Chapter (non-refereed)

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Salmon population studies based upon Scottish catch statistics: statistical considerations

K H LAKHANI
Institute of Terrestrial Ecology, Monks Wood Experimental Station, Huntingdon

1 Introduction

Our world is highly stochastic. Interactions and processes occurring around us are complex. Many aspects of nature appear chaotic and uncertain, and well beyond our understanding, for our abilities and resources are often restricted and inadequate. As scientists, in our search for patterns and the truth, we organize our labour, and we plan and we ponder, but we find nevertheless that, time and again, we are forced to describe and explain a particular part of nature from a limited amount of information.

Under these conditions, we cannot afford to rush into expensive investigations without first considering our prospects of success. With any given problem, the extent to which we succeed can only be measured by the extent to which we achieve our objectives. This, in turn, depends upon the nature of the population being studied, the properties of the variables of interest, the size of the sample and the quality of the sampling design, the accuracy of the measuring methods, and the appropriateness and adequacy of the mathematical, numerical, and, above all, scientific methodology that we use.

The first requirement of any study is a clear statement of the objectives. Such a statement is essential to define the statistical population which we need to study, because we have to be satisfied from the outset that our sample will represent this particular population. The available scientific methodology enables us to make inferences from a sample to the sampled population; however, having sampled and studied a particular population, there is no acceptable methodology which enables us to make inferences about some other, different, population. In a typical sampling study, the population is divided into parts called sampling units. Some of these sampling units are chosen using an appropriate sampling scheme (eg simple random sample, stratified random sample, multi-stage sampling scheme, etc), and the data arising from the sample are analysed to draw conclusions about the population of interest. Detailed accounts of sampling considerations are given in the works of Cochran (1963), Green (1979), Sampford (1962), Sukhatme (1954) and Yates (1960), while summaries are given by Jeffers (1979) and Lakhani (1981).

The purpose of this paper is to examine the statutory Scottish salmon catch statistics, published by the Department of Agriculture and Fisheries for Scotland (DAFS) (Anon 1983) and to consider the question: can these data be considered as a statistically satisfactory sample from the population of the salmon stock of interest to Scotland? If there are limitations in the data, is it nevertheless possible to attempt to take these limitations into account in analysing and interpreting the data, with a view to making trustworthy statements about fluctuations or trends in the salmon stock?

A number or research workers, notably from Scotland (see Dunkley 1986; Shearer 1986; Shelton 1986), have discussed a variety of factors which contribute to the distortions of the observed catch statistics. Shearer and Clarke (1983) examine the abundance of different stock components from catch statistics for 1952–81 for 5 regions. Various reports published by the International Council for the Exploration of the Sea clearly indicate the interest in using the catch statistics to assess the stock. The discussions of the various limitations imply, or give the impression, that if only these distortions are quantified, and somehow taken into account in interpreting the catch statistics, then the major problems underlying their use as an index of stock abundance would disappear. However, none of the authors (see above) has made the obvious but important point that the statutory data arise from within Scotland, while the fish spends its time in the deep Atlantic as well, and that the data simply cannot be regarded as a satisfactory sample from a well-defined and relevant population of the Atlantic salmon. Possible consequences are also discussed in the paper.

2 Scottish salmon catch statistics

2.1 Data

The Scottish salmon catch statistics are obtained under the provisions of the Salmon and Freshwater Fisheries (Protection) (Scotland) Act 1951. This Act empowers the Secretary of State to require the owner or occupier of any salmon fishery in Scotland to furnish DAFS with information on the catch of salmon and sea trout made in the fishery. The Act also provides that the catch statistics can be published for each Salmon Fishery District. However, some of the Districts are very small; and so, to maintain the confidentiality provisions required under the Act, the data from small Salmon Fishery Districts are pooled.

The published data relate to 62 Statistical Districts for the whole of Scotland, which have been grouped into 11 Regions. Separately for each of the 62 Districts, for each year since 1952, the published data show the total catches divided between salmon, grilse and trout (Anon 1983); these catches are recorded by number, by weight, and by method of capture (fixed engine, net

and coble, and rod and line). A more detailed account is given by Shearer (1986).

