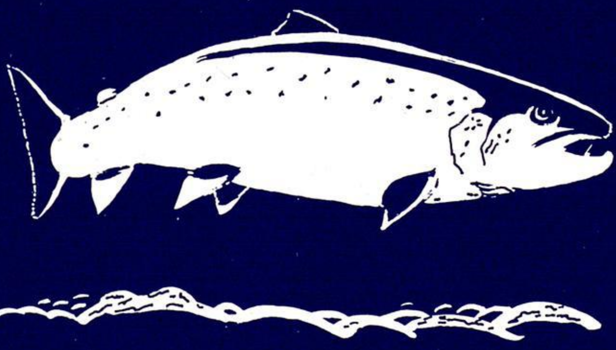
ATLANTIC SALMON TRUST

THE MEASUREMENT AND EVALUATION OF THE EXPLOITATION OF ATLANTIC SALMON

D. J. SOLOMON and E. C. E. POTTER



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FOREWORD

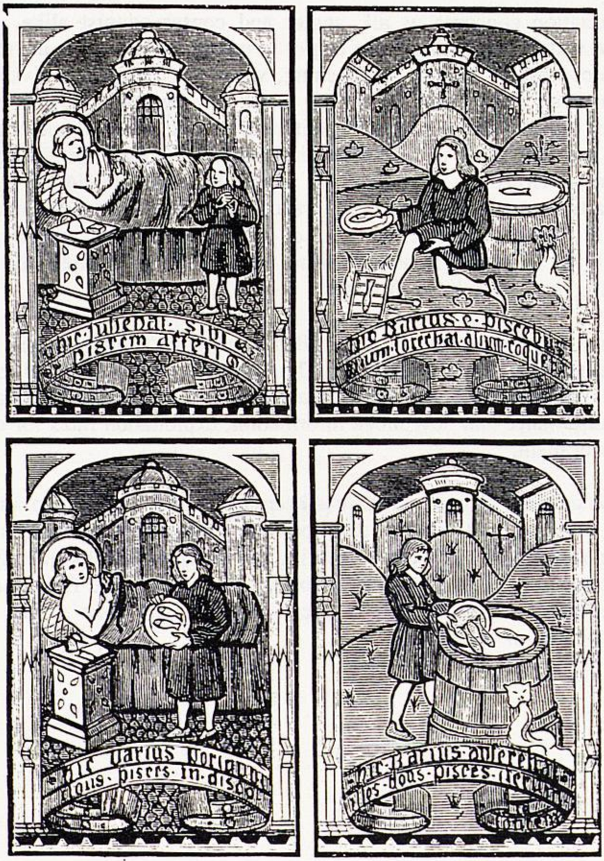
Salmon exploitation concerns us all, angler and conservationist alike, although our views may be widely dissimilar. The angler is usually paranoiac over how many fish the netsmen downstream of him are catching, while the coastal and river netsmen are concerned at how many fish are being taken by the high seas fisheries. The conservationist hopes that the rate of exploitation by both netsmen and anglers will not be excessive and that there will be sufficient spawners to maintain the optimum level of recruitment. However, the views of some of these individuals are inevitably subjective, partly out of unavoidable ignorance. The measurement and evaluation of exploitation is perhaps beyond the ken of most anglers and netsmen and might understandably be a subject to avoid due to the fear of the complicated mathematics with which it is thought to be enshrouded.

David Solomon and Ted Potter have distilled a synthesis of this subject discussed at length at a salmon scientist's workshop. The distillation is commended for its lucidity and interest. The authors have made it clear why reliable and complete catch statistics are of such importance and how much information, exploitation rates for example, can be derived from them.

Once an understanding of exploitation has been achieved it is easier to appreciate how this can be managed and why certain, perhaps unpopular, regulations have to be imposed. I guarantee that any angler reading this book will, subsequently, appreciate the terms catchability, fishing effort and exploitation rates more fully and understand why it is necessary to install fish counters, tag fish and have a full catch return submitted at the end of the season.

Derek Mills

Frontispiece



Concern over exploitation rates - an early example.

The above drawing of a stained glass window in the church at St. Neots, Cornwall, illustrates an interesting tale. St Neot apparently had permission from heaven to take one, but only one, of three fish each day from a pool. Overnight the fish was miraculously replaced. One day St Neot fell ill, and his servant Barius took two of the fish for his master, and cooked them both. On learning of this blatant overfishing St Neot immediately told Barius to return the fish to the pool, whereupon they were restored to life. It was apparent that this stock of remarkable fish was able to withstand a 33% daily exploitation rate, but not one of 67%.

CONTENTS.

1. SETTING THE SCENE.

The workshop in Dublin in April 1991 developed from discussions amongst members of the Atlantic Salmon Trust Honorary Scientific Panel which had been taking place over a number of years. There was felt to be a need to gain a better understanding of the levels of exploitation occurring in different types of fishery and to review the range of methods that were being used to estimate them. A logical next step would be to consider the implication of these levels of exploitation in fisheries management terms and the action that might be appropriate based upon this information.

The Workshop addressed a range of issues around the central theme of evaluation levels of exploitation. The meeting was based upon a number of invited reports and papers (listed in Section 10). However, authors were requested to limit their verbal presentations to a few minutes, and, in the manner of all good workshops, much valuable information came out of the discussions, which dominated the meeting. For this reason, this report does not follow the format of the meeting by discussing each paper presented in turn; rather the subject areas are discussed more generally, with reference being made to contribution by presented paper (P), discussion (D) and in a few cases, information provided on request from individuals not attending the workshop (I). This has also allowed this report to draw upon some additional relevant information that was not available at the meeting.

The report begins by addressing the problem of assessing the numbers of fish caught (section 2). Although catch statistics do not themselves indicate levels of exploitation, they are the basic measure of the performance of salmon fisheries. In some situations they represent the only data on fisheries or stocks that are routinely collected every year. In other cases, they form part of the raw data required to estimate levels of exploitation. It is therefore essential to try to collect complete and accurate data. This section considers the difficulties of obtaining reliable catch statistics and possible approaches to improving their comparability and completeness.

The report then considers exploitation; first by describing the terminology; then by discussing how it may be estimated; and finally by examining some of the levels recorded in commercial and sport fisheries. The first two parts of this discussion (sections 3 and 4) are an essential precursor to serious debate of exploitation, and the authors of this report make no apology for the fact that they are addressed in some detail. This is necessarily somewhat mathematical in places, but we have done all we can be keep the discussion clear and concise, and the following introduction may help the reader select the sections of greatest interest.

A simple definition of the level of exploitation is the percentage of a stock that a particular fishery takes. Thus if a fishery takes one in five of the fish returning to a river, the exploitation level will be 20%; this may also be expressed as a proportion (0.2). The term "rate" should only be used where time is taken into account. Thus "exploitation rate" means the proportion of a stock taken in a defined period. In the tale in the frontispiece, for example, the exploitation rate is 0.33 (or 33%) per day. Clearly this could only be maintained because of the remarkable powers of regeneration of the "stock". In practice the term exploitation rate is often used interchangeably with exploitation level to mean the overall percentage of the stock taken within the fishing season.

Such concepts may be easily understood where the fishery operates on an enclosed system such as a pond. However, it becomes more complicated when fish may enter or leave different fishery areas during the course of their life cycle and where different components of the stock, such as age groups, behave differently. It may then become useful, or necessary, to distinguish between the effects a fishery has on the population of fish that is in the area of the fishery at the time that it operates (termed fishery exploitation rate) and its effect on all the fish in the stock, wherever they are (termed extant exploitation rate). More detailed descriptions of the terminology used to describe the exploitation of salmon are provided in section 3.

As the definitions imply, exploitation rates are calculated by dividing a catch by the appropriate measure of the exploited population. This is rarely straightforward, either because the fishery may take salmon from several stocks simultaneously, or because it is very difficult to estimate the total number of fish surviving at any time, let alone decide whether they are vulnerable to a fishery. Some of these problems are addressed by marking (tagging) groups of fish and seeing how many are recaptured in different fisheries. Section 4 discusses the use of different types of tags and describes some of the mathematical approaches used to analyse the data. Some readers may find this section rather complex, and it is worth noting that a full understanding of these methods is not necessary to appreciate the subsequent sections.

Sections 5 and 6 provide estimates of the exploitation rates on a number of stocks in various commercial and sport fisheries. These data highlight the complexity of the life cycle and behaviour of salmon. Most fisheries exploit different sea age groups of fish at different levels, and in some fisheries the exploitation rate varies through the season, with the number of fish available, or their behaviour.

Comparison of exploitation rates can also be misleading. Different fisheries can take the same harvest of salmon, and thus have similar effects on a stock, but have different exploitation rates. The problems of comparing and combining exploitation rates in different fisheries is discussed briefly in section 7.

The final part of this report (Section 8) considers the implications of the various observed levels of exploitation for fisheries management. Stocks can only sustain exploitation because they tend to produce more adults in each generation than are required to provide sufficient spawners; some stocks sustain exploitation rates well in excess of 80% while others may warrent protection from all exploitation. However, the relationship between the stock size in one generation and number of fish produced in the next is complex and may be affected by a wide range of human activities in addition to exploitation. There is therefore no simple rule for deciding upon appropriate levels of exploitation. In additions, when considering control of exploitation it is necessary to examine not only the effects on all the stocks being exploited by the fishery but also the relationship between fisheries exploiting the same stocks. The various methods of control available are also discussed in section 8.

