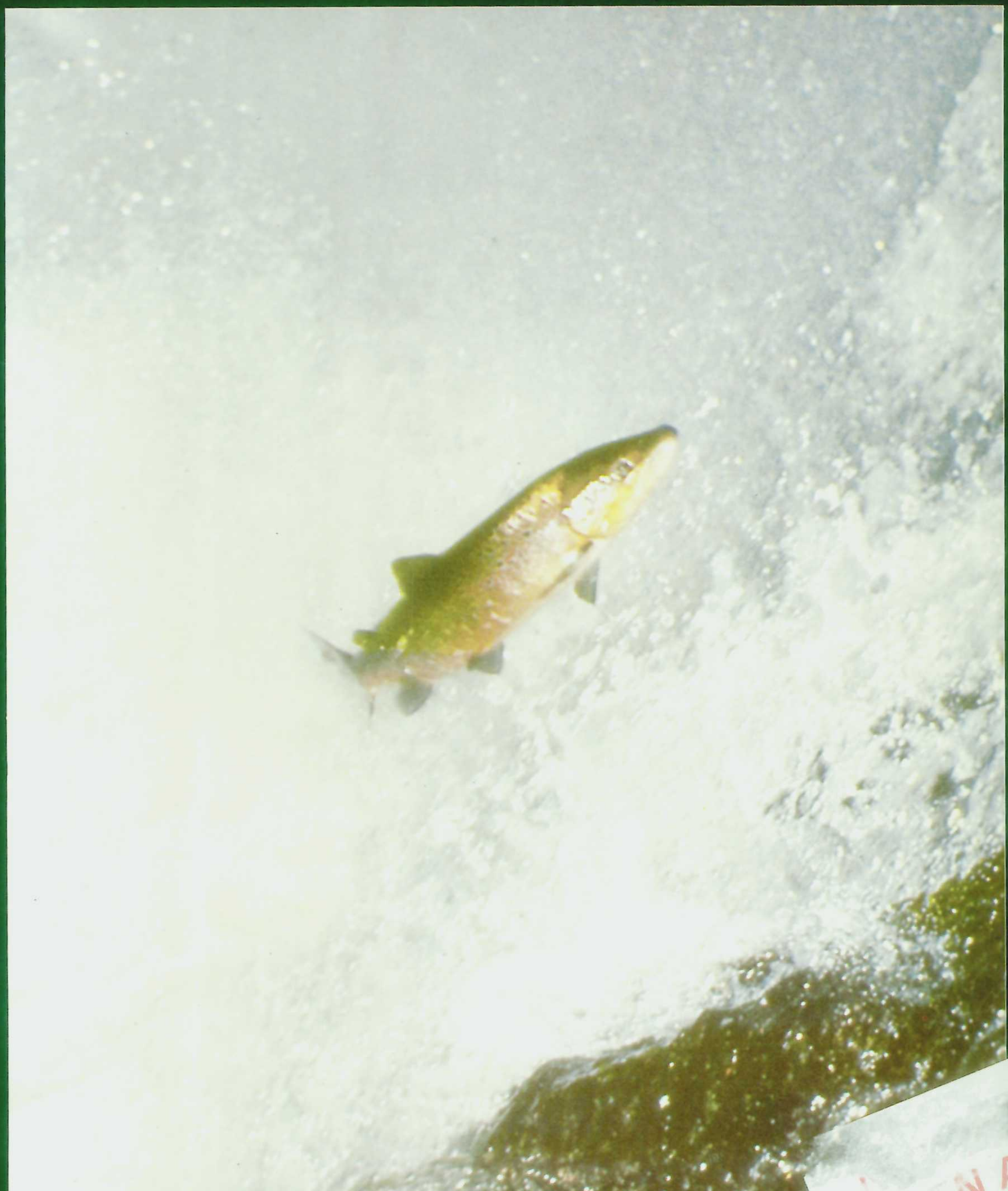
THE STATUS OF THE ATLANTIC SALMON IN SCOTLAND



