway, followed by Russia, Canada and Scotland. However, while the extra returns to northern European countries were spread fairly evenly between the years 1992-1995, those to southern European countries came mainly in 1994 and 1995 and those to North America solely in these latter years.

The majority of the MSW salmon saved by the suspension of the Faroes fishery are likely to have returned to Norway and Russia, and these countries along with Sweden and Finland should have experienced the greatest proportional increase in MSW stocks. Relatively few of these MSW salmon are likely to have returned to southern European countries (UK, Ireland, France and Spain). The 1SW salmon saved from the Faroes fishery, although relatively few in number, are likely to have been more evenly spread between countries. Recent tagging studies have shown that some North American salmon are also caught in the Faroes area, however insufficient data were available to estimate the numbers.

Canada should have been the greatest beneficiary from the two year suspension of fishing at West Greenland. Scotland has probably received the largest proportion of the extra fish returning to Europe, with smaller numbers returning to England and Wales and Ireland and few to most other countries. The greatest proportional benefit in Europe will have been to southern countries.

The effect of the increased numbers of returning salmon on catches in home waters will depend upon the levels of exploitation in the net and rod fisheries. As catches are subject to large natural variations, it has not been possible to demonstrate statistically significant increases resulting from the suspension of commercial fishing at Faroes and Greenland (Anon, 1995). Nevertheless it can be said with some confidence that more salmon will have returned and that the overall effect will have been beneficial to many home water stocks and fisheries. In comparison with some other management measures designed to protect or enhance stocks, it must be recognised that the benefits from the compensation arrangements will not necessarily be well targeted on those stocks most in need. However, while some other management measures such as stocking may generate mainly 1SW returns, over 95% of the extra fish returning as a result of the compensation schemes are MSW salmon, and many will be spring-running fish, the component of many stocks currently most under threat.

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Table 1 Quota and effort restrictions for the Faroes fishery agreed by NASCO, 1987-1995. Number of boats licensed and number operating, and nominal landings in the 1987/88 to 1993-94 seasons.

Year	Quota (t)	Maximum number of licences permitted	Maximum number of boat days permitted	Season	Number of licences issued	Number of vessels fishing	Nominal landings (t)
1987	596.6	26	1600	Commercial fishery			
1988	596.6	26	1600	1987/88	-	-	208
1989	596.6	26	1600	1988/89	19	12	309
1990	550	26	1600	1989/90	14	11	364
1991	550	26	1600	1990/91	13	8	202
				Research fishery			
1992	550	15	1200	1991/92	-	1	31
1993	550	15	1200	1992/93	-	1	22
1994	550	13	1200	1993/94	-	1	7
1995	550	13	1200	1994/95	-	1	n/a

* Season also restricted to maximum of 150 days in all years.

Table 2 Monthly catch per unit effort (CPUE) in the Faroes fishery for the three years before and after the commencement of the compensation arrangement.

Season	Monthly catch per unit effort						Mean CPUE (+/- SD)
	Nov	Dec	Jan	Feb	Mar	Apr	
1988/89	63	80	48	68	61	76	66.1 +/- 19.1
1989/90	81	86	38	56	87	77	
1990/91	81	97	-	35	39	51	
1991/92	-	93	-	72	77	50	63.2 +/- 22.7
1992/93	76	55	-	-	92	-	
1993/94	67	53	-	15	45	-	

Table 3 Mean annual sea age composition of catches of wild salmon taken in the research fishery in the 1991/92 to 1993/94 seasons (including discards) (from Anon, 1995).

Sea age	% in samples
1SW	9.1
2SW	71.6
3SW	18.6
4SW	0.7

Table 4 Estimate of the composition of the Faroes catch by country of origin based upon the run-reconstruction analysis (from Anon, 1991a).

Country	Results of Run Rec Model		Estimated stock composition (%)	
	1SW	MSW	1SW	MSW
Iceland	595	842	12.4	0.8
Finland	58	2,801	1.2	2.8
Russia	0	38,175	0.0	37.6
Norway	1,163	54,294	24.3	53.5
Sweden	190	877	4.0	0.9
Scotland	895	2,873	18.7	2.8
England and Wales	796	935	16.6	0.9
Northern Ireland	249	0	5.2	0.0
Ireland	651	341	13.6	0.3
France	184	296	3.8	0.3
Total	4,781	101,434	100.0	100.0

Table 5 Summary of the assessment of the effects of the reduced fishery at Faroes on the numbers of salmon returning to home waters.

				Average per season 1991/92 to 1993/94
Expected no fish landed if fishery operated (av 1988/89-1990/91				87,484
Discard rate =	10.9%			
Discard mortality =	80.0%			
Expected no fish killed per year if fishery operated =				96,046
Average no fish killed in research fishery (av 1991/92-1993/94) =				6,022
Total number of fish saved per year =				90,024
Proportion of farmed fish in catch =		27%		
Number farm escapees saved =				24,306
Number of wild fish saved =				65,717
Sea age composition of wild fish:	1SW	9.1%	Catch:	5,980
	2SW	71.6%		47,054
	3SW	18.6%		12,223
	4SW	0.7%		460
			1SW	MSW
Increased number of returns:	in first years		4,525	47,904
	in subsequent years		4,525	57,938

Country	Estimated stock composition		No extra wild fish returning		
			1SW	MSW	
	1SW (%)	MSW (%)	Each yr	1992	1993/94
Iceland	12	1	563	398	481
Finland	1	3	55	1,323	1,600
Russia	0	38	0	18,029	21,805
Norway	24	54	1,101	25,641	31,012
Sweden	4	1	180	414	501
Scotland	19	3	847	1,357	1,641
England and Wales	17	1	753	442	534
Northern Ireland	5	0	236	0	0
Ireland	14	0	616	161	195
France	4	0	174	140	169
	100	100	4,525	47,904	57,938

Table 6 Annual quotas and reported catches of salmon (tonnes) in the Greenland fishery from 1987 to 1995.

Year	Quota	Catch
1987	935	966
1988	915	893
1989	900	337
1990	924	227
1991	840*	437
1992	no quota set	237.5
1993	213	no fishery
1994	159	no fishery
1995	77	81

* set unilaterally

Table 7 Estimated composition of the European component of the West Greenland catch by country of origin.

Country	Recoveries from adult salmon tagging at WG		Estimates from R-R model (Anon, 1991)		Average %
	No recap's	%	No	%	
Iceland	0	0.0	281	0.2	0.1
Finland	0	0.0	330	0.3	0.1
Russia	0	0.0	0	0.0	0.0
Norway	0	0.0	6,388	5.3	2.7
Sweden	0	0.0	706	0.6	0.3
Scotland	25	64.1	77,641	64.8	64.5
England and Wales	8	20.5	11,037	9.2	14.9
Northern Ireland	0	0.0	100	0.1	0.0
Ireland	5	12.8	19,807	16.5	14.7
France	1	2.6	3,490	2.9	2.7
Spain	0	0.0	-	-	-
Total	39		119,780		

Table 8 Summary of the assessment of the effects of the reduced fishery at West Greenland on the numbers of salmon returning to home waters.

		Years	
		1993	1994
Expected catch (tonnes) if the fishery had operated (quota)		213	159
Mean weight of all fish caught (1990-92) =	2.71 kg		
Expected catch in numbers if the fishery had operated =		78,598	58,672
NCFM (excluding subsistence fishery) =	16%		
Total number of fish saved =		93,569	69,847
Survival on return migration to home waters =	90%		
Extra MSW salmon returning to home waters =		83,826	62,575

Numbers of MSW returning to different countries:

Country	Composition of European component (%)	Composition of total WG catch (%)	No of extra MSW returns	
			1994	1995
Iceland	0	0	45	34
Finland	0	0	53	40
Russia	0	0	0	0
Norway	3	1	1,028	768
Sweden	0	0	114	85
Scotland	64	30	24,856	18,555
England and Wales	15	7	5,731	4,278
Northern Ireland	0	0	16	12
Ireland	15	7	5,660	4,225
France/Spain	3	1	1,056	788
Total Europe:			38,560	28,784
North America		54	45,266	33,790

Table 9 Total numbers of extra MSW salmon estimated to have returned to North Atlantic salmon producing countries as a result of the compensation arrangements in the Faroes and West Greenland fisheries.

Country	Numbers of extra salmon returning to home waters						
	1SW	MSW					Total all ages 1992-95
	each year	1992	1993	1994	1995	Total 1992-95	
North America	0	0	0	45,266	33,790	79,057	79,057
Iceland	563	398	481	526	515	1,919	4,172
Finland	55	1,323	1,600	1,653	1,640	6,215	6,435
Russia	0	18,029	21,805	21,805	21,805	83,444	83,444
Norway	1,101	25,641	31,012	32,040	31,780	120,473	124,876
Sweden	180	414	501	615	586	2,115	2,835
Scotland	847	1,357	1,641	26,497	20,196	49,691	53,079
England and Wales	753	442	534	6,265	4,812	12,054	15,067
Northern Ireland	236	0	0	16	12	28	971
Ireland	616	161	195	5,855	4,420	10,630	13,095
France/Spain	174	140	169	1,225	957	2,491	3,188
Europe total	4,525	47,904	57,938	96,498	86,722	289,062	307,160
Total	4,525	47,904	57,938	141,764	120,512	368,118	386,217

GRILSE AND MULTI-SEA-WINTER SALMON: SOME SMOKE AND A FEW MIRRORS?

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North Americans have a good name for midges - "noseeums". Among salmon, springers are becoming "noseeums" or, at least "nowyoudonowyoudontseeums". Are these appearances and disappearances of springers real or just an illusion, a matter of some smoke and a few mirrors?

First we must ask what we believe springers really are, and here is where we encounter a little smoke. To the angler, springers are salmon that are available for capture by rods in the spring months (Youngson, 1995). They constitute a separate group within the more broadly defined "multi-sea-winter" salmon (MSWs ie salmon which have spent 2 or more years in the sea prior to spawning). MSW salmon are themselves something of a misnomer since some of them may enter rivers late in the year prior to spawning so that their second "sea-winter" is actually spent in freshwater. In recent years, most springers and indeed most MSW salmon, are, in fact 2+ SW fish some of which enter rivers in spring, some in summer and some even in autumn. To disperse some of this smoke which occludes our vision and to avoid some of the confusion about run timing, I will use the term spring fish or MSWs to cover all salmon which spawn only in the third, or later, winter after smoltification. This is, generally, the broad group which anglers and managers wish to see enhanced: by virtue of their later maturation they have had more time to grow in length and in weight and they are the prime target not only of the sport fishery but of the salmon-smoking trade.

MSWs can be identified by the sea-growth rings on their scales or, unequivocally, by microtags where these have been inserted earlier in individual smolts. But before these techniques were perfected and, in many cases still, where they cannot be conveniently availed of, spring fish were operationally identified on the basis of their size or weight. Salmon over a certain weight - often 8 lbs, or about 3.5 kg - were regarded as spring fish and those under that weight as grilse (1+SW). The weight or length chosen for the distinction is, of course, another source of smoke. Table 1, for example, shows the mean length of grilse and MSW fish returning to the Bundorragha River in the west of Ireland, together with the mean length of grilse (1+SW) fish returning to the River Shannon: the latter are, on average, much larger than Bundorragha grilse and a number of River Shannon grilse males are larger and heavier than Bundorragha MSWs (see below). Clearly the distinguishing length or weight for MSW fish may differ from river system to river system, and what falls to be called a grilse in one river could be regarded as a MSW fish in another.

A further complication is evident in the River Shannon data (Fig. 1): the mean length of male grilse is significantly greater than that of female grilse of the same, hatchery produced, stock and cohort. We know, because all the fish were microtagged and/or finclipped as smolts, that females over 72 cm in length are true MSWs (2+SW) whereas all those under 72 cm, with a mean length of about 62 cm, are true grilse. With males, only 12 individuals in Figure 2 are true MSWs (all these are over 85 cm) and the approx 1300 fish remaining are true grilse (1+SW) with a mean length of about 72 cm. So, unless the gender of the fish, as well as its river of capture, is known, little can be concluded about the status of any individual for which scales or tags are unavailable.

But now the smoke thickens. Table 2 presents the results of tagging experiments we have carried out on the ranched hatchery stock of the River Shannon between 1992 and 1995 dividing the fish into year classes, sea-age classes and gender. Summarising these data it is clear that the offspring of MSW crosses give a higher proportion of MSW adult returnees than do the offspring of grilse crosses; overall, there are far more female MSW returnees than male MSW returnees; and within both broodstock lines, female smolts give much higher MSW adult returns than male smolts do. Indeed in our breeding programme for MSWs, a shortage of ranched MSW sires is our greatest problem.

Nowadays, of course, we know all this and sufficient tags and scales are examined each year to permit us to see exactly what is, or is not, entering the rivers. It is when we come to compare to-day's spring fish or grilse frequencies with those of earlier years that the smoke creates the greatest problem. Because we cannot always be certain that the older length and weight data, on their own, reflect accurately the true nature of the fish running the rivers then we should be careful in concluding that the changes we see today are somehow novel or unique in kind or in magnitude. We simply cannot be certain: changes there certainly may be between then and now, but just how much is not at all as clear as we may like to think. This is particularly true when we compare annual changes in proportions of the two types of fish.

Table 1 Size of salmon returning to the River Bundorragha and to the River Shannon, west of Ireland, 1993 and 1994.

Type	Year of Release	Year of Return	Mean Length* (cm)
River Bundorragha			
Grilse	1993	1994	55.71 - 64.33
MSW	1992	1994	74.29 - 78.70
River Shannon			
Grilse	1993	1994	64.26 - 66.79
MSW	1992	1994	79.0 - 93.2
Grilse (females)	1992	1993	62.4
Grilse (males)	1992	1993	71.2

* Values given are the mean length of the smallest and largest groups of 9 groups of grilse and 4 groups of MSW in the Bundorragha and of 7 groups of grilse in the Shannon. For the River Shannon MSWs, the lower value is that of females and the higher value is that of males. The single value for the River Shannon 1992 grilse males and females are from broodstock recaptures at Parteen.