2.2 Statistical inadequacies

In contrast to data arising from an experiment, the catch statistics arise from a statutory data gathering programme which is not much different from a general monitoring scheme. On the Salmon Catches Return form (see Anon 1983; Shearer 1986, Appendix A), the stated objective is '...to provide information which will assist in protecting and developing the fisheries'. There is no indication about exactly which specific questions will be required to be answered by the information being collected. Indeed, at the time of the setting up of such observational programmes, it is not always possible to foresee what future problems will require to be considered on the basis of the sample information. However, that does not mean that there should be no attempt to base such studies on sound principles of science and logic. On the contrary, because of the inherent uncertainty attached to such projects, it is doubly necessary to check, and check again, that the basic statistical requirements common to all sampling studies are met from the outset, and that the adequacy of the adopted scheme is reviewed regularly.

A number of fishery biologists from DAFS (eg Dunkley, Shearer, Shelton, referred to earlier) have discussed the relationship between the catch statistics and the state of Atlantic salmon stocks in Scotland, and implied that a valuable usage of these statistics, if the discussed distortions could be allowed for, could be to help study the fluctuations in the stock of the Atlantic salmon of interest to Scotland. Thus, in his summary, Shearer (1986) states: 'This paper describes the sources of data which are available to assess the state of Atlantic salmon stocks in Scotland'.

However, in the case of salmon there is the practical difficulty of clearly defining the statistical population of interest, for the fish spends its time in Scottish waters as well as the deep Atlantic. The very nature of the catch statistics, based as these are on the statutory returns made by the owners or occupiers of fisheries in Scotland, ensures that the data indicate, at best, the abundance of the salmon stock, not in the Scottish waters and in the Atlantic, but in that subpopulation of it which happens to enter the Scottish waters. Further, the data cover, at most, the period February–September, missing out the other months every calendar year. Finally, there is no information on sampling effort; there is no direct and detailed information, from each fishery, every year, on the actual effort employed in catching the fish.

Some information is better than none, assuming, of course, that the limited nature of the information is recognized and understood, and the resulting complications are accounted for in processing the data and in interpreting the results. There is a real danger, however, that this provision may not always be made, or that it may not always be possible. To illustrate this point, consider the data on the total number of salmon + grilse caught by all methods during the period 1952–81 shown in Anon (1983, p 137). This 'total catch' picture obviously disregards the variation between regions, between catching methods, and between the ratio of grilse to salmon. Nevertheless, for the purpose of this illustration, suppose that our main interest is in the total population of grilse and salmon. Then, the figure shows clearly that the last decade has seen a marked decline in the overall values of the catch statistics, relative to their values in the previous decade. In any well-planned sampling study in which a defined population is studied by measuring the appropriate sampling units, it is possible, with standard statistical theory, to make use of the information contained in the sample data to make trustworthy statements about the parameters of the population of interest. However, the annual catches shown in this figure cannot be used in this way because the catch statistics are based upon unknown numbers of ill-defined sampling units, from an annually variable, unknown subset of the overall statistical population of the salmon prevailing in the Scottish waters and in the open Atlantic.

2.3 Resultant complications and other distortions

A number of factors, summarized below, contribute to the distortions of the observed catch statistics. Their collective distorting effect is of unknown magnitude from year to year, but is unquestionably capable of being large enough to render the observed catch statistics totally useless as an index of abundance of the overall total population of the salmon present in the Scottish waters and in the deep Atlantic. A detailed account of these factors is obtainable from the papers by Dunkley (1986), Shearer (1986) and Shelton (1986) mentioned earlier; but a brief account is given below.

i. The catch statistics cannot be interpreted satisfactorily without first knowing, for each catching method, the extent of the catching effort by each fishery. There are obvious difficulties in defining the 'catching effort' which cannot be expected to be of the same quality for different persons or fisheries. Further, in a non-experimental observational programme, as is used to obtain the Scottish catch statistics, the catch effort by each fishery is not fixed at the outset but is determined voluntarily by each fishery. This leads to further problems. Simply knowing the extent and magnitude of catch efforts is not enough; sensible and acceptable assessments of the catch statistics cannot be made unless we understand the reasons for the variation in catch efforts. For example, reduced fish abundance, or the prevailing market conditions, may induce a fishery to step up its catching effort, or alternatively to reduce or abandon fishing. Such differential behaviour by the fisheries can occur with variable

time lags between fisheries, or between years by the same fishery.