2. HOW MANY FISH ARE CAUGHT?

2.1. Nominal catch data.

Data on catches of salmon, while clearly the result of exploitation, do not in themselves give us very much information about the rate or level of exploitation. They do however represent a parameter of critical importance in the interpretation and management of exploitation for the following reasons:

- catch statistics are a basic measure of the performance of salmon fisheries, and are a measure of the "end result" of fisheries management;
- 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 stock can be calculated from reliable catch data.

It is therefore essential to try to collect complete catch data or to estimate the total numbers of fish taken by fisheries.

Efforts are made to collect and publish catch data in all major salmon producing countries around the North Atlantic. Signatories to the North Atlantic Salmon Conservation Organisation (NASCO) Convention, which include all North Atlantic countries with salmon interests, are required to provide catch statistics for salmon to the NASCO Council annually (Hutchinson and Windsor, P). More detailed data are also provided to the International Council for the Exploration of the Sea (ICES) for use in fishery and stock assessments.

The most commonly adopted system for collecting catch statistics in salmon fisheries is to license fishermen and to make it a requirement of the licence to provide catch returns. However, fishery licensing procedures and requirements for making catch returns vary considerably, and there are therefore significant differences in the completeness and comparability of catch data. In a few countries, catch returns are not required for recreational fisheries nor for by-catches in gear fished for other species. In addition, catches are not reported for the fisheries operating in international waters nor, of course, for illegal fisheries.

Proprietors or owners of river fisheries may also maintain catch records either for statutory returns (such as in Scotland) or for their own purposes. Some fishery records have been maintained for many years in a comprehensive and consistent manner; such records represent often the most valuable sets of catches statistics, justifying careful analysis.

2.2. Improving comparability of catch data.

Hutchinson and Windsor (P) noted that there are major differences in the catch statistics collected by different countries. For example, data are not always provided on both numbers and weight of fish caught, and not all catches are reported by gear type or divided into age classes. As a result, the parties of NASCO have agreed to consider means to improve the comparability of the data they collect in terms of:-

- inclusion of all components of the salmon fisheries in the statistics;
- inclusion of statistics for salmon caught in non-salmon gear where such retention is legal;
- collection of statistics for both number and weight of salmon caught according to sea-age;
- where ranching is practised the inclusion of such catches in statistics;
- the use of different conversion factors to calculate whole round weight.

These problems, however, may be relatively simple to address compared with unreported catches.

2.3. Unreported and illegal catches.

Fish mortality generated directly or indirectly by fishing which is not included in the recorded catch is termed non-catch fishing mortality and probably occurs in all fisheries. These losses, which were described by Ricker (1976), may be divided into two categories:

- mortalities associated with the fishing process but where the fish are not retained and therefore not recorded (eg discards and mortally damaged escapees).

- fish that are caught and retained but which do not enter into the recorded statistics (ie unreported catches).

The second group, unreported catches, includes landings by illegal fisheries and undeclared catches by legal fisheries. Rough estimates (or guess-estimates) of total annual unreported catches have been compiled by ICES (eg Anon 1991) each year since 1985, although only since 1989 have all countries provided figures. These data suggest that between 25-30% of the total landings of Atlantic salmon may be unreported (ie the true catch is 1.33 to 1.43 times the total reported catch) although levels vary considerably between fisheries. However, most countries are unwilling for the data to be published on a national basis, and it is clear that the data are not precise enough to indicate annual variations in this component of the catch.

In a survey of statistics collection procedures, Hutchinson and Windsor (P) noted six reasons why catch data may be incomplete:-

- absence of a requirement to make a return;

- suppression of information thought to be disadvantageous;
- local sale or consumption;
- innocent inaccuracy in making returns;
- fishing in international water;
- illegal fishing.

Even where it is compulsory to provide returns to the appropriate authority, there are various reasons why fishermen may suppress information. If, for example, the cost of licenses or rents is linked to the numbers of fish caught in previous years, then there may be an incentive for fishermen to under-report their catches. Alternatively, it is possible that catches could be exaggerated in order to enhance the market value of the fishery.

Innocent inaccuracies may include misclassification of salmon and sea trout (Winstone, P) and fishermen forgetting to make returns or failing to keep good records of their fishing. In England and Wales in 1989, the proportion of salmon anglers making returns (required by bye-law) varied between National Rivers Authority (NRA) regions from 21% to 100% (Russell and Buckley 1991); the higher figure is for a region dominated by "general" licences, which cover groups of anglers.

2.4. Estimating unreported catches.

2.4.1. Introduction.

Various approaches have been suggested for improving catch reporting rates or estimating total catches from incomplete data (Anon 1989). Winstone (D) noted the importance, however, of ensuring continuity in data records and thus of being able to provide a link between historic statistics and returns derived from improved collection procedures.

2.4.2. Sampling.

The standard system of collecting catch data relies upon fishermen to report all the fish they catch. An alternative approach is to estimate total catches by sampling a proportion of the landings. This may involve targeting those fishermen who account for the majority of the catch (Winstone, P), organising a sampling programme (B. Whelan, P) or making random checks on catches (Anon, 1989). Creel surveys, stratified in time and area, are used in New Brunswick to estimate catches (Chadwick, D), and a relatively modest sampling programme is thought to provide more reliable catch estimates than reported data. B Whelan (P) described various sampling strategies and advised the use of a number of different estimating methods in order to take account of bias. He also noted that detailed surveys in some years could provide base line data for the correction of statistics from other years, such as historical records.

Household surveys may also be used to estimate local sales and consumption where this is likely to account for a major component of the landings.

2.4.3. Logbooks.

Logbooks may be provided to anglers to encourage them to record details of catches throughout the season, rather than relying upon recall at the end of the season or when prompted. In a pilot study in Wales (Winstone, P), the provision of logbooks to a random sample of anglers did not increase the proportion making returns but did increase the average declared catch. There is a danger, however, that fishermen willing to complete log-books may not be representative of all anglers. This method may provide a useful supplementary source of information on the fishery allowing some corrections to be made to declared data. It may also provide more reliable effort data.

2.4.4. Carcass tagging.

Carcass tagging involves the labelling of all salmon immediately after capture. Fishermen are provided with tags which can only be used once. The system may have values in both improving the catch data and reducing illegal sales of fish. However, it is likely to be expensive to administer and there may be difficulties with the handling of farmed fish and fish imported from areas where tagging is not required. On the other hand, many fisheries managers consider carcass tagging to have major potential, and the fact that the salmon farming industry is moving towards carcass tagging as a means of brand advertising, means that a reconsideration of the approach may be timely.

2.4.5. Mathematical approaches.

Small (P) summarised various studies of methods to estimate total angling catches from incomplete returns. In order to improve catch returns, some authorities issue reminders to defaulting fishermen (Winstone, P). The data obtained and derivations are in the form:-

	Total	Unprompted	Prompted	Missing
Number of anglers reporting	A	Au	Ap	Am
Catch recorded or estimated	C	Cu	Cp	Cm
Proportion of effort	P(=1.0)	Pu	Pp	Pm
Calculated mean CPUE	M	Mu	Mp	Mm

Small and Downham (1985) showed the following relationship between total catch and the unprompted returns:

$$C/Cu = 1/Pu * M/Mu \qquad \text{Eq 2.1.}$$

Studies of returns arising from first and second reminders (South West Water Authority, 1977; Welsh Water Authority, 1981 and 1983) show that calculated mean catch per unit effort from unprompted returns is usually greater than from prompted returns and that the missing component tends to be small.

Small and Downham showed that the average catch per licence may be estimated from the average and the proportion of unprompted returns.

Small (1988) simplified their equation to:

$$M/Mu = Y + (1-Y)\,Pu \qquad \text{Eq 2.2.}$$

where Y is the intercept on the M/Mu axis.

Hence from equation 3.1:

$$C/Cu = Y/Pu + (1-Y) \qquad \text{Eq 2.3.}$$

Small used data from angling matches, which provide a complete record of effort and catch, to estimates values for Y. These results suggest that the following values of Y can be recommended for use in assessing trends of catches over a number of years:

All trout:	0.5 ± 0.18
Salmon:	0.3 ± 0.08

In making estimates for particular fisheries it may be necessary to establish estimates of Y appropriate to the particular local conditions. Returns from different types of licence holder (eg season and short term) must also be treated separately. This method also relies upon the unprompted returns being accurate, and alternative methods, such as logbooks, might also have to be introduced to improve the data used in this model.

2.5. Estimating illegal catches.

Catches in illegal fisheries can represent a very significant part of the total fishing mortality but, by their nature they are even more difficult to quantify than unrecorded legal catches. Considering their probable significance in many areas, little effort has been expended on estimating their magnitude. However, local inspectors or fishery officers frequently have a good idea of the number of individuals involved in illegal fishing activities and of the markets available for disposing of catches. It may also be possible to estimate the numbers of fish caught illegally based upon the numbers of illegal nets (or other gear) found in surveys of a particular area and the numbers of fish caught in those nets. Ideally, of course, efforts should be made to eliminate illegal catches; this is discussed in section 8.2.3.