INSTITUTE of TERRESTRIAL ECOLOGY

NATURAL ENVIRONMENT RESEARCH COUNCIL

Natural Environment Research Council

INSTITUTE OF TERRESTRIAL ECOLOGY

The status of the Atlantic salmon in Scotland

ITE symposium no. 15
Banchory Research Station
13 and 14 February 1985

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Printed in Great Britain by
The Cambrian News, Aberystwyth

Published in 1986 by
Institute of Terrestrial Ecology
Administrative Headquarters
Monks Wood Experimental Station
Abbots Ripton
HUNTINGDON
PE17 2LS

BRITISH LIBRARY CATALOGUING-IN-PUBLICATION DATA
The status of the Atlantic salmon in Scotland.—ITE symposium, ISSN 0263-8614; no 15
1. Atlantic salmon 2. Fishes—Scotland
I. Jenkins, D. (David), *1926-*
II. Shearer, W. M. (William)
III. Institute of Terrestrial Ecology
597'.55 QL638.S2
ISBN 0 904282 92 9

COVER ILLUSTRATION
Male Salmon leaping at the Falls of Muick, Aberdeenshire — photogragh D. W. Hay, Freshwater Fisheries Laboratory, Pitlochry.

Acknowledgements
The symposium was planned by a steering committee composed of Dr P S Maitland (ITE), Mr J A Forster (formerly NCC), Prof David Jenkins (ITE), and Mr W M Shearer (DAFS). Abstracts were typed at and circulated from the Marine Laboratory of DAFS and all the papers were retyped by Mrs L M Burnett, ITE Banchory. Considerable help during the symposium was received from Dr N G Bayfield, Mr J W H Conroy and Mr A D Littlejohn, and Mrs L M Burnett and Mrs J Jenkins assisted with its organization. Mrs K B King checked the references and Mrs P A Ward helped with the final editing and proof-reading. The photographs were selected by Mr N Picozzi.

The Institute of Terrestrial Ecology (ITE) was established in 1973, from the former Nature Conservancy's research stations and staff, joined later by the Institute of Tree Biology and the Culture Centre of Algae and Protozoa. ITE contributes to, and draws upon, the collective knowledge of the 14 sister institutes which make up the *Natural Environment Research Council*, spanning all the environmental sciences.

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Preface

It may at first seem strange that a symposium on Atlantic salmon should be held in an institute of terrestrial ecology, particularly since in recent years there has been a number of meetings on salmon, including some in central or northern Scotland. However, the divisions between scientists working on different aspects of the environment are narrowing, and one of the encouraging developments in the scientific world is the ever more ready exchange of ideas between terrestrial ecologists and fishery biologists and others who are interested in the total environment in which we live. It is proper that terrestrial ecologists should not only interest themselves in the results of the research of their colleagues in fishery research, but also understand the problems with which they are faced, and consider whether their experience in a different field can help to unravel problems in what may be technically more difficult habitats to study. The same applies the other way round, where, for example, work on marking marine mammals and big fish has led to developments in electronic micro-engineering of considerable interest to terrestrial scientists. This liaison has encouraged further flourishing contacts between marine biologists and other ecologists working on coastal species (sea-birds, otters). These scientists are all interested in the small species of fish which are eaten by a variety of wildlife but not yet exploited commercially.

The idea for the symposium developed when the editors were invited to contribute a chapter for a book on the wildlife resource of Grampian Region, in a symposium volume edited by the Nature Conservancy Council and Grampian Regional Council under the auspices of the World Conservation Strategy. While it was relatively easy to say something about the wildlife of the woods and mountains (though little was known about the wildlife of agricultural land), difficulties arose when considering the exploitation of salmon, partly because of the political considerations associated with the management of this resource, but also because there seem to exist firmly entrenched but opposing views on the availability and dynamics of the Atlantic salmon resource. On the one hand anglers were saying that there had been a disastrous decline in salmon numbers, while on the other hand the biologists were not sure whether there had been a real decline in stocks or whether it was part of a cyclical process. While there was no room for complacency, there was difficulty in obtaining hard facts for this paper, partly because these were not available to the general public until recently and partly because there were few or no data on the effort utilized in catching the fish which were said to be declining in numbers. The situation was further complicated by changes in fishery methodology, by the different sorts of data available for net fisheries in estuaries and in the sea and for rod and line fisheries on the rivers and lochs, and by changes in the sea age groups of salmon that were being caught in different periods of years and in different river systems.

