

THE INTERPRETATION OF ROD AND NET CATCH DATA

Proceedings of a Workshop held at the Centre for Environment, Fisheries and Aquaculture Science, Lowestoft, on 6-7 November 2001

Edited by Richard Shelton



The Atlantic Salmon Trust Moulin, Pitlochry Perthshire PH16 5JQ Telephone: 01796 473439



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A representative of the Scottish Executive Environment & Rural Affairs Department



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INTRODUCTION

Derek Mills

Chairman, Honorary Scientific Advisory Panel

Salmon fishermen and fishery scientists are at one in recognising the importance of keeping accurate catch records. They have value in themselves as the formal statistics of an economically important rural activity and are the end result of its management. When changes take place in the size and seasonal distribution of catches, fishermen and scientists join forces in seeking out the causes in case they indicate underlying problems with the stocks of salmon upon which the fisheries depend.

The Proceedings of this Workshop, which was held at Lowestoft by courtesy of the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), draw upon the accumulated experience of scientists and fishery managers from England, France, Ireland, Norway, Scotland and Wales. They show some of the ways in which catch statistics can be used alone, and in combination with other information, to help safeguard the future of our salmon resources. It is, of course, a *sine qua non* that, to be useful in this way, catch records must be reliable. The misleading effects of unreliability and the difficulties that scientists face in allowing for it are clearly brought out in the Proceedings.

The underlying theme of the contributions is that the key to making the most effective use of catch statistics in management lies in an understanding of the relationship between catches and the stocks of salmon from which they are obtained. During the Workshop, special emphasis was placed on this relationship as it applies to angling because, for many rivers, the records of anglers are the only indication of the status of the local salmon resource.

Catches are, in essence, samples of the stock of salmon present at the time the fishery takes place. If the vulnerability of the fish to capture (catchability) and the amount and quality of the effort expended by the fishermen are known, an estimate of the underlying stock can be obtained, at least for the period over which the fishery operated. Estimating both catchability and fishing effort demands an appreciation of the behaviour of both salmon and those who fish for them. Once again, the Proceedings show that these are areas where anglers and scientists have much to teach one another.

What are the prospects for drawing useful lessons from the raw statistics of rod-and-line catches which are increasingly becoming the principal source of data? The factors which must be considered when using eatch figures to assess population trends were discussed in detail during the Workshop. The insights gained will help fishery managers to judge how to make more effective use of their data for this purpose in the light of local circumstances. Specifically, application of the latest statistical techniques has shown, at least for "Spring" fisheries, that useful indications can be obtained of the status of the early-running populations of salmon upon which these important fisheries depend.

The main lessons of this Workshop are that it is important to keep good records of salmon catches, and that making sense of them demands the active co-operation of fishermen, fishery managers and scientists. Their common interest lies strongly in the future well-being of this vulnerable resource.

RELIABILITY OF REPORTED CATCH DATA

E.C.E. Potter

CEFAS, Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK

INTRODUCTION

In most countries, rod and net fisheries for Atlantic salmon (Salmo salar L.) are licensed, and there is usually a legal requirement for licensees to report their catches to the regulatory authority. Catch statistics are thus probably the most extensive data sets available for salmon stocks, both temporally and spatially, having been collected for fisheries on most salmon rivers for more than 30 years (ICES, 2001) and in some instances for more than a century (SAC, 1994).

Solomon and Potter (1992) emphasised the importance of trying to obtain or estimate complete catch data because of their importance in the interpretation of stock status and the management of exploitation. Catch statistics can provide both a measure of the success of a fishery and an index of the size of the stock that is being exploited. They therefore have several important uses;

- catch data are a basic measure of the performance of salmon fisheries and a measure of
 the 'end result' of fisheries management; rod catch statistics may, for example, be of
 particular importance to fishery owners because they can determine the market value of
 the fishery, while catches by different fisheries exploiting a single stock may be used by
 managers to determine their relative levels of impact;
- changes in catch figures, including changes in the monthly distribution of catches, are generally the first indicators of a stock problem that may require management measures;
- catch figures are usually an important element in deriving a measure of exploitation rates, where an independent estimate of the total run or the spawning escapement after exploitation is available; and
- catch statistics can be used to calculate the total stock size if the exploitation rate can be estimated by an alternative method (e.g. a mark-recapture programme); thus catch data are used as the basis for many stock assessments, such as the run-reconstruction models used to estimate the pre-fishery abundance (PFA) of salmon in the North American Commission (NAC) and North East Atlantic Commission (NEAC) areas of NASCO (Rago, et al., 1993; Potter et al, 1998).

However, catch statistics are also notoriously unreliable, there being a wide range of reasons why anglers and commercial fishers may under- or, occasionally, over-declare their catch, and this inevitably affects the value of the data for further analysis. This paper considers the reasons for the non-reporting of catches, methods for estimating mis-reporting rates, available information on the levels and trends in non-reporting, and the implications of using catch data in providing management advice.

DEFINITIONS

Nominal catches of fish (as published by ICES) generally refer to the declared landings expressed in 'tonnes round-fresh-weight' (i.e. ungutted); thus, where fish are gutted before being landed, as in the distant water salmon fisheries, a correction factor (approx. 1.1) is applied to the landed weight. For Atlantic salmon, ICES also provides **reported catches** in numbers of fish, where possible divided into sea-age groups (ICES, 2001). However, some 'nominal' and 'reported' salmon catches published by ICES include estimates of all (e.g. France) or parts (e.g. Canada) of the unreported catch (ICES, 2000).

Unreported catches, have been classed as part of the 'non-catch fishing mortality' (Ricker 1976), which may be defined as all the mortality arising as a result of fishing activities which is not accounted for in the declared catches. Unreported salmon catches have been defined by ICES (1989) as, 'harvests which are caught and retained, but do not enter into reported catch statistics; such harvests could be either legal or illegal, but would not include catch and release mortalities whether they arise from nets or angling gear. Such estimates would not include fish retained by public or private agencies for broodstock purposes destined for enhancement'.

The **rate of non-reporting** is expressed as the estimated non-reported catch (N) divided by the total catch (i.e. reported (R) plus non-reported). Thus:

Non-reporting rate = N / (R + N)

A non-reporting rate of 0.5 (or 50%) therefore indicates that the unreported catch equals the reported catch.

REASONS FOR INACCURATE REPORTING OF CATCHES

Since 2000, NASCO has sought explanations from Contracting Parties of how they derive their estimates of unreported catches, based upon a number of headings which indicate some of the reasons why catches may not be reported accurately (NASCO, 2000). These are as follow:

Absence of a requirement for statistics to be collected: In most countries both rod and net fisheries for migratory salmonids are licensed and there is a legal requirement for licensees to report their catches. However, there are some fisheries for which returns are not required (e.g. rod fisheries in Ireland and UK (Northern Ireland) (NASCO, 2000).

Suppression of information thought to be unfavourable: Commercial fishers may be concerned that their catch figures will be used to estimate their income and they may underreport their catches to avoid paying tax. Fishers may also feel that there is less chance of their fishing activities being restricted if they under-report their catches.

Local sale or consumption: Many salmon fishers take relatively few fish per day and therefore sell their catches directly to restaurants or the public. This does not usually affect their legal obligation to report the catch, but it may affect the reliability of some returns, possibly because fishers do not keep such good records or because they feel that unreported catches are less likely to be noticed. In some countries a substantial part of the unreported catch is thought to fall into this category (NASCO, 2001). In some years, the West Greenland quota has been restricted to local subsistence use only and, as a result, catches are thought to have been significantly under-reported (NASCO, 2000).

Innocent inaccuracy in making returns: Catch recording systems which depend upon fishers recalling information at the end of the fishing season can suffer from non-response and biases associated with faulty memory or exaggeration (Cowx, 1991a). Some anglers probably forget to make their return, particularly if they fish infrequently, and Cowx (1991a) suggests that the recall time interval should be kept to a minimum, and ideally less than two months. Anglers are also less likely to make a return if they do not catch any fish during the season. While this will not affect the unreported catch, it means that the total catch cannot be estimated by multiplying the average reported catch by the total number of licensees. In addition, the catch per unit of effort (CPUE) estimated from the reported catches will be higher than the true figure for the fishery. Inaccurate reporting may also include misclassification of salmon and sea trout and errors in subsidiary information such as fishing locations and size estimates.

These problems are less likely to arise in net fisheries, where fishers may feel under a greater pressure to submit returns in order to secure a licence in the following year. Non-reporting will also be exacerbated where there are inadequate systems for reporting catches. For example, problems are known to arise in Norway where anglers do not require a licence to fish for salmon in the sea. Although these fishers are expected to report any catches, they are thought to be deterred by the lack of a simple system for doing this (NASCO, 2000).

Illegal fishing: Catches made by unlicensed fishers are rarely included in the declared figures, although there may be some circumstances in which the fish are landed through legitimate markets, perhaps with the aid of licensed fishers, and recorded in the legal landings.

The above headings used by NASCO (2000) do not include fishers who simply don't bother to make returns, perhaps because they know that there is no effective penalty or deterrent. It is also thought that both rod and net fishers may occasionally perceive some advantage in over-declaring their catches. This problem may arise where the catch statistics are expected to be used to assess the value of rod fisheries or to calculate appropriate payments for compensating commercial fishers not to operate.

METHODS TO ESTIMATE UNREPORTED CATCHES

ICES (1996 & 2000) has described how non-reported catches have been estimated in different countries. The values provided to ICES are frequently termed 'guess-(es)timates' because of the highly uncertain nature of at least part of the figure. However, in many instances these data are supported, at least in part, by estimates based on some form of sampling. Unreported catch is derived from both illegal and legal fisheries, although failing to report legal catches may itself be illegal. Thus the 'problem' of unreported catches may be tackled by introducing measures to reduce illegal fisheries and to increase the proportion of legal catches that are reported.

Illegal catches: No returns are received from illegal fishers, and so values reported to ICES inevitably involve an element of guess-work. Illegal catches may be influenced by various factors including the availability of fishing licences, fish abundance, market prices and changes in legislation and enforcement practices. Some authorities base their estimates of total illegal catches upon estimates by fishery officers of the number of illegal nets and records of catch rates observed in legally or illegally set gear. In other areas, local inspectors or fishery officers are asked to use from local knowledge to estimate catches by poachers using rods, nets and other methods. It is possible that methods used to assess other crime statistics could be used to improve these estimates.

Illegal fisheries have also been reduced by the use of more sophisticated surveillance equipment and by the introduction of new regulations. For example, in England and Wales an offence of handling salmon in suspicious circumstances was introduced in 1986 (SAC, 1996). This makes it an offence for a person to possess a salmon where he/she knows, or where it would be reasonable for them to suspect, that the fish had been taken unlawfully. Similar legislation was introduced in Scotland, and, as in England and Wales, it is considered to have been an effective deterrent (SAC, 1996).

Unreported legal catches: As with illegal catches, there is a need for measures to both reduce and estimate unreported legal catches. Efforts to improve return rates may include an obligation for all salmon fishers to provide catch returns, but the process should be made as simple as possible and consideration could be given to providing incentives. In many rivers in Norway, a deposit on the fishing licence has been introduced which is refunded when a return is made. This has resulted in an improvement in the return rate of catch reports on these rivers to 85-95% (NASCO, 2000), although it does not guarantee the accuracy of the returns.

A variety of methods has been also used to estimate mis-reporting in licensed fisheries in one or more regions or countries (ICES, 1996; NASCO, 2000):

Logbooks: A sample of the fishers in a commercial or rod fishery may be asked to provide more comprehensive information on their fishing activities and catches, and these data may be used as a basis for estimating the total catch or correcting voluntary returns. Return rates for the log books can be improved by maintaining closer contacts with the fishers or paying them for the information. This approach has been used in sea bass fisheries in UK, and Pickett and Pawson, (1991) noted that that it is an enduring and relatively inexpensive method for collecting accurate catch and effort data.

Creel or commercial catch surveys: These may be used to estimate unreported catches by comparing observed and reported catches; for example, in Northern Ireland and England (Anon, 1991) catches observed by scientific staff scanning for code wire micro-tags have been compared with declared figures.

Mark-recapture studies: Both conventional tagging and radio tagging programmes have been employed to estimate exploitation rates and may also be used to provide information on the proportion of catches that are not reported. Radio tagging has the advantage of allowing the fate of fish that are not caught to be confirmed, thus providing a measure of the tag loss or other sources of mortality. Conventional tagging is used on the River Dee (Wales) to estimate total catches each year (Ian Davidson, pers comm), but it may not be practical to use these approaches on a large scale because of their costs.

Sequential reminders: Catch returns obtained from anglers in response to sequential reminders have been used to develop methods to estimate the total catch from the first (unprompted) returns (Small and Downham, 1985). Small (1991) has suggested that the total rod catch (C) in a fishery can be estimated from the equation:

$$C = C_u \times (b/P_u + (1-b))$$

where: C_u is the unprompted catch return

P_u is the proportion of anglers making unprompted returns

b is derived from historical data where: catch/effort = a * abundance b

This approach has been used by the Environment Agency in England and Wales (using a value of b = 0.3), and has produced similar results to estimates made by mark-recapture (Ian Davidson, pers comm).

Carcass tagging: Fishers in Canada, France and Ireland are now required to apply tags to any fish that are retained as soon as they are landed. This regulation is expected to reduce the illegal catches of salmon and to improve catch statistics.

In addition to the above methods that are currently used, ICES (1989) has suggested enumerating unreported catches by comparing landings in market categories to 'expected values', although it is not clear how these values would be estimated. It is also proposed that local sales in some communities could be estimated by surveying households or businesses for the number of salmon bought directly from fishermen. It is not known whether these methods have been employed.

LEVELS OF UNREPORTED CATCHES

ICES has provided estimates of unreported catches for the NASCO-NAC and NEAC areas since 1987, for the West Greenland Commission area since 1993, and by individual country since 1999 (Table 1). Overall, the non-reporting rate in the North Atlantic is thought to have remained fairly stable at around 32% for much of this period (Figure 1), although it fell to around 26% between 1994 and 1997. However, this masks a marked increase from about 10% to over 40% in the NAC area and a slight decrease from about 35% to 30% in the NEAC area over the period (Figure 2). In many cases these changes have resulted from modifications to the management regimes or regulations, although they may also reflect changes in the way the unreported catch has been estimated in some area. Estimates of the non-reporting rate in European countries have also been provided for the period 1971 to 2000 to estimate the pre-fishery abundance (PFA) of salmon stocks in the NEAC area (ICES, 2001). However, all countries have provided constant estimates for years prior to 1985, and so these data do not provide further insights into the trends in non-reporting.

The estimated unreported catches of Atlantic salmon for all countries in 2000 are shown in Table 2 and Figures 3 and 4. (Unreported catches for France are included in the reported figures and cannot therefore be distinguished.) The unreported catches in each country account for between 0% (Faroes and USA) and nearly 70% (Russia) of the national catches, and up to 16% (Norway) of the total North Atlantic catch.

It is possible that the differences between countries or regions are influenced by the methods used to estimate the unreported catches, and some countries have assumed a constant non-reporting rate over the past 20 years. Consequently, great care must be taken in interpreting these figures. However, they still represent the best available data and show that managers/scientists believe there to be marked differences in the levels and trends in non-reporting rates between regions/countries.

Figure 1. Total reported catches, guess-estimated unreported catches (see Table 1) and percentage unreported for all North Atlantic salmon fisheries, 1987-2000

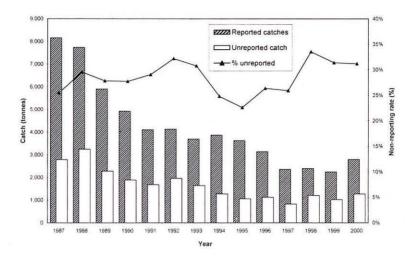


Figure 2. Percentage of salmon catches in North East Atlantic and North America that are guess-estimated to be unreported, 1987-2000

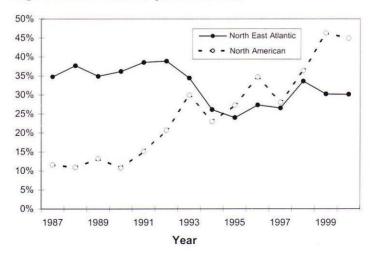


Figure 3. Estimated unreported catches of salmon in each country around the North Atlantic expressed as a percentage of the total North Atlantic catch, 2000

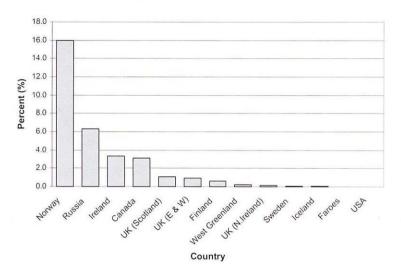


Figure 4. Estimated unreported catches of salmon in each country around the North Atlantic expressed as a percentage of the total national catch, 2000 (= Estimated national non-reporting rate)

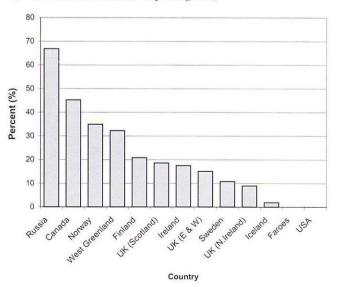


Table 1 Reported catches, estimates of unreported catches and % unreported within national EEZs in the North-East Atlantic, North American and West Greenland Commission areas of NASCO in tonnes, 1987-2000.

	Ň	North-East Atlantic	9	2	North-American		West Greenland	cenland		Total	
Year	Reported	Unreported catch	% unreported	Reported	Unreported catch	% unreported	Reported	Unreported	Reported	Unreported catch**	% unreported
1987	4,790	2,554	34.8%	1,787	234	11.6%	1.543	*	8,120	3,097	28%
1988	5,104	3,087	37.7%	1,313	191	10.9%	1,140	*	7.557	3,476	32%
1989	3,923	2,103	34.9%	1,143	174	13.2%	701	*	5.767	2,417	30%
1990	3,140	1,779	36.2%	915	Ξ	10.8%	589	*	4,644	2,008	30%
1661	2,477	1,555	38.6%	713	127	15.1%	571	*	3,761	1,796	32%
1992	2,868	1,825	38.9%	525	137	20.7%	265	*	3,658	2,015	36%
1993	2,800	1,471	34.4%	377	191	30.0%	23	< 12	3,200	1,644	34%
1994	3,272	1,157	26.1%	358	107	23.0%	9	< 12	3,636	1,276	26%
1995	2,979	942	24.0%	261	86	27.3%	06	20	3,330	1,060	24%
9661	2,514	947	27.4%	294	156	34.7%	93	20	2,900	1,123	28%
1997	2,024	732	26.6%	231	06	28.1%	59	5	2,314	827	26%
8661	2,186	1,108	33.6%	159	91	36.4%	17	=	2,363	1,210	34%
1999	2,047	887	30.2%	154	133	46.3%	61	13	2,220	1,033	32%
2000	2,631	1,135	30.1%	152	124	44.9%	29	10	2,812	1,269	31%

* estimated at 0.1 to 0.3 of the catch

** unreported catch at West Greenland for 1987-92 taken as 20% of catch

Table 2 Estimates of unreported catches by various methods in tonnes by country within national EEZs in the North-East Atlantic, North America and West Greenland Commissions of NASCO, 2000.

Commission Area	Country	Estimated unreported catch (t)	Unreported as % of Total North Atlantic Catch (Unreported + Reported)	Unreported as % of Total National catch (Unreported + Reported)
NEAC	Faroes	< 1	0	0
NEAC	Finland	25	0.6	21
NEAC	Iceland	2	0.0	2
NEAC	Ireland	132	3.3	18
NEAC	Norway	633	16.0	35
NEAC	Russia	250	6.3	67
NEAC	Sweden	4	0.1	11
NEAC	UK (E & W)	38	1.0	15
NEAC	UK (N.Ireland)	8	0.2	9
NEAC	UK (Scotland)	44	1.1	19
NAC	Canada	124	3.1	45
NAC	USA	0	0.0	0
WGC	West Greenland	10	0.3	32
	Total Unreported Catch	1269	31.i	

HANDLING UNREPORTED CATCHES

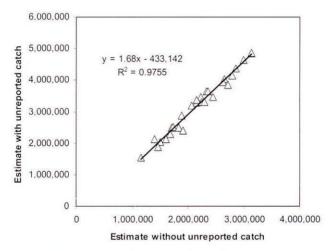
In view of the difficulty of estimating unreported catches, it is sometimes suggested that it might be better to ignore them in fisheries assessments. In fact, many freshwater and marine fisheries studies based on the analysis of catch data make no mention of non-reporting problems (e.g. see papers in Cowx, 1991b). In some circumstances this may be justified because the reported catch or the reported CPUE can provide a satisfactory index of changes in total landings. Thus, if non-reporting rates are not biased, reported catches can provide valuable information on trends and patterns in the fishery. Unfortunately, however, non-reporting rates frequently vary over time and space in response to differing management and enforcement strategies, and this will result in biases in the reported catch data relative to total catches.