3. AN EXPLANATION OF EXPLOITATION RATES.

3.1. Salmon and marine fish stock assessment.

While the concept of exploitation rates described in Section 1 is quite simple, the estimation of values can be complex and there is scope for considerable confusion in the terminology used. Because of the nature of the salmon's life cycle, it is not possible to carry out the same types of assessment as are used on some marine species. As a result, there are some differences between the terminology used in salmon and marine fish stock assessment. The purpose of this section is to describe and define the terms used by salmon biologists and which will be referred to later in this report.

3.2. Fishing mortality and exploitation.

When assessing the effects of fisheries on marine species, scientists usually refer to the level of fishing mortality on the fish stock. Paradoxically, instead of referring to deaths of fish, the definition of fishing mortality (F) used by marine fisheries scientists refers to survival. That definition is "the negative of the natural logarithm of the proportion of fish surviving fishing in a year" (Pope 1982). Thus:

$$\text{Proportion surviving} = \exp(-F) \qquad \text{Eq. 3.1.}$$

The main reason for using this apparently complicated definition is that it allows fishing mortality to be related to effort. Thus if, for example, the fishing fleet were doubled in size, the new situation should be:

$$\text{New proportion surviving} = \exp(-2F) \qquad \text{Eq. 3.2.}$$

This relationship does not apply in all fisheries, particularly rod and line fisheries where catch may not vary in direct proportion to effort (see section 6).

The level of exploitation (U) is the proportion of the stock that is killed which is thus the opposite of the proportion surviving (S). Thus:

$$U = (1 - S) = (1 - \exp(-F)) \qquad \text{Eq. 3.3.}$$

This may be expressed as a proportion or a percentage.

3.3. Salmon fisheries.

Salmon usually migrate through a number of fishery areas in their life cycle, and each fishery exploits each year class for a relatively short period. Thus it has been convenient to express the effects of each fishery as an exploitation level (U), which is equal to the catch (C) divided by the stock size before the fishery (N). Thus:

$$U = C / N \qquad \text{Eq. 3.4.}$$

More correctly, account should be taken of natural mortality during the period of the fishery. The definition of exploitation rate given by the ICES Working Group on

North Atlantic Salmon is thus as follows (Anon 1985):

> "The exploitation rate (U) is the catch (C) divided by the number of fish of the appropriate stocks and smolt year classes extant at the time when half the catch has been taken (Nh) plus the remaining half of the catch. That is:
>
> $U = C / (Nh + C / 2)$ Eq. 3.5.
>
> [In home-waters, Nh = Escapement + C/2]".

Although this may appear involved, the formula is designed to take account of fisheries which operate over a time period that is long enough for natural mortality to have a significant effect on the stock size. The formula therefore calculates the exploitation rate as if the fishery operated instantaneously on the median date. For most fisheries the difference between Eq 3.4. and Eq. 3.5 is small.

3.4. "Extant" and "fishery" exploitation rates.

The above definition gives the exploitation rate on the total stock that is extant at the time of the fishery. This is a useful measure when the concern is for the effect of the fishery on the total stock, regardless of whether all the fish are available to the fishery. For some other fisheries, however, it is more useful to consider the exploitation rate on one component of the population. Thus, for example, salmon from the same smolt year class of a single stock may be exploited at the same time both in home-waters as maturing "grilse" and at West Greenland as non-maturing one-sea-winter salmon. In this case it makes more sense to consider the exploitation rates in these fisheries on the separate non-maturing and maturing components of the stock. Thus the exploitation rate at West Greenland is calculated relative to the non-maturing population while exploitation in homewater fisheries, including rod fisheries, are usually calculated relative to the maturing component of the stock.

Not all the non-maturing one-sea-winter salmon will go to West Greenland, and the proportion that do will vary between stocks and from year to year. Thus the exploitation rate on the population within the fishery area will be greater than that on the total non-maturing component of the stock. In river fisheries, a similar problem may arise when only part of the stock enters the river during the legal fishing season. The exploitation rates described in the paragraph above should therefore be called extant exploitation rates, while fishery exploitation rate should be used to describe the level of exploitation on that proportion of the appropriate stocks and year classes that are estimated to be within the defined fishery area during the season. Thus, for example, if only half the population is available to the fishery, forwhat ever reason, the "fishery" exploitation rate will be twice the "extant" exploitation rate.

The extant exploitation rate therefore gives an indication of the total mortality caused by the fishery, while the fishery exploitation rate gives a measure of the efficiency of the fishery. Because different age groups of salmon are known to migrate to different areas and return at different times of year it is also useful to consider both measures of exploitation rates on the various age classes.

In some fisheries, particularly rod and line, the fact that fish enter or pass through the fishery over a long period further complicates the comparison of exploitation rate estimates. It must be remembered that low exploitation rates may occur for a number of reasons, including low effort, low fishing efficiency or the fish only being available to the fishery for a short time.

In mixed stock salmon fisheries, the fishery exploitation rate should be roughly the same for all stocks (exploited by the fishery), while the extant exploitation rate will probably be different for each stock, reflecting the different proportions of the stocks available to the fishery. Thus, for example, the fishery exploitation rate for the West Greenland fishery is thought to be greater than 50%. However, the extant exploitation rate by this fishery on non-maturing one-sea-winter English salmon may be around 15% while that on such fish from the River Bush (N. Ireland) has been estimated at less than 1%.

In summary, therefore, the definitions most commonly used are:

- Extant exploitation rate = the catch divided by the total size of the stock (or a component of the stock such as one age class) at the beginning of the fishing season.

- Fishery exploitation rate = the catch divided by the number of fish entering the fishery area during the course of the fishing season.

4. DERIVING ESTIMATES OF EXPLOITATION RATE.

4.1. The general approach.

As we have seen, the exploitation rates defined above relate catch to a measure of the population size. Where the population can be measured directly, for example using an electronic counter or trap and where reliable catch statistics are available, this is clearly straightforward. In other situations it may be possible to estimate the extant population, for example by redd counts or by a mark/recapture method. In some cases it is satisfactory to use a mark/recapture approach for direct assessment of exploitation, on the assumption that the recapture rate of marked fish is the same as the capture rate of the whole population.

4.2. Tagging and marking.

Marking is used to identify a sample of a population, or in some cases a whole population, of fish. The pattern of tag recoveries may then be used to calculate exploitation rates on the marked group or to estimate the total (marked plus unmarked) population in a given area. However, such experiments are often complicated by a number of factors including the possibility that the tagging may cause mortalities; tagged fish may lose their tags; and recaptures of tagged fish may go unreported.

Different tagging and marking techniques may be appropriate in different situations. Microtagging has, for example, been widely adopted for smolt tagging in order to reduced the effects of tagging and improve the reliability of returns in large fisheries. However, it will usually be necessary to use external tags to mark large fish or when recaptures are expected from small or diffuse fisheries.

A recent development of the mark/recapture approach is the that of radio tagging adult salmon. Fish with internal radio tags are also marked with an external tag, allowing reporting of recaptures. Although numbers tagged are generally small (of the order of tens or a few hundred), which reduces the statistical significance of the results, the method does overcome some of the disadvantages of conventional tagging. The exact number of extant fish is known, as is their distribution (eg how many were in the river during the angling season). The method also allows assessment of behaviour patterns in relation to exploitation for example the "catchability" of migrating fish. Estimation of exploitation rate is rarely a principle aim of tracking studies but represents a valuable spin-off observation.

4.3. Methods of estimation.

4.3.1. Catch/population estimates.

Dividing the reported catch figure (C) by a measure or estimate of the extant population (N) provides a direct figure for the level of exploitation. The approach (referred to as C/N in section 6) is most often used for fisheries within fresh water, where population size is most readily determined. However, where the spawning population is known, it is straightforward to estimate the number of fish passing through the estuary by adding to it the number of fish taken by anglers and the number estimated to have died naturally. If the proportion of the catch which is

3

derived from the river stock is known, it will then be possible to estimate the levels of exploitation in estuary fisheries.

4.3.2. Mark-recapture.

Tagging experiments may be used to estimate the subsequent levels of exploitation on particular groups of fish. Thus if a sample of fish (T) is tagged and some of them (R) are recaptured in a fishery, the ratio R/T gives an estimate of the level of exploitation in that fishery on the population from which the sample was taken. This is the type of experiment that has been carried out to estimate exploitation rates, in the Scottish coastal fisheries (Dunkley (P); Shearer (P)). However, such data can be difficult to interpret. If marked fish can leave the area, and/or unmarked fish enter then this will result in exploitation rates in the fishery area being under-estimated. As described above, radio tagging overcomes this problem to some extent.