Data for the Bundorragha are from Cullen, McDermott and O'Maoileidigh (1995).

Table 2 Returns to the hatchery of grilse and MSW lines of salmon bred and ranched from Parteen hatchery on the River Shannon, Ireland 1992-95.

Year Class		Released		Recaptures to 1995				MSW % of Recaptures
				Grilse		MSW		
		Year	No	(No)	%	(No)	%	
From Grilse (Phenotype) Parents								
1991	M	1992	50528	(314)	0.62	(1)	0.002	0.3
	F	1992	54738	(365)	0.67	(22)	0.04	5.7
1992	M	1993	72063	(331)	0.46	(0)	0.0	0.0
	F	1993	78068	(359)	0.46	(10)	0.01	2.7
From Multi-Sea-Winter (Phenotype) Parents								
1991	M	1992	75230	(599)	0.80	(12)	0.02	2.0
	F	1992	78300	(495)	0.63	(158)	0.20	24.2
1992	M	1993	50206	(159)	0.32	(2)	0.04	1.2
	F	1993	52000	(139)	0.27	(24)	0.05	14.7

So much for the smoke: we can at least see that some things have changed even if we cannot be certain as to exactly what. Is the change real? Is it simply an illusion? Is the nature of the fish stocks changing, or can the perceived decline in spring fish be arrested and even reversed? Here we are into the realm of mirrors, and distorting ones at that.

That there is an underlying genetic component to age-at-maturity in salmon (age-at-maturity is what the grilse fish and spring fish distinction is all about) is without question. Reference can be made to the papers of Naevdal (1983), Gjerde (1984), Herbinger and Newkirk (1990) and Wild *et al.* (1994) for this. The data presented above in Table 2, repeated over two years and using fish reared together in the hatchery confirm a distinct difference in MSW production between grilse and MSW brood lines, the nature of the data indicating that any genetic component is likely to be multifactorial ie is not determined in a simple way by a single or a small number of genes (see Wilkins, 1995).

Phenotypic variability due to multifactorial inheritance has three elements:-

$$Vp = Vg + Ve + Vge$$

Vp is the total variance which is observed (eg the observed frequency of different weights or lengths); Vg is the total variance of the underlying genetic elements governing the character in the stock or sample (ie no two individuals have the same genetic make up and Vg is a measure of all the genetic differences within the group); Ve is a measure of the variation caused by differences in the environments in which the animals are grown. Vge is a much more complex term and it refers to the way in which the expression of a genotype can alter in different environments. For example, a certain array of genes may give one kind of phenotype in one environment and a completely different phenotype in another. Vge is called the genotypic-environmental interaction and it is with this that we have to invoke the use of mirrors.

In multifactorial inheritance, the genotypic variance, Vg, is normally distributed as illustrated in Figure 2. We cannot, of course, "see" this variance at the genetic level: what we see is the phenotypic variance, Vp, ie the range of animals themselves, and from what we see we infer the underlying genetic variance. Now we already know that the actual phenotypes we will see will depend on the kinds of environments that the genotypes are expressed in and the flexibility of the genotypes' responses to these. Since each individual in a group lives out its life in its own microenvironment (just as no two individuals are genetically identical, excepting identical twins, so also no two individuals have exactly the same life history characteristics) we must allow that the whole range of microenvironments, acting on the whole range of genotypes in a complex way will determine precisely which

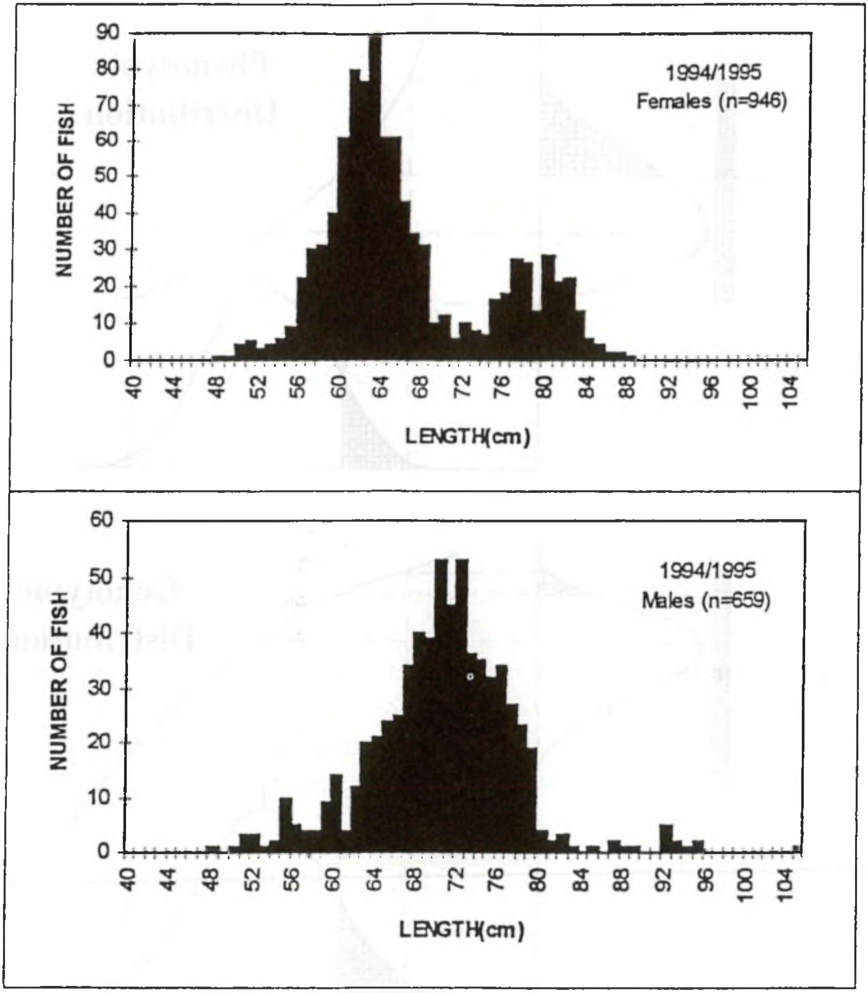

Figure 1 Length frequency distribution of salmon broodfish at Parteen Hatchery in 1994. Females up to 71 cm are grilse; females at 72 cm and over are MSW (n = 158). Males up to 84 cm are grilse; males at 85 cm and over are MSW (n = 12).

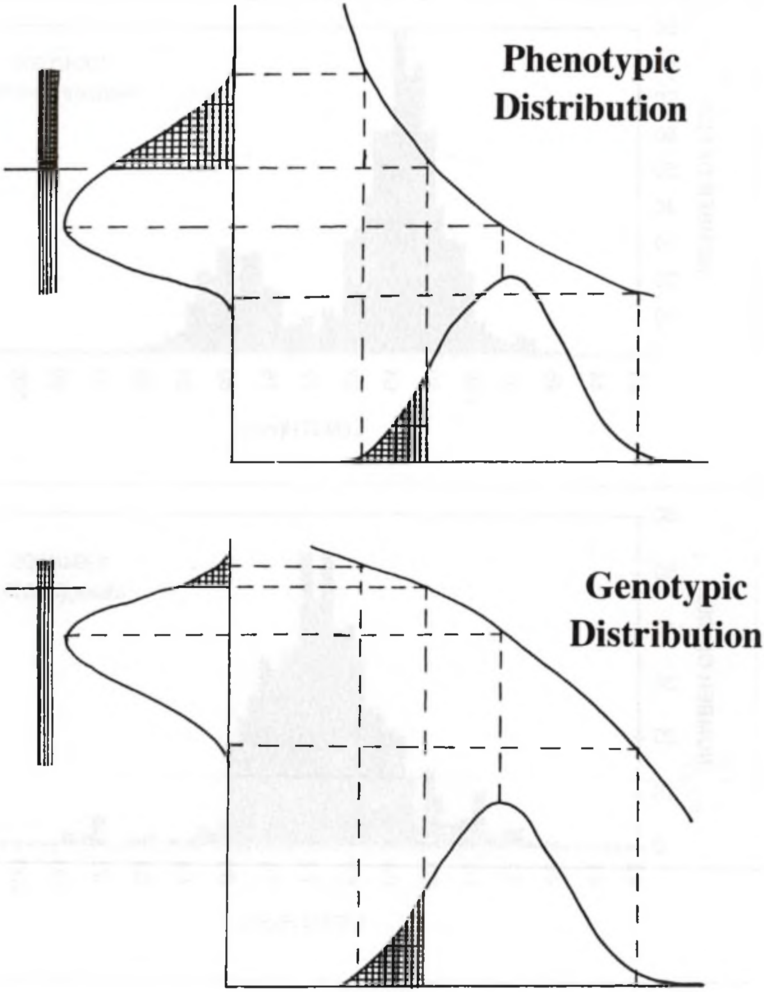

Figure 2 The relationship of genotype, norm of reaction and phenotype. The norm of reaction acts as a reflecting surface from which the invisible, underlying distribution of genotypes is reflected on the visible phenotypic axis.

The norms of reaction differs between the upper and lower graphs, but the genotypic distributions are identical. The distribution of the phenotypes is different between the graphs due entirely to the changed norm of reaction.

phenotypes will be expressed. We can call this combination of different environments and Vge the "norm of reaction". Norm of reaction acts like a distorting mirror in determining the range of phenotypes which any given range of genotypes will express.

This is illustrated in Figure 3(a). The range of genotypes is given as a normal distribution on the horizontal axis. We cannot "see" the genotypes, only the phenotypes. The norm of reaction is drawn as a diagonal reflecting surface. Each point on the genotype curve is reflected by the norm of reaction surface and appears on the vertical, phenotypic axis to give the observed distribution of phenotypes: what we see is the phenotypic distribution, which is a distorted reflection of the underlying, invisible genotypic distribution. Once this idea is clear then it is easy to see that, if the norm of reaction should change, as will inevitably happen when environment, climate, predatory pressure, fishing mortality etc changes, then the range of phenotypes which will be observed will change *even though the underlying genotypic distribution remains unchanged* (Fig. 3b). In Figure 3 one tail of the genotypic distribution is shaded to represent, say, MSW habit. In Figure 3a, the reflection of this tail on the phenotypic axis results in a relatively large proportion of the population appearing as MSW fish. In Figure 3b, although the genotypic MSW tail remains unaltered, the phenotypic distribution is distorted by the new norm of reaction to give a population with very much fewer MSWs. *The crucial point to note is that the observed proportion of MSWs can increase or decrease, even disappear and then reappear, without any change in the frequency of the MSW genotype. The genetic composition of the stock has not altered one iota*; the loss of MSWs will be arrested or reversed if and when the norm of reaction surface alters in the direction of its original state. Nothing is what it seems; change is largely a matter of mirrors! Observed changes in the proportion of MSWs may have nothing whatever to do with alterations in genotype although the underlying genotypic distribution, measured as "liability" to MSW habit is important and can be altered by selection. Let us now consider this aspect.

While many multifactorial traits show a continuous phenotypic distribution governed by an underlying continuous genotypic distribution, grilse and MSW phenotypes behave as a discontinuous distribution (a fish is one or the other type) governed by an underlying continuous genotypic distribution with a specific threshold of expression: genotypes above and below the threshold exhibit the different phenotypes and are said to be "more liable" (above the threshold) or "less liable" to express a certain phenotype. Referring now to Figure 3, a hypothetical example, all genotypes in the unshaded portion of the curve result in the grilse phenotype. Only those genotypes lying beyond a certain threshold (the shaded area in Fig. 3) have sufficient genes to express the MSW phenotype ie these genotypes represent a high liability to MSW habit. But we have already seen in Table 2, that there are much fewer male than female MSW fish at least in River Shannon broodstock and that females give a higher proportion of MSWs than males. How do we explain this?

The situation, in fact, is partly analagous to the occurrence of congenital pyloric stenosis in humans, a condition which is more common in males than in females. This is explained by a higher threshold of liability in females. As a consequence, fewer females exhibit the condition but those that do have a higher average genotypic liability, so that the frequency of the condition is higher among relatives of affected females than among the relatives of affected males. The differing thresholds for MSW habit in male and female salmon are illustrated in Figure 3(b). The genotypic distribution of liability to MSW condition is the same for both sexes, but the threshold for expression is higher in males than in females. As a result, very few males express the MSW phenotype. However, the average liability of MSW males is greater than that of females (the mean value of the area under the curve above the male threshold is greater than that above the female threshold); male MSW will therefore produce, on average, more MSW offspring than will female MSWs. Figure 3c illustrates the situation which may pertain when grilse and MSW stocks are compared. Once again a fixed threshold for expression is assumed, that of males being higher than that of females. A MSW stock has a greater overall liability to MSW habit than a grilse stock: this means its liability curve lies slightly to the right of the grilse curve and the result is obvious. Much fewer grilse lie above the expression thresholds, especially the male threshold. In a stock of mixed MSW and grilse types, a selective breeding programme for MSW habit, if successful, is equivalent to pushing the liability curve to the right, so that more and more individual genotypes come to lie above the threshold, thus increasing the expression. There are some lessons here for enhancing the MSW proportion of any stock:-

1. The optimum cross is the pure MSW male x MSW female cross; this will give the most MSW offspring, but will still give a great preponderance of grilse. If there is a shortage of males, each one can be used to cover a number of females.
2. The cross MSW male x grilse female is expected to give more MSW offspring than the reciprocal grilse male x MSW female. This is so, because the liability to MSW habit decreases in the order MSW male > MSW female > all grilse.

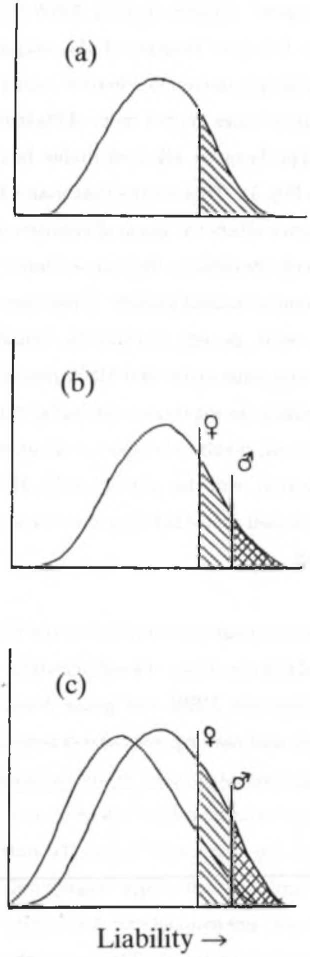

Figure 3 (a) Generalised depiction of a continuous distribution of genotypes (liabilities) with a threshold for expression.