There are clearly situations where excluding unreported catches from the analysis will provide an incomplete picture. For example, exploitation rates will tend to be underestimated if unreported catches are not taken into account in estimates derived from catch and counter data. The same is likely to be true in the approaches employed by ICES to provide catch options to NASCO (ICES, 2001), which are based upon estimating the PFA and subtracting the numbers that must be protected to provide the required spawning escapement. This, in simple terms, provides a measure of the maximum allowable harvest. In both the NAC and

NEAC areas, the estimation of the PFA depends upon catch data. The NEAC runreconstruction model incorporates the non-reporting rates for each country (Potter, et al, 1998), but the model can be quite sensitive to this parameter. For example, an increase in the non-reporting rate from 50% to 60% will increase the estimated numbers of returns, recruits and spawners by 25%, although an increase in the non-reporting rate from 10% to 20% will affect these estimates by only 12.5%.

The effects of ignoring the unreported catch in the NEAC PFA assessment has therefore been explored, and Figure 5 compares the PFA of maturing 1SW salmon estimated with and without this parameter. This analysis shows that the unreported catch not only accounts for about 40% of the PFA estimate but that there is a substantial temporal bias (the intercept = 433k) because both catches and the rate of non-reporting have decreased over time. Thus, failing to take account of unreported catches would mean that a substantial part of the stock would not be taken into account in any assessment, and this would clearly affect the validity of any catch advice.

Figure 5 Pre-fishery abundance of maturing 1SW salmon in the NASCO - NEAC Area estimated with and without the inclusion of unreported catches.



It is therefore essential that greater efforts are made to obtain reliable estimates of unreported catches and/or non-reporting rates using some of the methods described above. Further consideration should also be given to the methods currently used for incorporating unreported catches into analyses. In the current NEAC-PFA model, the proportion of the catch that is not reported is included as a single variable to correct the catch figure. Thus the first step in the analysis involves estimating the numbers of fish of age 'i' returning to homewaters in year 'n' (H_{ni}) as follows:

$$H_{ni} = (C_{ni} / (1 - R_{ni})) / U_{ni}$$

where

C is the reported catch

R is the total non-reporting rate.

U is the exploitation rate

Handling the unreported legal catches in this way is appropriate because it will tend to vary with the reported catch. However, the illegal catch may be more likely to vary in response to other factors, such as enforcement activities, and so it may be more appropriate to add the estimate of illegal catch to the estimated numbers of fish returning to home waters. The equation to estimate the number of fish returning to home waters would thus become:

$$H_{ni} = (C_{ni} / (1 - R_{Lni})) / U_{ni} + C_{Lni}$$

where:

C₁ is the illegal catch

R_L is the non-reporting rate in the legal fishery

and other variables are as indicated in the description of the model (above).

This revised approach has not been adopted by ICES at present, partly because most countries do not provide separate estimates of C_1 and R_L . However, it seems likely that attempting to improve the estimates of different elements of unreported catches will be the key to improving our overall estimates of non-reporting, and, once we have these data, we should ensure that they are employed in the most appropriate way in assessment models.

CONCLUSIONS

It is evident that unreported catches represent a significant proportion of the total fishing mortality in some areas, and uncertainties about their size can seriously compromise our ability to provide accurate stock assessments and management advice. While there are some situations in which unreported catches can be ignored, this is not appropriate in most situations where quantitative management information is required. There is, therefore, a need to address both illegal fisheries and non-reporting of legal catches, and it is essential that:

- management authorities should continue to take steps to reduce illegal catches both through legislation and enforcement;
- efforts must be made to improve the reporting of legal catches by ensuring there is a requirement to make catch returns, by providing convenient and simple methods for making returns and by providing feedback to user groups on the importance of these data in management;
- estimating non-reporting rates should be regarded as an essential part of the statistics
 collection process, and a range of methods should be employed to evaluate both illegal
 and unreported legal components of the catches in all areas in order to assess and validate
 estimates;
- the way that illegal and unreported legal catches are handled in assessment models should be re-evaluated where separate estimates are available;
- managers and scientists should continue to demonstrate the value of obtaining good catch data by presenting analyses to both rod and net fishers in easily accessible forms.

Scientists and managers all too frequently turn a blind eye to unreported catches because they are inconvenient and difficult to estimate. However, we will not be able to manage and restore our depleted salmon stocks adequately if we do not actively address this problem in all areas.

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THE SIGNIFICANCE AND INTERPRETATION OF NET CATCH DATA

N. Ó Maoiléidigh, E.C.E. Potter*, P. McGinnity, K. F. Whelan, A. Cullen, D. McLaughlin and T. McDermott

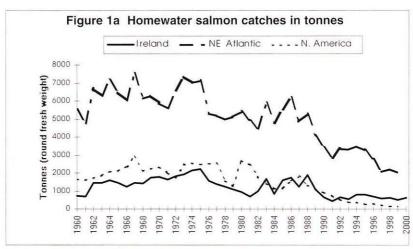
Marine Institute, Abbotstown, Dublin 15, Ireland *CEFAS,Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 OHT, UK

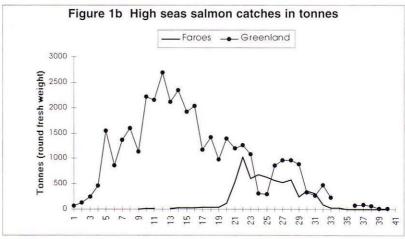
INTRODUCTION

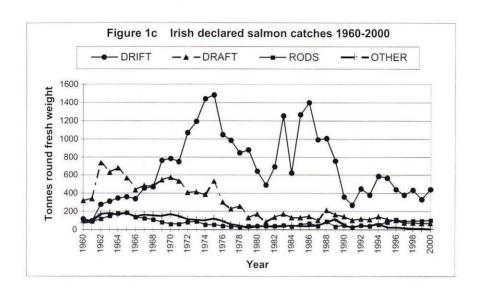
Total catches of salmon in the North Atlantic increased dramatically during the 1960s and peaked in 1973 (Figure 1a and 1b). This increase in the catch was associated with the expansion of marine salmon fisheries and the development of more efficient fishing technology and gears (including monofilament nets). The catch has declined dramatically in recent years from a maximum of over 12,000 tonnes in total in 1973 to only 4,000t in 1994. The provisional total catch for 1999 was 2,218t which is the lowest on record (Anon. 2000) and was 177t lower than the catch recorded in 1998 of 2,395t. This decline is partially due to control measures introduced by many countries to curtail fishing effort and close some fisheries. However, a reduction in the overall size of salmon populations has also occurred. Despite the very restrictive measures in force in the high seas fisheries off Greenland and Faroes in recent years, no increase in catches in homewater countries is evident (Figure 1b).

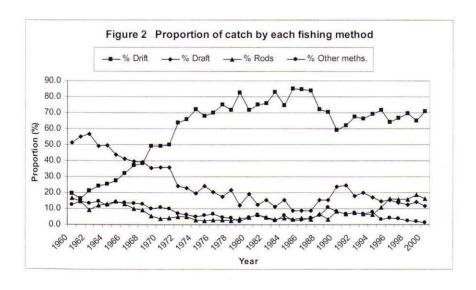
Irish homewater commercial catches also fluctuated widely in this period but appear to reflect the trend in total North Atlantic catches (Figure 1c). In the early part of the time series (up to 1968), the greatest proportion of the homewater salmon catch was caught by the inshore draft nets (Figure 2). From 1968 on, the draft net catch decreased, while there was a corresponding increase in the drift net catch to 1976. The subsequent sudden decline in the catch by all methods is attributable to several factors including the salmon disease, Ulcerative Dermal Necrosis (UDN), poor marine survival and some over-fishing. The drift net catch fluctuated in the 1980s with high catches recorded in a number of years, while the draft net catch remained low but stable. In the mid 1980s and early 1990s, the drift net catch decreased considerably. There was a slight recovery in the catch up to 1994 but this was not sustained and the present catch by all methods is still low compared to the 1980s.

While long time series of catch data are available for most countries, it is generally acknowledged that these data do not necessarily provide a good indication of changes in stock size, particularly in the short term. Use of other data (coded wire tags, stock and recruitment relationships etc) in association with catch data can provide a better interpretation of population dynamics particularly where individual river data are lacking or poorly known.









IRISH SALMON FISHERIES

There are seven designated salmon fishing regions around the Republic of Ireland. These regions are sub-divided into 17 geographical management areas (i.e. districts). Statistics are collected by staff of the Regional Fisheries Boards at the district level and collated into a national data set by the Marine Institute. Rod catch statistics are reported by the Regional Fisheries Boards and collated by the Central Fisheries Board.

The principal commercial fishing methods used in the Republic of Ireland are:

- 1 Drift nets surface gill nets fished at sea. (season opens in June and closes at the end of July – effectively fishing takes place for 17 hours per day, 4 days per week and 2 months per year).
- 2 Draft nets inshore and estuarine seine nets (season opens in mid-May and closes at the end of July. Some local variations occur). Two major draft net fisheries were suspended for 2000 as part of ongoing catchment management initiatives.
- 3 Traps (season opens mid-May and closes at the end of July). In 2000 no terminal traps were reported to have operated.
- 4 Snap nets similar to draft nets but operated between two small boats (season opens mid-May and closes at the end of July)
- 5 Loop nets, bag nets, pole nets local traditional methods (season opens in mid-May and closes at the end of July)

THE NATIONAL CATCH

New management and conservation legislation was brought into force in 1997 and continued to operate in the subsequent fishing seasons (1998-2000). These regulations, which were aimed at reducing effort in the fishery and facilitating enforcement included:

- Cap on public commercial fishing licences for draft nets and drift nets
- Area of fishing at sea reduced from 12 to 6 nautical miles
- Drift net season constrained to 1st June to 31st July
- Draft net fishery deferred to the 12th of May
- Restriction on night time fishing (0400 to 2100 hrs only)
- Reduction to 4 days' fishing per week

The new management measures were expected to reduce the declared marine and estuarial catches if a similar stock returned to the coast and if the measures were effective. The declared catch in 2000 was 621t which was higher than 1999 (515t) and similar to 1998 (624t). However, as expected, the catches in all three years were lower than in 1996 (685t) before the new regulations came into force. In order to show definitively whether there has been a change in the catch subsequent to the introduction of measures in 1997, the data were analysed using a Non-Parametric Random Ratio (NPR) test (Rago 1993, Anon.2000). This test compares the mean catch in the period following the introduction of new regulatory measures in 1996 (i.e. 1997-2000) with the mean catch reported in the preceding seven years (1990-96). The results of this test indicate that drift net catches in the most recent four years were significantly lower than the preceding seven years (p <0.01) in all individual regions except the Western Region. The increase in the West is due mainly to the increase in hatchery-reared returns in the last decade. Draft net catches were also significantly lower in

the most recent four years (p<0.01) in all regions, except the North Western Region where the Mov River draft net was suspended in 1994.

It is not possible to determine whether rod catches have increased as a result of the 1997 management measures using a similar analysis as rod catch data are known to be gross underestimates for most regions and most years prior to 1995.

BIOLOGICAL REFERENCE POINTS

In the Republic of Ireland, the management rationale to date has been to limit the time available and the gear permitted for fishing (effort limitation). While this regime regulates the fishery, it is not related to the stock available and the same level of fishing effort is allowed even when stocks are low. A Salmon Management Task Force was established by the Minister for the Marine and Natural Resources in 1996 (Anon. 1996) to review the management of Irish salmon stocks. The task force recommended a new rationale for management of salmon stocks based on achieving **spawning escapement targets** for each specific stock and maintaining stocks above conservation limits (CLs). The proposed new system provides that the number of fish available for capture is the surplus after the spawning requirements are met. This policy allows a faster response if the stocks are threatened.

In 1998, the North Atlantic Salmon Conservation Organisation (NASCO) adopted the precautionary approach to fisheries management (as outlined in FAO. 1996). Central to this was the agreement that management measures should be aimed at maintaining all salmon stocks in the NASCO Convention Area above a pre-agreed CL by the use of management targets. The CL for Atlantic salmon is currently defined by NASCO as "the spawning stock level that produces maximum sustainable yield" (also known as S_{MSY}) (NASCO 1998).

The wild salmon run on the Burrishoole River has been monitored continuously since the 1960s. Information is available on the total number of adult salmon ascending and the total number of smolts descending. It has been possible to derive an adequate stock-recruitment relationship from these data in order to establish a tentative CL for this system (Anon 2000, McGinnity pers. comm.). Since 1980, hatchery smolts from the same system have been tagged and released with coded wire tags (CWTs) to provide an estimate of marine survival and exploitation rates for both the wild and hatchery stocks. These data provide estimates of the total returns to the coast and the number removed in commercial and recreational fisheries. It is therefore possible to assess, over a significant period of time, the relationship between catch and attainment of the CL for the wild Burrishoole stock.

To establish CLs for salmon stocks in regions where there are no monitored rivers, a model has been developed to establish "pseudo"-stock and recruitment relationships based on catch data and estimates of exploitation rates and unreported catches (Potter et al, 1998, Potter and Nicholson 2001). Establishment of appropriate CLs can then be used to provide similar relationships between catch and the attainment of these CLs within defined regions. The method has been applied as an example to catch and CWT return data for the Bangor district of the North Western Fisheries Region to examine the history of CL attainment. Finally, the estimated difference between the overall return to the Burrishoole River specifically and to the corresponding fishery district and the spawning stocks after the fisheries is examined.

MATERIALS AND METHODS

Since 1970, there has been a full upstream and downstream counting facility for salmon on the Burrishoole River. The total counts of upstream migrating reared fish and the numbers of tagged fish taken in the fishery are available from the relevant Annual Reports of the Salmon Research Agency of Ireland (formerly the Salmon Research Trust).

Reared salmon smolts are micro-tagged and adipose fin-clipped before being released into the system. Tag recoveries are generated from international high-seas fisheries in the Faroes and Greenland and from homewater fisheries (drift nets, draft nets, angling etc). Data on declared salmon landings in each of the corresponding areas are collected by the seven regional Fishery Boards and compiled into a national data set by the Marine Institute. Salmon landings are also provided by the Foyle Fisheries Commission and tag recovery information is provided by the Dept. of Agriculture and Rural Development for Northern Ireland. The number of adult recaptures taken in these fisheries is estimated by multiplying the number of tags recovered in each fishery district by the ratio of the reported commercial catch in these districts to the sample size examined. Over 30 tag recovery locations, covering fish dealers and processors, are scanned for the presence of finclipped salmon. There is also a non-catch fishing mortality (NCFM) associated with these fisheries which includes losses from nets and non-reporting of catches. An estimate of NCFM is derived annually from local knowledge and experience. This can then be used to expand the net recovered tags to estimate the total number of tagged fish killed in the fishery.

The total stock returning to the river is estimated by summing the counts of reared salmon in the upstream trap, together with those taken by the recreational fishery. The total number of fish available to the coastal fishery can then be estimated by adding the number of fish killed to the number returning to the river. For the purposes of this analysis, it is assumed that the tags are randomly distributed throughout the fishery and that non-recognition or non-detection of tags is minimal. Exploitation is estimated by dividing the number of fish caught in a fishery by the number available to the fishery.

ESTIMATION OF TOTAL RETURNS PRIOR TO COASTAL FISHERIES (BURRISHOOLE) AND PRE-FISHERY ABUNDANCE (BANGOR DISTRICT)

Burrishoole

Examination of data on coded wire tagging and tag recoveries for the Burrishoole and other Irish rivers provides sufficient information to suggest that exploitation by commercial fisheries on wild stocks is generally less than on the hatchery fish (Anon. 2001). It also suggests that exploitation on the hatchery stocks has not varied significantly over the twenty year period examined (O' Maoiléidigh et al 1994, O' Maoiléidigh et al 1996). It has therefore been assumed that the maximum exploitation rate on wild Burrishoole salmon is 70%, and the annual wild fish exploitation rates are therefore 70% of the values for hatchery fish. This provides an estimate of total returns of wild fish prior to coastal fisheries.

Bangor District

Catch records from commercial dealers registers are available from 1970. The model used to estimate the pre-fishery abundance of salmon from countries in the NEAC area employs a

simple run-reconstruction approach similar to that described by Potter and Dunkley (1993) and Rago et al (1993). Following Potter et al (1998), the model takes the catch in numbers of one-sea winter (1SW) and multi-sea winter (MSW) salmon in each country which are then raised to account for estimates of non-reported catches and exploitation rates on the two sea-age groups. Finally, they are raised to take account of the natural mortality between January Ist in the first sea winter, which is the date they recruit to the first fishery (Faroes). As some of the above parameters cannot be estimated precisely (i.e. unreported catch and exploitation rate), minimum and maximum values are provided which are considered likely to encompass the true values (Table 1). These values are used to delimit uniform distributions for these parameters in a Monte Carlo simulation. The simulation, which uses the software package "Crystal Ball" (Risk assessment software add-in for Microsoft ExcelTM from Decisioneering Inc, Decisioneering UK, Ltd., 1996) is run in Microsoft EXCEL to generate estimated distributions of the PFA values by simulating 1000 runs of the model.

Table 1 Input data for Bangor district pre-fishery abundance analysis using Monte-Carlo Simulation

Year	Catch (numbers)		Unrep. as % of total 1SW	% of total		Unrep. as % of total MSVV		Exp. rate 1SW (%)		Exp. rate MSVV (%)	
	1SW	MSW	min	max	min	max	min	max	min	max	
1971	13,848	1.539	30	45	30	50	50	70	40	50	
1972	13,677	1,520	30	45	30	50	50	70	40	50	
1973	27,841	3,093	30	45	30	50	50	70	40	50	
1974	42,703	4,745	30	45	30	50	50	70	40	50	
1975	38,351	4,261	30	45	30	50	50	70	40	50	
1976	30,634	3,404	30	45	30	50	50	70	40	50	
1977	21,617	2,402	30	45	30	50	50	70	40	50	
1978	20,393	2,266	30	45	30	50	50	70	40	50	
1979	27,221	3,025	30	45	30	50	50	70	40	50	
1980	18,126	2,891	30	45	30	50	50	70	40	50	
1981	2,827	523	30	45	30	50	62	76	40	50	
1982	15,191	605	30	45	30	50	61	81	21	42	
1983	32,292	1,892	30	45	30	50	54	74	7	14	
1984	4,491	367	30	45	30	50	59	75	14	27	
1985	20,825	819	30	45	30	50	66	86	25	50	
1986	19,994	1,137	30	45	30	50	63	77	27	55	
1987	16,747	1,289	20	40	20	45	60	85	23	- 47	
1988	14,819	811	20	40	20	45	45	77	22	44	
1989	24,484	1,994	20	40	20	45	60	81	29	58	
1990	14,024	1,142	20	40	20	45	46	76	26	53	
1991	11,033	898	20	40	20	45	40	64	28	56	
1992	21,752	1,771	20	40	20	45	47	79	29	58	
1993	15,704	1,279	15	35	20	45	46	68	18	37	
1994	21,143	1,722	15	35	20	45	47	77	21	41	
1995	21,786	1,774	15	35	20	45	51	83	21	42	
1996	17,911	1,459	15	35	15	30	50	74	28	56	
1997	9,131	744	10	. 20	10	20	30	74	22	43	
1998	10,994	895	10	20	10	20	30	72	31	61	
1999	5,713	465	10	20	10	20	45	75	25	50	
2000	6,149	501	10	20	10	20	45	74	25	50	

ESTIMATION OF SPAWNING STOCKS AND CONSERVATION LIMITS (CL)

Burrishoole

Estimation of the total spawning stock for the Burrishoole is based on total trap counts of all ascending adults. Stock and recruitment curves were generated to identify reference points (McGinnity et al, in prep). Examination of the data set suggested that the period 1987 to 1993 provides a realistic model in terms of present day stock in the Burrishoole). In order to produce the maximum smolt output, the model indicated that 616 adult spawners would be required. Although this is not the MSY point, it is sufficiently close to be used here for illustrative and comparative purposes.