The situation is obviously extremely complex, but this fact should not deter ecologists in one field from taking an interest in the science of another. The decision to hold this symposium having been taken, a small steering committee including members of the Freshwater Fisheries Laboratory, ITE and the Nature Conservancy Council agreed that the subjects to be discussed should be as comprehensive as possible, including the regulation of the fishery, the biology of the fish, fishery methods, the statistics available on catches, and a comparison of views on the status of salmonids in Scotland with those of other stocks of the fish in other countries. The large attendance of fishery biologists at this meeting at a laboratory primarily concerned with terrestrial biology augurs well, at the least, for continued collaboration in the future.

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Brathens
June 1985

The law relating to salmon fishing

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1 Introduction
The proposition that the salmon, which by definition includes sea trout, has from time immemorial been a valuable natural asset in Scotland (1) is supported by the fact that, at Common Law, the right of salmon fishing is *'inter regalia'* (2), or is one of the attributes of the Sovereign. Further evidence of its value is the attempted statutory control of fishing. This control has been directed principally to the preservation of fish stocks by prohibiting or restricting their indiscriminate destruction, whether by making illegal methods of taking fish or by absolute prohibition of fishing during certain periods.

(This paper describes the law relating to salmon fishing as at February 1985.)

2 Mediaeval legislation
Statutory regulation of salmon fishing has its roots in statutes made by King David who is thought to have introduced the feudal system into Scotland. The earliest Act of the Scottish parliament still extant, ie unrepealed by subsequent legislation, was passed in 1424. This Act prohibits the construction of cruives in tidal waters and is in the following terms: 'it is ordanyt that all crufis and yaris set in fresche watteris quhar the see fillis and ebbis the quhilke distroyis the fry of all fischis be distroyit and put away . . . nocht gaynstandand ony priuilegis or fredome geifvn in the contrare under the payne of ane hundreth shillinges . . . .

Over the years, the statute must have been more commonly breached than observed. In 1478, the parliament of James III found it necessary to issue a reminder that the Act of 1424 remained in force. The Act also referred to the need for those who had cruives in fresh water to keep the laws 'anent the Setterdais slop' and that each heck of the cruive be 3 inches wide 'as the auld statut requiris maid be King Dauid'.

The 1424 Act was directed to maintaining the stock of fish by restricting the use of a method of fishing which must have been particularly successful. The 'Setterdais slop' is a reference to the weekly close time and applied to cruives and presumably to other forms of fishing. The slapping of cruives on Saturday may have been directed to maintaining fish stocks. However, it might alternatively have been imposed in the interests of preserving the souls of the fishers rather than the stock of fish.

3 Common Law
As far as the Common Law is concerned, the Scottish system of landholding is based on the feudal system. In theory at least, all land other than that held on a lease or tack is held ultimately of the Sovereign. The right to salmon fishing being *inter regalia*, all rights of salmon fishing must be traceable to a grant by the Crown. In the Law of Heritable Property in Scotland, salmon fishings are a separate heritable estate, which means that a landowner whose property is bounded by or includes a river does not necessarily own the salmon fishings in the river, and consequently the proprietor of salmon fishings in a river need not own any property rights in either the river bed or the banks.

In 1828, the Salmon Fisheries (Scotland) Act (3) was passed. The preamble is interesting in that it provides a brief resumé of the statute law affecting salmon fishing for a period of some 400 years. It is worth recording in full. 'Whereas by an Act passed in the Parliament of Scotland in the year One thousand four hundred and twenty four it was forbidden that any salmon be slain from the Feast of the Assumption of Our Lady until the Feast of Saint Andrew in winter: and whereas sundry other laws and Acts were made and passed at divers times by the Parliament of Scotland anent the killing of salmon, kipper, red and black fish in forbidden time and the killing and destroying of fry and smolts of salmon; which Laws and Acts were ratified, confirmed and approved by an Act passed by the said Parliament in the year One thousand six hundred and ninety six intituled "Act Against Killers of Black Fish and Destroyers of the Fry and Smolts of Salmon": and whereas it is expedient for the preservation of the salmon fisheries in Scotland that the penalties enacted by the said Acts should be augmented and the period of the forbidden time altered and extended and that sundry other regulations be made.' The Act made provision for proprietors of salmon fishings to meet and raise assessments for the purposes of ensuring that the provisions of the Act were implemented and, to that end, to employ clerks, water bailiffs and other officers (4).