(b) Continuous distribution of genotypes (liabilities) with differing thresholds for males (high threshold) and females (lower threshold).

© Two groups in which the mean distributions of liability differ but the thresholds for male and female expression of the trait remain fixed. The curve on the left could represent a grilse stock and that on the right, a MSW stock. Alternatively, the curve on the left could represent a stock before selection for the particular trait governed by the thresholds, and that on the right the same stock after a number of generations of selection.

3. Inbreeding may increase rapidly in pure MSW crosses, not only because of high selection intensity but also because of the exaggerated male effect. The male or "Carter" effect is the phenomenon whereby males express a threshold phenotype less frequently than females do, but more of their relatives (eg their offspring) also share the phenotype because affected males have a very high liability for the character (refer to Fig. 3). This means that many MSWs will be related.
4. Breeding in hatcheries alters the norm of reaction by altering the environment and the gene-environment interaction; this may enhance or inhibit the genetic gain from selection in a direction we cannot predict. If hatchery reared stock are being used for restocking in the wild, genetic variability should be maximised. This will be facilitated by crossing some grilse and MSW parental lines.
5. The higher the threshold for expression the higher the probability that small changes in norm of reaction will result in temporary disappearance of MSWs.
6. Response to selection will be slower with threshold characters than other continuously distributed traits because the exact liability of individuals cannot be accurately assessed.

In the stock restoration programme funded by the Electricity Supply Board (ESB) on the River Shannon in Ireland the above broad principles are incorporated into the mass breeding programme. Separate MSW and grilse lines are maintained by identifying broodstock before stripping and making pure line crosses from these. Pure bred fry which are excess to ranching requirements are used in the stocking programme. Adults returning as grilse from the MSW line (a large proportion still), and adults returning as MSWs from the grilse line (a few fish) are never mated into the pure lines. They are mated among themselves and with other grilse so that a large reservoir of fry - some pure MSW, some pure grilse, some inter-type crosses - are available for stocking out in the system. This maximises genotypic diversity in the stocked material. The pure lines are reared-on in the hatchery to smolt stage and then released to sea suitably tagged in order to ensure adequate broodstock for subsequent hatchery generations. The programme commenced in December 1990, the Po generation for both grilse and MSW lines being drawn from unpedigreed fish of the required phenotype. This was repeated in 1991 and 1992. From the 1993 broodstock year on, all hatchery returnees can be identified as to grilse or MSW pedigree by means of microtags. In 1993, therefore, the grilse broodstock was the microtagged F1 generation of the 1990 Po grilse. This year (1996) the returning grilse will be the microtagged F2 generation of the 1990 Po grilse (ie their "grandchildren"). The "children" of the 1990 MSW parents returned from the sea as F1 MSWs in 1994: the "grandchildren" will not migrate as smolts until 1996 and will not return to spawn as F2 MSWs until 1998. Salmon breeding, especially MSW breeding, needs time, considerable patience, financial commitment and some luck! Hopefully, the supposed seven years of bad luck associated with breaking mirrors will not affect the programme which has already achieved notoriety, if not guaranteed success, with the appearance of wild adult salmon high in the catchment for the first time in recent memory.

The studies reported here would not be possible without the continued support of the Electricity Supply Board of Ireland, through the unceasing interest of John Cantwell and Cyril O'Dowd. The staff of the Board's hatchery at Parteen, especially Paddy Barry, plays a crucial role in the breeding and restocking programmes. The tagging work and other aspects could not be carried out without the enthusiasm and hard work of William O'Connor and Tom McDermot and of many others working through the Board and the Fisheries Research Centre, Abbotstown, Co Dublin. We are grateful to them all.

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SPRING SALMON ENHANCEMENT ON THE DELPHI FISHERY, IRELAND

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Introduction

The Delphi Fishery is located in County Mayo on the western seaboard of Ireland (Fig. 1). It drains a mountainous catchment of some 52 km^2. The system includes a chain of three angling lakes, Glencullin Lough (54 ha), Doolough (304 ha) and Finlough (28 ha), discharging to the sea via the Bundorragha River (2.6 km) (Fig. 2).

Delphi has been well known to anglers since the early 19th century. Though best known for its sea trout, the fishery also produces salmon. Prior to 1986, when ownership of the fishery changed hands, Delphi produced average rod catches of less than 50 salmon and around 1,000 sea trout a year.

The angling season opens on 1 February and closes on 30 September. Most salmon angling is by fly only, though some early season spinning/trolling is permitted on Doolough. Traditionally, salmon angling has concentrated on the Bundorragha, Doolough and Finlough, in descending order of importance.

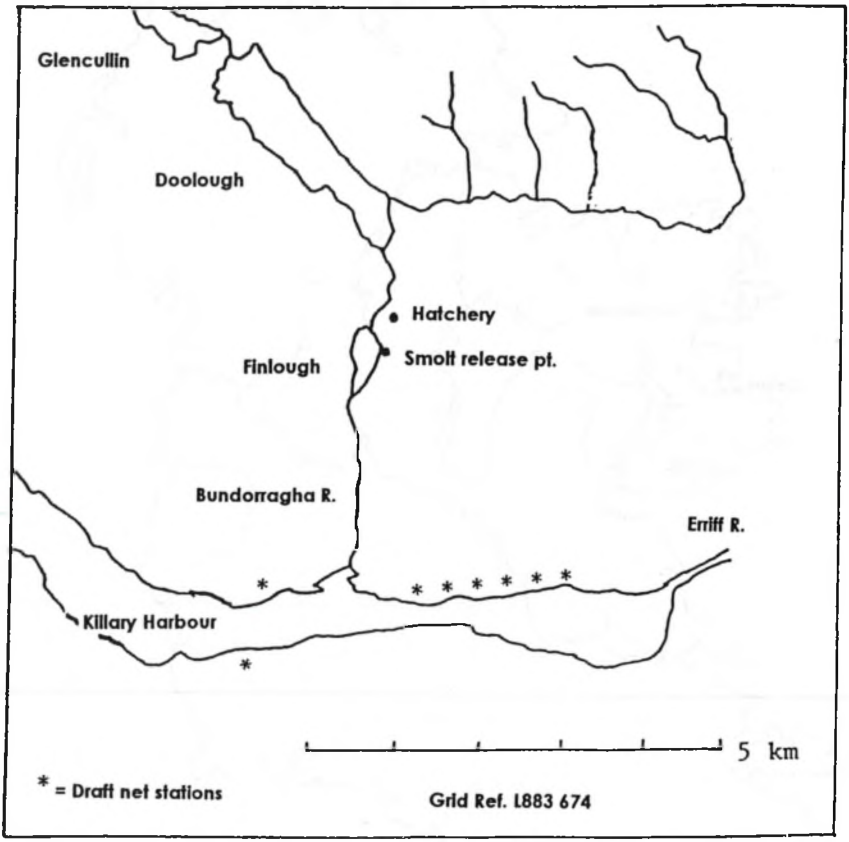
Multi-sea-winter (MSW) salmon may be caught from February on. Grilse (one-sea-winter fish) are taken from late May on. Such early runs of MSW salmon are rare in this part of Ireland (Went, 1970).

Delphi shares its estuary with the Erriff River, a 13 km spate river producing rod catches of up to 800 salmon a year. Though many of the Erriff's spawning streams rise in the same mountains as those of Delphi, catches of MSW salmon prior to late May on the Erriff are rare and the great majority of all salmon caught are grilse
(J Stafford, pers comm).

The estuary for both systems is Killary Harbour, a narrow fjord, 15 kms long, the topography, hydrology and geology of which have been described elsewhere (Keegan and Mercer, 1986). Salmon are exploited commercially in the estuary by up to 12 netting crews using draft nets (a form of shore-based haul net extended by canvas boat). Since the late

Fig. 1: Location of fisheries providing smolts for the Delphi programme

Fig. 2: The Delphi Fishery



1960s the netsmen have mostly concentrated on the grilse runs from late May, even though the legal draft netting season opens on 16 February (and closes in late July).

There is also an extensive drift net fishery along the coast outside Killary Harbour, as there is all round the Irish coastline. The drift net fishery generally opens on 1 April and closes in late July. In many locations, however, the drift net fishery rarely operates before late May.

Rod catches of wild salmon and sea trout from 1985 to 1995 are shown in Figure 3.

The serious drop in sea trout catches in 1987/88, culminating in the stock collapse of 1989/90 (Whelan *et al.*, 1993), prompted a major review of the rod fishery operation. After extensive consultations in the summer of 1990, notably with the Salmon Research Agency and the Department of Marine, Delphi's management decided to try to increase salmon runs, particularly in the summer months, to preserve fishing credibility.

Methods

It was decided to construct a 50,000-smolt hatchery with the aim of increasing average rod catches of salmon to around 200 per annum, the minimum considered necessary to attract substantial angling interest. The size of the hatchery was based on estimates at the time which suggested that on average 2% of smolts would return to Delphi, of which around 10% would be caught by anglers. Thus salmon catches should increase by 2 for every 1,000 smolts released so that, on average, a 50,000 smolt release would produce an extra 100 salmon to the rod.

The hatchery cost approximately IR£75,000 (US$112,000) to construct, with annual running costs, excluding depreciation, of approximately IR£40,000 (US$60,000). The hatchery employs one full-time person and up to five others when required.

Before the salmon enhancement programme was fully initiated, baseline studies of juvenile salmonid densities were conducted. Samples of genetic material were also taken from both wild and hatchery juvenile stocks by the Salmon Research Agency (Anon, 1994a).

The decision to rear and release smolts, rather than fry or parr, was motivated by a desire to protect wild juvenile populations and to circumvent the naturally limited nursery habitat of the Delphi system. It was also recognised that higher egg-to-smolt survival rates could be achieved than in the wild, and higher egg-to-adult return rates were probable for smolts as opposed to parr or fry.

Only one-year-old smolts (S1s) were used in the programme because of fears that S2s would be more prone to disease in the hatchery.

Increased smolt predation, particularly by cormorants, was anticipated and countermeasures put in place.

It was decided initially to import smolts from two other local salmon stocks - those of the Burrishoole and Corrib systems - for release alongside the progeny of Delphi's indigenous wild fish. These two stocks were chosen for their geographic proximity and their proven success as "ranching" stocks. There was a desire to verify that the Delphi stock could perform as well as the others.

Subsequently, it was decided also to import ova from these other stocks for ongrowing in the Delphi hatchery in order to see if this affected performance and straying rates.

A separate study was initiated to compare the performance of Burrishoole fish released at Burrishoole with the Delphi releases of Burrishoole smolts and ongrown ova. This has since been completed (Rogan, 1996).

The location of the hatchery and the smolt release point in Finlough were both chosen so as to maximise the scope for segregating wild and reared stocks and for ultimately removing reared adults, thereby preventing them from spawning or interbreeding with the wild fish. It was also hoped that, by homing to Finlough, the reared fish would particularly benefit angling in that lake and in the river, the areas considered most suitable for flyfishing.

The Burrishoole and Corrib smolts were brought to Delphi at least eight weeks before release so as to imprint them with the Delphi chemistry. Previous work had shown this to be a sufficient time period to achieve subsequent homing to the release location (McDermott, 1990). All release groups had their adipose fins clipped and were differentially tagged, using coded wire nose implants (a technique described by Bergman *et al.*, 1968).

Small numbers of Delphi parr and smolts, also clipped and tagged, had been released in 1989 and 1990, prior to the start of the main enhancement programme. In 1991, larger groups of Delphi, Corrib and Burrishoole smolts were released. In 1992, a fourth group, derived from Corrib eggs reared at Delphi, was also released. In 1993, no Corrib stocks were used and a group raised at Delphi from Burrishoole ova was released alongside a Delphi group. The numbers of fish released in each group are shown in Table 1.

Details of the broodstock which produced the imported smolts and ova are not fully known, although the Corrib-egg group was specifically requested to be the progeny of MSW salmon. It is believed that the great majority of all other imported groups derived from predominantly grilse parentage. Details of the Delphi broodstock used in each year are shown in Table 2.

Tags from returning adult salmon were subsequently recovered from offshore drift nets (Anon, 1991, 1992, 1993, 1994b), estuary draft nets, rod catches and post-season trapping within the Delphi system. For tag recoveries from within the Killary/Delphi system, the length, weight, sex and other characteristics of the fish were recorded and genetic material was taken to assist other studies.

Table 1 Reared stocks released on Delphi 1989-93.

Year	Stock	Number
1989	Delphi parr	4,241
1990	Delphi parr Delphi smolts	3,242 2,671
1991	Delphi smolts Corrib smolts Burrishoole smolts	4,659 10,863 9,741
1992	Delphi smolts Corrib smolts Corrib smolts (reared at Delphi) Burrishoole smolts	8,838 10,844 10,727 9,938
1993	Delphi smolts Burrishoole smolts (reared at Delphi)	33,600 13,718

Table 2 Broodstock for reared Delphi Groups.

Year	No of pairs	MSW*MSW	MSW*Grilse	Grilse*Grilse
1989-90	1		1	
1991	6	4	1	1
1992	11	-	-	-
1993	19	4	1	14

* Mixed parentage: breakdown unavailable, but predominately MSW.