Bangor District

Following Potter et al (1998), estimates of spawning stocks are derived as model outputs from the information on catches, unreported catch and exploitation rate. However, stock and recruitment relationships cannot be derived directly from these data because the spawners in year "n" contribute to the 1SW recruitment in year "n+3" to year "n+5", depending on the relative proportions of 1 to 3 year old smolts which could be produced. Thus, for example, spawners in year "n" may produce; 1 year old smolts in year "n+2" which generate 1SW recruits in year "n+3"; 2 year old smolts in year "n+3" which produce 1SW recruits in year "n+4" and so forth (Table 2).

Table 2 Lagged egg deposition analysis for the Bangor district

	Est 1SW spawners	Est MSW spawners	Fgg deposition	Smolt age	e composi	tion				Lagged egg dep	Total 1SW recruits	
Eqq	3400	7000	egg x 10 ⁻³	1 yr	2 yr	3 yr	4 yr	5 yr	буг	S	R	R/S
Fem	60%	85%		0.20	0.70	0.10	0.00	0.00	0.00	egg x 10 ⁻³		
1971	15,098	3,193	49,798							n/a	93,592	
1972	14,804	3,156	48,978							n/a	92,457	
1973	30,185	6,384	99,563							n/a	142,408	
1974	46,221	9,818	152,709	9,959						n/a	176,488	
1975	41,708	8,860	137,801	9,796	34,857					n/a	163,794	
1976	33,580	7,033	110,350		34,285	4,980				59,177	121,792	2.06
1977	23,469	5,016	77,723		69,694	4,898	0			105,134	98,279	0.93
1978	22,402	4,675	73,518	27,560	106,896	9,956	0	0		144,413	89,940	0.62
1979	30,066	6,271	98,649	22,070	96,461	15,271	0	0	0	133,802	125,816	0.94
1980	19,961	6,009	76,474		77,245	13,780	.0	0	0		89,905	0.84
1981	2,058	1,092	10,698		54,406	11,035	0	0	0		47,264	0.59
1982	10,323	2,390	35,278		51,463	7,772	0	0	0		99,390	1.26
1983	30,134	28,566	231,441	15,295	69,055	7,352	0	0	0		109,227	1.19
1984	3,555	2,518	22,233		53,532	9,865	0	0	0		29,884	0.48
1985	11,013	2,493	37,299		7,489	7,647	0	- 0	0		78,960	3.58
1986	13,957	2,944	45,991	46,288	24,694	1,070	0	0	0		77,059	1.07
1987	9,413	3,775	41,668	4,447	162,009	3,528	0	0	0		56,056	0.33
1988	14,245	2,606	44,567	7,460	15,563	23,144	0	0	0	46,167	71,697	1.55
1989	15,174	4,124	55,493	9,198	26,109	2,223	0	0	0	37,531	71,298	1.90
1990	13,673	2,766	44,349	8,333	32,194	3,730	.0	0	0	44,257	44,717	1.01
1991	15,399	2,028	43,482	8,913	29,166	4,599	0	0	0	42,678	46,962	1.10
1992	19.067	3,686	60.831	11,099	31,197	4,167	0	0	0	46,462	67,359	1.45
1993	16,631	5,316	65.555	8,870	38 845	4,457	0	0	0	52,171	52,789	1.01
1994	18,107	6,287	74,345		31,044	5,549	0	0	0		62,157	1.37
1995	15,291	5,969	66,712		30,438	4,435	0	0	0		55,680	1.18
1996	15.343	2,719	47,475		42,581	4,348	0	0	0		46,540	0.78
1997	11,414	1,926	34,745		45,888	6,083	0	0	0		27,022	0.40
1998	14,228	1,330	36,940		52.042	6,555	0	0	0		31,275	0.43
1999	4,734	990	15,548		46,698	7,435	0	0	0		14,352	0.23
2000	5.252	1.044	16,923		33,232	6.671	0	0	0		34,002	2.20

1SW and MSW salmon also contribute to recruitment in different proportions, principally because of the greater egg deposition from the MSW salmon resulting from their greater size and higher proportion of females. This is taken into account by converting the numbers of 1SW and MSW spawners into numbers of eggs deposited.

The egg deposition in year "n" is assumed to contribute to the recruitment in year "n+3" to "n+5" in proportion to the numbers of smolts produced of ages 1 to 3. Thus the number of "lagged eggs" which contribute to the recruitment of maturing and non-maturing 1SW fish in each year can be estimated.

The lagged eggs estimates provide a measure of the relative spawning level which gave rise to the recruitment figures expressed above as the PFA. These data can then be plotted to provide a "pseudo" stock-recruitment relationship and a number of reference points can be derived. It is not possible to estimate S_{MSY} from this relationship without making further assumptions about marine survival. As a result, a simple method for setting biological reference points from such noisy stock-recruitment relationships was developed by Potter and Nicholson (2001). The model assumes that there is a critical stock level below which recruitment decreases linearly towards zero stock and recruitment, and above which the recruitment is constant. The position of the critical stock level is determined by searching for the value that minimises the residual sum of squares. Potter and Nicholson applied this approach to similar quasi-stock-recruitment relationships (Figure 3).

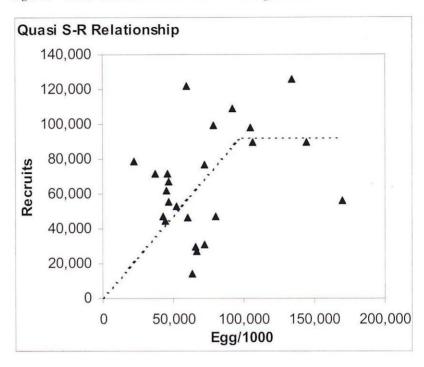
The final process is to convert the egg CLs derived from the above analyses to age-specific CLs, i.e. number of adult fish based on the expected sea age distribution of the population being examined, in this case the Bangor salmon. In this analysis the CL is compared to PFA and therefore is raised to take account of natural mortality between the 1st of January in the first sea winter and the time of return to homewaters. The adjusted value is referred to as the Spawning Escapement Reserve (SER) to allow a distinction to be made between this value and a CL.

HISTORICAL ATTAINMENT OF CONSERVATION LIMITS

Catches in the North Western Region and Bangor district are significantly correlated with the actual returns to the Burrishoole River (p < 0.01, Figure 4). Examination of the total returns of Burrishoole fish compared with the CL indicate that the CL would have been met in all years if all fish were allowed to enter the system. However, the spawning stock remaining subsequent to the commercial fisheries has been less than the CL in all years except one.

Similarly, total recruits (prior to the commercial fisheries) for the Bangor district have been above the CL in all years except 1981, 1984 and the most recent two years (1999 and 2000, Figure 5). The number of fish remaining after commercial catches (spawners) has only been above the CL consistently from 1973 to 1980. Subsequently, the number of spawners has been significantly less than the estimated CL.

Figure 3 Conservation limit estimation for the Bangor district



Conservation lin	mit:		
Eggs /1000	1SW	MSW	Total salmon
98,590	28,874	6,670	35,544

The percentage of the CL attained for the Burrishoole has fluctuated considerably and has been as low as 60% under-attained in some years (Figure 6). Greater than 70% under-attainment has been suggested for the Bangor district in some years (notably the most recent two years) although in the past there was a considerable return above the required CL (Figure 7).

With these data it is possible to estimate the proportion of the catch which was available provided the CL had been achieved. This is illustrated for the Bangor district (Figure 8). A consistent period from 1973 to 1980 is apparent where the catch could have been higher and the CL would still have been achieved. However, from that period on, reductions in catch would have been required in order to meet CLs and in some instances it would have required a complete cessation of fishing to achieve the CLs.

Figure 4 Comparison of Burrishoole returns and regional and district catches

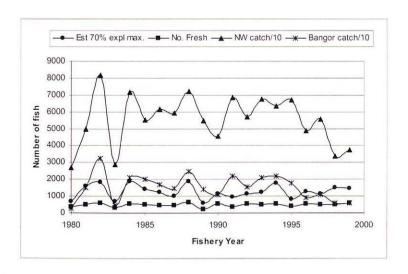


Figure 5 Attainment of conservation limit for the Burrishoole River.

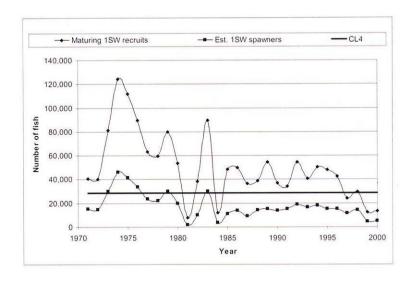


Figure 6 Attainment of conservation limit for the Bangor District

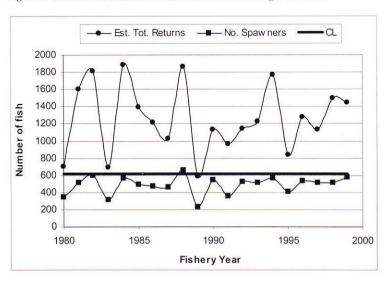
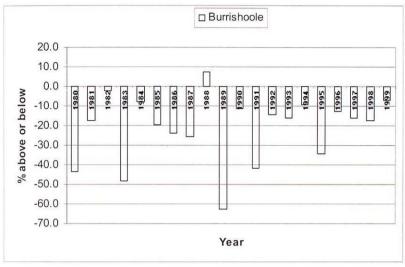


Figure 7 Percentage of conservation limit achieved



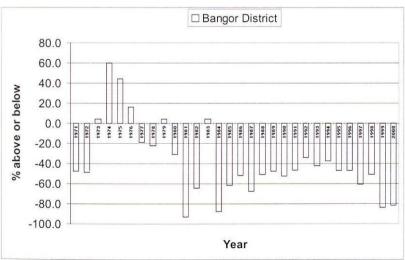
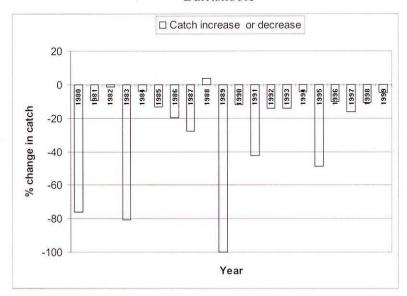
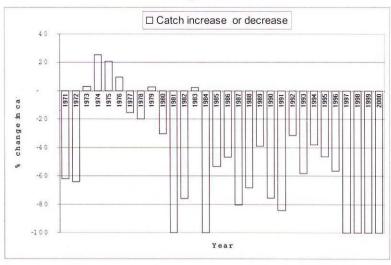


Figure 8 Illustration of the percentage of the catch increase possible or the catch decrease necessary relative to attainment of the conservation limit for the Burrishoole stock and combined Bangor district stocks

Burrishoole



Bangor District



DISCUSSION

Catch statistics alone have do not provide a sufficiently reliable index of the stocks of salmon returning to the coast or of the number of fish surviving to spawn. However, very long time series of catch data is available in the Republic of Ireland, and, in general, these catches have been reported in a consistent manner throughout these periods. With the development of new concepts in salmon fisheries management (i.e. CLs and other biological reference points) and the general acceptance of the Precautionary Approach it has been necessary to look again at the contribution catch statistics can make to salmon stock assessment, once the best information from other sources has been applied to them. The extensive data sets generated on marine survival and exploitation rates from the national coded wire tagging and recovery programme have provided key results which can be applied to the catch data to produce estimates of recruitment, total returns and spawners. Development of fishery models has allowed the establishment of biologically-based reference points to aid managers in allocating this resource to the relevant user groups while still providing sufficient spawning capacity to safeguard national stocks.

The example above using the Bangor District of the North Western Fisheries Region illustrates a possible method of applying CLs to stocks where individual river CLs cannot be set due to lack of information. Examination of the historical attainment of the CL may prove to be useful in determining starting points for quotas, set-asides, buy-outs etc. However, the analysis is limited to providing the relative attainment for the previous year or years and may not be a true reflection of the potential stock (or catch) in the current year. Development of predictive Pre-Fishery Abundance models or in-season assessments will be required in order to set true quotas.

This analysis is equally applicable to all other fishery districts in Ireland. While CLs can be derived they are very much preliminary at present and more work is required to ensure that they reflect real events in individual fisheries. It should also be noted that, where district CLs are being met, this does not necessarily mean that all of the individual river stocks are above their CLs (and *vice versa*) and caution should be exercised in applying the CLs in the absence of other supporting information which may be available.

ACKNOWLEDGEMENTS

Members of staff of the Salmon Management Services Division of the Marine Institute, the Electricity Supply Board and the Western Regional Fisheries Board are gratefully acknowledged for providing hatchery-reared fish for tagging and associated release and recovery information. We are indebted to staff of the Central and Regional Fisheries Boards for provision of catch and other data in general and also for providing invaluable assistance during tagging operations. Declared salmon landings are also provided by the Foyle and Carlingford Loughs Agency The efforts of the many bursar students who participated in the National Coded Wire Tagging and Recovery Programme are acknowledged.

This programme could not have been carried out without the full co-operation and assistance of salmon fishermen, licensed dealers and processors, to whom we are sincerely indebted. Information and assistance from anglers and angling fishery owners and managers is also gratefully acknowledged

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FACTORS AFFFECTING ROD CATCHES - CATCHABILITY

R.G.J. Shelton

School of Environmental & Evolutionary Biology
University of St. Andrews, St. Andrews, Fife, KY16 9TS*
*Address for correspondence: "Dallraoich", Strathtay, Pitlochry, Perthshire PH9 0PJ

INTRODUCTION

Provided they are reported accurately, the catch statistics of fisheries have value in themselves as an account of the industry which they record. They also have value to the population dynamicist as part of the information he requires to estimate the size, and where possible, the structure of the stock of fish from which they were obtained. To quote Solomon & Potter (1992);

- "changes in catch figures, including a change in the monthly distribution of catches, are generally the first indicator of a stock management problem;
- the catch figure may be an important input to deriving a measure of exploitation level, where an independent estimate of total run or residual run (after exploitation) is available;
- if exploitation level is available from a different approach (eg a mark and recapture programme), total stocks can be calculated from reliable catch data."

Regrettably, for many salmon fisheries, the statistics of its reported catches are the only semiquantitative data available to inform management decisions. Furthermore, as net-fishing effort declines in response to market forces, stock scarcity and 'buy-out' schemes, so fishery managers have had to place increasing reliance on the reported catches of anglers. The interpretation of such limited data poses special problems.

FIRST PRINCIPLES

In classical fishing theory, the catch in numbers by any one method at any one time can be derived from the number of fish in the available stock (N), the catchability of those fish (q) and the fishing effort (f) exerted. Thus, provided the values of f and q are known, catch is an index of stock which can be used directly for management purposes. Rod fisheries for homing migratory species like Atlantic salmon deviate substantially from the idealized picture presented above. N is not a single entity representing a stock of fish in one area against which an enclosing or pursuing gear is directed. In essence, rod-&-line fisheries for salmon are interceptory and are based upon groups of fish temporarily-resident or passing through fishing zones. Often there are important differences in the run-timings and age structures of the groups and some may be members of quite different self-sustaining populations (Verspoor, 1995). Also, because capture depends as much upon action by the fish as by the angler, q may vary within wide limits, some of which are set internally (the subject of this paper) and some of which are strongly influenced by environmental conditions. Furthermore, in many rivers, substantial numbers of fish may pass through the fishing zones outwith the angling season or die from natural and other unrecorded causes. It follows that,

however well estimated f and q may be, the raw statistics of a rod-&-line fishery for wild salmon can never provide more than an index of the status of the more or less mixed stock of fish available at the time the fishery takes place. With all these caveats, it is not surprising that many arguments between anglers and scientists arise directly from different interpretations of catch statistics. This paper considers how the potential utility of selected rod-and-line statistics may be increased through a better understanding of the behavioural and physiological attributes of salmon that affect their catchability by angling. The summary statistics of the Scottish salmon fishery are the starting point.

THE STATISTICS OF THE SCOTTISH SALMON FISHERY

The annual statistics of the Scottish salmon fishery as reported to The Scottish Office (now The Scottish Executive) since 1952, record the results of the rod-and-line and the two principal netting fisheries (fixed engine and net-and-coble) separately. Whereas the total catches of the net fisheries fluctuate in a pattern broadly in line with independently-obtained estimates of marine survival levels, and known changes in net-fishing effort, the rod-and-line statistics for all salmon and grilse combined show no such pattern (Fig.1); indeed, they show rather little annual variation of any kind.

Two main possibilities (other than changes in the levels and distribution of angling and net fishing effort) suggest themselves, first the statistics of the rod-and-line fisheries may be seriously mis-reported. Given that the Salmon Fishery Board levy on fishings and Local Authority rates in areas without District Salmon Fishery Boards are linked to catches, the temptation to under-report cannot be dismissed. *Per contra*, the sale values of fisheries are also linked to catches and those contemplating future sale may tend, if not to inflate reported catches, at least to ensure that nothing is missed out. Secondly, a number of scientifically-inclined anglers have advanced the hypothesis that, at least over a short period, catch rates increase with stock numbers up to limits set by the availability of 'lies'. Some have even gone so far as to suggest that over-crowding at lies may even reduce catch rates. Separately or in combination, both of the above effects would tend to constrain reported catches within narrower limits than those of the stocks from which they were obtained. Nevertheless, when reported rod-and-line catches are plotted separately on an expanded 'Y' axis, as spring salmon (Fig.2), summer salmon (Fig.3) and grilse (Fig.4) some signals apparently emerge.

SPRING SALMON, SUMMER SALMON AND GRILSE

'Spring' salmon are defined in the statistics of reported rod-and-line catches as salmon caught before 1 May. Virtually all are multi-sea-winter salmon (MSW), i.e. fish which are deemed to have spent 2 or more winters at sea prior to entering rivers in winter and spring. The record of their catches is one of sustained and widespread decline (Fig.2). Accompanying the decline in the numerical strength of the catch has been a marked reduction in the relative representation of older sea age classes to the point where the spring catch now largely consists of 2 SW fish (Youngson 1995). Such a change in age composition is entirely to be expected in a stock of fish subjected to a sustained increase in total sea mortality rate which, by definition, poses the greatest risks to the fish exposed to it longest.

Figure 1



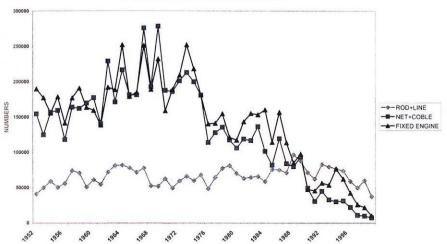


Figure 2

ROD-CAUGHT SPRING SALMON (BEFORE 1 MAY)

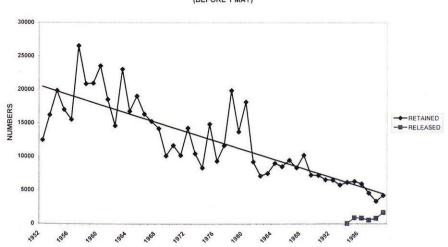


Figure 3

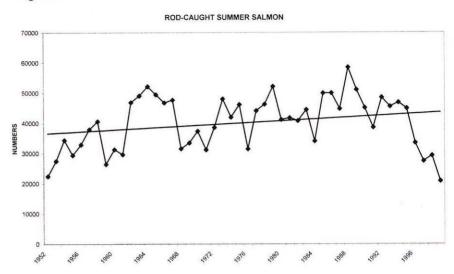
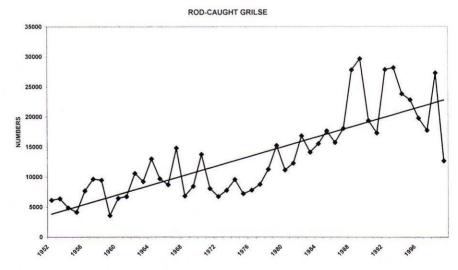


Figure 4



'Summer' salmon are defined as fish caught at any time from 1 May until the end of the fishing season. The rod-and-line catch of this category is very mixed. It includes some MSW salmon which have entered rivers in the previous winter or spring, summer and autumn-running MSW salmon, and considerable numbers of grilse (1 SW salmon) misidentified by anglers as MSW fish. The overall trend for this conglomerate is weakly upward (Fig.3).

The reported rod-and-line catch of grilse comprises those fish regarded by anglers to be too small to be entered into the game book as salmon! Most of the fish so-reported are correctly identified. The reported rod-and-line catch of grilse exhibits a marked upward trend. Given that the summer 'salmon' catch also includes grilse, it would seem that the availability of these fish to the angler has generally increased since 1952.