4.3.3. Run modelling.

Tagging experiments may also be used in attempts to model the changes in populations. A sample of marked smolts, for example, may be released, and recaptures recorded in different fisheries. If estimates can be made of the number of tagged fish surviving at different points in the life cycle, then "extant" exploitation rates can be calculated from the tag recovery data. In practice, it is difficult to estimate the numbers of adults surviving from a batch of tagged smolts because the natural mortality during the first sea year is thought to be high and variable. In addition, "forward running" models require estimates to be made of the proportion of stocks maturing at different sea ages in order that the extant stock can be divided into the maturing and non-maturing components.

These problems are largely overcome by the back-estimation process of run-reconstruction (run-reconstruction) modelling (Anon 1989). In such models the starting data is the number of fish (usually tagged) of each sea age class returning to spawn. The numbers of fish alive at earlier stages in the life cycle are then back-calculated by adding the estimated mortality from both fishing and natural causes. For example, the stock size (N) just before the homewater net fisheries begins to operate equals the number of spawners (Sp) plus the number of fish caught by anglers (Cr) multiplied by a survival factor (exp Mt) to take account of the proportion that would have died from natural causes; to this is added the number taken by the nets (Cn). Thus:

$$N = [(Sp + Cr) * \exp Mt] + Cn \qquad \text{Eq.4.1.}$$

Natural mortality is thought to be relatively low on salmon after the first sea year, and a value of M of 0.01 per month (t = the number of months) is usually used (Anon 1985). Losses to fisheries are estimated from the recoveries of tags.

If the tag recovery data are good, this model is fairly robust because it is relatively insensitive to the only other input variables, M and t. Varying M between 0.02 and 0.005 per month has relatively little effect on the results.

The proportion of each sea-age group "maturing" (ie attempting to return to home-waters) becomes an output parameter from this model. The numbers of smolts tagged, and the mortality in the first year in the sea do not have to be considered as long as the surviving marked fish can be assumed to behave in the same way as unmarked fish after this time.

The run-reconstruction model has been used to estimate extant exploitation rates in the Faroes, West Greenland and several home-water fisheries for about six monitored stocks in the North-east Atlantic (see section 5).

Run-reconstruction models are more difficult to use when two or more fisheries operate on the same component of a stock simultaneously. This is not thought to be a problem for fisheries exploiting European stocks, as all fish taken in home-water fisheries are thought to be maturing. However, non-maturing one-sea-winter salmon from North American stocks are exploited in the Newfoundland and Labrador fisheries and in the West Greenland fishery at the same time. Assessment of these fisheries has therefore required the development of modified models (eg Anon 1990) to estimate the numbers (or relative numbers) of fish available to the fisheries. These have provided estimates of the "fishery exploitation rate" for West Greenland.

It is reasonable to expect that the "fishery exploitation rates" on different stocks (whether from North America or Europe) at West Greenland will be roughly the same. The proportion of a stock going to West Greenland is therefore equal to the extant exploitation rate on the stock (estimated by run-reconstruction modelling) divided by the fishery exploitation rate at West Greenland. Thus if we estimated that the extant exploitation rate on English .non-maturing one-sea-winter stocks at West Greenland was 15% and the fishery area exploitation rate on Maine stocks at West Greenland is about 60% (Anon 1989) we could estimate that about 25% (15/60 x 100%) of the English stocks go to the West Greenland fishery area.

4.3.4. Constraints models.

This approach has been proposed by the ICES Working Group on North Atlantic Salmon to provide better estimates of the fishery exploitation rate at West Greenland (Anon 1991). A model has been developed which describes the exploitation rate on Canadian stocks at West Greenland in terms of the fraction of the population going to West Greenland and the exploitation rate in Canadian homewater fisheries. These parameters have not been estimated precisely but must lie within certain feasible limits. As a result the range within which the exploitation rate at Greenland falls must also be limited. The range of feasible results can be further constrained because the proportion of the one-sea-winter fish in home waters that are non-maturing also lies within certain limits.

4.3.5. Catch analysis models.

One example of this approach is described by Gee and Milner (1980). This entails analysis of the changes in catch per unit effort with increasing effort (as indicated by numbers of licences). Small changes in catch per unit effort for grilse may indicate a low exploitation rate, whereas large changes for three-sea-winter fish may indicate that exploitation was already high. This approach is dependent upon a number of assumptions that may not be valid. These include the use of licence numbers as an indicator of effort; constancy of stock abundance over a period of years; and lack of trends in sea-age composition.

4.4. The role of fish counters.

Cragg-Hine (P) pointed out the value of fish counters in providing stock data for estimating exploitation rates in fisheries operating in fresh water. The modern generation of counters, which are microprocessor controlled, are more reliable and require less maintenance than earlier versions, although they still require regular attention. Such an approach has been used to estimate exploitation rates in the North Esk (Scotland) net and rod fisheries (Dunkley, P). Potter (D) noted that counters could be used to provide data for the run-reconstruction model if the proportion of the run that was tagged could be estimated. This might be achieved by linking a camera to the counter, or by other sampling regimes. This is being evaluated on certain English rivers.

A large volume of data can be generated by fish counters and methods are required to log and analyse it (Cragg-Hine, D).

4.5. The use of indicator rivers.

It is generally impractical to assess exploitation rates on all or even a large proportion of the salmon stocks in a region or country. As a result the idea of "indicator stocks" has been proposed (eg Anon 1988). These might be individual stocks or groups of stocks which would be representative of the stocks in a larger geographic area. However, this is a theoretical concept and it is not known whether real examples could be found.

There has been some confusion between the concept of "indicator rivers" and that of "index rivers" which was the term used by the ICES Working Group on North Atlantic Salmon (Anon 1985) to describe the small group of systems, like the Imsa (Norway) and N.Esk (Scotland), on which intensive research was being carried out. Patterns of change in the salmon stocks in these rivers are not necessarily considered to be representative of larger groups of stocks. In order to avoid this confusion it has been suggested that the "index rivers" be referred to as "monitored rivers" (Anon 1991).

Kennedy and Crozier (1988) demonstrated that data for the River Bush were broadly applicable to the Northern Irish fishery in general. Data from the North Esk, on the other hand are not thought to be representative of Scottish stocks (Shearer, D).

5. MEASURES OF EXPLOITATION RATE IN COMMERCIAL FISHERIES.

5.1. Sources of data.

Data on exploitation rates in commercial fisheries have mainly been derived from studies of a limited number of "monitored" (or index) stocks (Anon 1991) on which detailed tagging studies have been undertaken; these are listed below:

Europe		North America	
Burrishoole	(Ireland)	Western Arm Brook	(Canada)
Bush	(N. Ireland)	Saint John	(Canada)
Drammen	(Norway)	Mirimichi	(Canada)
Imsa	(Norway)	Penobscot	(USA)
N. Esk	(Scotland)	Merrimack	(USA)
Lagan	(Sweden)		

In these rivers samples of the emigrating smolts are tagged, and the numbers of tagged fish returning to the river are counted. For European stocks, where there are no simultaneous fisheries on non-maturing fish, this allows the use of the run-reconstruction model to estimate extant exploitation rates in different fisheries. For most of these stocks there are therefore estimates of exploitation rates in high-seas and home water fisheries on one-sea-winter and multi-sea-winter fish. For some of the North American stocks alternative models have been used to estimate the fishery exploitation rates at West Greenland and in the Canadian fisheries. In addition, estimates based on mark-recapture experiments are available for some areas.

5.2. Distant water fisheries.

5.2.1. Faroese fishery.

In recent years, the Faroes fishery has taken predominantly two-sea-winter fish, which are expected to return to home waters as multi-sea-winter salmon. Some one-sea-winter fish are caught, but the majority of these are less than the minimum landing size of 60 cm and are therefore discarded. This makes it more difficult to estimate the exploitation rates on the one-sea-winter component of the stocks. Extant exploitation rates have been calculated for the Faroes fishery for fish tagged on the six European "monitored rivers". Results have been reported by ICES (eg Anon 1991) and data were also provided by Shearer (P), Potter (P) and Dunkley (per. com.); these are listed overleaf:

Stock	Age	Seasons	Extant Range %	exp. level Mean %
Drammen (H)	1SW	1984/5 - 89/90	0- 5	1
	2SW	1985/6 - 89/90	3-45	24
Imsa (W)	1SW	1981/2 - 89/90	0	0
	2SW	1982/3 - 89/90	3-50	22
Imsa (H)	1SW	1981/2 - 89/90	0- 2	1
	2SW	1982/3 - 89/90	10-45	28
N. Esk (W)	1SW	1981/2 - 89/90	0- 5	<1
	2SW	1982/3 - 89-90	0-14	6
	3SW	1983/4 - 89/90	0-25	5
Lagan (H)	1SW	1984/5 - 89/90	0- 3	1
	2SW	1985/6 - 89/90	0-22	13

(H = Hatchery reared smolts, W = Wild smolts)

For two other monitored rivers, the Burrishoole and Bush, there have been relatively few tag recaptures and extant exploitation rates are estimated to be less than 1% (Anon 1991, Crozier and Kennedy (P)). Data from other tagging experiments in the United Kingdom and Ireland confirm that stocks from these countries are relatively minor contributors to this fishery. Exploitation rates in the Imsa stocks have declined since the 1986/87 season; this coincides with and may be related to the Faroese imposing tighter restrictions to keep the long-lining operations within their EEZ.