ii. As the overall salmon population consists of the fish in the Atlantic as well, the harvesting of the salmon from the Atlantic is liable to lead to reduced catch statistic values, because some of the harvested salmon could have otherwise found their way into the Scottish waters. Fish of known Scottish origin are presently thought to be harvested off Greenland and the Faroes, and off the coast of Ireland and north-east England. The Greenland fishery began in the early 1960s and the catches reached a peak in 1971, but they have declined in recent years. On the other hand, catches in the Faroese long-line fishery were not large before 1979, and since 1982 have been limited by quota. The drift net fisheries off the coasts of Ireland and north-east England increased their catching power during the 1960s because of the introduction of more efficient, synthetic twine nets. In addition, an unknown number of salmon are removed from the population but do not get recorded. This number includes all non-reported catches by legal means, salmon caught both in the Atlantic and in the Scottish rivers by illegal means, and fish dropping out of nets either dead or dying. This unquantified, lost fraction of the salmon catch is unlikely to be constant from year to year, or from area to area.

iii. The Scottish catch statistics cover, at most, the period February–September each year for each fishery, missing out the close season months each year, and indeed the months when, for whatever reasons, a given fishery had remained inactive. In recent years, there is some evidence of a change in the seasonal behaviour exhibited by the fish; they appear to have drifted out of phase with the calendar seasons. Thus, for example, Dunkley (1986) reports that in the years 1981, 1982, 1983 and 1984 of the total number of fish which entered the North Esk, including net and rod catches in the lower reaches, 23%, 33%, 41% and 44% respectively did so after the end of the net fishing season. In an examination of the catch statistics over a short time period, such behavioural changes can easily distort the underlying true trends in population abundance.

iv. Other factors which require taking into account in assessing the catch statistics are the effects of adjacent land use and of acid rain and other pollutants. These factors may have a differential effect on fish subpopulations in different regions of Scotland, as well as on the fish populations in the Scottish waters and in the Atlantic.

3 Discussion

The various factors discussed above unquestionably distort the catch statistics. However, the very action of listing them gives the misleading impression that there are no other major distorting factors, and that the catch statistics could readily be used as an index of stock abundance if these distorting factors could be quantified and taken into account in analysing the data. This is not necessarily so.

It should be clearly understood that the 'sampling scheme' underlying the present catch statistics is such that it is inherently unsatisfactory to rely on the data arising from the scheme. It is, of course, possible that at the initial stage of this data collecting scheme no particular thought was given to any attempt to obtain a representative sample of the relevant population of interest. Or, if such a thought was in fact given, then clearly it has not been pursued satisfactorily, as can be judged from the presence of so many (now) known distorting factors. Whatever the true background, the existing scheme is unsatisfactory in providing reliable information about the stock. The statutory scheme applies only to salmon collected in Scotland, but the fish spends its time in Scottish waters as well as the deep Atlantic, and events and processes occurring in the Atlantic can have an effect on the stock of salmon of interest to Scotland.

Consequently, even if the catch statistics had been obtained subject to an agreed, predetermined and fixed amount of catching effort by each and every fishery in Scotland, and, in addition, even if there had been no exploiting (removal) of potentially Scottish salmon in the high seas by any interception or illegal fishing, the use of the catch statistics as an index of the size of the overall statistical population of salmon both in the Scottish waters and in the Atlantic need not necessarily be satisfactory. Thus, for example, if for the i^{th} year the true abundance of the statistical population of salmon is denoted by N_i, and if, for the same year, the total annual catch statistic under the simple and favourable conditions described above is denoted by n_i, then the validity of using n_i as an index value for N_i requires the assumption that for every year, i, the expected value of n_i is $r \times N_i$, where r is a constant, which does not change from year to year. If this assumption fails to hold, then any trend in the N_i values is liable to be exaggerated or camouflaged by a possible trend in the true r values; this can easily happen, at least in the short term, for example, by a trend in the proportion of salmon from the sea returning to the fresh water.

Like justice in a court of law, science must not only be done, it must be seen to be done; and so the reasonableness of the assumption described above will require to be checked. This, in turn, requires the estimating of the r value each year to demonstrate that these values do remain reasonably constant from year to year. However, given the n_i values, estimating the ratio $r = n_i/N_i$ for each year, i, amounts to obtaining an independent estimate of N_i each year; but this is the very task which the procedure to use n_i as an index of

N_i is supposed to avoid! Nevertheless, it should be noted that, after estimating the value of r every year initially, if r is found to be reasonably constant from year to year, we may be prepared to take a risk and check the value of r every 5 years or so, and, after some experience, only occasionally or in atypical years. For a small risk, it may be possible to show long-term savings in the total cost of the observational programme; but we do have to understand clearly the nature and extent of the risk taken.