On superficial inspection, and in the absence of comprehensive catch sampling data, it would seem that the statistics of the total Scottish rod-and-line catch of summer salmon represent too mixed a derivative of the stocks from which they were obtained to be of much use for assessment purposes. The statistics of the spring rod-and-line fishery and that for grilse seem to offer greater potential, especially now that both catch data sets largely represent single sea year classes. Neither set of statistics is without its problems. Winter and spring-running salmon are vulnerable to capture until the end of the fishing season. Indeed, the rod-and-line catch of these fish may be especially important in May (Youngson 1995), by which time they are reported as 'summer salmon'. In the same way, the earliest-running grilse, which are also the smallest, are biologically-speaking an integral part of the early-running populations from which 'springers' are derived. Even with these provisos it would seem that the statistics of the spring and grilse fisheries merit further examination in the light of what is known about long-term changes in the rate and distribution of fishing effort and of changes in catchability within each fishing season.

OBSERVED EXPLOITATION LEVELS

Salmon fishery biologists traditionally define the effects of rod-and-line fishing in terms of exploitation levels; that is to say the proportion that the angler catches of the stock of fish available to him. The estimation of exploitation levels for fish migrating through fishing zones is never straightforward. In addition to the statistics of the fishery it demands some kind of independent measure of the total stock and, ideally also, a measure of losses suffered from causes other than directed fishing. Sometimes the independent measure of stock may be the output of a fish counter or the results achieved at a counting fence. Alternatively, the stock may be estimated on the basis of tag returns. A useful account of the ways in which rod-and-line fishery exploitation levels may be estimated is found in Solomon & Potter (1992). They summarized the results of 18 attempts to estimate exploitation levels in the rivers of Great Britain and Ireland. Despite wide differences apparently attributable to the methods and assumptions adopted, a number of biologically-interesting conclusions emerged:

- The rivers with the lower overall exploitation levels tended to be fished predominantly by fly and those with the higher levels included a greater proportion of fish taken on baits such as prawn or worm which offer olfactory as well as other sensory attractions.
- Exploitation levels tend to increase as stock size falls and may do so sharply at the lowest stock levels.

- Exploitation levels on MSW fish (which usually run earlier than grilse in both early and late-running populations) tend to be higher than those for grilse (ISW).
- Catchability appears to be highest for recent, early entrants to fresh water especially
 during the initial weeks of migratory activity. Subsequent capture events were found to
 be sporadic until September, perhaps in response to pre-spawning activity and greater
 migratory responsiveness to minor flow events.

The results summarised by Solomon & Potter (1992) have, in general, been confirmed by the results of radio-tagging studies in Scotland on relatively robust stocks. Recurrent themes of this work is the great vulnerablility to angling pressure of early-running salmon in the early weeks following entry to fresh water and that willingness to attack a lure is often associated with migratory activity, especially in response to changes in flow (Laughton, 1991, Webb, 1989).

CATCHABILITY AND SALMON BEHAVIOUR

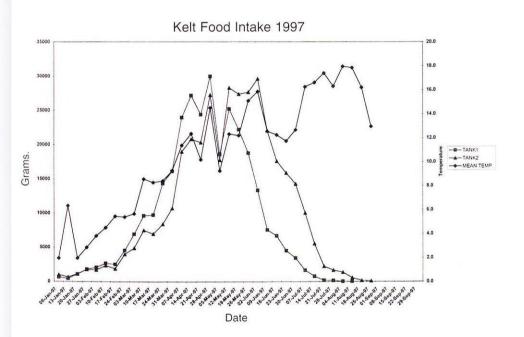
Angling is a form of line fishing and, like all line fishing, depends for its success on the decision by the fish to attack a lure. Typically, the purpose of the lure is to act as a source of visual, acoustic or olfactory stimuli, either separately, or combined in such a way as to elicit a feeding response in the quarry. Angling for salmon in fresh water is unusual in that the quarry has ceased to feed at the time the fishery takes place. This paradox is a source of endless fascination to angling authors and it is to one of their number (Falkus 1984) that we owe a critical account, based on his direct observations of individual fish, of the responses of salmon to lures. In suggesting an explanation for the variety of reactions seen, some of which he interprets as 'play', Falkus advances the hypothesis that modified feeding behaviour and aggression in defence of lies and spawning opportunities are the two primary reasons for attacks on lures.

It is implicit in Falkus' interpretation, although not explicitly stated, that feeding behaviour is not a single action but a hierarchy of motor events in which potential prey is sighted, followed, grasped and swallowed. In wild adults in fresh water this sequence is attenuated and swallowing is rare. Some insight into the attenuation process may be gained by watching the recovery of captive wild salmon kelts. In these fish, food intake tracks water temperature (Fig.5) (Miles & Keay 1995) until the late spring, after which it falls sharply and ceases altogether by early autumn. As food intake falls, and for a short time after it ceases, some fish will attack food but then eject it from their mouths (Miles, personal communication). Satiated fish may exhibit this behaviour at any time. The suppression of appetite seen in the captive fish appears to be directly linked to the endocrine changes associated with maturation. Interestingly, although it is common to find marine prey in the stomachs of fresh-run salmon in early spring, it is rare to find the freshly-eaten remains of marine prey in salmon caught in coastal waters beyond the end of June (Fraser 1987).

It is the earliest stage of maturation which triggers the spawning migration of all salmon from their sea feeding grounds to coastal waters and rivers (Youngson & Hay, 1996). Winter and spring-running salmon enter fresh water many months before spawning. Their gonads at entry are much less developed than those of later-running fish. By analogy with the observations on recovering kelts, the willingness of early-running salmon to take a lure boldly might reasonably be regarded as an attenuated continuation of behaviour recently indulged in at sea.

Falkus (1984) also describes in detail the behaviour of much less willing 'takers'. Such fish may suck small flies or other drifting objects into their opened mouths so gently that they are expelled before the angler is aware that his fly has attracted attention. A salmon behaving in this way has usually been in the river for some time and has established itself at a lie much in the way that as a parr it would have dominated a feeding station (Armstrong et al, 1999). Fish at lies may also attack larger lures, including parr and trout appearing suddenly above or in front of them. Here the adult salmon appears to react to an 'intruder' rather like a parr defending its feeding station against a competitor. Falkus (1984) notes that the "territories" of adults which are not over-crowded appear to extend "with a radius of two or three feet all round extending like an inverted cone towards the surface".

The tendency for sea-run adults to attack parr becomes more strongly developed prior to and during spawning activity (Jones 1959). Both sexes indulge in this kind of behaviour but subsequent observations suggest that it is more strongly developed in sea-run males for which the mature male parr represent serious sexual competition (Youngson & Hay, 1996).



CONCLUSIONS

It is clear from the inspection of catch statistics, the observations of anglers, the return rates of tagged fish and what is known of the behaviour and maturity status of adult salmon in fresh water, that catchability by angling varies greatly. The decision by a salmon to take a lure is influenced by both external and internal factors. Most anglers would agree that the most important of the former is the 'condition' (especially with respect to flow) of the river and, of the latter, biologists would lay emphasis on the maturation status of the gonads. Both factors appear to affect the state of 'alertness' of salmon in the river and their willingness to indulge in attenuated feeding, defensive or sexually-competitive behaviour.

At most times the angler's lure is exposed to a stock of fish which is heterogeneous in terms of the catchability of individual fish. Furthermore, the degree of heterogeneity increases as the season progresses and fresh-run fish make up a decreasing proportion of the total stock. On the face of it, the prospects for deriving CPUE data from annual angling returns which accurately reflect the underlying status of the stock complex from which the catch has been derived appear remote. The best chances for success appear to lie with the analysis of catch returns from anglers of known reliability fishing over specified parts of the fishing season. In large rivers the statistics of the spring fishery, which are based on the most homogeneous and catchable portion of the stock, are likely to prove the most rewarding to the population dynamicist. Unfortunately, the raw data currently show such strong evidence of sustained decline (Youngson 1997) that depensatory increases in catchability (Solomon & Potter 1992) may already be influencing returns.

Despite the clear-cut upward trend in reported rod-and-line catches of grilse, and their likely freedom from the undue inclusion of MSW fish, the 'loss' of mis-reported grilse to the summer and autumn catch inevitably means that CPUE values derived from reported grilse catches will be serious under-estimates. The least biased results are likely to be obtained by concentrating on the results of rod-and-line fisheries in short rivers known from sampling to be dominated by grilse taken over relatively brief periods around spates.

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FACTORS AFFECTING ROD AND LINE CATCHES – EFFECTIVENESS OF EFFORT

R. Gardiner

Fisheries Research Services, Freshwater Laboratory, Pitlochry, Perthshire PH16 5LB, UK

INTRODUCTION

It is self-evident that the number of fish that are available to be caught and the fishing effort (sum of the number of fish capture units x the time each fishes) are likely to be strong explanatory factors in determining fishing catch. In the case of sport fisheries on rivers, river flow has also been shown to be an important explanatory factor (e.g. Champion et al, 2001), although it is not considered in the present paper. The simple model,

catch / fishing effort \propto abundance (or, catch \propto fishing effort x abundance),

Model 1 Model 1a

has often been assumed, even where there is schooling or clumping behaviour of fish combined with fishermen being able to target areas where fish are concentrated, which would allow catch / fishing effort to be maintained at higher than expected levels as abundance declines (Paloheimo and Dickie, 1964). In such cases a power function

catch / fishing effort ∝ abundance^b

Model 2

has sometimes been used to model the relationship of catch / fishing effort with abundance, with 0 < b < 1 giving an appropriate shape to the relationship. Various studies have shown that this model often provides a reasonable fit to catch, effort and abundance data for sport fisheries for migratory salmonids (e.g. Peterman and Steer, 1981; Gardiner, 1991; Small, 1991). Nonetheless, it is evident that the model is not ideal in that it would predict impossibly high values for catchability (i.e. catch / fishing effort / abundance) and exploitation (i.e. catch / abundance) as abundance tends towards zero, and that it can predict a catch of more than the abundance if the fishing effort is sufficiently high.

An example of data for annual catch per rod day and annual count of salmon is given in Figure 1. Because of good background information, this particular data set is believed likely to be a reliable one for investigation.

- The beat involved is directly downstream of a dam in which the electronic fish counter is placed, so the counter should give a reliable indication of fish available to anglers.
- The counter was operated on a consistent basis
- There were no changes in operating procedure at the dam which could have led to variations in how long fish would be available to anglers.

- The fish pass in which the counter is sited concentrates the fish close to the counter electrodes, which aids fish detection.
- Many different anglers fished the beat each year, so the degree of expertise of particular anglers should matter less.
- There were no changes in fishing rules that might affect the effectiveness of anglers.
- Because of close supervision of the anglers, the information on rod-days fished and fish caught is highly reliable

The power relationship was found to provide a reasonable fit with b=0.39 (SE(b) 0.18).

Similar relationships have been found for other similar datasets for salmon catch per rod day and annual counts. In an analysis of data sets for nine rivers, Small (1991) found best estimates of the exponent, b, in the above relationship, all in the narrow range of 0.38 to 0.64 with SE(b) ranging from 0.09 to 0.25. The estimates of b were significantly different from 1 at a 95% level in the data sets for 8 of the 9 rivers. Although the similarity of the fitted relationships for the different rivers would suggest that an exponent of about 0.5 might be applicable to many salmon rivers, there remains a need to confirm the extent to which this value is indeed transportable to other situations.

NEED FOR CONSISTENT INFORMATION ON EFFORT TO INTERPRET CATCH DATA

The satisfactory fits of catch/effort to abundance data imply that a consistent measure of effort will be necessary to deduce abundance from catch data.

However, a consistent measure of effort may not be easy to obtain. There may be changes in the anglers fishing from year to year and their skill, or changes in the methods that anglers are allowed to use or in the number of fish that they are allowed to catch in a day. Detailed local information (perhaps through the implementation of logbook schemes) may be useful in assessing the extent to which effort in rod days is likely to give a consistent measure.

Take for example the continuation of the data set given in Figure 1, now with data for the years from 1990 inserted (Figure 2). In 1990, there was a change in the operating regime at the dam immediately above the beat with the introduction of salmon diversion screens to assist ascending salmon to find the fish ladder. Although, this could have influenced the length of time fish would be available to the anglers, it appeared not to affect the relationship between eatch per rod day and count. However, in 1996, a ban on the use of shrimp and prawn as bait was introduced on the beat (up to 1995 about 80% of the annual catch was on these baits), and more recently there has also been the introduction of voluntary bag limits. The plot shows that these conservation limits have had a clear impact on the effectiveness of anglers' effort. In the absence of knowing this, quite the wrong deductions about abundance might have been made from unqualified information on eatch and rod days fished alone.

Figure 1. Catch per rod day against annual count at Pitlochry Dam 1975-1989, showing power-fit line.

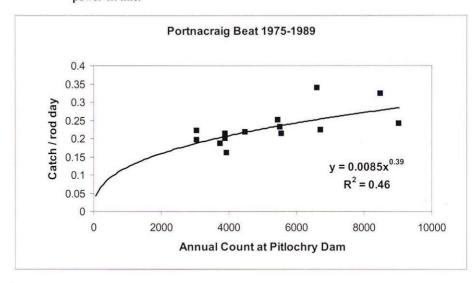
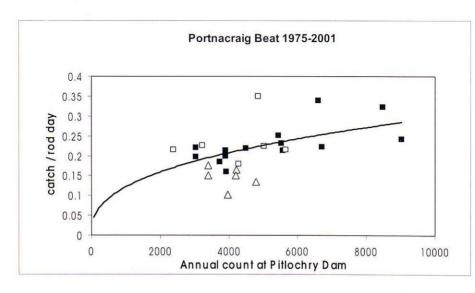


Figure 2. Catch per rod day against annual count at Pitlochry Dam 1975-2001. The solid squares show the 1975-1989 points, the hollow squares the 1990-1995 points, and the hollow triangles the 1996-2001 points. The fitted line is the power-fit line for 1975-1989.



OTHER MODELS

This paper has so far only considered the simple power relationship,

catch ∞ fishing effort x abundance^b.

Model 2a

Although this has the advantage of simplicity, it is not the only possible model. Bannerot and Ausin (1983) gave a more general formulation of the type given below that allowed non-linearity in eatch against both effort and abundance,

 $catch \propto fishing effort^a x abundance^b$.

Model 3

Such a model may well be more realistic in that it allows a fall off in the effectiveness of effort as effort increases.

As well as the power-fit model (2), Peterman and Steer (1981) also investigated an asymptotic type model,

catch / fishing effort = $c \times abundance / (1 + d \times abundance)$

Model 4

as well as a power fit model. This asymptotic model was further developed by Richards and Schnute (1986), who included an additional parameter to allow catch / fishing effort $\neq 0$, when abundance = 0. Such asymptotic models are more realistic than the power fit model in that they allow for saturation of fishing gear at high abundance, rather than the catch / effort increasing to impossibly high values as abundance increases. In addition, predicted catchability (i.e. catch / fishing effort / abundance) and exploitation level (i.e. catch / abundance) will be constrained at reasonable values as abundance tends towards zero. Nonetheless, these models will break down too at high effort levels in that they will predict catches of more than the abundance if the fishing effort is sufficiently high.

At the Workshop, I noted that models of the relationship of catch to fishing effort and abundance, which are asymptotic with respect to both fishing effort and abundance of the type,

catch = $c \times (effort/(1 + e \times effort)) \times (abundance/(1 + d \times abundance))$, Model 5

could be constructed which preclude the possibility of the predicted catch exceeding the abundance. Limited exploration of such models, which are straightforward to fit by non-linear regression, against some data sets that I had to hand, has shown promise for some of them. However, there is no guarantee that the fits to these more complicated models will prove more useful or transportable between rivers than the simple power fit model (Model 2).

IS INFORMATION ON FISHING EFFORT ALWAYS NEEDED?

But are there situations when it may be possible to work around a lack of good information on effort? Where fishing effort from year to year is fairly constant, a simple relationship of catch to abundance^b would be expected. However, even in this case knowing the number of rod days expended in taking the catch should be of value in working towards standard relations that might be transportable between different rivers being established. Similarly, information on likely trends in effort should allow at least a partial analysis.

But is it necessarily the case that even where effort varies greatly from year to year, a consistent measure of effort will be necessary to deduce abundance from catch data? A recent study (Crozier and Kennedy, 2001) on the River Bush in Northern Ireland, where for the period 1984-2000 the annual rod catch gave a good straight line relationship to abundance, and angling effort and catch were not found to be significantly correlated, despite an apparently wide range in angling effort from year to year. So, how could this arise? A proportional relationship of catch to abundance could arise in cases where angling effort increases with stock abundance sufficiently to offset the expected decrease in catchability as abundance increases. However, in such cases, angling catch and effort would still be correlated, which does not apply to the Bush data set. Or, one could speculate that true effort on the Bush is relatively constant from year to year, despite the wide variation in effort measured by ticket sales. Then a simple proportional relationship between catch and abundance would arise in the power fit model (Model 2), if the exponent, b, is close to 1. However, we have no evidence that this is the case on the Bush. Alternatively, if Model 5 is considered, effort would not be a useful explanatory factor in cases where all effort levels were sufficient to produce a maximum catch for the particular abundance level. However, this would seem unlikely to be the case on the Bush. Whatever the explanation, I believe that the Bush 1984-2000 data set is a special case, the results of which will not be generally transportable to other situations.

ACKNOWLEDGEMENTS

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THE USE OF ROD CATCHES TO ESTIMATE SALMON RUNS IN ENGLAND AND WALES

N.J. Milner, I.C. Davidson, R.E. Evans, V. Locke, R.J. Wyatt

National Salmon and Trout Fisheries Centre, Environment Agency, St Mellon's, Cardiff CF3 0LT

INTRODUCTION

In England and Wales, salmon angling is confined to the rivers. Rod catches provide a means of estimating the runs of salmon in individual rivers that is available across all the significant salmon (and sea trout) rivers in the country and offers a long time sequence of data. There are two main applications for declared catch data. First, catches are used as a primary measure of fishery performance. Second, they are used to make inferences about the runs of fish passing upstream to spawn. This latter application introduces a number of difficulties over the relationship between catch and stock (e.g. Small, 1991; Small and Downham, 1985). This paper describes the basic data sources and their use, and looks towards some future developments. The focus is on relationships between rod catch and stock (in-river annual run or annual spawning escapement, depending on context) for salmon, but reference is made to sea trout where this is appropriate. We consider first the circumstantial evidence for links between catch and stock from spatial and temporal patterns seen in national catch statistics, then examine those cases where independent stock estimates are available.

DESCRIPTION OF ROD CATCH DATA

Rod and net fisheries catches have been recorded nationally since 1952, although angling records go back much further for some rivers. The number of rivers for which catches are routinely reported has increased from 31 in 1952 to 68 in 1998 and now cover all the rivers with any consistent salmon fishing (Fig 1). Some of this increase is due to fishery recovery following environmental improvements, mainly removal of barriers and improving water quality. Net catches still dominate the national catch (Fig 2), representing 60-80% of the total, although their number has declined (Fig1). Catches in both fisheries are currently declining at around the same rate (Fig 2). Big changes in net licence sales, effort and gear efficiency make interpretation of the net catch data difficult for stock assessment purposes. Whilst changes have also occurred in the rod fisheries, their ubiquity and greater stock specificity (most net fisheries are more mixed than rod fisheries) make them more useful for stock and fishery assessment.

Most rod fisheries are found in the spate rivers of the North, West and South West, but some important and, historically, productive fisheries are also found in the chalk rivers of southern England (Fig 3).

Rod catch data have been collected by a licence return and reminder system since 1923, but the reliability of return statistics is difficult to establish, for most rivers, until 1974, when powers were extended. The current system, based on reminders issued since 1994, is estimated to give licence return rates of 71-76%. Using Small's (1991) method, this is estimated to record around 90% of actual legal rod catch.

The current declared salmon rod catches are not large by many standards (median annual catch for 1994-98 = 93 fish/river, range 3 to 1779) and have decreased greatly since the 1970s, a change that has been particularly marked in the early running (pre-June) component.

Figure 1 Numbers of rivers with fisheries catch data 1952 to 1998.