Tag recovery rates for each group were engrossed by raising factors to establish the survival-to-catch rate (STC), which is the survival implied by the total exploitation (all methods - offshore, estuarine and in-system). The STC is expressed in terms of the number per 1,000 smolts released. The raising factors applied to estuary and drift net catches are

Fig. 3: Delphi sea trout and wild salmon rod catches 1985-95

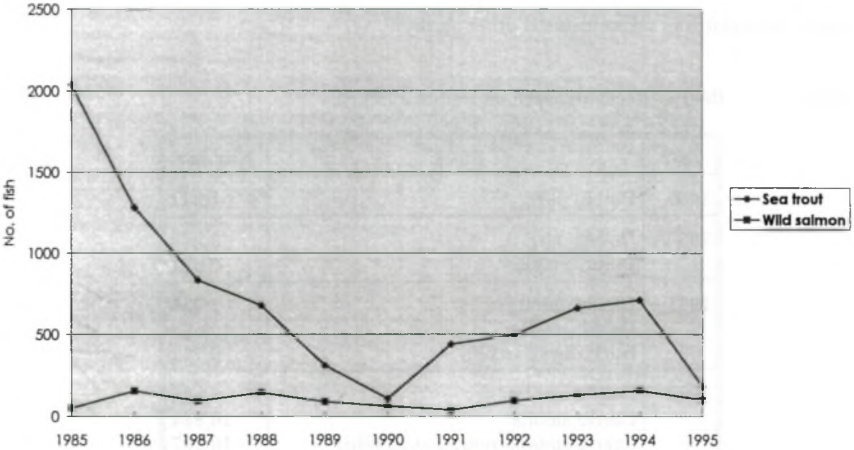
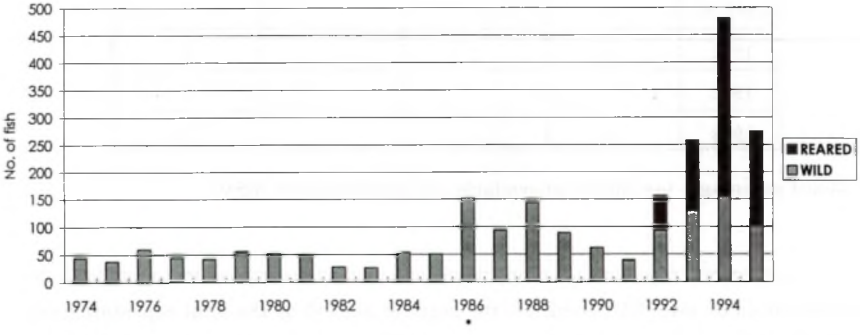


Fig. 4: Delphi wild and reared salmon catches 1974-95



* Change of ownership

Fig. 5: Delphi rod catches of MSW salmon and grilse 1986-95

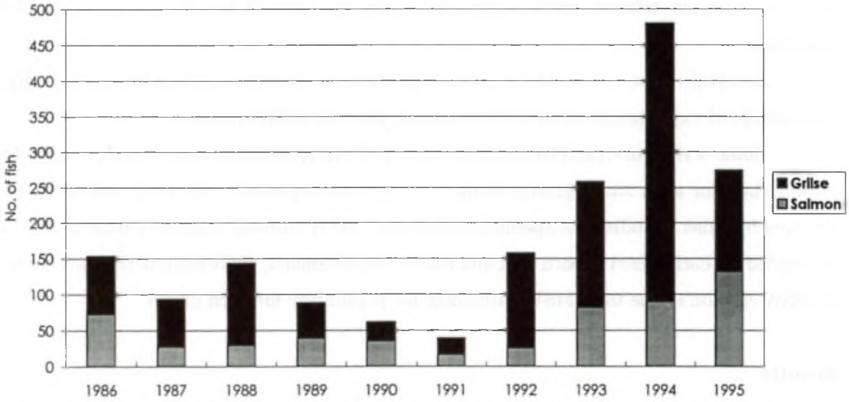
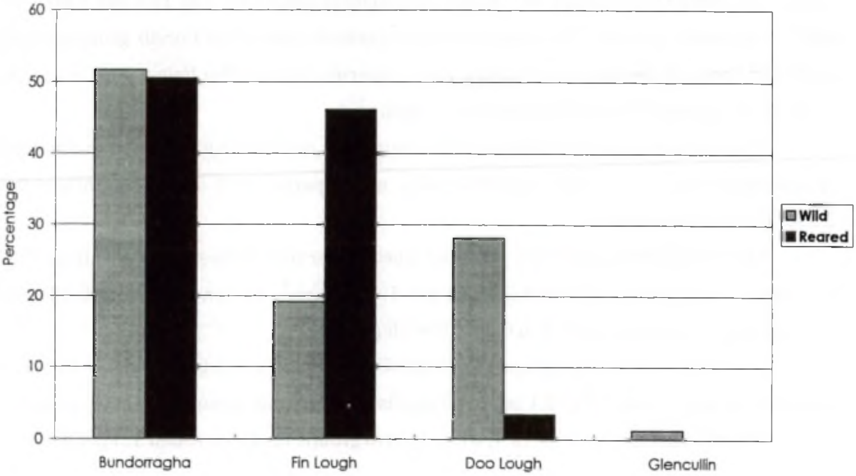


Fig. 6: Capture location of wild and reared salmon caught by Delphi anglers 1992-95



estimates of total netted populations based on sample inspections of local and national commercial catches. In addition, drift net catches were further raised to incorporate Department of Marine estimates of unreported net catches and other coastal mortality factors for adult salmon, collectively known as the "NCFM factor" or non-catch fish mortality.

Survival to the river and rates of escapement to spawn were then calculated using estimated rod exploitation rates (15% for grilse, 25% for MSW salmon).

Home-water-survival (HWS), being the rate of return to Irish coastal waters, was also established for each smolt group, using the same raising factors for drift and draft net catches but also including escapement estimates. MSW salmon-to-grilse ratios were also calculated for each cohort of both wild and reared Delphi smolts, expressed as the percentage of MSW salmon in the total MSW salmon/grilse population for each group.

Results

The smolt release programme at Delphi resulted in significantly increased rod catches of adult salmon (Fig. 4, Table 3). Catches of MSW salmon and grilse from 1986 to 1995, including reared fish, are shown in Figure 5.

Seven out of the ten smolt groups released between 1990 and 1993 produced rod catch rates in excess of the 2 per 1,000 target (Table 4). The lowest catch rate was 0.6 per 1,000 smolts (the 1992 Corrib smolt release) and the highest catch rate was 12.7 per 1,000 (the 1993 Burrishoole group). The relatively poor performance of all Corrib groups, which produced three of the four lowest catch rates experienced over the four years, led to the eventual dropping of Corrib fish from the programme.

The rod catch rate of the Burrishoole groups was consistently higher than the other groups, ranging from 4.7 to 12.7 per 1,000 smolts, as compared to 1.9-5.7 for Delphi and 0.6-2.2 for the Corrib groups.

The Delphi groups, however, produced much higher rod catches of MSW salmon than the other groups, ranging from 1.5 to 4.1 per 1,000 smolts, as compared with 0.3-0.9 for Burrishoole groups and just 0.1 to 0.7 for Corrib groups.

In contrast, the Delphi groups were relatively poor producers of grilse to the rod, with catch rates ranging from 0.2 to 3.4 per 1,000 smolts. Burrishoole groups, however, produced grilse rod catch rates as high as 12.4, while Corrib groups never exceeded 1.5 per 1,000.

The tendency of the Delphi groups to produce MSW salmon is reflected most strongly in the rod catches, with 49% of all reared Delphi fish taken by rods over the four years being MSW salmon.

Between 1992 and 1995, 50% of all reared fish taken by Delphi anglers were caught in the Bundorragha River, almost exactly matching the proportion of wild salmon taken in the river (Fig. 6). In contrast, 46% of reared fish were caught in Finlough, as opposed to only 19% of the wild fish. In 1994, 212 salmon were caught on Finlough, 177 or 83% of which were reared, as compared to a total catch for that lake in 1991 of only five wild fish. Management's hopes for boosting Finlough angling and for segregating reared from wild fish were therefore achieved to a notable extent.

Conversely, Doolough, which is upstream of both the hatchery and the smolt release point and closer to many of the primary spawning grounds, delivered only 4% of the reared fish rod catch but 29% of the wild salmon catch. Of these reared fish caught in Doolough, 67% were of Delphi origin - even though only 44% of all reared fish caught in the system as a whole were Delphi. Thus, the indigenous groups had a greater tendency to overshoot Finlough than the non-indigenous fish.

Table 3 Delphi rod catches, wild and reared salmon 1986-95.

Year	Wild	S	G	Reared	S	G	Total	Smolts released*
1986	153	72	81	0	0	0	153	0
1987	93	27	66	0	0	0	93	0
1988	143	29	114	0	0	0	143	0
1989	88	39	49	0	0	9	88	0
1990	61	35	26	0	0	0	61	2,671
1991	38	16	22	1	0	1	39	25,263
1992	92	20	72	64	4	60	156	40,437
1993	128	45	83	130	36	94	258	47,317
1994	154	54	100	326	35	291	480	50,600#
1995	100	50	50	174	81	93	274	46,400#

S = Multi-sea-winter salmon, G = Grilse, # = not part of study

* Smolt releases in year n contribute to grilse catches in year n+1 and MSW catches in year n+2

Table 4 Survival-to-catch and exploitation rates (per 1,000 smolts).

Rel date	Stock origin	Survival to catch			Rod catch		Draft nets		Drift nets		River nets		Strays	
		Tot	S	G	S	G	S	G	S	G	S	G	S	G
10/89	D#	2.1	0.2	1.9	0.0	0.2	0.0	0.0	0.0	1.7	0.2	0.0	0.0	0.0
5/90	D#	3.4	0.9	2.5	0.9	0.0	0.0	0.0	0.0	2.2	0.0	0.3	0.0	0.0
4/90	D	6.4	2.6	3.8	1.5	0.4	0.0	0.0	1.1	3.4	0.0	0.0	0.0	0.0
4/91	D	13.3	6.6	6.7	4.1	0.2	0.0	2.4	0.0	3.9	2.5	0.2	0.0	0.0
	C	79.1	2.0	77.1	0.7	1.5	0.0	30.3	0.0	41.5	1.3	2.9	0.0	0.9
	B	140.3	2.5	137.8	0.9	3.8	0.4	47.3	0.3	77.4	0.9	4.0	0.0	5.3
4/92	D	27.4	6.6	20.8	2.7	1.5	2.0	3.4	0.3	10.4	1.6	5.5	0.0	0.0
	C	37.2	2.5	34.7	0.1	0.5	0.6	5.2	0.6	22.4	1.2	6.6	0.0	0.0
	CE	19.9	3.6	16.3	0.4	0.3	1.4	1.9	1.0	12.5	0.6	1.6	0.2	0.0
	B	96.7	1.7	95.0	0.3	7.1	0.4	9.0	0.6	61.7	0.4	16.7	0.0	0.5
4/93	D	74.8	8.4	66.4	2.3	3.4	3.4	6.9	1.1	49.7	1.5	6.4	0.1	0.0
	BE	147.4	1.9	145.5	0.3	12.4	0.6	22.7	0.9	83.9	0.1	24.7	0.0	1.8

D = Delphi, C = Corrib, B = Burrishoole, E = Eggs reared at Delphi,
S = Multi-sea-winter salmon, G = Grilse, # = Parr (all other releases were smolts)
NB The figures for draft and drift net catches incorporate raising factors (see "Methods").

Homing into the Delphi system was high for all groups, with lower straying rates in Delphi groups than in the non-indigenous stocks (Table 4). The highest straying rate was 5.3 per 1,000 smolts, derived from the 1991 release of Burrishoole smolts which returned as grilse in the dry summer of 1992 and some of which entered the larger Erriff River nearby. Rates of straying by MSW salmon were negligible.

The relative overall performance of the different groups, expressed in terms of survival-to-catch rates (STC), broadly mirrored the rod catch rates. The Delphi groups, however, recorded progressively higher STC rates over the four years (rising from 6.4 to 74.8 per 1,000 smolts released), while the STC rates of the Delphi MSW salmon component rose from 2.6 to 8.4 per 1,000.

The lowest STC rates of all groups were those recorded by the Delphi parr releases in 1989 and 1990 of 2.1 and 3.4 respectively, in contrast to the Burrishoole smolt groups which achieved STC rates of up to 147.4 per 1,000 and never lower than 96.7.

Similarly, home-water-survival (HWS) of Burrishoole groups as grilse was consistently higher than the other stocks and consistently over 100 per 1,000 smolts released (Table 5). The HWS rate of Delphi groups as grilse was invariably lower than that of other groups, with the exception of the 1992 Corrib-egg group (which derived from MSW salmon parentage). However, the HWS of the Delphi groups as MSW salmon was consistently 4 to 6 times higher than the Burrishoole MSW salmon groups.

Survival to the river mouth (RS) of Delphi MSW salmon was higher than for Delphi grilse from the same cohort for all release years except 1993 (Table 5). Delphi's MSW salmon were predominantly early-running, whereas the few Corrib and Burrishoole MSW salmon were predominantly late-running (Fig. 7). Since early-running fish may avoid much of the commercial netting effort, the Delphi stocks have a natural advantage.

Exploitation of Delphi MSW salmon by drift nets was comparatively low, ranging from zero to 16% of those returning to the Irish coast. This is four to 10 times lower than for all other groups of MSW salmon except one Corrib group. However, draft net exploitation of Delphi MSW salmon is increasing, from zero in the 1992 and 1993 netting seasons to 15% of home water survivors in 1994 and 25% in 1995 (Table 5, Fig. 8). Some draft net crews are now operating in March and April for the first time in many years (Nixon, pers comm).

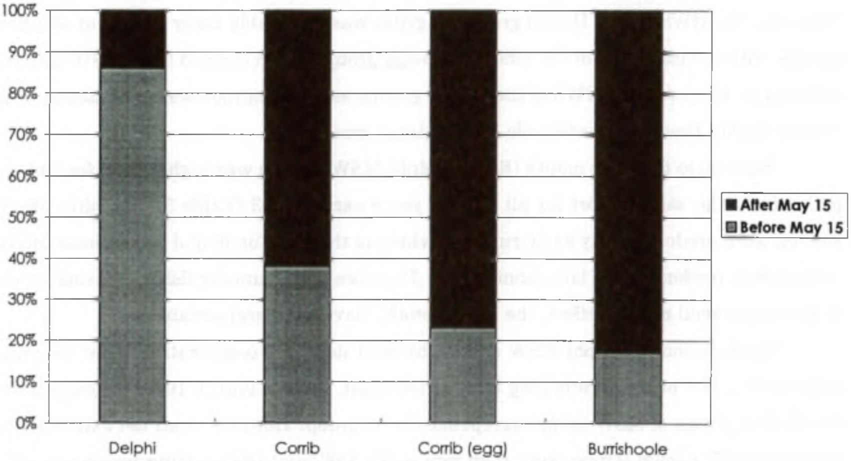
The increase in draft net catches was particularly significant in summers with low rainfall such as 1992 (Anon, 1995) when exploitation of grilse by draft nets exceeded 31% of all home water survivors respectively.