The above paragraphs illustrate that, if a scheme under which data are collected happens to be statistically unsatisfactory for a particular purpose, then removing some of the limitations from such data cannot convert the unsatisfactory scheme into a satisfactory scheme. This point has not been made by other workers discussing biases in data (see, for example, Shearer's (1986) discussion of 'Biases in data').

Shelton (1986) gives a good summary of the various reported studies attempting to estimate the effects of the exploitation of salmon by the high seas fisheries on the European and Scottish home water stocks. It has been estimated that more than 90% of the fish taken in Northumberland drift net fishery were en route to Scottish east coast Fishery Districts from the River Tweed to the River Bervie. For the west Greenland fishery, a series of tagging experiments has been conducted during 1965–71, followed by a relatively large study in 1972. These studies demonstrate that at least some of the fish feeding at west Greenland return to rivers on both sides of the Atlantic.

However, it has not been possible to obtain reliable estimates of the population parameters of interest, largely because of local differences in reporting rates, and because of post-tagging mortality, leading to low numbers of recaptures. These attempts to assess the effects of the removal of salmon by the fisheries on the high seas on home water stocks are subject to a fundamental objection, described below, which appears not to have been discussed in the literature. If no exploitation had occurred in the Atlantic, then, of the entire 'potentially home water stock' in the Atlantic, some would have died due to predation, disease, starvation, etc, and would not have been available in the home waters. The real loss to the home water stock is, therefore, an unknown proportion of the potential home water stock in the Atlantic. This proportion is variable from year to year.

However, as long as the activity of the fisheries in the Atlantic continues, the very action of the removal of the fish materially alters the biological circumstances (ie prevailing density of fish, crowding, competition for food, etc), making it unlikely that biologists can obtain trustworthy estimates of the unknown proportion in different years. The 'proportion' here is that fraction of the hypothetical and imaginary population of salmon which, had it been not removed, would have been available in home waters. Shelton (1986) summarizes the difficulties and limitations in the data and the approach used (as described in papers by ICES) to assess the effects on Scottish home water stocks of open sea exploitation of Atlantic salmon. The discussion of natural mortality of salmon at sea by Shelton and other workers contains no reference to the complication that the very action of exploiting the fish alters the fish density.

We have to be clear about the nature of the above objection. The argument is based on 'armchair thinking', taking into account our knowledge about the population dynamics of most species. For most species, the greater the density, the higher the mortality due to various factors, such as disease or starvation. Increased density of a prey species can lead to an abundance in predators, leading to eventual decline in prey numbers followed by a crash in the predator abundance. What has been said above is that the very action of exploitation of salmon removes a large number of fish from the sea. The complex interactions which result between the salmon, its food supply, pathogens and parasites cannot be expected to be the same under the condition of salmon exploitation as compared with those under the condition of no exploitation. This argument, of course, does not stop any fishery biologist from assuming that salmon mortality under the condition of exploitation is comparable to the mortality under the condition of no exploitation. But the onus of showing that such an assumption is reasonable is, in my view, upon the scientist who makes such an assumption.

There are, of course, other long-term effects well known to the fishery biologists, such as that a fish removed in the Atlantic is lost to the population at once, while a fish not removed may continue to contribute to the reproductive potential of the stock. Such long-term effects cannot be assessed unless there is detailed information, not only about the extent of exploitation, but also about the total abundance and age/size distribution of the stock, a clear understanding of the growth curve, the survivorship pattern and the reproductive behaviour of salmon, as well as information about how these processes correlate and interact with other factors (eg temperature, predators, food availability, etc) in the sea and and in fresh water.