A fundamental change in the law of evidence was introduced by this Act. It provided that a conviction could be obtained by proof on oath by one or more credible witnesses (5). The provisions of this Act were extended by the Salmon Fisheries (Scotland) Act 1844 (6), which for the first time specifically made it an offence for a person not having a legal right or permission from the proprietor of the salmon fishings to take salmon *inter alia* upon any part of the sea within one mile (1.6 km) of low water mark (7). These Acts were obviously not precisely what fishery proprietors were seeking in the way of protection because in 1862 a further Salmon Fisheries (Scotland) Act was passed (8). This Act could well be said to be the foundation of the machinery for the enforcement of salmon fishery legislation today because it provided for the setting up of District Salmon Fishery Boards (9). In terms of the Act, Commissioners were appointed to undertake various duties in relation to the Boards. These duties were to fix the estuarial limits, to fix the boundaries of the District Boards, to fix the point in each river for determining the upper and lower proprietors, to fix the annual close time, and to make regulations with regard to such matters as the observance of the weekly close time, the construction and use of cruives, the construction of mill dams so as to afford reasonable means of access for salmon, the mesh of nets, and the obstruction of rivers to the ascent of salmon (10). The period allowed to the Commissioners for undertaking the duties imposed upon them (11) proved to be inadequate, and legislation had to be passed annually to extend the powers of the Commissioners (12).

The final legislation resulted in the Salmon Fisheries (Scotland) Act 1868 (13) which, together with the 1862 Act, forms the basis for the administration of salmon fisheries in Scotland under the aegis of 106 District Salmon Fishery Boards. These Boards, with a note of the limits of the Districts and the point dividing upper and lower proprietors, are listed in detail and at length in Schedule 'A' to the 1868 Act. Schedule 'B' sets out the estuarial limits, and Schedule 'C' specifies the annual close times with the permitted extension for rod fishing. The close times vary between 27 August and 10 September for the commencement, and between 10 and 24 February for the close. The rod extensions vary from 15 October to 15 November. In the case of one or 2 rivers, there is an extension for rod fishing before the close season ends. The earliest time for rod fishing is 11 January.

While the 1862 Act had made provision for the setting up of District Salmon Fishery Boards and included provision for their funding (14), it did not deal with detailed administrative provisions. These are dealt with in the 1868 Act (15).

4 Modern Fishery Boards

A District Salmon Fishery Board has a life of 3 years (16), and consequently all proprietors of salmon fishings meet every third year in order to elect members from among their number to serve on the Board. The meetings are announced in the press and separate meetings of upper and lower proprietors are held because the constitution of the Board calls for 3 upper and 3 lower proprietors. The proprietor with the largest rateable value in the District is Chairman *ex officio* (17). The maximum size of any Board is therefore 7 people. Where there are insufficient proprietors to produce 7 members, the size of the Board is restricted to the maximum number of either upper or lower proprietors, because there must always be equality of representation as between the upper and the lower proprietors (18). Should there be only one proprietor in any District, he has the right to exercise the rights of the District Salmon Fishery Board in that District. Those entitled to attend the triennial election meetings are the persons whose names appear on the current Valuation Roll as proprietors of salmon fishings; and in this respect a 'Roll of Proprietors' certified by the Regional Assessor is evidence of the right to vote (19).