Exploitation by nets (all types) of grilse groups was always higher than for MSW salmon groups. Net exploitation rates fluctuated from year to year but were never less than 50% of home water surviving grilse and reached a maximum of 87% of Corrib grilse in both the 1992 and 1993 netting seasons.

Almost 98% of the Burrishoole fish caught by all methods during the programme period were grilse, compared to 91% of Corrib and only 83% of Delphi fish (Table 6). In all, 4,103 tags were recovered from the 123,082 tagged smolts and parr released between 1989 and 1993, a recovery rate of 3.33%.

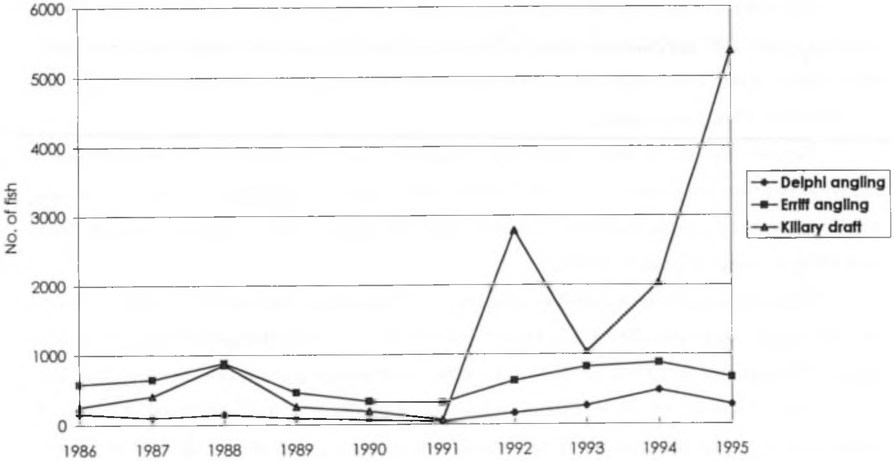
The grilse caught in the drift net fishery were larger than the survivors to the estuary for all groups except one (Table 7). There appears to be a relationship between smolt size and resulting grilse size (Table 8). However, of the four smolts groups released in 1992, the smallest smolts in terms of length and weight (the Corrib-egg group) produced the largest grilse (and then the smallest MSW salmon) (Table 9). It was discovered that all of these

Fig. 7: Percentage of MSW salmon caught* before and after May 15



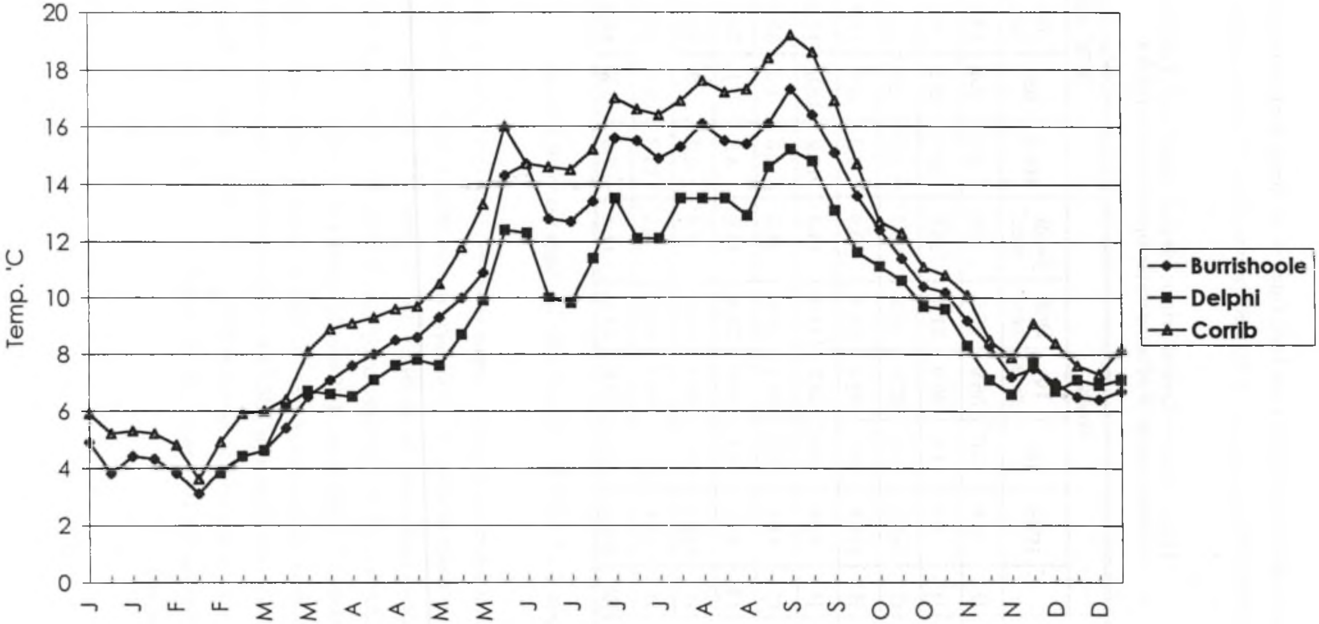
* catches = drift and draft nets + fresh rod-caught fish, from 1992-95

Fig. 8: Delphi and Erriff* rod catches and Killary draft net* catches 1986-95



* Source: S. Nixon, Western Regional Fisheries Board

Fig. 9: Temperature profiles for hatchery stations 1991



grilse were male fish, which have been found to be larger than females of the same age (Went, 1943), while all but one of the MSW salmon from the same group were female.

Table 5 Home water survival, river survival (both per 1,000 smolts) and net exploitation (as % of home water survival) of reared fish.

Group		Grilse					MSW Salmon				
		HWS	RS	Tot nets	Drift nets	Draft nets	HWS	RS	Tot nets	Drift nets	Draft nets
1990	D	6.0	2.6	56.0	56.0	0.0	7.1	6.0	15.8	15.8	0.0
1991	D	7.5	1.5	80.0	51.4	28.6	16.3	16.3	0.0	0.0	0.0
	C	82.6	10.7	87.0	50.3	36.7	2.9	2.9	0.0	0.0	0.0
	B	154.8	30.6	80.2	49.8	30.4	4.3	3.7	14.3	4.8	9.5
1992	D	23.6	9.8	58.3	44.0	14.3	13.2	10.8	17.9	2.6	15.3
	C	44.8	17.2	61.7	50.2	11.5	2.6	1.3	50.0	25.0	25.0
	CE	16.6	2.1	87.0	75.8	11.2	4.5	2.1	54.2	23.0	31.2
	B	119.3	48.1	59.7	52.1	7.6	2.2	1.2	45.4	27.3	18.2
1993	D	78.8	22.7	71.1	62.6	8.5	13.6	9.4	30.8	5.9	24.9
	BE	191.6	84.7	55.8	44.4	11.8	2.6	1.5	44.4	22.2	22.2

D = Delphi, C = Corrib, B = Burrishoole, E = Eggs reared at Delphi

The sex ratios of adult salmon recovered from draft nets and within the Delphi system are shown in Table 10. Delphi grilse were predominantly male (75%), while Delphi MSW salmon were mostly female (80%). The sex ratios of Corrib groups varied. Burrishoole MSW salmon were also predominantly female (91%), while the more prolific Burrishoole grilse exhibited a more even 51/49 overall male/female ratio.

Based on ratios derived from rod catches, Delphi reared fish produced proportionately more MSW salmon than their wild counterparts (Table 11). This MSW salmon ratio appears to be stable in the wild at between 25% and 48% of rod catches. The high (95%) MSW salmon ratio of the 1991 reared Delphi group included the only two three-sea-winter fish caught on rod.

Table 6 Tag recoveries 1989-95.

Rel date	Stock origin	No released	Tags recovered			Rod catch		Draft nets		Drift nets		High seas		River nets		Strays	
			Total	S	G	S	G	S	G	S	G	Gr	Fa	S	G	S	G
10/89	D#	4,241	6	1	5	0	1	0	0	0	4	0	0	1	0	0	0
5/90	D#	3,242	7	3	4	3	0	0	0	0	3	0	0	0	1	0	0
4/90	D	2,671	11	5	6	4	1	0	0	1	5	0	0	0	0	0	0
4/91	D	4,659	44	32	12	19	1	0	2	0	8	1	0	12	1	0	0
	C	10,863	318	22	296	8	16	0	66	0	180	0	0	14	32	0	2
	B	9,741	485	24	461	9	37	2	92	1	282	2	1	9	39	0	11
4/92	D	8,838	162	45	117	24	13	5	15	1	40	-	0	14	49	0	0
	C	10,844	227	19	208	1	6	2	28	3	100	-	2	13	72	0	0
	CE	10,727	113	20	93	5	3	4	10	4	63	-	0	6	17	1	0
	B	9,938	532	10	522*	3	71	1	45	2	237	-	0	4	167	0	1
4/93	D	33,600	1,166	156	1,010	78	114	15	61	12	622	-	0	50	212	1	1
	BE	13,718	1,032	11	1,021	4	170	1	84	4	423	-	0	2	339	0	5

D = Delphi, C = Corrib smolts, B = Burrishoole smolts, E = Eggs reared at Delphi, S = Multi-sea-winter salmon, G = Grilse (one sea-winter salmon), Gr = Greenland, Fa = Faroes

* Includes one tag recovery from Scotland, # Parr (all other releases were smolts)

Table 7 Grilse sizes - drift nets v rod/draft nets.

Group		Drift				Rod/draft			
		n	cm	n	kg	n	cm	n	kg
1990	D	3	64.7	3	3.20	-	-	-	-
1991	D	5	63.4	5	2.82	2	61.7	3	2.17
	C	103	63.1	100	2.88	80	60.1	80	2.26
	B	145	60.7	142	2.61	124	58.0	124	2.06
1992	D	25	62.0	24	2.90	28	60.2	28	2.38
	C	61	62.5	62	2.90	33	61.4	33	2.56
	CE	45	62.4	43	2.86	13	65.4	13	3.20
	B	138	60.5	136	2.60	115	60.0	115	2.35
1993	D	292	60.9	335	2.66	172	55.9	172	1.85
	BE	174	58.2	213	2.35	252	54.5	252	1.76

Table 8 Detailed comparison of sizes of 1993 smolt batches with returning adults.

Batch and no	Smolt		Grilse				MSW salmon			
	cm	g	n	cm	n	kg	n	cm	n	kg
1993 D										
10,562	14.3	32.9	219	58.5	173	2.29	42	74.8	28	4.08
10,374	14.3	33.3	226	58.9	163	2.33	38	74.0	21	4.01
10,605	15.0	38.4	182	60.5	142	2.56	34	74.9	18	4.16
2,059	15.7	44.0	30	61.7	30	2.74	10	75.1	9	4.55
1993 B										
3,378	13.9	29.2	189	55.8	119	1.96	-	-	-	-
10,245	14.6	36.3	541	56.5	342	2.05	4	71.5	2	3.30

The sizes of reared Delphi grilse in the rod catch resembled that of wild grilse caught (Table 12). The length of wild smolts migrating from Delphi in 1960/61 had previously been estimated at 13.2 cms and a high proportion of smolts in those years was found to have migrated after two or even three years in freshwater. None migrated after just one year (Went, 1964). If this is still true of the wild smolts today, then the hatchery-reared smolts differ from their wild counterparts in both age and size.

Eggs stripped from Delphi MSW salmon were 40% larger than those taken from Delphi grilse in 1993 and 31% larger in 1994.

It is not known how effective the post-season netting of reared fish was at Delphi and thus how many non-indigenous fish survived to spawn. However, population estimates extrapolated from rod catches would indicate that these formed a clear minority of the overall spawning population, consistently less than a third and often much lower. Furthermore, those that did spawn may have done so in discrete areas not used by wild fish. Visual observations revealed extensive spawning activity in the vicinity of the hatchery outflow, an area not normally used by wild stocks. Over the programme period, less than 2% of all fish netted during November/December in Finlough and close to the hatchery were wild. Most of the main wild spawning areas are well upstream of the hatchery, off Doolough and Glencullin Lough.

The programme has revived angling income at Delphi, which had dropped significantly in the wake of the 1989/90 sea trout collapse, and it has contributed to increased accommodation sales at Delphi Lodge (Table 13) and to the maintenance of the fishery's capital value.

Discussion

The salmon enhancement programme at Delphi was primarily driven by commercial angling considerations. However, it has had the incidental benefit of providing a large volume of information on:

- The performance of different stocks reared and released under similar conditions
- The potential for enhancing spring salmon
- The impact of commercial netting on Irish rod fisheries

Table 9 Sizes of all reared smolts and recovered adults.

Stock		Smolt		Grilse				Salmon			
		cm	g	n	cm	n	kg	n	cm	n	kg
90	D	14.2	33.1	3	64.7	3	3.23	3	75.7	3	4.53
91	D	14.4	34.0	9	63.6	9	2.62	29	77.2	17	4.38
	C	16.0	43.0	217	62.0	184	2.61	22	76.9	8	4.68
	B	16.1	46.8	310	59.2	277	2.34	20	74.4	10	4.54
92	D	15.3	42.3	116	61.1	53	2.61	42	77.2	30	4.59
	C	16.6	52.9	207	61.8	96	2.75	16	78.7	4	5.13
	CE	14.7	38.4	91	63.2	58	2.95	15	74.3	11	4.28
	B	15.2	41.0	517	60.3	251	2.44	8	75.5	4	4.78
93	D	14.6	35.4	657	59.3	508	2.40	124	74.6	75	4.14
	B	14.4	34.6	729	56.3	461	2.03	5	70.8	3	3.34

Table 10 Sex ratios for adult salmon sampled 1991-95.