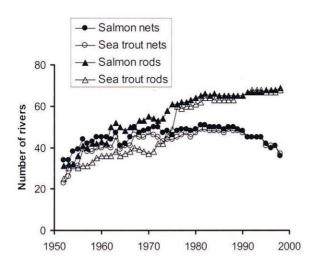


Figure 2 Total rod and net catches of salmon 1974 to 2000, adjusted for reporting rate (LOWESS smoothed curves).

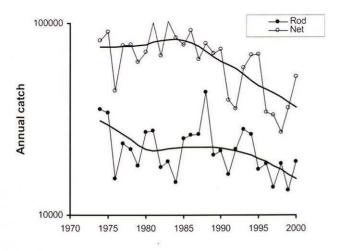
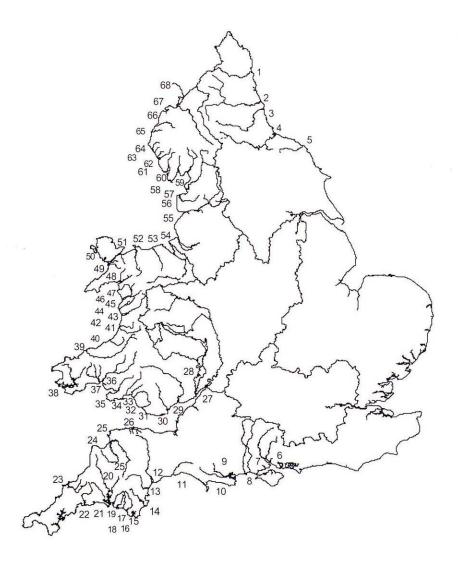


Figure 3 Location of salmon rivers



SPATIAL AND TEMPORAL PATTERNS IN CATCH, EFFORT AND CATCH PER EFFORT DATA

Effect of catchment dimensions

Juvenile salmon smolt production in rivers (and hence numbers of returning adults, other factors being constant) is held to be approximately proportional to its spawning area and juvenile carrying capacity (Symons, 1979; Gibson, 1993). These features are likely, from first principles of river structure, to increase with wetted area; so a reasonable hypothesis is that the run of salmon into a river is proportional to the river's size, or some surrogate. If rod catch is any index of annual run, then, assuming roughly equivalent exploitation rates, significant correlation between river size and annual rod catch should be expected.

The average annual catches (C), effort (f) (summed values, period 1992-2000) for each river were significantly positively correlated with catchment area (Fig.4). Catch per unit effort (C/f) was also positively weakly correlated with catchment area, suggesting some features such as accessibility, vulnerability or catchability were also related to river size

Simultaneous changes in catch, effort and catch per effort

Effort data (rod days fished in each river) have been collected since 1992 and were used to derive catch, effort and C/f for all rivers combined (Fig 5). None of the regressions, for the three variables against year (combining all rivers), during this period was statistically significant (P>0.05).

Synchronous variation in Dee, Wye and Usk rod catches

Analysis of three rivers in Wales, the Dee, Usk and Wye (Fig 3) is outlined here as an example of the coherence seen amongst some rivers. They were selected because they all have long time series of data and broadly similar stocks dominated by Multi-Sea-Winter (MSW) fish.

Seasonally-collected scale data from the Dee have shown that runs before 1st June comprise MSW salmon only, but after 1st June 2SW and 1SW salmon occur in roughly equal numbers. Catch data have been collected in different ways in these rivers. In the Wye, catches have always been based on owners' returns. In the Dee, catches came from owners' returns up to 1976 and thereafter through licence returns to the regulatory authority. In the Usk, data have always come through licence returns.

Pre- and post-June catches have changed over time in all the rivers, but to different extents, with the former declining considerably, compared with the more stable post-June catch (Fig 6). Inspection of Fig 6 shows a close correspondence between the three rivers over most of the time period. Correlation analysis indicated highly significant association amongst the three rivers for pre- and post-June catches separately (Table 1).

Correlation of long-term data may be driven by long term trends, within which short term variation might be weak or non-existent. Variance of catches was partitioned in order to estimate temporal variance, which is a measure of synchrony or the extent to which individual rivers respond in concert. A random effects two-way ANOVA was used, using the Minitab Generalised Linear Modelling (GLM) procedure. An additive model was fitted to log₁₀-transformed data:

$$C_{ij} = m + a_i + b_j + a \cdot b_{ij} + e_{(ij)}$$

Where C_{ij} = catch in river i in year j, m= overall mean catch, a_i = effect due to river i, b_j = effect due to year j, and $e_{(ij)}$ = error, including measurement error and interaction between river i and year j.

Variance was partitioned into spatial (Vs), temporal (Vt) and error (Ve) components of variance from:

$$V_s = (MS_s - MS_e)/m$$

$$V_t = (MS_t - MS_e)/n$$

$$V_e = MS_e$$

$$V_T = V_s + V_t + V_e$$

where

and

 V_T = total variance MS_s = mean square (rivers) MS_t = mean square (years) MS_e = error mean square m = number of years n = number of rivers.

Full analyses are given in Appendix I, but, in summary, show that temporal variance was high (and statistically significant) in pre- and post-June catch, representing 46% and 24% of total variance respectively in the two groups (Table 2). These results show that rod catches amongst the rivers were giving very similar signals about catch levels, even though the catch data were collected in different ways, suggesting that they were probably responding to common changes in run.

Such strong coherence might not be expected for all 68 E&W rivers, because they are variously subject to a wide variety of factors determined by location and geography, that in turn influences for example marine migration and survival or character and diversity of run groups. Such varying influences are reflected in different trends, which are seen when all rivers are compared together.

National river grouping based on catch

Locke (in prep) has analysed the salmon rod catch for each of the major salmonid rivers using linear regression to assess the performance of each river over the 25-year period. The regression lines were compared around the country to give a simple overview of rivers with decreasing catches over the 25-year period and those with increasing catches (Fig 7).

The analysis demonstrates considerable variation around the country, showing that total national catch trend hides a complex mosaic of regional and smaller scale variation, reflecting local circumstances. Thus the recovering rivers of NE England and SE Wales, contrast with the declining rivers in the Southern England and in much of West Wales. An interesting increase in the North West rivers reflects both genuinely increasing catches and, it is thought, an improvement in catch recording brought in during the 1980s. Thus data recording method may be as important as other factors.

A matrix of river-by-river catch correlation coefficients was constructed and multivariate cluster analysis was carried out (Locke, in prep.). This identified three main clusters, characterised by respectively increasing, stable and decreasing rod catches.

Table 1 Correlations amongst log 10 salmon rod catch in three Welsh rivers, 1952-98. Pearson Correlation coefficient (df=45)

	Wye pre- June	Wye post- June	Dee pre- June	Dee post- June	Usk pre- June
Wye post- June	0.337*				
Dee pre- June	0.844***	0.090 NS			
Dee post- June	0.009 NS	0.428**	-0.052 NS		
Usk pre- June	0.868***	0.295*	0.835***	0.026 NS	
Usk post- June	-0.021 NS	0.597***	0.026 NS	0.374**	0.224 NS

*** P=< 0.001 ** P=< 0.01 * P=< 0.05 NS Not Significant

Table 2 Variance partitioning for salmon rod catch in the rivers Wye, Usk and Dee, for the period 1952 to 1998, full analysis given in Appendix I.

Source of variance	Log 10 Pre-June % variance	Log10 Post-June % variance
River	48.4	61.8
Year	45.8	24.1
Error	5.8	14.1
Total variance	0.4628	0.1898

These results show that catch data do not vary randomly between or within rivers, but show quite specific and repeatable spatial and temporal patterns. Moreover, these are are explicable in terms of 1) effects of river size, 2) coherence of national trends in catch, but moderated by 3) effects of local influences. As indices of fishery performance, rod catch returns are thus regarded as usable measures for management. Often, catches are also taken as an index of stock (in-river run) and much of the discussion above has a tacit assumption that stock is the principle variable influencing catch. This issue is examined in the next section.

CATCH AND STOCK RELATIONSHIPS GIVEN INDEPENDENT STOCK MEASURES

Relationship between annual catch and stock

Assume that the relationship between catch (C_i) and in-river run (N_i) in year i is described by

$$C_i = N_i^{\alpha} k \tag{1}$$

where k = constant. Transforming Equation (1) to logarithms gives

$$Log C_i = \alpha . Log N_i + Log (k)$$
 (2)

A plot of Log C_i and against Log N_i will be a straight line. If the slope $(\alpha) = 1$, then C_i will be directly proportional to N_i and the exploitation rate will be constant with changing stock size. Very few rivers have independent measures of run size to compare against catch. However, such data, obtained from counters and trap (Dee) were available for seven rivers (Test, Itchen, Frome, Tamar, Fowey, Dee and Lune).

Log C_i was significantly correlated with Log N_i in all rivers except the Fowey and Dee (Table 3, Fig 8), although even in the latter the slopes were similar to other rivers (Fig 8). Slopes were not significantly different from 1 in all rivers except the Test and the Tamar, but the lower 95% confidence limits were close to 1 (Table 3). In the Test and Tamar α >1, implying that exploitation rate would increase with run size, which is a counter-intuitive result. This analysis shows that catch was significantly correlated with run, as might be expected, but ignores the effect of annual variation in effort.

If effort is accepted as an annually changing variable, the expression relating catch to run becomes

$$C_i = N_i^{\beta} \cdot f_i \cdot q \tag{3}$$

where

 f_i = fishing effort in year I

q = catchability, a constant, being the proportion of the stock taken per unit of fishing effort and

 $f_{i}.q = < 1$.

The annual exploitation rate U_i is thus

$$U_{i} = C_{i}/N_{i} = f_{i}.q.N_{i}^{\beta-1}$$
(4)

From Equation (3) a high catch may be due to a low run coupled with high effort, similarly, low catch may be due to high run and low effort. There is no way of knowing, without independent effort estimates, what is driving the variation in catch, either between or within rivers. This conundrum has been a recurring problem in the use of catches to estimate stock and to resolve it requires independent data on run size and effort. When effort data are available, a more informative analysis is possible. Equation (3) is rearranged to give

$$\log(C_i/f_i) = \beta.\log N_i + \log q \tag{5}$$

A plot of log (C_i/f_i) against log N_i is a straight line, with slope = β .

Fishing effort (licence days) has been systematically recorded only since 1993, but has been inconsistently reported for the Test and Itchen, where owners returns (unfortunately omitting effort) are the principal recording method. For this reason the Test and Itchen were omitted from the next stage of analysis. Plots of log (C_i/f_i) against log N_i (Fig 9) were constrained by fewer years of data, but showed that β was not significantly different from 1 for four out of five rivers (Table 4). Analysis of covariance, using the Minitab GLM procedure, showed no significant differences amongst slopes or intercepts of the rivers. The exception was the River Dee in which β <1, implying that exploitation follows a curvilinear relationship with exploitation rapidly increasing at low run sizes.

If it can be assumed that β approximates to 1, then from Equation (3) $C_i = N_i.f_i.q$. Analysis of variance demonstrated significant differences between rivers in values of U, f and q, but these variables showed similar degrees of variation between years, as estimated by coefficients of variation (Appendix II).

Exploitation rate (U) decreased with run size in most rivers (Fig 10), but the data were insufficient to test the form of this relationship.

Long term changes in true exploitation rates (i.e. fish killed) in most rivers showed decline in recent years (Fig 11), an effect partly attributable to catch and release, which has increased from 20% to 43% between 1995 and 2000 (Environment Agency, 2001).

Within-river variation and the effects of byelaws

While exploitation rates are comparatively stable within rivers, there is nevertheless some variation between years (coefficient of variation ranged from 20.5% to 35.5% amongst the seven rivers, Appendix II), but even more variation within season. A tagging and recapture programme on the River Dee, North Wales has provided a description of the exploitation experienced by salmon entering the river in different months. Early season entrants were subject to much higher exploitation than those entering later (Fig 12). The effect is also seen in the overall annual exploitation rates which were 17% and 10%, pre- and post-byelaws, respectively.

Regulation changes are occurring more frequently in salmon fisheries, with the explicit aim of changing exploitation rate, so this needs to be taken into account when looking at interpretation of historical catches. This example is a, probably unique, demonstration of byelaw effects changing exploitation rate (Davidson *et al.*, 2000).

Table 3 Regression statistics, Log10 (C) = $\alpha_{\rm L}$ Log10(N) + log10k

River	Е	intercept	Lower	Upper	slope	Lower	Upper	R2	ĹĽ,	Ь
		log 10(k)	95% CL	95% CL	(α)	95% CL	95% CL			
Test	13	-1.7293	-2.7144	-0.7442	1.3943	1.0544	1.7342	0.881	81.52	<0.001
Itchen	12	0.1379	-0.7680	1.0438	0.8062	0.4568	1.1556	0.726	26.43	<0.001
Frome	12	-0.5252	-1.4932	0.4428	0.8482	0.5423	1.1542	0.792	38.16	<0.001
Tamar	7	-4.0537	-6.4319	-1.6755	1.8144	1.1583	2.4705	0.910	50.53	0.001
Fowey	9	1.4785	-1.3996	4.3566	0.2052	-0.7364	1.1468	0.084	0.37	0.578
Dee	6	0.7588	-3.6388	5.1565	0.5016	-0.6781	1.6814	0.126	1.01	0.348
Lune	6	-0.0743	-1.6209	0.8383	0.8383	0.4245	1.2521	0.766	22.95	0.002

Table 4 Regression statistics, Log10 (C/f) = β .Log10(N) + log10(q)

River	=	intercept	Lower	Upper	slope	Lower	Upper	R2	[*	Ь
		log 10(q)	95% CL	95% CL	. (g)	95% CL	95% CL			
Frome	7	-2.3531	-11.1323	6.4261	0.4119	-2.4474	3.2712	0.027	0.14	0.726
Tamar	7	-6.2469	-10.3490	-2.1448	1.4591	0.3274	2.5908	0.687	10.98	0.021
Fowey	9	-3.4773	-5.9442	-1.0105	0.7022	-0.1049	1.5092	0.593	5.83	0.073
Dee	8	-1.6323	-3.8111	0.5465	0.1119	-0.4715	0.6952	0.035	0.22	0.655
Lune	~	-4.5662	-5.5727	-3.5598	0.9323	0.6642	1.2005	0.923	72.38	<0.001

USE OF CATCHES TO ESTIMATE EGG DEPOSITION

In England and Wales, salmon runs are estimated from rod catch in order to derive spawning escapement to test compliance with conservation limits (Milner *et al*, 2000). In the absence of river-specific exploitation data, current procedures use a simple regression model to derive a single exploitation value based on angling effort per unit catchment area (Environment Agency, 1996)

The calculations are performed separately for 1SW and MSW fish after an initial split and are finally summed to give total eggs. The following definitions apply:

"true" rod catch =
$$C_1 = C_d \times 1/r$$

where C_d = declared annual catch, r = proportion of true catch declared through licence returns. Rod catch is split into 1SW (C_{tg}) and MSW (C_{tm}) components using the proportion of 1SW (P_g) in the catch, derived from scale or weight data; then, for each sea-age component, spawners (S) are estimated from

$$S = C_t ((1/U) - 1) \times s$$

where U = extant rod exploitation rate, expressed as proportion of the total annual run, and s = proportion of fish surviving in-river phase. Egg depositions are then estimated using methods given in Environment Agency (1996). Default values for the parameter estimates have been defined that can be altered for each river depending on available data (Environment Agency, 1996). For many rivers, U is not known and is estimated from an empirical model between fishing intensity (rod days per catchment area) and U for those rivers where a U estimate has been possible. Clarifying the errors in U estimates and the factors contributing to between-river variation are important for this reason.

DISCUSSION

The analyses here demonstrate that rod catches are not randomly distributed spatially or temporally, but are responding to common influences. The common-sense proposal that big rivers have bigger catches is borne out, but they also have more fishing effort, so the relationship between effort and catch is of fundamental importance if the object is to interpret catch in terms of run size. Bigger rivers have higher catch per effort, but it is not clear if this is due to greater productivity per unit area, or to some feature of bigger rivers conferring higher catchability on their stocks. For example, such features might be prevalence of earlier running fish, access to fish holding areas, more fish passing through fishing zones or more stable fishing conditions.

The model for between-year variation in catch and run in equation (1) is clearly toosimplistic, because effort is known to vary between years. Equation (3) is an improvement, but still makes the assumption that catchability (q) is temporally constant for each river. A further difficulty applying to both equations is that C becomes greater than N at very high effort values. Nevertheless, as a useful preliminary model, application of equation (3), and its linear form (5), to a wider range of rivers with better data than available here would enable estimates of catchability to be derived for different rivers. This would reveal how stable this parameter is and if there are systematic differences between rivers. Small's (1991) work of ten years ago pointed the way in this subject and could usefully be extended now that there are more data sets and improved data handling methods available.

Figure 4 Relationship between rod catch (C), effort (f) and (C/f) and catchment size, England and Wales. (df=60, r=0.731,P<0.001; r=0.732,P<0.001 and r=0.296,P<0.05 respectively).

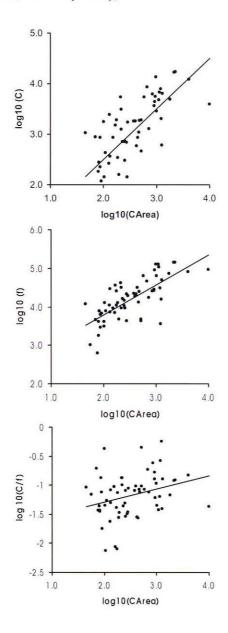


Figure 5 Changes in log10 catch (C), effort (f) and catch per effort (C/f) for 63 rivers in England and Wales, means of logged values and 95% confidence limits.

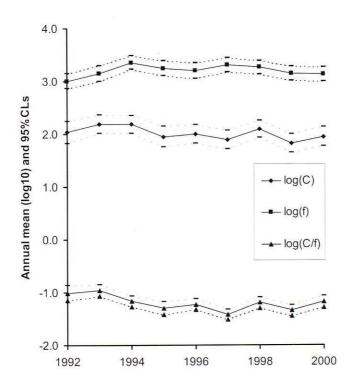
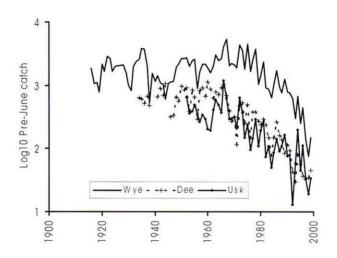


Figure 6 Temporal change in pre- and post-June salmon in three rivers



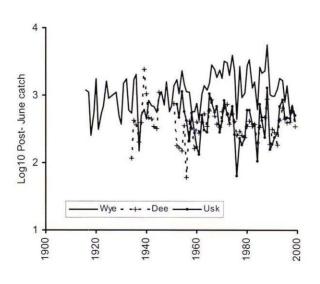


Figure 7 Spatial variation in the rate of change of rod catches for salmon around the rivers of England and Wales, over the period 1974 to 1998 (from Locke in prep). Numbers refer to rivers shown in Figure 3, shading identifies different Environment Agency regions.

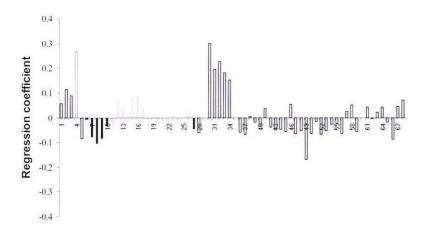


Figure 8 Variation in influence of run size (N) on catch (C) in different rivers.