No estimates are available of the fishery exploitation rate at Faroes. However, it must be greater than or equal to the greatest extant exploitation rate on an individual stock, and this suggests that it is usually at least 40%.

5.2.2. European stocks in West Greenland.

In most years, about 95% of the salmon catch at West Greenland comprises one-sea-winter fish which would have returned to home waters as two-sea-winter salmon. The remainder of the catch is made up of multi-sea-winter fish ($\approx$ 4%) and previous spawners ($\approx$1%). Estimates of extant exploitation rates are available for five of the European monitored stocks in the West Greenland fishery (Anon 1991, Crozier and Kennedy (P), Shearer (P) and Dunkley (pers. com.)).

Stock	Age	Seasons	Extant exp. level Range %	Mean %
Bush (W)	1SW	1984-90	-	<1
Drammen (H)	1SW	1984-88	0-19	4
Imsa (W)	1SW	1981-89	-	0
N. Esk (W)	1SW	1982-89	0-48	10
Lagan (H)	1SW	1985-90	-	<1

When compared with the estimates of fishery exploitation rates for the West Greenland fishery (see section 5.2.3), these extant exploitation levels indicate that only a relatively small proportion of some of these stocks are vulnerable to this fishery. However, fewer data are available for major stocks from the UK and Ireland, having greater proportions of multi-sea-winter fish; these may make a greater contribution to catches at West Greenland. Recaptures of Burrishoole salmon at West Greenland are too infrequent to provide reliable estimates of exploitation rates on this stock. However, there is a concern that although the number of fish caught may be small, it may represent a significant proportion of the potential multi-sea-winter component of the stock (Browne, D). This may also apply to many other small stocks or stocks dominated by grilse returns.

5.2.3. North American stocks in West Greenland.

Estimates of the fishery exploitation level on Maine (USA) origin non-maturing salmon at West Greenland have been made using various modified run-reconstruction models (Anon 1990 and 1991). These models depend upon making certain assumptions about the proportions of the fish that go to West Greenland, stay in the Newfoundland - Labrador fishery or go elsewhere.

On the basis of these models, it appears likely that the fishery exploitation rate at West Greenland has been of the order of 60-70% in recent years, although estimates range from 40-90%. The extant exploitation rate on one-sea-winter Maine fish is thought to have averaged between 40 and 60% over the past 10 years while the average for two-sea-winter fish is thought to have been between 75 and 82% (Anon 1991).

Because of the uncertainties about the distribution of other North American stocks between the fishery areas it has not been possible to provide good estimates of exploitation rates. However, it appears that extant exploitation rates at West Greenland on North American stocks are probably greater than on European stocks indicating that a larger proportion of the North American fish are probably available to the fishery.

<u>5.3. Homewater commercial fisheries.</u>

5.3.1. European homewater commercial fisheries.

The trapping and monitoring programmes on the six European rivers listed above also enable extant exploitation rates to be estimated for certain homewater fisheries. For the Norwegian rivers, Drammen and Imsa, data are given for the periods before and after the closure of the coastal drift net fishery in 1989.

Stock	Age	Fishery	Years	Exploitation Rates Range%	Mean%
Burrishoole (W)	1SW	coastal nets	1985-90	54-82	76
Bush (W)	1SW	coastal nets	1984-89	61-89	71
(H)	1SW	(all Ireland)	1984-89	57-95	a
(W/H)	2SW		1987-90	36-60	45
Drammen (H)	1SW	coastal nets	1985-88	57-81	68
	1SW		1989-90	5-40	23
	2SW		1986-88	47-59	50
	2SW		1989-90	40-59	50
Imsa (W)	1SW	coastal nets	1985-88	51-79	65
	1SW		1989-90	60-65	63
	2SW		1985-88	80-95	88
	2SW		1989-90	42-72	58
N.Esk (W)	1SW	river nets	1985-90	23-40	32
	2SW		1985-90	29-37	34
Lagan (H)	1SW	coastal nets	1985-90	73-93	80
	2SW		1986-90	25-84	60

(H) = Hatchery reared
(W) = Wild
a = includes different rates for 1 and 2 year old smolts.

The fishery exploitation rate on salmon entering the N. Esk during the netting season is normally up to about 50% greater than the extant exploitation rate, although there is considerable year to year variation and in 1983 there was a 3.5 fold difference for grilse (Shearer, P). The difference is usually smaller for multi-sea-winter salmon than grilse, many of which may enter the river after the end of the netting season.

Exploitation rates in net fisheries have also been estimated for salmon tagged at various coastal netting stations in Scotland between 1954 and 1988 (Shearer, P). These studies suggest that between 4 and 17% of salmon tagged on the west, north-west and north coasts are subsequently exploited by fixed engine and net and coble fisheries. Subsequent levels of exploitation by nets on salmon tagged on the north-east coast and in the Moray Firth varied between 5 and 25%. For salmon tagged on the east coast the levels of exploitation by nets were between 42 and 63%.

Where the rod exploitation rate has been estimated for a river (section 6.1) it should be possible to back-calculate the number of fish passing through the estuary. The extant exploitation rate for the stock in an estuarine net fishery can then also be estimated. This assumes that all the fish caught are homing to that river or that the proportion that are not is known. Recent tracking studies have allowed assessment of this proportion, but variations between estuaries suggest that in the absence of such direct observations extrapolation is of doubtful validity. One study for which all the appropriate information is available is that based upon radio tracking on the River Avon (Solomon, D). Here the exploitation rate by estuary nets is estimated to have ranged from 7.3 to 12.1% between years (1986-90).

5.3.2. North American home-water commercial fisheries.

The only commercial fisheries for Atlantic salmon in North America operate in Canada (and St Pierre et Miquelon). Fishery exploitation rates for commercial fisheries have been calculated from Carlin tagging studies on salmon stocks from the Conne River in 1989 and Exploits River in 1988-89 (Anon 1990). Assuming a tag reporting rate of 0.7, these experiments gave the following estimates of extant exploitation rates in the coastal fisheries:

Stock	Fishery	Years	Exploitation Rates
Conne River	Newf' coastal	1989	3%
Exploits River	Newf' coastal	1988-89	57-61%

The low exploitation rate on the Conne salmon relative to those from other Newfoundland rivers is related to the early run-timing of this stock.

Estimates of extant exploitation rates on Saint John River two-sea-winter salmon in home waters have been estimated as part of the assessment described above (section 5.2.3).

Stock	Fishery	Years	Exploitation Rates
Saint John	Coastal	1975-98	12.5-69.8% mean 40.6%

5.4. Commercial exploitation rates on different sea-ages.

It is apparent from the data presented above that most commercial fisheries exert different exploitation rates on one-sea-winter and older salmon. This reflects the fact that the stock components migrate to different areas in the open sea and return to their home rivers through coastal and estuarine fishery areas at different times of year.

At least 90% of the catch in the Faroes fishery has usually comprised two-sea-winter salmon with the remainder being made up of similar proportions of three-sea-winter and one-sea-winter fish, most of which would return to home waters in the same year. Exploitation levels are difficult to estimate on the smaller stock components in the catch because relatively few tags are recovered. However, while the extant exploitation rate on one-sea-winter fish appears to be very low, that on three-sea-winter fish may be much higher because of their relatively lower abundance.

The West Greenland fishery does not exploit any salmon destined to return to home waters as grilse. Most of the fish caught would have returned after two sea-winters and a very small number after three sea-winters. As at Faroes, however, the exploitation rate on potential three-sea-winter fish may be relatively high, particularly if each year class of three-sea-winter fish is exploited in the fishery in two consecutive years.

Thus the overall level of exploitation on one-sea-winter fish is very low in the distant water fisheries while that on older fish may be quite high for certain stocks. This position is sometimes reversed in homewater commercial fisheries, which are often concentrated at the time that the one-sea-winter fish return. In fact, as multi-sea-winter stocks have declined in recent years, fisheries operating early in the year, when these stock components tend to return to home waters, have become less profitable, and the levels of exploitation are believed to have fallen.

Crozier and Kennedy (P) also observed differences in the marine exploitation of hatchery reared fish of different freshwater ages; fish released as 1+ smolts were more heavily exploited than 2+ smolts. A similar bias was evident for fish released into the Burrishoole (K. Whelan, P). The reason for this is not clear but it may be related to the slightly different time of return of fish of different smolt age.

5.5. Relationship between stock size and commercial exploitation rate.

Relationships between exploitation rates and stock size tend to be difficult to assess in commercial fisheries because most operate on a mixture of stocks. However, it is generally assumed that the exploitation rate is not directly affected by stock size. In practice, changes in stock size, and thus catch, will affect the profitability of the fishery and thus influence the effort. In most fisheries when catches fall below a certain level, effort tends to decline thus reducing the exploitation rate. This is believed to have occurred on the Faroes fishery in recent seasons (Anon 1991).

In some fisheries there will also be an optimum number of gear units (eg nets or boats). Above this level, fishermen may be unable to operate effectively, for example because of lack of suitable fishing stations. Thus the exploitation rate will not increase in direct proportion to effort.