Group		Grilse			MSW Salmon		
		M	F	M%	M	F	M%
1990	D	2	2	50	na	na	na
1991	D	2	2	50	9	21*	30
	C	63	49	56	4	17	19
	B	82	77	52	2	16	11
1992	D	56	20	74	12	31	28
	C	84	21	80	3	12	20
	CE	29	0	100	1	15	6
	B	131	138	49	1	7	12
1993	D	297	88	77	22	122	15
	B	304	283	52	0	6	0

na = not available
* = includes two 3-sea-winter fish
NB Samples taken from rod catches, draft net catches and in-system netting.

Table 11 Ratio of MSW salmon to grilse, wild and reared, caught on rod 1985-93 (Delphi only).

Smolt cohort	Wild		MSW	Reared		MSW
	G	S	%	G	S	%
1985	81	27	25			
1986	66	29	30			
1987	114	39	25			
1988	49	35	42			
1989	26	16	38			
1990	22	20	48	1	4	80
1991	72	45	38	1	19	95
1992	83	54	39	13	24	65
1993	100	50	33	114	78	41

G = Grilse, S = Multi-sea-winter salmon (MSW)

Table 12 Size of rod-caught reared Delphi fish* v wild fish.

Year	Grilse				2-sea-winter				3-sea-winter			
	n	cm	n	kg	n	cm	n	kg	n	cm	n	kg
1990												
Reared	0	0	0	0	4	73.7	4	4.26				
Wild	19	57.9	22	1.95	17	72.8	20	4.09				
1991												
Reared	0	0	1	1.70	17	75.9	17	4.38	2	86.7	2	6.40
Wild	65	56.0	72	1.74	41	71.6	45	3.87				
1992												
Reared	13	58.5	13	2.04	24	76.2	24	4.50				
Wild	79	58.0	83	2.06	51	73.8	54	3.86				
1993												
Reared	113	55.4	114	1.77	76	73.9	76	4.15				
Wild	92	55.5	100	1.83	46	73.2	50	4.07				

* = Delphi groups only ie Burrishoole/Corrib groups excluded.

Table 13 Delphi fishing and accommodation income 1985-94.

	Fishing IR£	Accommodation IR£	Fishermen as % of guests
1985	5,500	Nil*	-
1986	13,755	Nil*	-
1987	25,671	Nil*	-
1988	26,515	20,751	93
1989	23,379	56,517	88
1990	13,475	71,395	53
1991	8,218	100,676	28
1992	12,145	100,090	31
1993	19,891	135,250	50
1994	29,065	180,246#	57

* Lodge derelict until July 1988.
\# Lodge capacity expanded by 60% in May 1994.

Arguably the most important result of the Delphi programme in the context of this conference is the consistently superior performance, expressed either in terms of rod catches or total catches, of the Delphi groups as MSW salmon, in contrast with the relatively poor MSW salmon returns from other groups. Further, the tendency of the Delphi MSW fish to run in the spring, prior to mid-May, contrasts strongly with the later average run times of other MSW groups.

Prospects for enhancing spring salmon angling would therefore appear to depend not merely on the production of MSW salmon, but particularly of early-running MSW salmon.

The Delphi programme shows that it is possible to significantly enhance spring salmon runs through large scale releases of S1 smolts. This was, however, an accidental result of the programme and it is not entirely clear how it came about. There are nonetheless a number of indications in the data as to what makes a spring salmon and these have been assembled to form a hypothesis as a basis for further analysis and research.

What makes a spring salmon?

The spring salmon component present in the wild Delphi population appears fairly stable, based on rod catches. Other work has shown rod catches to be a reasonably reliable indicator of populations entering a river (Gudjonsson *et al.*, 1995). The reared Delphi fish have also consistently produced high proportions of MSW salmon in the rod catches, in fact higher than those of the wild fish. This is perhaps due, as discussed below, to broodstock selection - the highest MSW salmon ratio derived from broodstock with a high MSW content, while the lowest ratio resulted from the use of predominantly grilse broodstock.

In contrast, the Burrishoole ova group, reared under similar conditions and released simultaneously at Delphi, produced few MSW salmon and even fewer early-running or spring salmon. Burrishoole fish released at Burrishoole have tended not to result in many MSW salmon (Piggins, 1973). It might therefore be deduced that these reared groups of both Delphi and Burrishoole smolts are broadly mimicking their wild counterparts.

Prior to the advent of intensive drift netting, it was estimated that the size of male salmon was greater than females for all sea age groups and that this size differential increased with age. Further, the proportion of females increased with sea age (Went, 1940).

MSW salmon returns from all three stocks released at Delphi reveal a predominance of females. Other studies have shown that male salmon tend to be larger and to mature earlier than their female cohorts. The females, it has been suggested, require greater energy accumulation before they can mature (Crandall and Gall, 1993b).

The Delphi programme has shown male MSW salmon to be relatively rare, though present in the highest proportion in the Delphi groups, based on recoveries from the estuary and fishery. In all of the groups of Delphi fish and some of the Corrib groups, the high female ratios in the MSW salmon component were matched conversely by high male ratios in the grilse component of the same groups. This implies that more males than females are maturing in their first year at sea, unless the drift net fishery is selecting females from the population prior to the sex ratio sampling. Given the larger size of males and the fact that the larger mesh size of drift nets selects larger fish (Twomey, 1980), it is unlikely that the drift nets are selecting females.

The Delphi results indicate that survival-to-catch rates of MSW salmon vary from year to year. But they also show consistent differences between the performance of the three stocks as MSW salmon in the same year groups, despite similar release sizes. In particular, the surviving female component was not constant between the three stocks. This strongly implies that sex and the slower maturation of females, while relevant, is far from being the sole factor in the production of MSW salmon.

A study comparing spring and summer salmon (early- and late-running MSW salmon respectively) of both sexes found that summer salmon were, on average, considerably smaller than spring salmon of the same smolt class at the end of both the first and second sea winters. Also, incremental growth was greater for the spring fish than the summer fish (Went, 1940). Spring fish have also been found to be in better condition than summer fish (Went, 1940, 1943; Hewetson, 1961).

This suggests that the rates of growth of the different types of salmon - grilse, spring salmon and summer salmon - are not constant, even though larger smolts were found to maintain their relative advantage over smaller smolts as they grew at sea (Table 8).

It could therefore be concluded that arrival at the maturity threshold which will produce a spring salmon is a function of growth rate, sex and condition achieved. These factors are in turn under genetic control, interacting with the environment through the relative survival or fitness of different salmon populations.

It is suggested that stocks which survive poor environmental conditions, arising for example from low freshwater temperatures, produce progeny with an intrinsically reduced metabolic rate. This appears to result in slower maturation and, in the worst cases, the fish may become summer salmon, while less extreme but still adverse conditions may result in progeny that mature a little earlier as spring salmon. More benign environmental conditions may lead to still earlier maturation, resulting in grilse.

Spring salmon, then, are unusual, not least because their maturation compels them to migrate home and stop feeding for up to a full year before they spawn. In energy terms, the higher condition factor of spring salmon allows them to do this. Other factors such as river length and river access may also be critical in determining fitness or reproductive ability.

The most critical factor in the production of springers therefore appears to be stock origin and past enviro-genetic interactions.

Genetics and temperatures

Although genetic variation is generally assumed to be neutral, there is evidence to suggest that natural selection can occur in freshwater salmon populations, revealed in genetic variation at the ME-2 locus (Verspoor and Jordan, 1989). Examination of ME-2 genotype frequency distributions in Atlantic salmon from 95 river systems in North America and Europe revealed a correlation with latitude on both sides of the Atlantic and a high correlation with freshwater summer temperatures (ibid).

The enzyme encoded by the ME-2 functions metabolically to assist conversion of substances which are important to the generation of energy. It has been suggested that these enzymes have a prominent role to play in metabolism (Skorkowski, 1988). Differences in the timing of maturity may reflect kinetic differences in the ME-2 allozyme.

Investigations into the adaptive significance of ME-2 variation in the Delphi system have revealed significant differences between grilse and MSW salmon (Anon, 1994a).

Two possible explanations for this have been put forward. First, that there is only one breeding population and that fish with the potential to become spring salmon diverge at sea from the grilse component. On return to spawn, the two groups, though significantly different in terms of ME-2 following selective survival pressures in the marine, interbreed and the original ME-2 frequency is re-established.

The second possibility is that there are two or more breeding populations, each with its own distinct ME-2 profile and one with a greater potential to produce grilse. ME-2 analysis of juveniles sampled from Doolough's main spawning tributary in 1991 supports the suggestion of two different breeding stocks. The ME-2 profiles of some juvenile samples were almost identical to those of MSW salmon returning two years later (Anon, 1994a).

Evidence for the first explanation comes from Iceland, where it has been found that climatic changes in the marine environment may be responsible for long term changes in the sea age composition of salmon stocks (Gudjonsson *et al.*, 1995)

At Delphi the three stocks released performed very differently in relation to MSW salmon production, despite being reared and released in similar conditions. Since all three stocks appeared in the high seas fisheries, they might be presumed to have experienced broadly the same marine conditions. This would therefore lend weight to the second explanation - that it is the freshwater rather than the marine environment which results in variations in MSW salmon production between populations.

Other studies support the suggestion that the sea age of salmon is determined in freshwater (Chadwick *et al.*, 1987). Elsewhere it has been suggested that age and size at maturity are influenced strongly by environmental factors and that growth rates in freshwater, and thus smolt age, depends inter alia on the productive capacity of the river and its temperature regime (Thorpe and Mitchell, 1981).

A study of freshwater temperatures at Delphi, Burrishoole and Corrib did reveal significant differences between the locations from April to September, with the Delphi temperatures being consistently the lowest (Fig. 9).

Production of higher numbers of spring salmon at Delphi than in the other systems may therefore revolve around the lower temperature regime experienced at the individual or stock level. The slow rate of growth experienced in nursery tributaries or within microhabitats of a system, where fitness is assured by adoption of slower growth rates to match poorer conditions, may be hereditable.

Through the greater egg size of the Delphi MSW salmon, leading to larger alevins, the progeny may be conferred with a greater fitness advantage than those from grilse ova, leading ultimately to an increased ability to survive the poorest environmental conditions - at the expense of delayed maturation.

Exploitation rates

Even though the Delphi programme has greatly increased rod catches, only a very small proportion of survivors to the Irish coast managed to regain the river. Any enhancement programme in Ireland must contend with the extensive drift net fishery and, in some locations such as Delphi, with an estuarine net fishery. Smaller grilse and early-running MSW salmon may avoid heavy drift net exploitation but are vulnerable to extended estuarine netting, which may be rejuvenated by an enhancement programme.

Exploitation rates will depend on the size and therefore the sex of the fish. The high exploitation by drift nets of the 1992 Corrib-egg group can be explained by the sex ratio. All grilse from this group taken in the river were male. It has previously been found that males of all ages in the Shannon and Corrib stocks were larger at maturity than females (Went, 1940, 1943). Based on rod catches, these Corrib-egg grilse were indeed comparatively large and may therefore have been subject to heavy exploitation by drift nets. It is not clear, however, what happened to all the females, few of which appear to have survived at sea.

Financial and other impacts

The (unexpected) boosting of spring runs of salmon at Delphi, albeit to a modest extent, has added significant commercial value through extending and improving the viable angling season. While anglers' expectations from spring salmon fishing by fly are lower than for grilse, they must believe they have a reasonable catch prospect, something that the Delphi programme has enhanced. (The extent to which these early runs of MSW salmon have also benefitted from the removal of high seas nets by the North Atlantic Salmon Fund is a matter for speculation, but a significant impact is suspected on 1994 and 1995 rod catches at Delphi.)

The desired boost to summer angling prospects has not, however, materialised beyond mid-July. The hitherto highly sought-after sea trout angling month of August remains relatively moribund at Delphi. June and early July, in contrast, are now highly sought-after months due to the enhanced runs of grilse, most notably deriving from the Burrishoole groups.

With Scottish fishery values frequently exceeding £6,000 per average salmon caught, a sustained increase of 100 salmon a year could be worth over £600,000 in capital terms. In that context, Delphi's capital expenditure of £75,000 on the hatchery and annual costs of £40,000 could perhaps be justified. Irish fishery values, however, are generally much lower (and less objectively calculated) than those of Scotland and it is therefore more difficult to justify the Delphi programme in capital value terms alone. However, the average catch increase deriving from the Delphi hatchery in 1993 to 1995 was 210 salmon per annum and the impact of this on angling and associated accommodation revenue broadly justifies the programme in financial terms.

Conclusion

Enhancement of spring salmon in Ireland through large scale smolt releases is possible, but not easy. It is also expensive. The main biological barrier to such enhancement is the identification of broodstock which have the necessary genetic ingredients to produce early-running, multi-sea-winter salmon. This in turn means finding a stock with just such a natural proclivity, rather than one which produces late-running MSW salmon.

Having identified a suitable stock, best results are likely to derive from crossing only MSW salmon. This is hindered by the relative rarity of male MSW salmon.

Once smolts from a suitable stock and parentage have been reared and released, they face an arduous sojourn at sea, with a much lower expectation of survival than their grilse counterparts. At best, less than two out of every thousand will make it back to coastal waters.

In Ireland, they then face the offshore drift net fishery, which, though not normally very active in the spring, may change its habits to take advantage of the additional spring salmon runs arising from the curtailment of the Greenland fishery or other enhancement initiatives. Safely past the drift nets, they may in some locations be confronted by an estuarine draft net fishery, legally operating from February on.
These are formidable obstacles.

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ENHANCEMENT OF SPRING SALMON - SUMMING UP THE EVIDENCE

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The following "Summing up" is based on both the proceedings of the Conference held on 26 January and on the results of the Scientific Workshop held on the afternoon of the previous day.