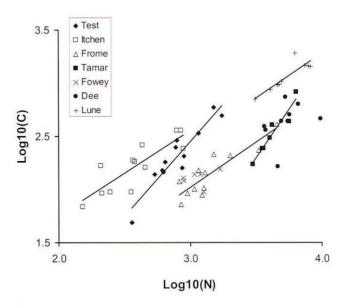


Figure 9 Influence of run size on catch per effort in different rivers

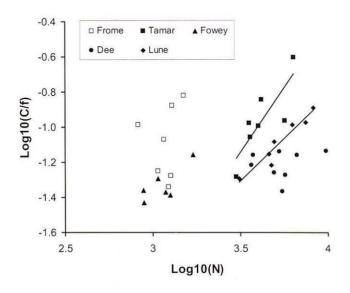
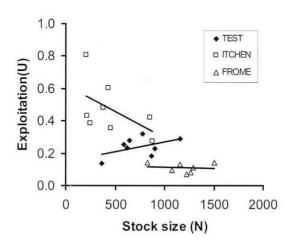


Figure 10 The effect of stock size on exploitation rate (NB only Tamar regression is significant, P<0.05)

A) Chalk rivers



B) Spate rivers

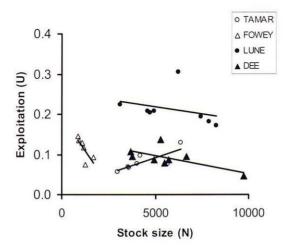


Figure 11 Trends in true exploitation rate (retained fish)

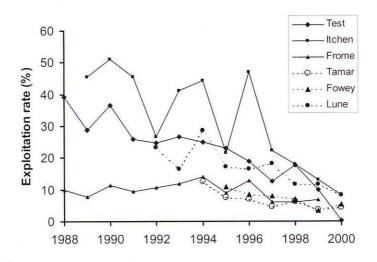
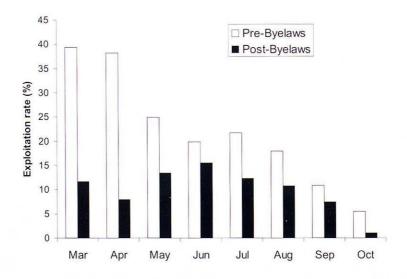


Figure 12 Variation in exploitation rate on monthly entrant groups of salmon in the River Dee, North Wales, covering pre-byelaw (1992-95) and post-byelaw (1996-2000) periods.



The relationship between exploitation rate and run size has not been clearly established. Direct (β =1) (Gargan *et al.*; Whelan *et al* this workshop) or curvilinear (β <1) (Solomon and Potter, 1992; Beaumont *et al.*, 1991) relationships and statistical independence (Crozier and Kennedy, 2001) have variously been reported. There may be good reasons why the relationship should vary between or within rivers, and many have been advanced; but these have yet to be tested and compared systematically across the range of rivers for which data are available.

Variation in catchability within and between rivers is to be expected. A prime cause of this is likely to be flow, which probably acts by influencing fish behaviour, availability and angler behaviour (e.g. Beaumont *et al.*, 1991; Clarke and Purvis, 1989; Gee, 1980; Millichamp and Lambert, 1966, Mills *et al.*, 1986; Small, 1991). The incorporation of flow into the fishery models is a topical area of current research in the search for flow standards to protect fisheries (e.g. Solomon *et al.*, 1999), this work may enable catchability to be modelled in terms of flow or related variables.

Exploitation rates are used in two contrasting contexts. Firstly, to estimate escapement, in which case the number of retained fish is the principal measure of interest. Secondly, to provide an index of run size, in which case captured and released fish should be considered, including the incidence of repeat captures. Catch and release is common and increasing in UK salmon rod fisheries and might be expected to alter the catchability of released fish. The effects of this practice on the interpretation of catch-effort-run data need to be better understood.

Effort data are measured only as total days fished per licence return. An ability to measure the seasonal allocation of effort would be useful in examining catches of different runs groups. A start has been made for England and Wales in 2001 by recording effort fished before and after the 1st June, separately. Further differentiation will require judgements about the loss and quality of information as the complexity of return forms increases.

While the mechanisms and controlling factors influencing exploitation need more investigation, stock and fishery assessments will continue to be based on rod catches for most rivers, so improvements to data treatment are essential. New methods for the interpretation of catch statistics are being developed in three main areas. First, there is an increased emphasis on estimating the uncertainty associated with stock assessment from catch statistics. In particular, Bayesian methods are being used to describe uncertainty in probabilistic terms, and to provide a quantitative basis for fishery management decision-making. Secondly, hierarchical modelling techniques are being used to estimate run size from catch statistics on rivers with no independent measure of run size. Such approaches use data from rivers with counters or traps to assess river-to-river patterns in exploitation rates, which are then used to estimate the range of possible run sizes on rivers with no counting facilities. Finally, population models are being used to integrate rod and net catch statistics with other sources of river-specific data, such as electro-fishing surveys, smolt traps, habitat surveys and GIS. Formal integration of several data sources provides a more powerful basis for diagnosing problems in salmon stocks, and for choosing between alternative management options.

SUMMARY

 Rod catch quality has varied greatly over time and between rivers. Despite records going back to 1952 and much further in a very few cases, it is only recently (since 1974) that recording has been systematic enough to enable comparative analysis of catches. Effort data are even scarcer, although they have been routinely collected since 1993.

- Rod catches are considered to provide ubiquitous primary data of great value for 1)
 describing fishery performance and 2), more problematically, estimating annual in-river
 run size.
- 3. Rod catches show synchronous variation in geographically separate rivers, in which catches are recorded by different means, indicating that they are responding to common influences. There are at least three major groupings of rivers around England and Wales that show different long-term trends in catch.
- The influences on catch may be run, effort or catchability, or combinations thereof.
 Distinguishing between the effects these and their mechanisms is the principal objective of catch-run analysis.
- 5. Effort and catchability mediate the relationships between catch and run (exploitation rates), which in turn are shown to vary between and within rivers. Simple equations can be used to establish systematically the differences in these relationships between rivers, but these need independent measures of run size, of which there are still few.
- Further work is needed to establish the variation within and between rivers, in catchability
 and the relationship between exploitation rate and run size, in order to investigate the
 underlying mechanisms
- 7. New approaches to statistical treatment and modelling are necessary to make fuller use of catch and effort data and to set them in alongside other assessment methods. There should be parallel developments in 1) understanding and accounting for the variation seen in the catch/stock relationships and 2) quantifying the uncertainty that surrounds them and building this into management risks.

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APPENDIX I Analysis of variance, salmon rod catches, Wye, Usk and Dee

Analysis of Variance for Log10 Pre-June, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
River	2	20.67100	20.67100	10.33550	386.42	0.000
Year	46	20.72518	20.72518	0.45055	16.84	0.000
Error	92	2.46071	2.46071	0.02675		
Total	140	43.85689				

Analysis of Variance for Log 10 Post-June, using Adjusted SS for Tests

Source	DF	Sea SS	Adj SS	Adi MS	F	P
River	2	10.86191	10.86191	5.43096	156.54	0.000
Year	46	5.80377	5.80377	0.12617	3.64	0.000
Error	92	3.19190	3.19190	0.03469		
Total	140	19.85759				

APPENDIX II Summary statistics for seven rivers, period 1993-2000.

River		Run es	Run estimate (N)			Rod catch (C)	tch (C)		Fis	Fishing Effort, licence days (f)	licence da	iys (f)
	п	mean	ps	CV	п	mean	ps	cv	п	mean	ps	cv
Test	~	738.6	240.6	32.6	~	183.4	83.5	45.6	×	434.3	244.6	56.3
Itchen	8	457.9	269.3	58.8	∞	194.8	88.9	45.7	×	521.5	153.6	29.5
Frome	7	1190.3	208.7	17.5	7	131.3	42.3	32.2	7	1587.6	370.4	23.3
Tamar	7	4335.3	1228.8	28.3	7	373.7	217.7	58.2	7	3062.6	534.6	17.5
Fowey	9	1164.7	300.5	25.8	9	129.0	21.0	16.3	9	2768.8	438.7	15.8
Dee	8	5656.0	1931.6	34.2	∞	490.5	125.8	25.7	8	8042.4	1894.0	23.6
Lune	∞	5904.0	1841.5	31.2	∞	1233.6	387.4	31.4	∞	13990.9	2265.5	16.2
		Catch	Catchability (q)			Exploitation rate (U)	n rate (U		Ü	Catch per Unit Effort (PCU)	t Effort (F	(U)
	u	mean	ps	cv	_	mean	ps	cv	=	mean	ps	cv
Test	∞	0.00066	0.000304	46.3	×	0.24	0.059	24.6	8	0.125	0.053	42.9
Itchen	∞	0.00105	0.000774	73.4	~	0.47	0.167	35.5	×	0.161	0.070	43.2
Frome	7	0.00008	0.000034	44.8	7	0.11	0.029	26.8	7	0.090	0.041	46.0
Tamar	7	0.00003	0.000008	28.8	7	0.08	0.024	28.1	7	0.121	0.062	51.5
Fowey	9	0.00004	0.000000	15.6	9	0.12	0.029	25.6	9	0.048	0.012	24.7
Dee	∞	0.00001	0.000004	34.0	×	0.09	0.026	27.3	×	0.062	0.011	17.4
Lune	~	0.00002	0.000001	0.6	∞	0.21	0.043	20.5	~	0.089	0.027	30.5

THE RELATIONSHIP BETWEEN SALMON ROD CATCH, STOCK SIZE, ROD EXPLOITATION AND ROD EFFORT ON THE ERRIFF FISHERY, WESTERN IRELAND

P. Gargan*, J. Stafford** and N. Ó Maoiléidigh***

*Central Fisheries Board

**Western Regional Fisheries Board

***Marine Institute

INTRODUCTION

The Erriff Fishery in Connemara, Western Ireland, has been managed by the Central Fisheries Board since its purchase by the Irish Government in 1982. Management was transferred to the Western Regional Fisheries Board in 2000. The fishery comprises eight miles of salmon and sea trout angling on the Erriff river and sea trout angling on Tawnyard lake in the upper catchment. A Logic resistivity fish counter has been in place on the river since 1986 and annual counts of salmon are available. Accurate salmon rod catch data are also available annually over this period and these are plotted against salmon counter data to determine trends and assess the value of rod catch data as a measure of stock abundance. Annual salmon rod effort data are also used to assess the relationship between effort, catch and stock abundance.

STUDY AREA

The river Erriff is located at the head of Killary Harbour near the village of Leenane, Co. Galway. The Erriff is a spate river with a catchment area of 166.6 sq.km. The main soil types are peaty podsols and the underlying rock derives from the Ordovician period. A major waterfall, 250m from the estuary, Aasleagh Falls, at a height of 4m, prevents migratory salmonids ascending upstream and fish must ascend through a fish pass located to the left of Aasleagh Falls. The river is a renowned salmon (predominantly grilse) and sea trout fishery with a daily rod capacity of twenty two rods. The river is divided into nine salmon angling beats, beats 1-8 located above Aasleagh Falls and the resistivity counter and beat 9 located below the falls and counter. No salmon spawning occurs along beat 9, below the counter, and all salmon not taken on the rod on beat 9 will ascend upriver through the counter.

MATERIALS AND METHODS

Salmon ascend the river through a series of V-notch weirs located to the left of Aasleagh Falls. Fish enter a trap, 5m in length, with steel in-scales. At the head of the trap are steel gratings and, in the centre, a tunnel through which fish must pass to move upstream. A Logic resistivity fish counter has been in place in the tunnel since mid 1985. This counter was designed to count upstream migrating salmonids with a minimum target length of 55cm. O'Farrell et al. (1989) used fish counter data and salmon rod catch data from the Erriff over the 1986-1988 period to examine rod exploitation. These data are re-examined here together

with data collected over the 1989-2001 period. Over the 1986-1996 period, very few upstream migrating sea trout were included in the salmon count, as O'Farrell et al. (1989) and Gargan (2000) have shown that less than 1% of sea trout from the Erriff were greater than 55cm in length.

A new Logic resistivity fish counter was installed in 1996 together with a video camera for count verification. Two tubes were installed end-to-end, one with electrode spacings of 55cm. and the second with electrode spacings of 25cm. This set-up allows discrimination between salmon and sea trout, as the upstream count from one set of electrodes is taken from the second to give a sea trout count.

Very accurate rod catch and rod effort data are available from the Erriff fishery. Anglers stay at Aasleagh Lodge on the river and are allocated beats by the resident fishery manager. Occasional day-trip anglers must also report to the fishery manager before and after fishing. Salmon and sea trout catches are weighed and recorded from each beat on the river on a daily basis. This reporting procedure has been in place since 1985.

Annual salmon count data only, rather than monthly counts, are available for 1986 and 1988 while individual monthly data are missing for some months in 1987, 1989, 1991, 1992, 1995 and 2001. Missing data result either from the counter being inoperative (June 1989, 1992) or from the counter not being maintained after the angling season in September. By calculating the percentage of the annual run by month in years without missing data, an overall mean monthly percentage was estimated. In years with missing data, annual counts were then raised by the mean monthly percentage for missing data to give a more robust annual count.

RESULTS

The salmon counter data from the Erriff fishery over the period 1986-2001 are shown (Table 1). The mean percentage monthly salmon count is also shown for years without missing data. Over 98% of salmon enter the river before the end of the angling season in September. In years with missing data, annual counts were raised to give a more robust annual count (Table 2). Annual salmon counts have ranged widely from 1132 to 4757 fish with a mean count of 3087 fish. The salmon rod catch recorded on the Erriff fishery over the period 1986-2001 is shown (Table 3). A mean rod catch of 568 salmon was recorded over the sixteen year period. The salmon rod catch on Beat 9, below the resistivity counter, is added to the raised annual counter data to give the total salmon stock available. A mean rod exploitation of 19.3% was recorded over the period. Rod effort data are also presented on an annual basis (Table 3).

Table 1. Monthly Salmon Count Data – Aasleagh Counter, Erriff River

Year	Janry	Febry	March	April	May	June	July	Augst	Sept	Oct	Nov	Dec	Tot
2001	7	12	22	41	31	596	465	136	29				133
2000	1	3	5	18	57	627	851	180	47	122	0	0	19
1999	13	11	16	37	135	891	942	364	95	90	0	2	25
1998	0	1	10	22	101	1077	1446	400	164	9	0	0	32
1997	0	2	6	1	40	682	750	250	73	89	22	0	19
1996	0	0	3	10	46	360	481	172	24	36	0	0	11
1995	0	1	5	49	184	1165	2751	106	430		0	0	46
1994	0	0	6	43	128	2734	2208	513	100	106	0	0	58
1993	0	0	7	11	141	1574	2044	523	138	1	0	0	44
1992	8	0	4	17	31		1107	346	49	14	0	No.	15
1991	0	0		0	53	573	611	121	41	21	20	0	14
1990	0	0	0	31	45	739	991	68	23	2	0	0	18
1989	0	0	5	34	124		127	756	148		0	The same	11
1988													43
1987	6	9	3	35	157	1516	1810	384	153		SHEW T	0	40
1986													40
					= Data	incomplete	e /Counter	rinoperative					

Mean Monthly Percentage Salmon Count

Janry	Febry	March	April	May	June	July	Augst	Sept	Oct	Nov	Dec	
0.08	0.11	0.25	0.9	3.2	36.1	44.5	9.3	3.85	1.4	0.12	0.01	

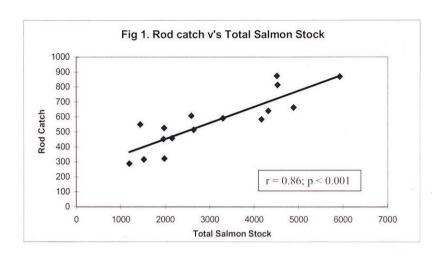
Table 2. Raised Monthly Salmon Count Data – Aasleagh Counter, Erriff River

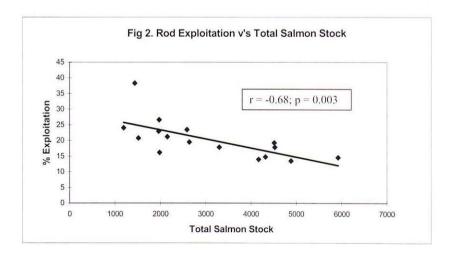
Year	Janry	Febry	March	April	May	June	July	Augst	Sept	Oct	Nov	Dec	Total
2001	7	12	22	41	31	596	465	136	29	19	2	0	136)
2000	1	3	5	18	57	627	851	180	47	122	0	0	191
1999	13	11	16	37	135	891	942	364	95	90	0	2	2593
1998	0	1	10	22	101	1077	1446	400	164	9	0	0	323)
1997	0	2	6	1	40	682	750	250	73	89	22	0	1915
1996	0	0	3	10	46	360	481	172	24	36	0	0	1132
1995	0	1	5	49	184	1165	2751	106	430	66	0	0	4757
1994	0	0	6	43	128	2734	2208	513	100	106	0	0	5833
1993	0	0	7	11	141	1574	2044	523	138	1	0	0	4439
1992	8	0	4	17	31	890	1107	346	49	14	0	0	2466
1991	0	0	4	0	53	573	611	121	41	21	20	0	1444
1990	0	0	0	31	45	739	991	68	23	2	0	0	1899
1989	0	0	5	34	124	689	127	756	148	17	0	0	1900
1988													4397
1987	6	9	3	35	157	1516	1810	384	153	58	5	0	4136
1986													4047

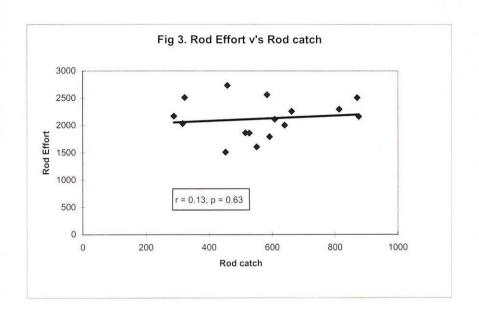
Table 3. Salmon Catch Data - Erriff Fishery

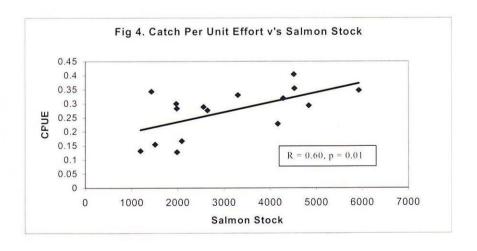
	Total	Rod Catch	Raised	Total	Total Rod	Rod	Catch per
Year	Rod Catch	Beat 9	Annual Count	Stock	Exploitation	Effort	unit effort
2001	551	66	1360	1426	38.6	1606	0.343
2000	527	64	1911	1975	26.6	1860	0.283
1999	515	42	2596	2638	19.5	1863	0.276
1998	592	69	3230	3299	17.9	1795	0.330
1997	452	45	1915	1960	23.0	1509	0.300
1996	288	59	1132	1191	24.1	2174	0.132
1995	662	79	4757	4836	13.7	2259	0.293
1994	870	83	5838	5921	14.7	2507	0.347
1993	813	86	4439	4525	17.9	2297	0.354
1992	608	86	2466	2552	23.8	2113	0.288
1991	316	63	1444	1507	20.9	2033	0.155
1990	322	81	1899	1980	16.2	2515	0.128
1989	458	184	1900	2084	21.9	2735	0.167
1988	875	114	4397	4511	19.4	2165	0.404
1987	640	145	4136	4281	14.9	2006	0.319
1986	584	118	4047	4165	14.0	2562	0.228
MEAN	568	88	3074	3162	19.3	2159	0.27

There was a positive relationship between the salmon rod catch and total salmon stock (Figure 1, r = 0.86, p < 0.001, n = 16) indicating that the greater the stock available, the greater will be the rod catch. The relationship was also evident if the outlier year of 2001 is omitted, (r = 0.89, p < 0.001, n = 16). There was a negative relationship between rod exploitation and total salmon stock (Figure 2, r = -0.68, p = 0.003 n = 16) indicating that the lower the salmon stock the greater the rod exploitation. This relationship was also significant if the outlier year of 2001 is omitted, (r = -0.74, p = 0.001, n = 16). No relationship existed etween rod effort and rod catch (Figure 3, r = 0.13, p = 0.63, n = 16). There was a positive relationship between eatch per unit effort and total stock (r = 0.60, p = 0.01) indicating that angling success increases with stock size.









DISCUSSION

Although no critical assessment of the performance of the resistivity counter in place over the 1986-1995 period was attempted, the installation was carefully maintained and regularly monitored. Regular monitoring indicated that counts were not registered during periods of very high discharge (O'Farrell et al., 1989), i.e. during periods of low conductivity and increased counter sensitivity (Dunkley and Shearer 1982). Video verification has shown that the new counter installed in 1996 has an accuracy of about 95% (O'Maoileidigh, pers comm.).

The positive relationship between salmon rod catch and total salmon stock shown here for the R.Erriff was also noted for the River Bush (Crozier & Kennedy, 2001), the Burrishoole (Whelan et al. 2001), the Coquet (Solomon & Potter, 1992) and the River Drammenselv (Hansen 2001). A negative relationship between rod exploitation and total salmon stock was recorded for the R.Erriff. Several other studies (Peterman & Steer, 1981; Beaumont et al., 1991; Hansen, 2001) have also recorded increased rod exploitation rate at lower stock size. A mean rod exploitation rate of over 30% in the last two years on the R. Erriff could have serious implications for the spawning stock, particularly as total stock numbers were low, and points to the need to manage rod fisheries in real-time, where possible, with reference to stock abundance. No relationship was found between rod exploitation and salmon stock on the Burrishoole and Whelan et al. (2001) attribute this to the mixed nature of the stock, both reared and wild, and to the fishery being almost exclusively a lake fishery. The lack of a relationship between rod effort and rod catch on the R.Erriff is not surprising as the spate nature of the river results in the majority of fish being caught during short periods around flood events.