Crozier and Kennedy (P) noted that, for the River Bush stock, exploitation in the coastal fishery tended to be high in the years when stock abundance was low. However, this appears to be related largely to the effects of different weather conditions on the movements of the fish. Elsewhere, studies have shown that weather conditions may also have a significant effect on the efficiency of the gear.

6. MEASURES OF EXPLOITATION RATE IN SPORT FISHERIES.

6.1. Observed exploitation level.

The estimates of rod exploitation rates (all sea-age classes combined) for all studies identified in the British Isles are shown in the following table. The methods used are discussed in section 4.

River	Method	Extant exp.* level	Fishery exp.* level	Reference
N.Esk	MR	≈5		Shearer (1986)
	C/P (counter)	5-16,	6-19	Dunkley (P)
Spey	MR	≈7		Shearer (1986)
Burrishoole	C/P (trap)	7.3-23.3 (15.6)		C. Mills (P)
Bush	C/P (trap)	13.9-19.0 (15.9)		C. Mills (P)
Erriff	C/P (counter)	13.7-19.5 (16.1)		O'Farrell et al (1989)
Coquet	C/P (trap)	6.5-42.0		Champion (I)
Frome	C/P (redds)	22.9-36.6 (27.6)		Solomon (D)
	C/P (counter)	5-27 (11)		Beaumont et al (P)
Wye	CA	25-47		Gee and Milner (1980)
Tamar	MR (radio tags)	≈7.5		C. Mills (P)
Test	C/P (counter)	28.7-39.1 (34.7)		C. Mills (P)
Itchen	C/P (counter)	49.0		C. Mills (P)
Avon (Hants)	MR (radio tags)	12.7-19.3 (15.6)	15.6-19.3 (17.6)	Solomon (D)
	C/P (redds)	72		Beaumont et al (P)
Twyi	MR	<25.0		C. Mills (P)
Lune	C/P (counter)	13.7-19.7	15-27.6	Cragg-Hine (D)
Kent	C/P (counter)	13	16.5-17.6	Cragg-Hine (D)

Note. MR = Mark recapture, C/P = catch/population, CA = catch analysis.
For explanation see section 4.3. *For definitions see section 3.4.

In three cases (N.Esk, Avon and Frome) there are two estimates obtained by different methods. On the N.Esk, mark/recapture experiments gave an indication of about 5% exploitation, whereas figures for later years using counter data gave a range of 5-16% (mean 9%) between years. In the case of the Frome and Avon, measures gained by estimating the population size from redd counts gave a much higher figure than those derived from counter data (Frome) and mark/recapture experiments (Avon). Although the figures were derived from different years, it is suggested that the validity of the overall figures derived from redd counts is so doubtful that these are ignored in further discussions.

The range of extant exploitation rates derived for rod fisheries is therefore 5 to 49%. In four cases there are comparable estimates of fishery exploitation rate; these are generally higher, reflecting the fact that not all the extant stock enters the river within the angling season.

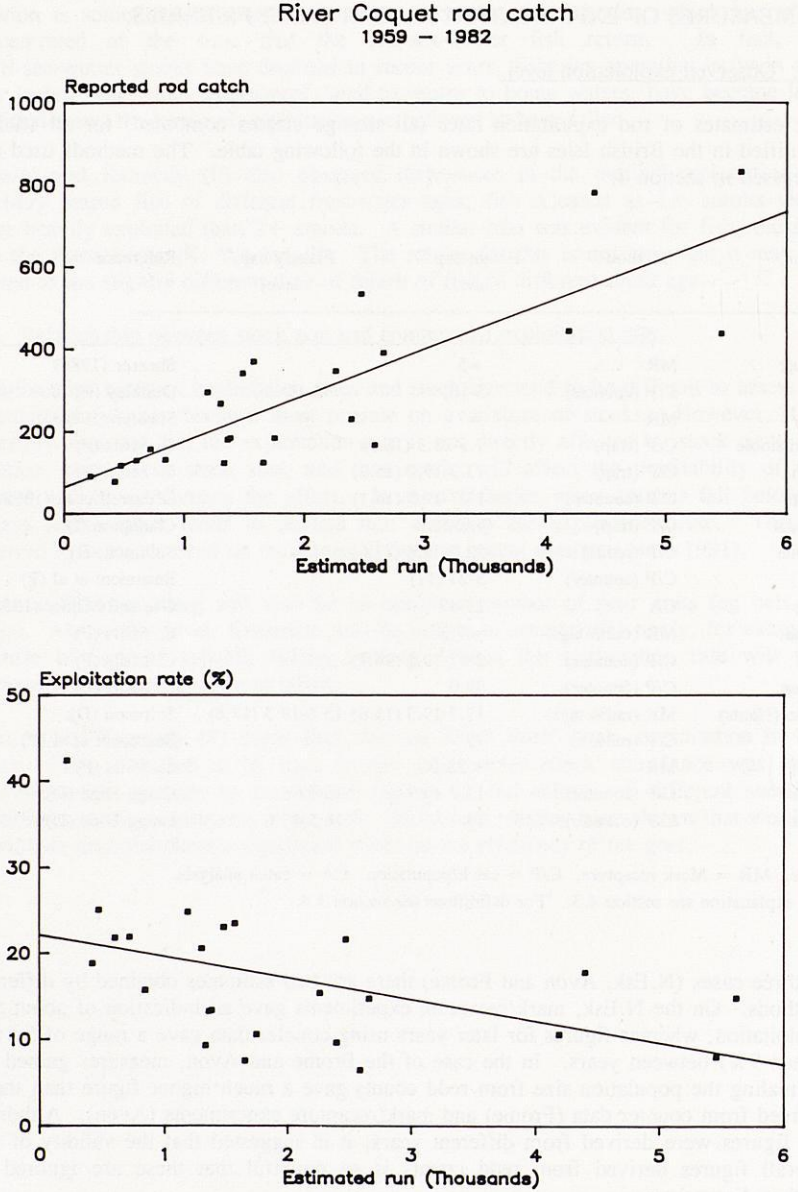


Fig 6.1. Relationship between estimated population size and rod catch (above) and exploitation rate (below) on the River Coquet. The run is estimated from trap catch. Data from A Champion (pers. comm.), reproduced by permission of the National Rivers Authority, Northumbrian Region.

In discussion of the variation in exploitation rate between rivers, it was suggested that the rivers with the lower overall rates tended to be fished predominantly by fly fishing, whereas those showing the greatest overall rates generally included a significant proportion of fish caught by other methods, eg prawn or worm bait. Care is needed, however, in attributing exact cause and effect. Those fisheries fished predominantly with bait tend to be the more heavily-fished ones, often with a lower stock level. Higher exploitation rates are often associated with lower levels of stock (see section 6.2).

6.2. Relationship between stock size and rod exploitation rate.

Two of the studies so far considered indicated that exploitation rates increased as stock levels fell. This is seen for the Coquet in Fig 6.1 (Champion, I) and the Frome in Fig 6.2 (Beaumont, P). In both cases, a three fold variation in exploitation rate is attributable to variations in stock level within the range observed. A similar situation has been recorded for sea trout by Mills et al (1986). This phenomenon has two fundamental implications for fisheries management:

- Stock size varies to a greater extent than catch. In the case of the Frome, an analysis of part of the time series suggests that the stock varied by a factor of 6.60 between years whereas the catch varied by only 2.45 (Solomon D). Equivalent figures for the Coquet are 26.1 and 10.7 respectively. Thus, in using catch as an indicator of stock well-being, a moderate decreasing trend in catches may in fact be due to a much more substantial downward trend in stocks.

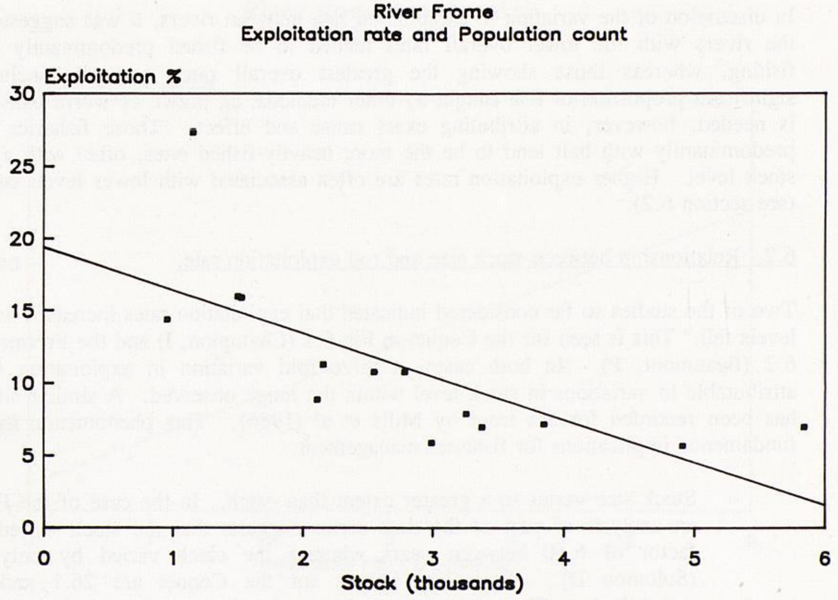
- Management of a depleted stock is perhaps both very difficult and very important as a much higher proportion of a depleted stock is likely to be taken by anglers. A model of the Frome exploitation suggests that the relationship is not linear and that exploitation rate accelerates sharply as stock levels fall to a very low level (Fig 6.2).