District Salmon Fishery Boards are financed by the raising of fishery assessments on the fishery proprietors whose names appear on the Roll of Proprietors. Fishery assessments are fixed annually as a percentage of the rateable value of the fisheries, and are recoverable in the same way as Local Authority rates. There is at present an anomaly between net and rod fishings in that net fishings are de-rated, ie they are exempt from payment of Local Authority rates, while rod fishings are not de-rated. Whereas, therefore, net fishings bear only the District Salmon Fishery Board assessments, rod fishings are burdened with both Local Authority rates and District Salmon Fishery Board assessments.

There was no fundamental change in the law until 1951, when the Salmon and Freshwater Fisheries (Protection) (Scotland) Act 1951 (20) came into force, following the Maconochie report on methods of combating poaching and illegal fishing for salmon (which increased after the Second World War). This Act is one of the few parts of the Scottish law on salmon and trout which is relatively modern.

The 1951 Act created new offences, and the punishment for others was increased (21). One major change effected was that, whereas any member of a District Salmon Fishery Board previously, under the earlier Acts, had powers of arrest, these powers were now restricted to the police and bailiffs (22). The power to stop and search was restricted also, in that, while the police retained the right to stop and search on the public highway, bailiffs' powers in this respect were restricted to private land (23). Offences under the Act are prosecuted by the Procurator Fiscal, but the District Salmon Fishery Boards retain the right to prosecute offences under the 1862 and 1868 Acts. The 1951 Act is not, however, the last word on the matter, but subsequent legislation has made no dramatic changes in the general scheme of the salmon fishery administration. There is perhaps one notable exception, ie an Order made under the Sea Fish Conservation Act 1967 (24) which prohibits the use of drift nets for the catching of salmon at sea.

The principal objectives for which the District Salmon Fishery Boards were set up were to preserve and, if possible, increase the stock of salmon within the Boards' areas (25). This area extends seawards for 3 miles (5.56 km) from low water mark (26). This definition can cause considerable problems with regard to illegal fishing at sea, particularly where the fishing is taking place at the limit. The general view is that the mile referred to is a nautical mile, but whether the Act refers to a statute mile has never been judicially decided. To enable District Salmon Fishery Boards to fulfil their duties, various offences have been created, some of which are directed to securing the rights of the individual proprietors of fishings. However, the majority of offences are directed to preventing the wholesale destruction of fish.

The law is enforced primarily by water bailiffs appointed by the District Salmon Fishery Boards. Ideally, bailiffs work in close co-operation with the police. The powers of bailiffs, although fairly wide, are somewhat less than the powers of the police. Having regard to the cost of equipment and the restricted financial resources of the Boards, the police are usually better equipped than the bailiff staff. Accordingly, a high degree of co-operation between the police and bailiff staff is desirable, and in certain areas the extent of the co-operation is such that radios fitted to the Boards' vehicles have direct access to the police waveband.

5 Bailiffs' powers and statutory offences

The bailiffs' warrant cards provide a condensed statement of their powers and the principal offences against the Salmon Fishery Acts. The bailiffs' powers are the following (27).

1. To examine any dam, fixed engine or obstruction, or any lade, and for that purpose enter on any land.
2. To stop and search any boat which is used in fishing or any boat which there is reasonable cause to suspect of containing salmon or trout.
3. To search and examine nets or other instruments used in fishing or any basket, pocket or other receptacle capable of carrying fish, which there is reasonable cause to suspect of containing salmon or trout illegally taken.
4. To seize any fish, instrument or article, boat or vehicle liable to be forfeited under the Act.
5. To search any vehicle thought to contain evidence of the commission of an offence on any private land adjoining any water within the District of the Board.
6. To arrest any person committing an offence.

Offences under the various Salmon Fishery Acts are listed below. The offences (28–36) fall into various categories which are directed to ensuring that the provisions of the Salmon Fishery Acts are observed. For example, a number of offences are associated with the annual and weekly close times, the illegal use of nets, various forms of the taking of fish illegally, and obstruction of the enforcement agency.