The relationships shown here may usefully be applied to other predominantly grilse-dominated spate systems where stock size is unknown. Rod exploitation data point to the need for caution when using rod catch alone as a measure of stock abundance as moderate rod catches can be made in years of very low stock abundance.

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CATCH AS A PREDICTOR OF SALMON STOCK IN THE BURRISHOOLE FISHERY, CO. MAYO, WESTERN IRELAND

K.F. Whelan1, B.J. Whelan2 and G. Rogan1

¹ Marine Institute, Furnace, Newport, Co. Mayo ² Economic and Social Research Institute, Burlington Road, Dublin 4

INTRODUCTION

The Burrishoole system in the west of Ireland, has been extensively researched by the Marine Institute and its predecessors the Salmon Research Agency of Ireland and the Salmon Research Trust of Ireland, since 1955.

The Burrishoole system (9°55'W, 53°55'N) is a fully dedicated research facility. The operations of the Institute, conducted at installations lying between Loughs Furnace and Feeagh, possess the unique advantage of being able to monitor all movements of fish to and from fresh water. The trapping facilities at the Mill Race, constructed in 1959 and the Salmon Leap, completed in 1969, consist of full upstream and downstream traps.

The Burrishoole valley lies in a north-south direction; Parker and West (1972) and Parker (1973) described the principal features. The freshwater catchment has a total area of 8,949 ha. There are three main lakes, L. Furnace (brackish lake – 141 ha), L. Feeagh (410 ha) and Bunaveela L. (46 ha) and a number of smaller lakes such as L. Avoher and L. Namaroon. Some 45km of small shallow streams, particularly to the west; the Altahoney, Marmarata and Glenamong and to the east; the Goulaun, Rough, Lodge and Cottage rivers drain the catchment area.

The Burrishoole system has a run of both grilse (1SW) and salmon (2SW). There is only a small spring fish component in the Burrishoole stock, normally <10% of the total run. It has not exceeded 100 fish since the early 1960s. Reasons for this decline were early season drift netting of L. Furnace (ceased in 1965), the Greenland Fishery from 1962 to date and UDN from 1967 to the mid-1970s (Whelan et al., 1998).

MATERIALS AND METHODS

The unique trapping facility in place on the Burrishoole system has allowed a complete census of descending smolts and ascending adults since 1970.

The Burrishoole rod fishery traditionally took place on the lower lough, L. Furnace and the upper lough, L. Feeagh. However, since 1994, the rod fishery for wild fish has been largely run on a catch-and-release basis and angling on L. Feeagh was suspended, as a conservation measure.

In addition to the wild stock, reared smolts have also been released into the system since 1956 (Mills and Piggins, 1983). By 1964, sufficient adults were available to establish a breeding population and since that time all ranched smolts have been derived from the Burrishoole ranched strain. Due to a requirement for additional stocks to compensate for the sea trout stock collapse in the late 1980s, and also as a result of major experimental ranching programmes, the numbers of ranched smolts released increased significantly in the past decade.

The Burrishoole rod fishery has been in operation since the 19th century and was one of the west of Ireland's premier sea trout fisheries. Despite the presence of both multi-sea-winter salmon and grilse the large numbers of both resident and transitory sea trout present in Lough Furnace ensured that sea trout were the primary quarry of the angler. However, following the sea trout stock collapse in the late 80s, and the increased level of ranched salmon in the system, the angler's main quarry is now reared and wild grilse (Whelan and Poole, 1996).

The fishery was in private hands until 1980 when its owner, Major Charles Roberts, donated it to the former Salmon Research Trust of Ireland. Since almost all of the angling takes place from boats, frequently manned by local ghilles, a full annual angling census has been possible since 1970. The twin sets of data relating to the total trap returns and the total rod catch census offer a unique opportunity to assess the relationship between rod catch and total stock (Table 1).

RESULTS AND DISCUSSION

Since the Burrishoole Fishery has, to date, comprised an integral part of the research facility, it is possible to examine in fine detail the many interacting and complex factors affecting anglers' catches (Mills et al., 1985). However, in the context of general fishery management, many of these data are not available, and the fisheries are often run solely on the basis of daily catch and effort data. For this reason, we decided to approach our analysis on the premise that the Burrishoole Fishery was a stand-alone rod fishery for both wild and reared grilse, which had available daily catch records for the fishery as a whole. We have, however, separated the data into wild and reared stocks so as to examine any apparent differences.

Mills et al. (1986), found that the single most important determinant of catch was fishing effort (r =0.81). They also found a strong correlation between catch and stock (r = 0.72) but, in the case of salmon, found no correlation between low stock abundance and an increase in exploitation by angling. Both Gargan et al. (2001) and Hansen (2001) found a strong correlation between rod catch and stock. They also found a strong negative correlation between rod exploitation and total salmon stock, indicating that the lower the salmon stock the greater the rod exploitation. Gargan et al. found no relationship between rod effort and rod catch.

In the case of ranched salmon from the Burrishoole fishery the total stock is seen to increase significantly in the late 80s due to an increase in the numbers of ranched smolts released (Table 1). The rod exploitation rate ranged between 3% and 33%, with an overall average of 14.6%, and the effort per unit catch averaged 7.4 days. The most remarkable feature of this data set is the 1998 return, which showed, not only the highest escapement, but also by far the highest exploitation rate. Angling conditions were quite exceptional in 1998; cool, wet, windy weather prevailed throughout June, July and August, and angling bookings were high due to the previous season's catches of large (15lb+) reared salmon.

Table 1 Burrishoole rod catch statistics 1970 to 2000

'ear	Reared		Wild		Effort	Exploitat	ion Rate	Effort per Catch	Unit
	Stock	Catch	Stock	Catch	Rod days	Reared	Wild	Reared	Wild
1970	312	45	1748	309		14%	18%		
1971	136	11	915	75		8%	8%		
1972	682	83	1694	355		12%	21%		
1973	113	10	1955	190		9%	10%		
1974	60	10	1037	214		17%	21%		
1975	280	67	1020	161		24%	16%		
1976	262	42	973	156		16%	16%		
1977	102	6	735	115		6%	16%		
1978	164	5	478	35		3%	7%		
1979	411	18	1042	100	435	4%	10%	24	4
1980	163	8	771	51	461	5%	7%	58	9
1981	228	10	447	32	360	4%	7%	36	11
1982	247	30	561	75	489	12%	13%	16	7
1983	196	59	624	71	569	30%	11%	10	8
1984	87	10	313	47	473	11%	15%	47	10
1985	976	61	604	61	632	6%	10%	10	10
1986	1080	177	609	84	926	16%	14%	5	11
1987	566	64	507	60	958	11%	12%	15	16
1988	1013	85	615	87	922	8%	14%	11	11
1989	1106	199	680	127	1057	18%	19%	5	8
1990	836	123	261	42	1049	15%	16%	9	25
1991	577	44	628	65	836	8%	10%	19	13
1992	1077	197	378	57	916	18%	15%	5	16
1993	672	75	659	82	1088	11%	12%	15	13
1994	1128	100	542	102	1096	9%	19%	11	11
1995	889	185	523	141	1163	21%	27%	6	8
1996	1032	176	447	119	1557	17%	27%	9	13
1997	848	93	598	125	1561	11%	21%	17	12
1998	1682	560	572	80	1696	33%	14%	3	21
1999	395	35	576	40	1060	9%	7%	30	26
2000	1257	129	638	70	909	10%	11%	7	13
All years	18577	2717	23150	3328	20213	15%	14%	7	6

Analysis of catch, stock and effort data (Fig. 2 to 4), for the reared component, shows a strong correlation between catch and stock (r = 0.81) and between catch and effort (r = 0.70). When the 1998 outlier is omitted, the correlation between catch and stock increases to r = 0.86. The equation relating reared stock and catch is therefore;

$$stock = 308 + 3.32 x catch$$

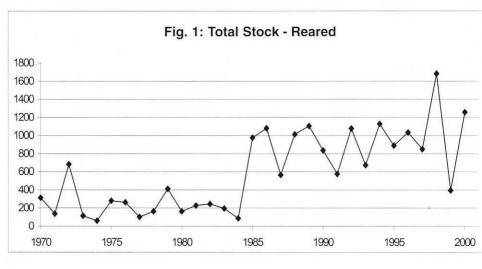
A weak positive relationship was observed between rod exploitation and total salmon stock (r = 0.35), but this may have been due to the inclusion of the 1998 outlier.

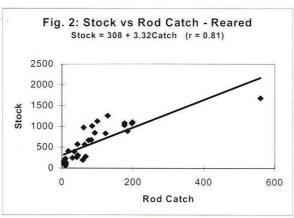
In the case of the Burrishoole wild stock, a strong downward trend in overall stock abundance is evident from the early 70s. Since 1980, the total escapement has fluctuated around 500 fish (Fig. 5). The rod exploitation rate ranged between 7% and 27%, with an overall average of 14.4% (Table 1). The effort per unit catch averaged 6.1 days. It should be noted that exploitation rates for wild salmon, post 1994, are an amalgam of catch and release data and catch and kill data. No account has been taken in this analysis of the possibility that some salmon were caught more than once. Tagging experiments indicate that this is rare (<2%) in the Burrishoole system.

Analysis of catch, stock and effort data (Fig. 6 to 8), for the wild component, shows a strong correlation between catch and stock (r = 0.82) and a moderate correlation between catch and effort (r = 0.52). However, no relationship was observed between rod exploitation rate and total salmon stock. The equation relating wild stock and catch is therefore;

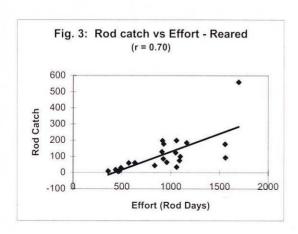
$$stock = 273 + 4.42 \times catch$$

The lack of any relationship is apparent both from these data and from the analysis carried out by Mills et al. (1986). This result may be due to the mixed nature of the Burrishoole rod fishery (reared and wild stocks) or because angling takes place, almost exclusively, in stillwater conditions. A series of multivariate analyses was also carried out on both the reared and wild stock data, but no significant results were obtained.

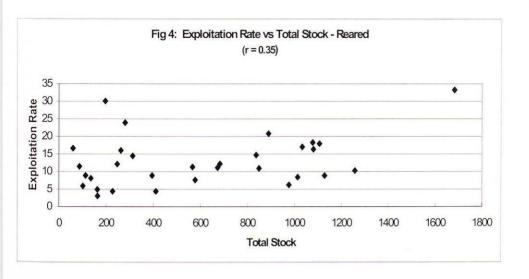


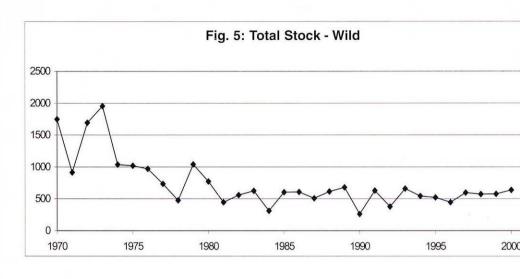


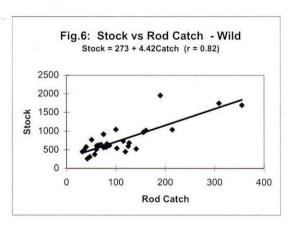
	Value	Significance
Mult, R	0.815	0.00
Intercept	307.947	0.00
X co-efficient	3.324	0.00



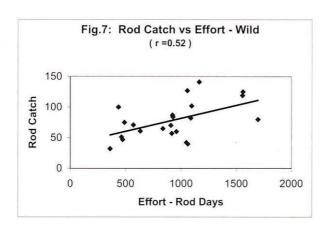
	Value	Significance
Mult. R	0.700	0.00
Intercept	-93.478	0.08
X co-efficient	0.222	0.00



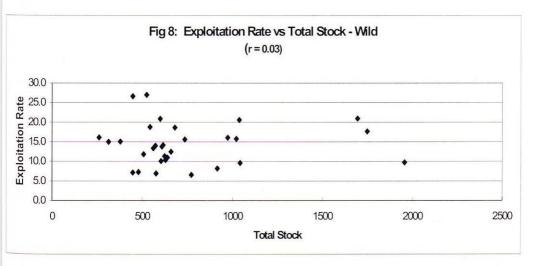




	Value	Significance
Mult. R	0.825	0.00
Intercept	272.744	0.00
X co-efficient	4.416	0.00
Stock = 273 + 4.42		



	Value	Significance
Mult. R	0.525	0.01
Intercept	39.06	0.02
X co-efficient	0.043	0.01



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RELATIONSHIP BETWEEN CATCHES, ROD EXPLOITATION AND TOTAL RUN OF ATLANTIC SALMON IN THE RIVER DRAMMENSELV, NORWAY

L.P. Hansen

Norwegian Institute for Nature Research P.O. Box 736 Sentrum N-0105 Oslo, Norway

INTRODUCTION

In Norway, Atlantic salmon are exploited in commercial net fisheries on the coast and in fjords, and by anglers in fresh water. There are more than 600 rivers in Norway supporting salmon, but although catches are recorded from many of them, little is known about the level of exploitation on these stocks. One of the rivers where exploitation rates have been studied for some time is the River Drammenselv (Hansen et al. 1986; Hansen 1990) where rod exploitation rates have been estimated since 1985.

This paper summarizes some of the available information on the relationship between catches, abundance and exploitation of salmon in the River Drammenselv. More information will soon be available from a detailed study of the rod fishery in this river (Sandhaugen & Hansen, In press).

RIVER DRAMMENSELV

The river Drammenselv drains large areas of south east Norway (drainage area = $17 \ 140 \ m^2$). In its lower reaches, the average annual water discharge is about 225 m²s⁻¹ and the width is about 200 m. During spring floods, the water discharge may reach 1 500 m²s⁻¹.

At the end of the last century, the total reported salmon catch in the river was around 20-25 tonnes (Figure 1); the great majority was taken in the commercial fisheries. Due to pollution and river regulations, the size of the salmon stock decreased considerably, but in recent years, the water quality in the river has again improved, and this, combined with a systematic stock enhancement programme, has again improved the salmon stock.

In 1987, however, the parasitic fluke *Gyrodactylus salaris* was observed on salmon parr in the lower reaches of the river. This parasite attacks salmon parr and causes heavy mortality (Johnsen, 1978; Johnsen & Jensen, 1986). It was probably introduced to the watercourse by escaped infected rainbow trout from a fish farm in Lake Tyrifjord farther upstream. As a result of this, the salmon catch has again declined (Figure 1). To counteract losses of salmon parr from the parasite, young salmon (fry, fingerlings and smolts) are now systematically released in areas where there is no infection of *G. salaris*, and the main, or total salmon run, is now maintained through this stocking programme.

At present, salmon are exploited in the river by rod and line only. A salmon ladder is installed at the hydro-electric dam at Hellefoss, about 19 km from the estuary. In the upper end, the ladder catches all ascending salmon, where the fish are recorded and examined for tags. Below the ladder, angling as well as salmon spawning are mainly restricted to an area reaching from the dam and ca. 3 km. downstream. At present, salmon can ascend to Dovikfoss, about 12 km. upstream of Hellefoss.

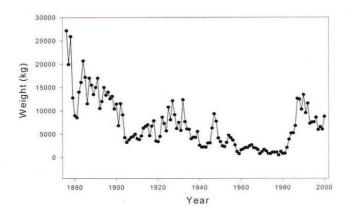


Figure 1. Total catch of salmon and sea trout in the River Drammenselv since 1876

METHODS

The total run of salmon to the River Drammenselv was estimated using catch statistics, visual counts of salmon in the fish ladder at Hellefoss and by use of a mark-recapture procedure downstream of the fish ladder to estimate the number of spawners below the Hellefoss (Hansen et al., 1986; Hansen 1990). The catch statistics in the river are very accurate, and the trap in the Hellefoss catches all ascending fish. To estimate the number of salmon at the spawning grounds downstream the Hellefoss, about two weeks prior to spawning 100-200 fish, were caught by drift nets (spun nylon with thick twine), tagged, kept under observation for 3-6 days and subsequently released back into the area. No mortality of the salmon was observed during this period. A week later the area was again fished using the same procedure. Fishing was carried out until 10-20% of the tags were recovered. The estimated number of salmon was then calculated using the Peterson method (see Ricker 1975). Exploitation rates were estimated as the proportion (%) of the number of salmon caught relative to the total run of salmon in the river.

RESULTS AND DISCUSSION

The estimated total number of salmon ascending the River Drammenselv from 1985 to 2000 is shown in Figure 2. During this period, the number of fish has varied between 2400 and 6100, with a maximum in 1990, just before the effects of *Gyrodactylus salaris* were detected.

Similarly, catches of salmon downstream of the Hellefoss varied between 1000 and 2400 fish in the same period with a maximum in 1988 (Figure 3). There was a positive relationship

between the total number of salmon ascending the river and the rod catch downstream of the Hellefoss (Figure 4; r = 0.75, p = 0.001, n = 16) suggesting that the more fish available, the more fish are caught. On the other hand, rod exploitation rates downstream of the Hellefoss tended to decline with increasing abundance of salmon (Figure 5; r = -0.49, p = 0.057, n = 16).

Despite the fact that *Gyrodactylus salaris* causes heavy mortalities of salmon parr in the River Drammenselv, it has been possible to maintain the stock by stocking young fish in areas not infected by the parasite. The facilities available, as well as enthusiastic help from local angling clubs and river owners, have improved the quality of the data collected from the fisheries. Although the variables in the correlation analyses are not entirely independent, the results suggest that the more fish that enter the river, the more fish are caught. But it is also interesting to note that anglers apparently are unable to harvest the same proportion of salmon independently of the total abundance of fish. The exploitation rates by anglers appear to be higher at low than at high abundances of salmon. This implies that more caution has to be taken to regulate fishing pressure when the salmon abundance is low.

Many factors may determine angling exploitation levels in rivers. Some may be related to physical conditions in the river, such as water temperature, flow, turbidity and morphology. Others related to the anglers are effort, gear types, skills, and factors related to fish such as size, habitat requirements, time spent in the river etc.

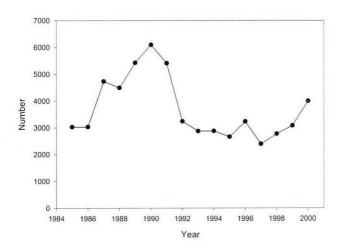


Figure 2. Estimated total run of salmon in the River Drammenselv since 1985

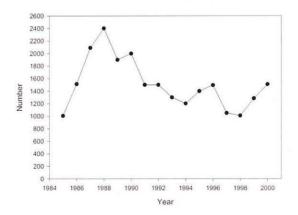


Figure 3. Catch of salmon downstream of the Hellefoss since 1985.

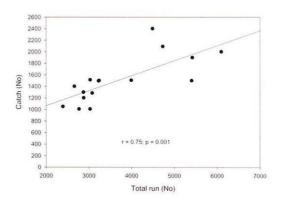


Figure 4. Relationship between total run of salmon in the River Drammenselv and catch downstream of the Hellefoss.

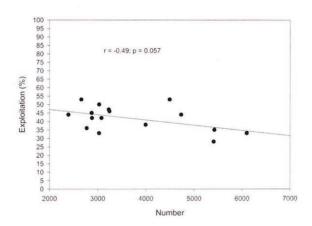


Figure 5. Relationship between total run of salmon in the River Drammenselv and rod exploitation rate downstream of the Hellefoss.

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USE OF ROD CATCH DATA IN ASSESSING TRENDS IN RELATIVE ABUNDANCE

J.C.MacLean, A.F.Youngson and R.J. Fryer*

FRS Freshwater Laboratory, Pitlochry, Perthshire, UK. *FRS Marine Laboratory, Aberdeen, UK.

BACKGROUND

It has been recognised, at least in the Scottish context, that the salmon fisheries and the stocks that they exploit are complex composites of minor contributions. As is well known, salmon return from the sea to the rivers in which they reared as juveniles. It is less well known that homing occurs within river catchments at finer scales that correspond to the dimensions of the separate breeding units (or populations) to which the individuals belong (Youngson *et al.*, 1994; Quinn *et al.*, 2000). For fish originating from any single population, homing is a strong influence on spatial patterns of distribution both on the coast as the fish head for natal rivers, and within river catchments as they target natal areas.