6.3. Rod exploitation rate on different sea-age classes.

Where information is available it appears that the exploitation rate of multi-sea-winter fish is higher than for grilse. Dunkley (P) reported that the mean rod exploitation rate on fish entering the North Esk during the angling season was only 3.7% for grilse, but 24.6% for two-sea-winter and older fish. Gee and Milner (1980) calculated that less than 10% of fish of less than 3.2 kg (mainly one-sea-winter fish) were caught by rod on the Wye, whereas the figure for fish over 6.8 kg (mainly three-sea-winter fish) was in excess of 90%. Beaumont et al (P) reported that on the Frome the exploitation rate on three-sea-winter fish was highest and on grilse lowest.

There are a number of reasons why multi-sea-winter fish may be relatively easier to catch than grilse. These include:

- as multi-sea-winter fish are nowadays generally fewer in numbers than the grilse and tend to enter the river earlier in the year, the mechanism discussed in section 6.2 whereby exploitation rates are greatest at low stock levels may operate.



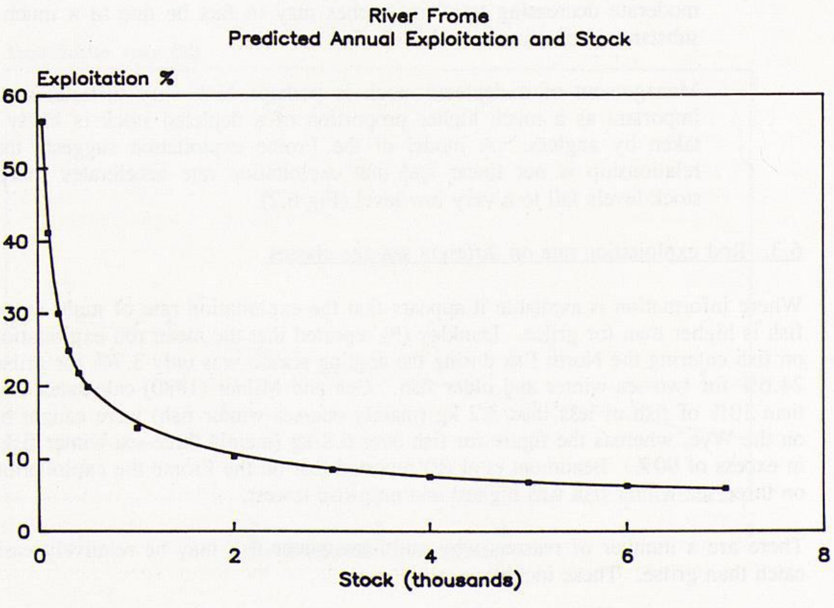


Fig 6.2. Relationship between stock size (as measured by electronic counter) and rod catch on the River Frome. Above - straight line regression for the plotted data. Below - derived predicted relationship. Data from Beaumont (P) and Beaumont et al (1991).

- fish entering the river at lower water temperatures, as multi-sea-winter fish tend to, may remain takeable for a longer period (see section 6.4).

- fish entering early in the year may have been feeding more recently than those entering late, and thus retain a greater tendency to take a lure or fly. It has been noted that salmon in coastal waters early in the year are far more likely to have food in their stomachs than fish taken later (eg Fraser, 1987).

Whatever the reasons, this phenomenon is clearly important in terms of fisheries management for the following reasons:

- a depleted catch of large spring salmon may be indicative of a stock of such fish that is very small indeed;

- it may be difficult to effectively manage a fishery to allow recovery of a depleted multi-sea-winter stock;

- a programme of stock enhancement that boosted numbers of multi-sea-winter fish by only limited numbers may nevertheless make a major contribution to rod catches.

6.4. Effect of period of river residence on catchability.

It has been known for many years, from angling folklore and experience, that salmon are most vulnerable to capture while still relatively "fresh" in the river, and when stimulated to migrate by a rise in water level. Recently, radio tracking of salmon has allowed a more thorough examination of this phenomenon.

A five-year study involving the radio tagging of 437 adult salmon in Christchurch Harbour has recently been completed (Solomon D). Of these, 274 entered the River Avon within the angling season, of which 43 (15.7%) were reported caught by anglers. Twenty (46.5%) of the 43 recaptures occurred within 10 days of tagging in the estuary, and 29 (67%) within 20 days. This 20 day period generally coincided with the period of initial migratory activity during which the fish may penetrate well into the river system. There generally followed an extended period of little migratory activity, during which very few fish were caught. The other recaptures were spread through the remainder of the fishing season, with a definite increase in vulnerability during September, possibly reflecting the onset of pre-spawning migratory behaviour. This also coincided with an increasing tendency to recommence migratory activity in response to minor flow events.

Clarke et al (1989) observed a similar pattern both of movements and tag recaptures of radio-tagged fish on the Twyi; six out of eight recaptures were made within 15 days of the fish entering the river. In a tracking study on the River Spey, seven of eleven recaptures by rod (64%) were made within twenty days of tagging in the estuary (Laughton 1991).

7. OVERALL LEVELS OF EXPLOITATION.

7.1. Sequential exploitation.

Comparing both numerical catches and exploitation rates between sequential fisheries requires careful interpretation. For example, we may compare the effects on one stock of the distant water fisheries at West Greenland and Faroes; homewater net fisheries in coastal waters and the estuary; and rod fisheries. If the spawning escapement was 1000 grilse and 500 multi-sea-winter fish, we can estimate the catches if each fishery took 30% of the extant stock (maturing or non-maturing components as appropriate) at the time they operated. Alternatively, we may compare the levels of exploitation in these fisheries if they each caught 500 fish of each year class. These estimates are shown below:

Fishery	Estimated catches assuming equal extant exploitation rates (=0.3)		Estimated extant exploitation assuming equal catches (=500)	
	1SW	MSW	1SW	MSW
Faroes	2825 a	657	8% a	19%
West Greenland	996 b		15% b	
Homewater coastal	920	466	19%	25%
Homewater estuary	619	309	25%	33%
Rods	429	214	33%	50%
Spawners	1000	500	1000	500

"a" some potential MSW returns
"b" all potential MSW returns

This should only be taken as an example of this effect, as the results will change significantly with the size of the spawning stock and the levels of exploitation/catches. However, it illustrates the difficulty of comparing even extant exploitation rates directly.

It should also be noted that the catch estimates for the different fisheries should not be compared directly because some of the fish caught would not have survived to return to their home river. The numerical loss to the spawning escapement "L" can be estimated by correcting for natural mortality as follows:

$$L = C * (\exp - Mt) \qquad \text{Eq. 8.1.}$$

where C = catch in the fishery
M = instantaneous monthly rate of natural mortality
t = time from the mid-point of the fishery to when the spawning escapement is measured.

7.2. Combining exploitation rates.

In order to calculate the combined effect of several sequential fisheries, we may express the exploitation in each fishery as a "fishing mortality" (see section 3.2); the values of "F" for each fishery are then additive, along with natural mortality (M). The proportion of the stock surviving the fisheries can then be calculated using Equation 3.1. In the example below the combined effect of the three fisheries is to reduce the overall survival by 78%:

	Extant exploitation rate "U"	Fishing Mortality "F"
Fishery 1	30%	0.36
Fishery 2	60%	0.92
Fishery 3	20%	0.22
Total		1.50

Proportion surviving all fisheries = exp (-1.50) = 22%.

Only extant exploitation rate estimates may be combined in this way, although this may be for the total stock or for some component of the stock (eg maturing one-sea-winter fish). Fishery exploitation rates cannot be combined in this way.

It is not the aim of this report to consider the relative economic values of different fisheries or the allocation of catches between fisheries, and these topics were not addressed by the workshop. However this has recently been the subject of two studies in Great Britain (Mackay Consultants 1989; Radford et al, 1991). These studies adopted different approaches to valuing fisheries (Radford and Hatcher P), highlighting the complexity of this subject area.

8. MANAGEMENT OF EXPLOITATION.

8.1. Stock and recruitment.

The relationship between the numbers of fish spawning in one generation and the number of adult fish so produced in the next is fundamental to any attempt to manage numbers of spawners by control of exploitation. However, this is a complex subject, and despite extensive investigations and erudite argument a full understanding remains elusive. A full examination of the subject was beyond the scope of both the Workshop and this document, but the opportunity was taken to consider the current status of knowledge and hypothesis.

The maximum number of smolts that can be produced by any river is inevitably limited by the availability of space and food for the parr. Clearly, a heavily depleted spawning stock would not be capable of producing this number of smolts. There must therefore be a minimum required number of adults that will produce this maximum level of smolt output. It is not clear whether a population of spawners larger than the minimum required will also produce the maximum number of smolts or whether the production could be reduced for example by over-cutting of redds or depressed growth rates at higher densities. This latter possibility is described by the "dome-shaped" stock and recruitment curve. In either case, however, there may be seen to be some wastage because either more adults spawn than are required or less than the maximum number of smolts are produced.