1. Fishing for salmon in the annual close time.
2. Fishing for salmon during the weekly close time, except by rod and line.
3. Fishing for salmon on Sunday with rod and line.
4. Using a net with a mesh contrary to Byelaw provisions.
5. Using a net to catch salmon at falls, etc.
6. Preventing passage of or catching salmon at fish passes.
7. Contravention of any Bye-Law.
8. Buying, selling or possessing salmon roe.
9. Buying, selling or possessing young salmon, disturbing spawn, etc.
10. Buying, selling, taking or possessing unclean or unseasonable salmon.
11. Buying, selling or having in possession salmon taken in close season.
12. Failing to remove boats, nets, etc, in close season.
13. Failing to observe weekly close time arrangements for nets.
14. Fishing for salmon without legal right or written permission.
15. Fishing by illegal methods.
16. Illegal fishing by 2 or more persons acting together.
17. Use of explosives, poisons and electrical devices.
18. Unauthorized removal of dead salmon or trout.
19. Obstruction of water bailiff, constable, etc.
20. Fishing for salmon in weekly close time (other than by rod and line).
21. Fishing for salmon on Sunday (with rod and line).
22. Refusing or neglecting to provide statistics.
23. Contravention of regulations relating to packing of salmon and trout.
24. Fishing for salmon or migratory trout by drift net or hang net not secured to shore.

There is a general exemption from a number of these offences in favour of those conducting scientific research.

Net fishing may be carried out legally by fixed engines such as a bag net or stake nets at sea or by net and coble. Net and coble is the only legal method of net fishing in a river. With some minor exceptions, most of which are peculiar to the Solway Firth, all other methods of net fishing for salmon are illegal.

As far as rod and line fishing is concerned, the principal offences are the use of illegal tackle and illegal methods of fishing. Illegal tackle and illegal methods tend to complement each other because much illegal tackle has to be fished illegally. Strangely enough, some tackle which is perfectly legal when used with a spinning rod is not greatly different from illegal tackle used with a rod and line for ripping. The criterion is that legal tackle attracts the fish to take it, and a fish legally taken with rod and line will normally be caught by the mouth, whereas illegal tackle tends to catch the fish other than by the mouth.

The enforcement of the provisions of the Salmon Fishery Acts is in the nature of a negative approach to the problem, in that preservation of fish stocks is being achieved by limiting the destruction of fish. Most District Salmon Fishery Boards, however, take a more positive attitude towards their duties. Many Boards have their own hatcheries from which they plant eyed ova, particularly in areas which are suitable for use as nursery streams but which are either impossible or difficult for fish to reach naturally.

District Salmon Fishery Boards work in close co-operation not only with the police but also with the River Purification Boards because of their common interest in controlling pollution. Apart from the prevention of pollution, which many would contend is still unacceptably high in certain areas, legislation is required to deal with the abstraction of water for spray irrigation purposes. At the present time, there is in force the Spray Irrigation (Scotland) Act 1964 (37) which provides machinery for the control of spray irrigation. Its provisions are, however, said to be unworkable by the authorities empowered to control spray irrigation. Urgent consideration is being given to amending legislation, principally because of the disastrous effects which this technique had on some of the smaller streams in the dry summer of 1984. Some Boards also have a close association with both the Marine Laboratory and the Freshwater Fisheries Laboratory of the Department of Agriculture and Fisheries for Scotland (DAFS).

6 Prosecution of offences

Opinions vary widely on the success of the statutory provisions in achieving their objectives. It is for consideration whether the present method of administration, which is largely based on statutes over 100 years old, is in need of overhaul. There is considerable criticism from various quarters of the effectiveness of the Boards in combating the illegal taking of salmon. Much of this criticism is directed not against the Boards themselves, but against the method of prosecution under Scots law, which in this respect is sometimes compared unfavourably with the enforcement of fisheries legislation in England. All prosecutions under the 1951 Act are in the hands of the Procurator Fiscal who is, of course, a public prosecutor. It is argued that, because of the wide scope of crimes and offences with which the Procurator Fiscal is concerned, he cannot be an expert in salmon fishery legislation (38).