Both sessions were notable for the wide measure of agreement achieved on the nature of the changes in the size and structure of salmon populations in British rivers which have given rise to the current shortage of "springers". This consensus is doubly helpful. First, it greatly simplifies the task of summing up by obviating the need for labourious reference to the large number of written and oral contributions made over the two days. Secondly it helps point the way more certainly than is sometimes the case, when scientists and laymen gather, about what can and cannot be done to rescue a salmon stock component in trouble.

Springers and Where They Come From

To the fisherman, a springer is a salmon which is available for capture in the spring months, that is to say from the start of the fishing season until some arbitrary date such as the end of April or the end of May. The former time was identified by Youngson (1995 and this Blue Book) as marking the end of the spring run and the latter the end of the rod-and-line fishery on fresh run springers, although not of course on the increasingly-coloured spring entrants which remain vulnerable to angling until the end of the fishing season.

Sampling of catches has shown that springers are invariably multi-sea-winter (MSW) salmon (as distinct from one sea winter [1SW] grilse) and further that they show no evidence of "plus" (new season's) growth on their scales. Helpful as this definition is to the fisherman in describing the fish which comprise his spring catch, a range of long term studies, especially in the North Esk (Shearer, 1990, 1992), Dee (Youngson, 1995) and Tay (Struthers, 1984), has shown that MSW salmon without plus growth are merely one category within a much more widely-based population of early-running salmon. These fish, which comprise winter and spring-running MSW fish (predominantly female) join with early-summer 1SW fish (predominantly male) and mature parr (entirely male in the UK) to form the spawning population from which the next generation of "springers", mature parr and early-summer grilse are derived.

In those systems where the distribution of spawning populations of salmon is not truncated by obstruction or poor habitat quality, there is increasing tag recapture and radio-tracking evidence that early-running fish within both the 1SW and 2SW classes home to and spawn in upper catchments (Hawkins and Smith, 1986; Laughton, 1991; Webb, 1992) in contrast to summer salmon and late-running grilse which are fish of the lower river. In highland Britain, upper catchments provide a shorter, cooler growing season for young salmon. Thus the juvenile progeny of early-running fish in highland rivers tend to have slower development rates than those of later-running fish growing to smolthood lower down the catchment.

Evidence From Catch Records

With the exception of a very small number of long term studies at index sites, where it has been possible to follow the fate of successive generations of salmon (Shearer, 1992; Youngson, 1995), the main sources of evidence that the availability of spring salmon to the fisheries is not constant is provided by the statistics of catches. Thus Martin and Mitchell (1985), Summers (1995) and the Salmon Advisory Committee (Anon, 1994) have reviewed long term net and rod-and-line catch statistics which provide clear evidence of long term changes both in apparent run timing and in the sea age composition of catches. Since 1952, the Scottish Office has published national statistics sub-divided by method, and reported nominal sea age (salmon or grilse). Separate returns are presented for salmon caught before the end of April. These data also show clear evidence for a steep decline in the proportion of the catch taken in the spring by all methods (Fig. 1) and further that the proportion, although not the absolute amount, of the spring catch taken by rod-and-line is now at an historic high (Fig. 2). These data need to be interpreted with caution. Early-running salmon are vulnerable to capture throughout the fishing season so the reported summer catch of salmon will include a small proportion of fish which entered rivers during the winter and spring. The summer salmon catch will also include a proportion of early grilse (which, as we

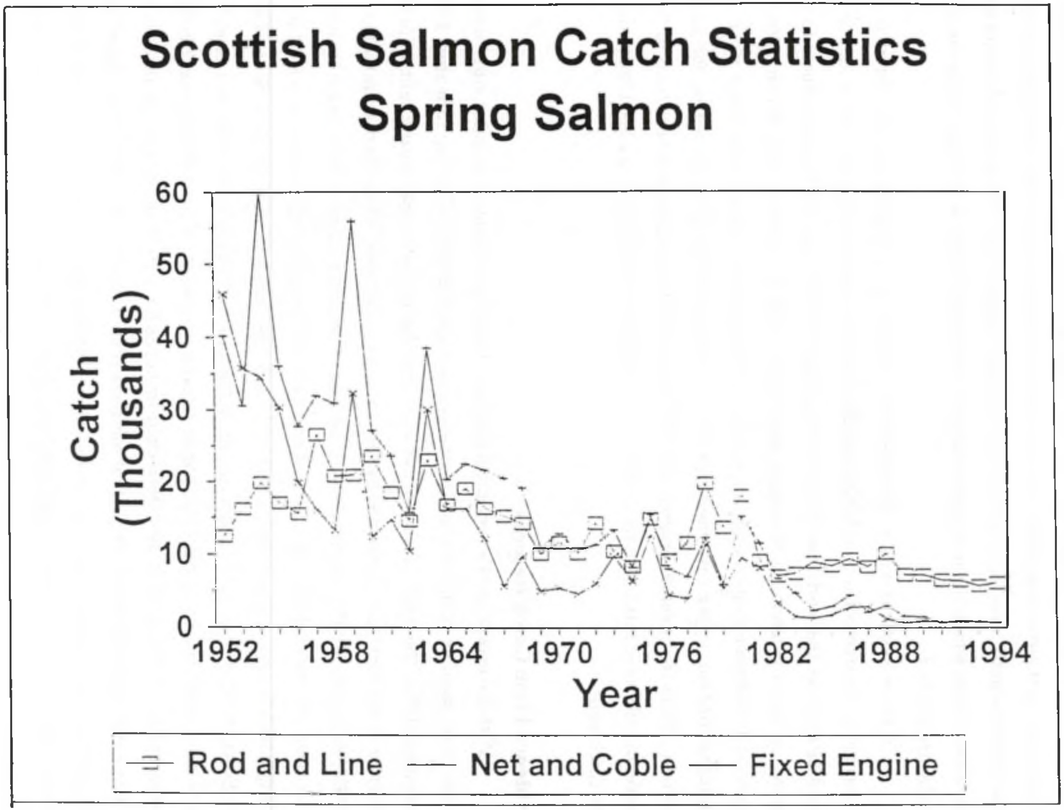

Figure 1 Scottish salmon catch statistics, spring salmon.

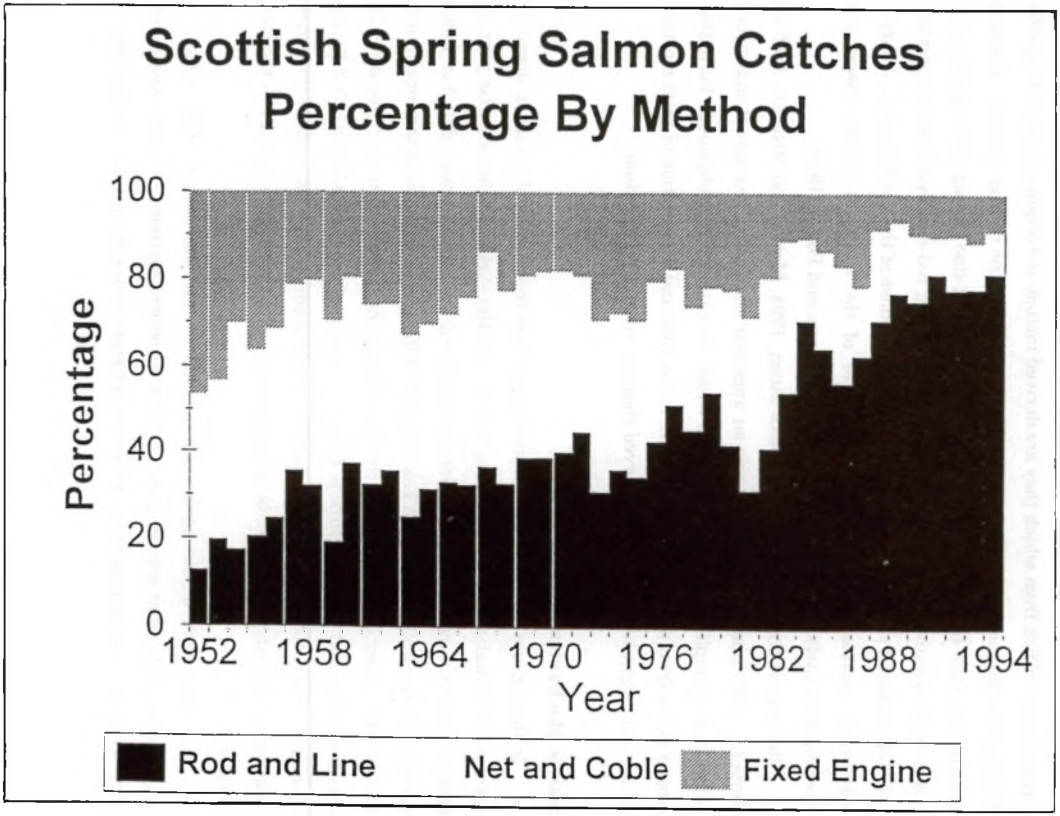

Figure 2 Scottish salmon catch statistics, percentage by method.

have seen, are an integral part of the early-running sub-stock) mis-reported as salmon. This latter error is likely to be small because early grilse, having had a relatively short period of sea feeding, tend to be small fish.

Other factors which reduce the value of the reported statistics as indices of the populations of fish from which they are derived include reductions in net fishing effort and changes in the timing of the runs relative to the dates of the fishing seasons. Youngson (1995 and this Blue Book) concluded that, because rod-and-line fishing effort in the spring has been well sustained since 1952, the statistics of spring rod-and-line fisheries provide a much better index of underlying population status than those of the net fisheries. A further factor which increases the value of this sector of the statistics is the proven high vulnerability of early-running salmon to lures (Solomon and Potter, 1992).

Reviews of the longer catch data sets (Anon, 1994; Martin and Mitchell, 1985 and Summers, 1995) place special emphasis on apparent changes in sea age at maturity in catches and, by implication, the stocks from which the catches were obtained. Both direct changes in the dynamics of maturation and in the rate and distribution of total mortality with sea age might lie behind the observed changes in catch composition.

Possible Mechanisms

In those rivers where it has been possible to follow the pattern of return in detail, the general rule is that the older the sea age of the fish the earlier in the calendar year it is likely to enter the river. This relationship has been described in most detail in fishery returns and fish counts in the North Esk (Shearer, 1992) and in patterns of tag return in the Tummel and Almond tributaries of the Tay (Struthers, 1984). A similar apparent link between sea age and time of return is known for some sea trout populations (A F Walker, pers comm). For both species the relationship would seem to be an example of the general phenomenon that circannual events in vertebrates tend to take place earliest in the oldest individuals.

A consequence of the age/run-timing link is that any factor which affects the representation of different sea age groups in the returning population will have consequences for the availability of salmon to the fishery at different times during the calendar year.

One such factor would be a direct alteration in the proportion of the population maturing in any one sea year in response to improved marine feeding opportunity. It is possible that the longer term changes in the representation of different sea age groups reported by Martin and Mitchell (1985), Shearer (1994) and Summers (1995) largely reflect changes in the dynamics of maturation. However, it was the unanimous view of the pre-conference Workshop that the continued fall in the representation of spring-running salmon in our rivers which has characterised the last ten or so fishing seasons is driven by increased levels of marine mortality, exacerbated in some instances, by subsequent shortfalls in smolt production from early-running sub stocks as a result of spawning stock inadequacy.

Two pieces of information point strongly to the dominant recent role of high levels of total marine mortality, the fact that shortages of MSW salmon have not been accompanied by increased numbers of grilse and the evidence admirably summarised by Reddin (this Blue Book) and Youngson (1995 and this Blue Book) that the survival of non-maturing 1SW salmon in the NW Atlantic appears to be influenced by the same sea surface temperature conditions that affect the return rates of European springers.

The pre-conference Workshop provisionally concluded that current shortages of springers are consistent with a high level of marine mortality on all sea year classes (which inevitably has the strongest impact on the older sea age groups because they are exposed to it longest) together with selectively higher losses, especially during the first sea winter, of early-running stock components.

Nature and Nurture During the Freshwater Phase

That there are inherited differences in the development rates of salmon populations has been known for many years to the salmon cultivation industry which prizes stocks with "low grilsing rates". That such differences are real has also been demonstrated under controlled conditions in the laboratory (Thorpe *et al.*, 1983). More recently it has been shown that variation at the ME-2 locus in the Atlantic salmon is linked with differences in development rate and further that differences in the representation of the "fast" and "slow" alleles appear to be maintained by natural selection with fast alleles being better represented in warmer systems and *vice versa* (Verspoor and Jordan, 1989). Recent stocking experiments on the Delphi system in Ireland using both local and "alien" smolts (Mantle this Blue Book) have provided further evidence that both development rate and run-timing are to some extent stock-specific. It might reasonably be concluded that current shortages of early-running salmon reflect the reduced overall "fitness" of this component of our salmon stocks to cope with the growth and survival opportunities encountered by these fish in the sea (Youngson, 1995 and this Blue Book).

A supplementary hypothesis is that there is a functional link between run-timing and development rate which may be open to environmental influence (Shearer, 1990). This interesting idea is based on the observation, originally shown for the North Esk but also demonstrable in other rivers, that, within a sea age group, the earliest running adults tend to have the highest smolt ages. One interpretation for Shearer's (1990) observation, which is based on returns to a complete river system, is that smolt age reflects growth opportunity in different parts of the catchment. Slow-developing juveniles are then seen as the inevitable result of homing to the cool upper habitats favoured by early-running fish. That smolt age may therefore be no more than a "label" of tributary of origin is suggested by the results of Struthers' (1984) studies of the Tummel and Almond tributaries of the Tay where it was shown that two years old smolts returned as adults to the upper tributary (the Tummel) before three years old smolts returning as adults to the Almond (the lower tributary). As Youngson (1995) suggests, Struthers' (1984) observations provide circumstantial evidence that environmentally-driven speeding-up or slowing-down of juvenile salmon development rates do not affect necessarily their subsequent run-timing within a sea age group as adults. However, the Tummel and the Almond are distant from one another in a large catchment and, given what is known about homing accuracy in salmon, could reasonably be regarded as quite separate stocks of fish (Stahl, 1987) with inherited differences which make inter-tributary comparisons between development rates difficult to interpret. Clearly there is scope for further experimentation before unequivocal management advice can be provided.

What Can be Done?