Thus the minimum number of adults that will produce the maximum number of smolts can be considered an optimum spawning population. However, there remains a number of questions about this relationship which could have a significant effect on the way we manage stocks and fisheries. These include:

- does production decline above the optimum spawning population?
- below the optimal level, how many fish in the next generation does each pair of spawners produce?
- how many excess spawners are required to take account of poor distribution through the river?

Hay (P) noted a slight downward trend in recruitment on the Girnock Burn at high stock levels but considered the matter unsettled. Chadwick (P) noted a greater variation in recruitment at high spawning stock levels, but the year of highest stock on the Western Arm Brook produced the greatest smolt output. Kennedy and Crozier (P) also concluded that the evidence for a dome-shaped stock and recruitment curve, at least at the densities studied, was equivocal. Dome shaped curves have been noted for parts of life-cycles (eg Shelligan Burn - eggs to 1st and 2nd autumn - Hay (P)) but there appears to be scope for matters to even-out at a later stage. Chadwick (P) reported that smolt-to-adult survival was less when smolts were numerous as they tended to be smaller.

Consideration of a range of stocks (Kennedy and Crozier (P), Solomon 1985) suggests that healthy productive salmon populations are able to support levels of exploitation of the order of 80 - 90% and still achieve near-maximal production in the subsequent generation in most years. However, exploitation at that level leaves the stock vulnerable to increased natural mortality, for example in the sea.

Kennedy and Crozier (P) described a model for deriving the target spawning stock on the River Bush, based upon an optimal deposition of 1.5-2.25 million ova. They were then able to propose target exploitation rates to achieve this level of spawning and maintain the stock on a stable basis. It is stressed, however, that there is little evidence that ova deposition above these levels will lead to a reduced stock in the next generation.

The optimal spawning population may be a valid concept for a small stream or tributary where the spawners and juveniles are likely to be able to distribute themselves optimally throughout the whole area, but in a larger system optimal dispersion is unlikely; there are bound to be relatively more spawners in some areas than others. Thus while on odd occasions, by chance, the "optimal" number of spawners will generate the maximum stock in the next generation, under most circumstances the recruitment from that level of spawning will be somewhat lower. Increased numbers of spawners above this level are likely to result in better utilization of spawning and nursery grounds. Thus rather than the relationship forming a line on a stock and recruitment graph, we see a scatter of points especially around the "optimum" number of spawners. Hay (P) suggested that this phenomenon should be viewed as an "envelope" rather than as a best-fit line on a stock recruitment relationship.

On anything but the smallest and simplest river system, it is therefore more appropriate to consider an optimal spawning stock for each tributary. This is an important concept when such sub-stocks may enter the river and be vulnerable to fisheries at different times and to a differing extent. We may be some way from being able to manage our salmon fisheries on this basis, but it may well come. Solomon (1984) describes such sub-stock management of commercial fisheries for Pacific salmon on the Fraser River. He quoted a series of extracts from the fishery regulation record for 1982, for example:

> "19 August. In order to harvest additional Chilko River sockeye the Commission approved Area 29-7 and 9-17 of Canadian Convention Waters open to gill nets on 20 August for 12 hours fishing."

8.2. Control of exploitation.

8.2.1. Why control?

There are a number of valid reasons for wishing to control exploitation of salmon in various fisheries. These include:-

- the fishery is illegal, and is perceived to be damaging or potentially damaging to legal catches and/or spawning stocks.

- overall exploitation is considered too high, and may be reducing the spawning stock below the perceived optimal level.

- the fishery (eg coastal nets) may be perceived to be reducing the catches of a subsequent fishery (eg rods).

- the fishery may be considered to be over-cropping one component of the stock eg multi-sea-winter.

- the fishery may be cropping mixed stocks, making individual stock management more difficult.

8.2.2. Methods of control for legal fisheries.

The most appropriate approach to controlling or reducing exploitation will depend upon the type of fishery involved and the perceived problem that it represents. D Mills (P) presented a framework for consideration of approaches to limiting exploitation. There was considerable discussion on this matter during the workshop, and examples were described. The three main approaches are control of effort, control by quota, and fishery closure.

Effort control may be effected by the following methods:-

- close season. Close seasons for net fisheries are generally more restrictive than those for rod fisheries, presumably in recognition of the potentially higher exploitation rates of the former. A disadvantage of the close-season approach is that it concentrates exploitation on a limited part of the run, and could in theory result in selective pressure and changes in run-timing. Equally, adjustments in close season could be a valid approach to protecting a depleted fraction of the stock, eg those entering the river early in the year. This approach is currently under consideration by the NRA for rehabilitation of spring runs on the Hampshire Avon.

- close times. Weekly (eg 48 hours at weekends) and daily (eg at night) close times are generally applied to coastal and estuary net fisheries with a view to allowing part of the run to pass the fishery unmolested; clearly the fish must have passed beyond the fishery area within the close time for this approach to be fully effective; it is therefore less appropriate for rod fisheries. Increased close times have been applied in many UK fisheries in recent years to reduce exploitation.

- area limits. Many commercial fisheries have fixed limits beyond which they may not operate. Under agreement via NASCO, signatory countries do not allow fishing beyond coastal waters except in the case of the Faroes and Greenland fisheries, which are limited to 200 mile zones. In most estuary net fisheries in England and Wales there is an upstream limit, usually well below the tidal limit.

- limit access. Many private fisheries (eg Scottish net fisheries, most UK river fisheries) effectively limit effort by restricting access. It can be particularly effective where a large part of the coastal or in-river exploitation is under single management eg River Erriff, River Thurso. Most public net fisheries in England and Wales are limited by Net Limitation Order, with only a fixed number of licences issued. Many have been decreased over the years, few have been increased.

- <u>limit method or gear.</u> Many commercial fisheries are limited in the type of gear they can use or in the extent of the gear (eg length of nets, mesh size). Many rod fisheries or whole rivers are restricted in the type of lure or bait that may be used; examples include fly only, no natural bait, no worm bait, and no prawn bait; these may apply for the whole season or only for a part. Although often of relatively little effectiveness in causing a great reduction in catches and thus exploitation rate, angling gear limitations may nonetheless be very effective where the exploitation rate is high.

The quota approach is of course the one used in the control of the Faroes and West Greenland fisheries in recent years. While effective at limiting catches, it would appear to be a somewhat unprogressive approach as it does not take account of fluctuation in stocks, whereas most other approaches to catch limitation do. If on the other hand it were possible to adjust monthly or annual quotas according to a reliable measure or predictor of stock abundance this approach would become near ideal. This approach is currently under investigation in Canada (Chadwick D). The difficulty with most commercial fisheries is that they exploit a mixture of stocks. Thus quotas or exploitation rates have to be adjusted to protect the weakest stock or that with the highest extant exploitation rate.

Rod quotas are also applied in some areas. As a measure to allow recovery of depleted stocks in the River Torridge in Devon, the NRA have proposed a bye-law limiting each anglers catch to two salmon per day, three per week, and five per season. In North America, daily weekly and season limits for anglers catches are often applied, sometimes being different for wild and hatchery (as indicated by a well-healed adipose clip) fish. In view of the observation that in many rivers a large proportion of the catch is taken by relatively few anglers (Solomon D) this approach, if feasible, may be very effective. Carcass tagging (see section 2.4.4) would greatly facilitate adoption of this approach.

A number of commercial fisheries have been closed-down over the years largely as an approach to limiting overall exploitation. In public fisheries in England and Wales, this has been done by reducing the Net Limitation Order to zero (which is then achieved by "natural wastage" as licensees retire or die) or by bye-law disallowing certain methods in certain areas. There has also been a trend in recent years towards the buying-out of private fisheries, and then not exercising the right to fish. The Atlantic Salmon Conservation Trust (Scotland) has acquired the rights of many Scottish commercial net fisheries. In England and Wales, the NRA and its predecessors have acquired, or been given in trust, rights to a number of private net fisheries, including seine net fisheries on the Frome, Exe and Dart, and fixed engines on the Wye and Usk.

8.2.3. Control of illegal fisheries.

Control of illegal fisheries is often more difficult. Donaldson (P) described the considerable problems involved in policing the Irish drift-net fishery operating with illegal quantities or types of gear, and/or beyond the fishery limit. Problems included personnel safety, threats of violence, and the logistics of catching those responsible. He raised the principle of legalising certain aspects of the fishery which were effectively beyond control, for example use of monofilament nets. Walker (P) described the similar problems encountered by the NRA, Northumbria Region in controlling illegal fishing activities.

A point raised in discussion was the extent to which the existence of a legal fishery acted to reduce illegal activity in some areas, by the legal fishermen effectively policing the fishery. However, it was also suggested that a legal fishery could act as a cover for marketing illegally caught fish. Little evidence appears to be available concerning the extent of either of these mechanisms.

Carcass tagging (see section 2.4.4) is used in Canada and France to control illegal fishing by making it an offence to be in possession of untagged fish. Tags are only available to licensed fishermen.

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