Individual fisheries, both at sea or in rivers, operate at fixed locations that are generally quite local in extent. All the fisheries therefore catch fish at what are essentially point locations on an extended course that runs from the sea, along the coasts and through rivers towards their targeted spawning grounds and are therefore interceptory in nature. This quality imparts an obvious spatial dimension to each of the fisheries and each is distinguished from the others, and from the overall national fishery.

In some comparisons, the differences may turn out to be very marked. For example, an estuary fishery has the potential to exploit fish that target every part of the catchment above, while a head-water fishery has no access to those of the river's fish that target spawning locations farther downstream. Obviously, assessment data should be gathered at spatial scales that are consistent with the scales that define the units of production (populations) and the contribution of individual populations to the fisheries. Aggregating data at larger scales will obscure local problems that may well be of great importance. Experimental field data (Youngson et al., 1994) suggest that an indicative spatial scale extending down to about 10km for in-river fisheries is likely to capture the spatial effects of population structure on river fisheries.

The primary effects of population structuring are spatial but they are made more complex by temporal variation in run-timing among populations. These effects are separately evident for the two sea-ages classes that currently dominate the Scottish fisheries. For all Scottish salmon populations, run-timing among 2SW fish extends from before February until after December; the pattern is curtailed among 1SW fish and these start to run only about June. Radio-tagging studies demonstrate unequivocally that run-timing is a spatially variable trait among populations and clearly confirm that run-timing variation is expressed quite differently in 1SW and 2SW fish. Typically, those fish that run relatively earlier within either of the sea-age classes target spawning locations in upper catchment locations. This is the case for the Spey, Dee, Tay and Little Gruinard – although the case of the Tweed appears to be more complex. For most rivers, however, the run-timing effect is a progressive one in which

relatively later river entrants target spawning areas relatively nearer to the sea (Laughton and Smith 1992; Walker and Walker 1992; Webb and Campbell 2000). Alternatively, viewed from a population perspective, it can be seen that for most rivers, fish homing to upper catchment areas run rivers earlier in the season. Field experimentation confirms that runtiming is a genetic property of populations and that it is strongly heritable (Stewart et al., In press).

Run-timing variation determines the temporal representation of populations within the spatial framework represented by the fisheries. For example, an estuary fishery is potentially capable of exploiting all catchment populations but each will pass through the fishery area at a different time in the season. Furthermore, whereas 2SW fish heading for upper catchment locations may be exploitable for a period from February onwards, early-running 1SW fish belonging to the same populations will not be present until June. In an upper catchment fishery, only early-running salmon and grilse will be exploited and, in each case, they will be present later than for the estuary fishery. In many places, these temporal effects have an overriding effect on fishery value and assessment must try to capture this. Equally, assessments that are aggregated across time risk obscuring local problems of great importance. Because the run-timing effect is separately evident for 2SW and 1SW fish, failure to account for seaage, as well as time and location in the fisheries - will impede assessments targeted at the population level.

From an assessment point of view, the determining characteristics of each fishery are therefore place, time, and sea-age and, in addition, it is desired to estimate abundance. From a fishery point of view, the determining characteristics of each population are location, runtiming, sea-age composition and number. Given this obvious convergence, the critical question is; can the abundance of populations be deduced from the seasonal fortunes of the fisheries? By good fortune, catches in the Scottish fisheries have been documented since 1952 for catch, location, time and sea-age with temporal (monthly) and spatial (beat level) resolution on scales that are appropriate for the assessment of populations. Near-total national coverage of the fisheries has been achieved each year.

At this point, it is important to concede that populations are numerous and poorly definable and that their contributions to the fisheries are similarly inexact. With a very few exceptions, therefore, management of individual populations is not a credible target. On the other hand, catches are highly coherent across large scales within Scotland (Youngson et al., In press), leading to the proposition that, for management purposes, populations should be aggregated into a smaller number of functionally related groups (Youngson et al., In press). An example of this might be the population grouping represented by the Scottish catch for, say, March.

There are a number of reasons why an assessment approach based on rod catch might not be valid. First, rod catch may be substantially independent of stock, especially at higher stock levels. Second, effort is likely to be an effect on exploitation rate. Net fishery methods are essentially passive and the numbers of nets and the duration of fishing can be estimated and used to derive meaningful estimates of fishing effort. In contrast, anglers deploy time and techniques in a highly strategic manner in Scottish conditions, in ways that vary among individuals. Measures of time expended on angling are not likely to be a sufficient measure of effective effort for expert or for inexperienced anglers, and the same measure will certainly not be applicable to both groups. Therefore, useful estimates of the effective effort of the angling community appear not to be a realistic target, at least in the Scottish context. This is unfortunate since effort is potentially a large effect on exploitation rate.

Table 1. Kendall's coefficient of concordance (W) for monthly catches within rivers, and for catches from different rivers within months. Also shown are Spearman correlation coefficients between pairs of catch time series with a value greater than 0.3; values are rounded down to the first decimal place and values greater or equal to 0.6 are shown in bold.

	Helmsdale	Ness	Spey	Deveron	Dec	Tay	Tweed	Scotland
W	0.48	0.58	0.71	19.0	0.74	0.59	0.78	0.77
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April	.3 .6 -	- 7. 4.	- 6. 5.	.3 .8	- 8: 9:	.9. 6.	8. 9.	8.
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une	.5 .7	3 .6	7. 9. 5	. 8. 7. 8.	4 6 5 7 -	3 9 %	. 8 9 1 9 -	3 7 7 8

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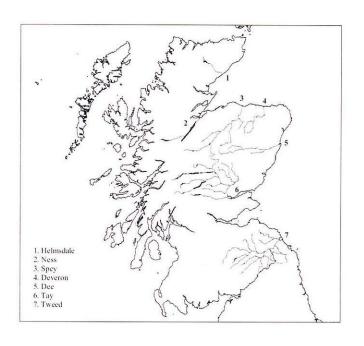
On the other hand, the operational difficulty posed by the lack of an estimate of effort is reduced, in practice, to any extent that variation in effort mirrors variation in stock. The third problem is that catches may be reported inaccurately for a number of reasons that can only be speculated upon. Overall, the most telling point to be made here is that none of these effects can be tested explicitly. An empirical approach to the rod catch data and an inferential approach to measures of its robustness are required, as below.

THE ROD CATCH ANALYSIS

Rod catch trends for MSW salmon in the each of the months February to June for seven major east coast rivers (Figure 1) have been examined (Youngson et al., In press). A generally uniform association of trends across rivers for any given month was evident. However, the degree of association in trends among months within rivers was weaker with greater separation between the months compared (Table 1).

Additional, coherent associations were evident among the residuals from the fitted trend lines, both within months and within rivers. The most likely explanation for this is that annual perturbations from the emerging trend are due to annual variations in abundance, suggesting that catch does indicate stock. An alternative explanation, that catchability, affected by climatic variables, for example, is responsible for this variation. However this is considered unlikely on the grounds that such effects would not be expected to act on a Scotland-wide scale but, rather, on local scales comparable with the observed scales for climatic variations. Inter-annual trends for the monthly components of the Scottish rod and line catch were investigated further. The monthly catches were shown to vary at different rates (Figure 2). Clear declines were demonstrated within the spring months, with the earlier months declining at the greater rates.

It follows from a consideration of run timing that, since different run-timing types home to spatially distinct spawning grounds, management units can be defined on temporal as opposed to a spatial scales. At first glance, this proposition does not appear to offer any advantages over spatial management units, and in both dimensions it appears to remain impractical. However, the potential complexity of the problem is eroded by the fact that monthly catch trends mirror each other across rivers. In other words, there is more variation within months on any river than there is among rivers for any month. These findings lend support to the concept of temporal management units comprising several or many functionally-related populations.



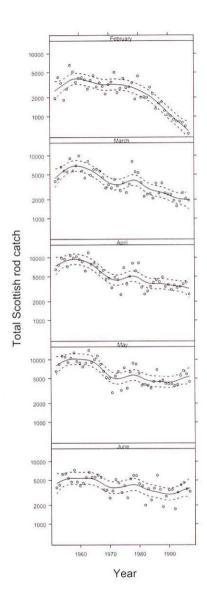


Figure 2. The total Scottish rod catch for February-June plotted on a log-scale. A smoother (solid line) is fitted to the catches for each month. The dashed lines are approximate pointwise 95% confidence limits.

FUTURE DEVELOPMENT

To date, the study has been restricted to the seven major rivers of the Scottish east coast and will be extended to achieve even greater coverage in future work. However, the rivers examined cover the entire geographical range of the east coast, from the river Helmsdale in the extreme north east to the river Tweed on the border with the English fishery area. The rivers examined support about 90-95% of the total Scottish resource of early-running MSW salmon. Bearing this coverage in mind, the rod catch analysis indicates that early-running MSW fish in Scotland could be managed effectively on the basis of just five temporal conservation units (February - June).

Our proposed next steps are to investigate the catch patterns for the following run timing groups:

- February to June MSW salmon on the west coast rivers.
- July to November MSW salmon on all Scottish rivers.
- May to November 1SW salmon, as above.

Until such analyses are performed we cannot determine how the variation in all the Scottish catches components may be partitioned among and within rivers. However, should the outcome be broadly similar to that described for the February through June series for MSW salmon, it is possible that all the complexity of the salmon resource in Scotland could be managed effectively using conservation limits for just 17 temporal groupings; five early-running MSW groups (February-June), five late-running MSW groups (July-November) and seven 1SW groups (May-November).

DISCUSSION

These analyses demonstrate the potential utility of rod catch data in two principal respects. First, the catch trends are consistent among months within rivers and, more especially, the monthly trends are consistent among a set of rivers spanning all the diversity of the Scottish east coast. Secondly, all the annual residuals for months are highly coherent among rivers, indicating a broad-scale consistency of effect. The catch data therefore capture some consistent feature of the fisheries. The trends themselves are generally downwards and in line with data on abundance gathered from other sources for early-running fish.

It remains questionable, however, whether catch can be used as a predictor of stock abundance without further refinement of the argument (see accompanying paper by R. Gardiner). Indeed, it is quite likely that catch is not linearly related to stock. Thus, in many cases, the tactical application of predatory effort by anglers is based on an intuitive appreciation of variations in catchability due to hydrological variation, for example, and an intuitive knowledge of variations in the abundance of exploitable stock. Exploitation rate is therefore likely to vary with stock abundance and it is likely to change on all scales from hours to years. Even so, the relationship between exploitation rate and stock is expected to be a proportionate one (which is helpful in the context of assessment). The relationship is also likely to be non-linear (which will limit interpretation). Taking these factors into account, leads to the conclusion that eatch data can probably be used freely in making comparisons of relative abundance among years, among population groupings, or among rivers.

This alone is an extremely useful position. Beyond this, however, catch cannot be directly converted to absolute measures of stock abundance, or to absolute measures of spawning escapement, without knowing exploitation rates. Furthermore, to be relevant, exploitation rates must be resolved at scales that are consistent with the spatial and temporal scales defined above for the other factors that determining the effects of populations on fisheries. This is a major constraint on the direct approach that probably cannot be resolved. An indirect approach is therefore required that calibrates catch data as a support for the ultimate target of fishery management, namely the optimisation of spawning escapement at the population level.

Two options can be identified that differ in their ambition. An expedient approach to target setting for spawning escapement is to define escapement in terms of the catch according to some arbitrary standard. For example, the catch supported by a population grouping, when it was observed at some previous time not to be limited by parr densities or smolt production, might be used to define a catch and, by default, a target for escapement. This approach requires steady-state conditions. It is weakened by the assumption that the relationship between abundance and exploitation rate does not vary, say, on decadal scales. This is assumption is probably relatively secure for the earlier parts of the fishery record and they can be interrogated on this basis. However, for recent years, the assumption has become less workable because of the advent of catch-and-release and with the seasonal closure of some fisheries. Recent restrictions (2001) due to foot-and-mouth disease in cattle are a further effect. In future, the fisheries may revert to their original steady state or a new steady state may emerge in which case the approach will probably become secure once again.

A second possible approach is to calibrate catch to recruitment, via escapement, more directly, using density estimates for juvenile fish obtained by electro-fishing. In Scotland, real time fishery management is possible on this basis because of the extended delay between spawning and smolt migration and the interactions of succeeding cohorts by which later cohorts take up productive potential not utilised by the earlier groups with which they compete. Where 2- or 3-year-old smolts predominate, annual shortfalls in recruitment can be identified and rectified retrospectively since a period of two or three years elapses before the effects of any shortfall at spawning feed irrevocably through to the coming fishery and the next wave of spawner recruitment. This approach is limited by the relative insensitivity of the standard electric fishing data to spawner abundance, although insensitivity is least likely to be a constraint when spawner levels are so low that radical management action is most required.

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SUMMING UP

R.G.J. Shelton

The salmon stocks of the north east Atlantic are unusual among modern European fishery resources in several ways. They are relatively lightly exploited and most of that exploitation is under domestic control. Furthermore, the limits set by freshwater habitats, together with the fact that more than one year class usually contributes to smolt populations, confer a stability upon recruitment that is the envy of scientists struggling to understand the large fluctuations in year class strength that characterise so many marine species.

Despite all these advantages, the proceedings of this Workshop highlight the many problems that still remain for those charged with providing management advice for Europe's wild Atlantic salmon. One difficulty is that the size and structure of the adult populations that are the targets of the home water fisheries are a function, not just of the dynamics of growth and mortality, but also of maturation. The latter is a complication in itself but, because most salmon die after spawning, the opportunity to follow the fate of a sea year class through its representation in catches over several years, is largely denied and the possibility of conventional virtual population analysis along with it.

Gaining an understanding of the relationships between generations which is a pre-requisite for successful salmon management is, by definition, a population-based activity. There is now widespread acceptance that more than one population of salmon may return to some rivers, spawning and developing as juveniles in different parts of catchments, and ideally requiring management appropriate to the differing life history characteristics of each population.

To support them in their assessment task, salmon biologists rely on both intensive and extensive sources of information. Monitored river studies form the core of the first group and juvenile surveys and the statistics of the fisheries are the most important of the latter. The focus of this Workshop is on the use of catch statistics both as part of monitored river studies and as indicators, in their own right, of the populations of fish from which they were derived. Information from both net and rod-and-line catches has a place in the proceedings but the emphasis is on the interpretation and use of rod-and-line statistics. This is because, nowadays, the reported results of angling are often the only river-specific data available to the fishery regulator.

In contributing to the Workshop, authors have sought answers to assessment questions in two main ways, 'asking the data' through innovative analysis and 'asking the fish and fishermen' about the mechanisms that underlie capture by rod-and-line. In asking the data, contributors have:

- Questioned the relative reliability of catch statistics and its consequences for assessment
- Looked at ways in which catch records can be used in combination with other data in comprehensive assessment.
- Taken the analysis of rod-and-line catch statistics to its limits in exploring the contribution catch records alone may be able to make to population-based assessment.

In asking the fish and fishermen, contributors have:

- Considered the effects of both internal physiological and external physical and ecological influences on the decision by salmon to take a lure.
- Emphasised that, in incorporating a catchability term into assessment models, both the
 vulnerability of the fish and the action of the angler contribute to the catchability
 coefficient, 'q' and thereby the effectiveness of angling effort, 'f'.

In structuring its discussion, the Workshop covered five main topics, each led by a contributor.

- Catch/Stock relationships and the estimation of exploitation rates (Nigel Milner).
- Unreported catches (Ted Potter)
- Catchability (Stuart Welton)
- Effectiveness of effort (Ross Gardiner)
- Population-based assessment (Julian MacLean)

The results of the discussion are summarised below.

1. Catch/Stock Relationships

Catches result from the effects of fishing effort upon stocks. Both the size of a stock and the magnitude of the fishing effort directed at it may affect the size of the catch derived from it. In some fisheries, notably those for well-dispersed species taken in towed gears, catch per unit of effort (CPUE) may be used as a simple index of total stock size. In the same way, CPUE data for some salmon net fisheries may be used as indices of the stock of fish present at the time the fishery takes place. However, such data cannot be used on their own as indices of total stock because net fishing does not take place over the whole of the calendar year. Similar limitations apply to the use of CPUE data derived from rod-and-line fisheries for salmon. In this instance, additional complications arise from the fact that capture is not a passive event but the result of an active choice by the fish. Thus catchability, and therefore, the fishing mortality it generates, is not constant. It may vary with environmental factors, the physiological condition of the fish and even the numbers of fish present at the site of the fishery. Angling effort is also difficult to measure, not least because of differences between the effectiveness of individual methods and of individual anglers.

It was concluded that, although much is to be gained from examining a wider range of catch data than was available to the Workshop, real progress requires access to catch records derived from stocks for which there are independent measures of their population structure and abundance, and from a greater understanding of salmon behaviour in the presence of lures.

2. Unreported Catch

Given the difficulty of relating accurately-reported catches to stocks, any uncertainties arising from illegal fishing and the non-reporting of legal catches pose serious barriers to salmon stock assessment. At worst, management advice from assessments flawed in this way may threaten the resource itself and thereby the fishing communities responsible for the misreporting. The discussions emphasised the importance of recognising the existence of the

unreported catch problem at international, national and fishery levels, discussed ways of reducing the problem through better and novel enforcement initiatives and publicity, and considered approaches to estimating and allowing for unreported catches in assessments.

3. Catchability

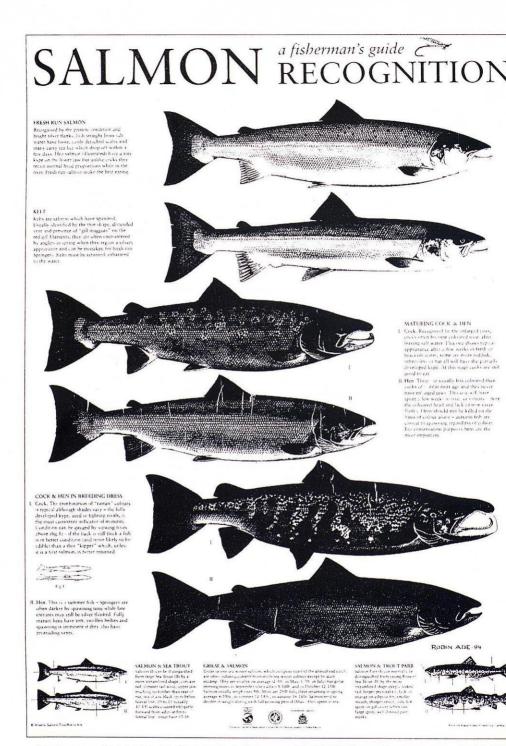
This discussion concentrated upon the estimation of catchability by rod and line as an amalgam of the attenuated feeding and aggressive responses by adult salmon to the actions of anglers. The responses by salmon were discussed in terms of the effects of intrinsic factors such as maturity status and freshwater residence time, and external influences, such as water temperature, flow and the local densities of sea-run salmon. A related discussion took place on the behaviour of anglers and their lures. The overall conclusion was that, although the additional analysis of published data on radio-tracked salmon exposed to angling pressure may prove rewarding, the greatest insights are likely to come from the direct investigation of salmon and lure interactions in aquaria and in the field.

4. Effort

This discussion addressed the problem of assessing angling effort and understanding the influences of factors like angler's skill, choice of lure and environmental conditions. Although it was agreed that the ideal measure of effort by an individual angler would be rod/days by date, the reality is likely to be by rod/days by period. Ways of weighting the estimation of total angling effort to take account of angler's skill, technical improvement and environmental change were considered as was the possibility of issuing log books to anglers of known reliability.

5. Population-based Assessment

The stocks of salmon at which angling effort is directed often comprise more than one component population, homing at spawning time to different parts of the catchment and differing in such characteristics as development rate, size-at-age and run-timing. Within populations, run-timing tends to be structured by sea age, with the oldest fish entering the river first and therefore, being exposed to fishing mortality longest. Clear evidence that temporal/spatial structuring can be detected in catch returns from rod-and-line fisheries directed at early-running salmon was presented at the meeting. The value of recognising the importance of population structuring in salmon assessment was agreed. Future initiatives include the extension of the analysis of Scottish river catches to later parts of the fishing season, consideration of data from other sources and the simulation of the management consequences of ignoring population structuring.



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