The proceedings both of the Workshop and the meeting were agreed that the primary reason for current shortages of springers is that prevailing conditions in the marine environment do not favour high survival rates for early-running salmon. Indeed it could even be argued that the problems currently faced by springers and early grilse are merely an extreme example of the generally lower sea survival rates suffered by most wild populations of Atlantic salmon in recent times.

Given that we are in no position to influence sea surface temperatures is there anything that can be done to make the north Atlantic a safer place for early-running salmon? Part of the answer lies in reducing directed fishing salmon in the high seas through NASCO, in discouraging high seas fishing in international waters by nations not party to the North Atlantic Salmon Conservation and, where possible, in paying high seas fishermen not to fish their NASCO quotas. As Potter (this Blue Book) has suggested, useful increases in the numbers of MSW salmon may be achievable via the latter "buy out" option. What is less clear is what proportion of the "saved" MSW fish would run in the spring rather than the summer. Present indications, from the inadequate tag return data base currently available, are that the spring-running population has most to gain from buy-outs at West Greenland rather than Faroe.

One of the most worrying conclusions of our proceedings is that, although the primary problem would appear to be marine, there is increasing evidence for some systems, and the Wye as described by Winstone (this Blue Book) is a particularly sad example, that spawning populations of early-running salmon are now so low that egg deposition rather than habitat constraints now control smolt production. In this situation it behoves the fishery manager to remove all unnecessary causes of death whether caused by netsman, angler or polluter.

As we have seen, anglers have an especially important part to play because of the high proportion of the spring catch currently taken by them. While complete cessation of fishing on depleted stocks is the biological ideal, socio-economic constraints usually dictate otherwise. Alongside temporary changes in fishing season and realistic bag limits, there is increasing evidence that catch and release, if carefully practised, can make important contributions to spawning stocks without compromising sporting enjoyment. Indeed many anglers find that releasing their catch enhances their day.

So far, preserving spawning stocks has been discussed solely in relation to maintaining and increasing the numbers of eggs laid by early-running salmon. In so doing a more important qualitative result may be achieved, namely conserving the genetic material from which early-running salmon of all sea ages are derived so that when, as historical records tell us they should, conditions once again favour fish following this life history pathway, recovery of the stocks can take place without delay. Early-running grilse, upper catchment mature parr and early-running MSW fish of both sexes are important repositories of valuable genetic material and, as Wilkins (this Blue Book) emphasised, spring-running MSW males may be of particular value.

So far as stocking is concerned, choice of brood-stock is a crucial concern. Local early-running material is the ideal but it is often unattainable except through such expensive processes as kelt reconditioning or the on-growing of upper catchment juveniles in a fish farm. The temptation to use alien material is often difficult to resist but resisted it must be if a sustained recovery of the stock is to take place. If suitable brood stock is available and vacant or grossly-underpopulated habitats can be found within or above parts of the catchment known to be used as spawning sites by early-running fish, stocking with eyed ova, unfed or fed fry is likely to be beneficial. For most large systems, however, stocking on a scale sufficient to show up in increased adult returns against a background of year-to-year variation will be difficult to achieve. Stocking at the smolt stage is the most expensive management option of all. Mantle (this Blue Book) has shown that it can have a useful place in small depleted systems but the return on investment when "ranching to the rod" would seem to be marginal unless hotel-related income is included.

On present evidence, the best accompaniment to the rational control of exploitation would seem to be habitat improvement through the easing of obstructions, the stabilisation of banks, reduced silt input and sympathetic land use. Over-grazing, ill-planned forest planting (especially in acidified catchments) and excessive abstraction are all correctable evils as are all forms of pollution. It nevertheless has to be said that habitat improvement to improve salmon production is an inexact and largely untested art. Potentially it has far more to offer than any form of stocking. However, it is not without its pitfalls. Encouraging bankside vegetation to help stabilise banks and to increase food production is an admirable objective provided the main beneficiaries are not freshwater-resident trout at the expense of a depleted salmon stock. In the same way, if there is any truth in the hypothesis, that environmentally influenced development rates are functionally linked to adult run-timing, increasing the food supplies to tributaries could be counter productive, at least until numbers have built up, if an increase in the numbers of early-running adults is required.

Conclusions

1. Early-running salmon are a mixture of winter and spring-running MSW fish plus 1SW fish running in the early summer.
2. Early-running salmon tend to home to specific parts of river systems, especially upper catchment sites.
3. Growth and survival opportunities in the sea are currently unfavourable for salmon of all sea ages following the early-running life history pathway.
4. The paramount priority for management is so to control exploitation on the high seas, in home waters and in rivers that the production of smolts from early-running homing units is not compromised by limitations in egg supply or genetic material.

5. Given the proper control of exploitation, useful enhancement is possible through carefully-planned stocking and habitat manipulation programmes.

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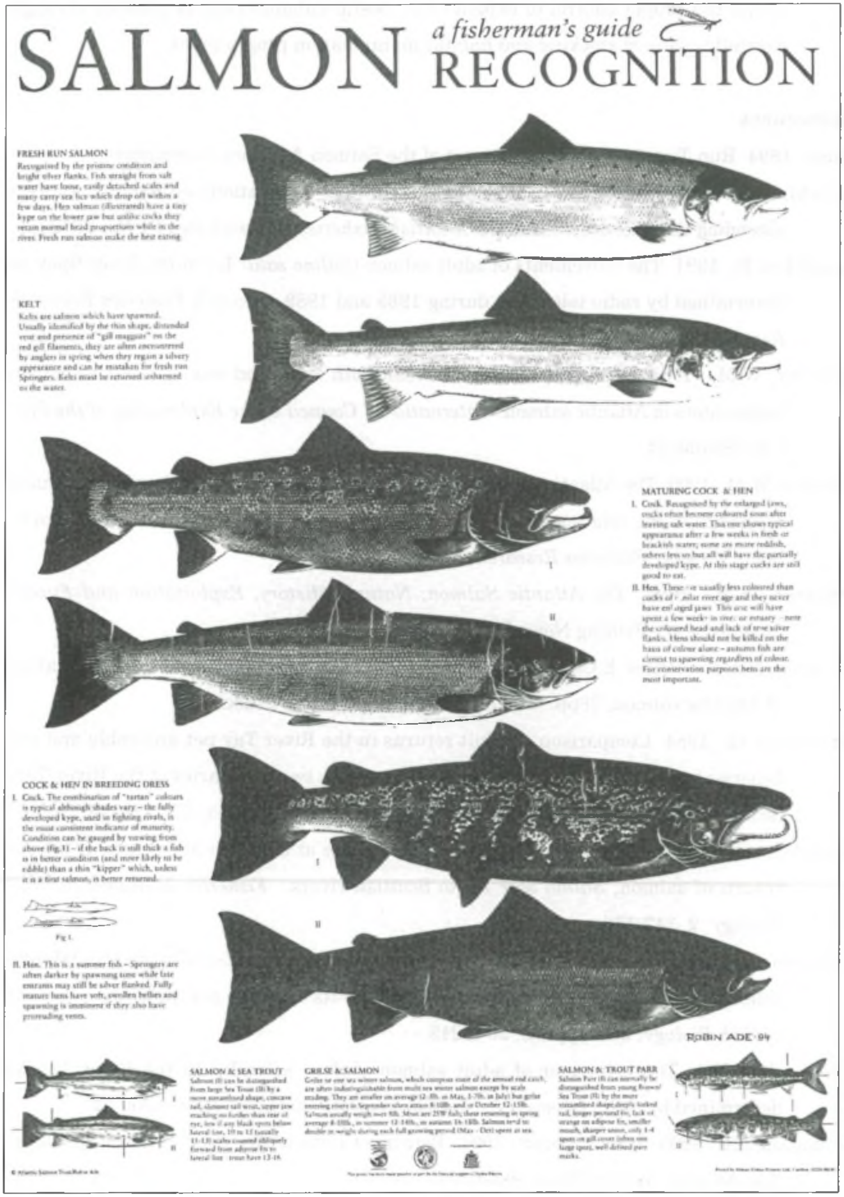

SALMON *a fisherman's guide* RECOGNITION

FRESH RUN SALMON

Recognised by the pristine condition and bright silver flanks. Fish straight from salt water have loose, easily detached scales and many carry sea lice which drop off within a few days. Hen salmon (illustrated) have a tiny kype on the lower jaw but unlike cocks they retain normal head proportions while in the river. Fresh run salmon make the best eating.

KELT

Kelts are salmon which have spawned. Usually identified by the thin shape, distended vent and presence of "gill maggots" on the red gill filaments, they are often encountered by anglers in spring when they regain a silvery appearance and can be mistaken for fresh run Springers. Kelts must be returned unharmed to the water.

MATURING COCK & HEN

I. Cock. Recognised by the enlarged jaws, cocks often become coloured soon after leaving salt water. This one shows typical appearance after a few weeks in fresh or brackish water; some are more reddish, others less so but all will have the partially developed kype. At this stage cocks are still good to eat.

II. Hen. These are usually less coloured than cocks of similar river age and they never have enlarged jaws. This one will have spent a few weeks in river or estuary – note the coloured head and lack of true silver flanks. Hens should not be killed on the basis of colour alone – autumn fish are closest to spawning regardless of colour. For conservation purposes hens are the most important.

COCK & HEN IN BREEDING DRESS

I. Cock. The combination of "tartan" colours is typical although shades vary – the fully developed kype, used in fighting rivals, is the most consistent indicator of maturity. Condition can be gauged by viewing from above (fig.1) – if the back is still thick a fish is in better condition (and more likely to be edible) than a thin "kipper" which, unless it is a first salmon, is better returned.

II. Hen. This is a summer fish – Springers are often darker by spawning time while late entrants may still be silver flanked. Fully mature hens have soft, swollen bellies and spawning is imminent if they also have protruding vents.

SALMON & SEA TROUT

Salmon (I) can be distinguished from large Sea Trout (II) by a more streamlined shape, concave tail, slimmer tail wrist, upper jaw reaching no further than rear of eye, few if any black spots below lateral line, 10 to 13 (usually 11-13) scales counted obliquely forward from adipose fin to lateral line – trout have 13-16.

GRILSE & SALMON

Grilse or one sea winter salmon, which compose most of the annual rod catch, are often indistinguishable from multi sea winter salmon except by scale reading. They are smaller on average (2-8lb. in May, 3-7lb. in July) but grilse entering rivers in September often attain 8-10lb. and in October 12-15lb. Salmon usually weigh over 8lb. Most are 2SW fish; those returning in spring average 8-10lb., in summer 12-14lb., in autumn 16-18lb. Salmon tend to double in weight during each full growing period (May - Dec) spent at sea.

SALMON & TROUT PARR

Salmon Parr (I) can normally be distinguished from young Brown/Sea Trout (II) by the more streamlined shape, deeply forked tail, longer pectoral fin, lack of orange on adipose fin, smaller mouth, sharper snout, only 1-4 spots on gill cover (often one large spot), well defined parr marks.

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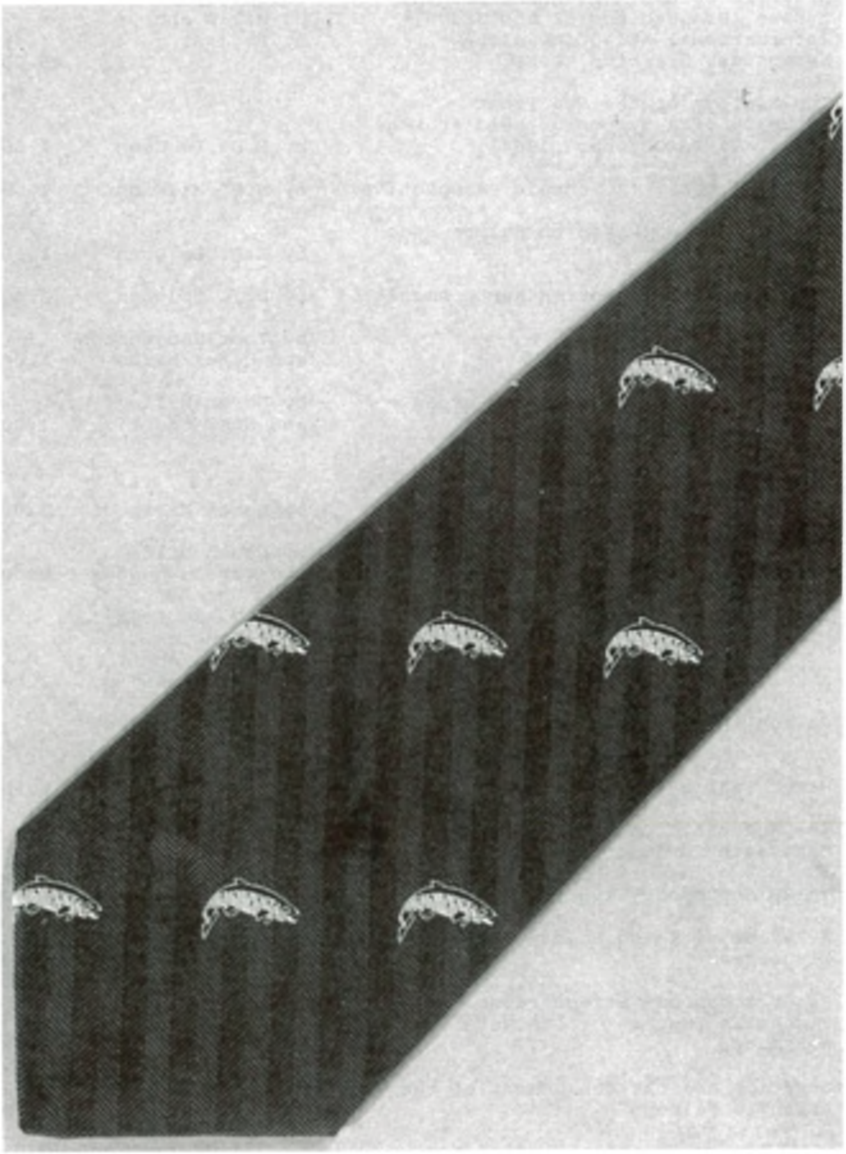

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