For the purpose of monitoring the trend in the statistical population of salmon in Scottish waters as well as in the Atlantic, we cannot rely on the catch statistics alone. An index of abundance of the fish in the Atlantic may be obtainable using a traditional, large-scale capture-mark-release-recapture approach. In theory, an alternative is to use a variation of the standard quadrat sampling approach, which amounts to requiring research vessels or commercial drift netters to put in a fixed amount of effort to catch the salmon in the Atlantic, at different locations. Obviously, the use of such approaches every year is a

prohibitively expensive proposition. A third, possibly practical approach, but with obvious statistical and biological limitations, is to rely upon all, or some suitable part, of the harvesting which is already being carried out in the high seas, together with the actual effort underlying this activity, as providing a working index of the population fluctuations in the sea. If the present Scottish catch statistics are adequately augmented by detailed information about the corresponding catching effort employed by the fisheries, then a simultaneous examination of the trends, both in the Scottish catch statistics standardized for the catching effort, and in an additional, independent index of abundance of fish in the deep Atlantic, may give a valuable insight into the status of the Atlantic salmon of interest to Scotland.

Despite what has been written above, the catch statistics collected under the 1951 Act cannot be dismissed as worthless. These data indicate the size of the harvest each year, as well as the breakdown of the harvest by the size of the fish and by areas and months. Such basic information is likely to be essential for the formulation of policy affecting salmon fisheries. Equally, if there is an interest in obtaining an index of abundance of Scottish salmon stocks in the Scottish home waters in a given season, then the catch statistics adjusted for the catching effort employed could provide such an index if (and only if) the catch effort data are reliable and free from the difficulties discussed earlier, and if other complications are relatively unimportant.

4 Summary

The statutorily collected salmon catch statistics cannot be regarded as satisfying the basic statistical requirements of a sampling study. They cannot, therefore, indicate satisfactorily the status of the Atlantic salmon of interest to Scotland. The activities of the legal and illegal fisheries in the Atlantic, and other factors, introduce complications which reduce the value of the catch statistics as indicators of stock. However, even if these complications and distortions could be assessed, which is not an easy task, the catch statistics are liable to be inherently poor indicators of stock.

Some workers have attempted to quantify the loss to European home water stocks through the removal of salmon by fisheries operating on the high seas. This quantification has implications for possibly improving the catch statistics by estimating the distortions due to such exploitation of salmon. It is pointed out here that such estimates are not reliable because they are highly sensitive to the prevailing biological conditions, which are altered by the very action of removing the fish from the Atlantic.

The paper discusses a number of alternative approaches for the intrinsically difficult task of monitoring the salmon population of interest to Scotland. However, none is considered very satisfactory.

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6 References

Anon. 1983. *Scottish salmon catch statistics 1952–1981.* Vols 1 & 2. Edinburgh: Department of Agriculture and Fisheries for Scotland.

Cochran, W.G. 1963. *Sampling techniques.* New York; London: Wiley.

Dunkley, D.A. 1986. Changes in the timing and biology of salmon runs. In: *The status of the Atlantic salmon in Scotland,* edited by D. Jenkins & W. M. Shearer, 20–27. (ITE symposium no. 15). Abbots Ripton: Institute of Terrestrial Ecology.

Green, R. H. 1979. *Sampling design and statistical method for environmental biologists.* New York: Wiley.

Jeffers, J.N.R. 1979. *Sampling.* (Statistical checklist 2). Cambridge: Institute of Terrestrial Ecology.

Lakhani, K.H. 1981. Strategy for successful survey. In: *Ecological mapping from ground, air and space,* edited by R. M. Fuller, 8-15. (ITE symposium no. 10). Abbots Ripton: Institute of Terrestrial Ecology.

Sampford, M.R. 1962. *Introduction to sampling theory.* Edinburgh: Oliver & Boyd.

Shearer, W.M. 1986. An evaluation of the data available to assess Scottish salmon stocks. In: *The status of the Atlantic salmon in Scotland,* edited by D. Jenkins & W. M. Shearer, 91–111. (ITE symposium no. 15). Abbots Ripton: Institute of Terrestrial Ecology.

Shearer, W.M. & Clarke, D.R. 1983. *Long-term trends in Scottish salmon catches, 1952–1981.* (CM 1983/M:24). Copenhagen: International Council for the Exploration of the Sea.

Shelton, R.G.J. 1986. Aspects of open sea exploitation of Atlantic salmon and the problems of assessing effects on Scottish home water stocks. In: *The status of the Atlantic salmon in Scotland,* edited by D. Jenkins & W. M. Shearer, 28–36. (ITE symposium no. 15). Abbots Ripton: Institute of Terrestrial Ecology.

Sukhatme, P.V. 1954. *Sampling theory of surveys with applications.* Iowa: Iowa State College Press.

Yates, F. 1960. *Sampling methods for censuses and surveys.* 3rd ed. London: Griffin.