Prosecutions for offences under the 1862 and 1868 Acts at the instance of the Clerk to the District Salmon Fishery Board are still competent. Where, as in England, the prosecution of offences is in the hands of a private prosecutor, it is alleged that considerable expertise in presenting prosecutions can be achieved by virtue of the fact that the Prosecutor is acting in a fairly restricted field, and can therefore rapidly master the technical difficulties which he will require to overcome to secure a conviction. Proposals have, of course, been made for the setting up of a system of public prosecution in England which will presumably be modelled largely on the Scottish system. Whether this move will be acceptable to those involved with the enforcement of fishery legislation in England remains to be seen. If the criticism of the Scottish system is sound, it is possible that efforts will be made to have prosecutions under the English Fishery Acts excluded from the operation of the Public Prosecutor system.

There may well be considerable merit in the argument in favour of authorizing the District Salmon Fishery Boards in Scotland to prosecute offences under the 1951 Act. However, it is extremely doubtful whether there is any evidence that private prosecutors were any more successful in achieving convictions than are the Procurators Fiscal at the present time. There is no doubt that the resources available to the Fiscal as regards investigation could not be equalled by District Salmon Fishery Boards, at least as they are presently financed.

In Scotland, all prosecutions are dealt with in the Sheriff Court by Sheriffs who are legally qualified. In England and Wales, most cases are heard before Magistrates, who are usually lay people. Whereas in England efforts are made through the Magistrates Association to ensure that there is a general level of punishments for various offences under the Salmon Fishery Acts, this is not the case in Scotland where Sheriffs jealously guard the discretion which they have as to the amount of penalty which they may impose for offences of various types. This situation gives rise to complaints of inconsistent sentencing between one Sheriff and another. This particular criticism is, however, not restricted to prosecutions under the Salmon Fishery Acts. Because of technical problems relating to the law of evidence, there is concern that apparently good cases do not always result in successful prosecutions. Sometimes there are alternative charges which can be brought, and the penalties may vary quite considerably for offences which appear to be similar, and the Procurator Fiscal alone has the right to decide under which Act he is to proceed.

7 Hunter Committee

As to the future, one has strangely enough to look back to the year 1962 when a Committee under Lord Hunter was set up to prepare a Report which was intended to lead to reform of Scottish Salmon Fishery legislation (38). The Report appeared in 1965, and yet almost 20 years later virtually none of the recommendations of that Report have been implemented. One of the objectives which the Hunter Committee set itself was to maintain a reasonable balance between commercial and rod fishers, and yet allow a reasonable escapement for breeding purposes (38). It is interesting to note that the Hunter Committee was of the view that Section 4 of the 1951 Act, which makes illegal the use of explosives, poisons and electrical devices, should be extended to prohibit the use of illegal forms of netting, underwater swimming, fishing equipment and similar devices (38).

Those involved in the work of District Salmon Fishery Boards consider that, in many respects, the existing salmon fishery legislation has failed to keep pace with developments in fisheries management techniques. Although the number of Boards set up in terms of the 1868 Act is large, only a fraction of them actually operate, with the result that there are vast areas, particularly on the west coast of Scotland, where there is virtually no policing of Districts at all. The Hunter Committee recommended larger Boards with extended membership and powers and a licensing system to provide the necessary finance (38), but so far no legislation has been forthcoming. In England, fishery protection work is largely the concern of the Water Authorities, who have power to charge rates for the services they provide. Accordingly, the whole body of ratepayers is contributing to the protection of fisheries through the water rate. In Scotland, the suggestion of multi-purpose authorities was considered but rejected (38). The result is that the cost of fishery protection work, in so far as it is the responsibility of District Salmon Fishery Boards, is restricted to what the proprietors of salmon fishings are prepared to pay by way of fishery assessments. There is urgent need for updating the whole machinery of fishery protection in Scotland.

8 Suggestions for future legislation

The problem of the illegal catching of fish can be approached from 2 directions. One is to increase the efficiency of the District Salmon Fishery Boards in combating the illegal taking of fish. The Hunter Committee's recommendations for enlarged Boards would go some considerable way to increasing efficiency. However, as the funding of District Salmon Fishery Boards is for political reasons not to be supplemented by a licensing system, and as the idea of a multi-purpose Board with general rating powers does not apparently commend itself, the funding of the Boards will presumably require to remain with the fishery proprietors. Because of reducing numbers of fish caught by the netsmen, particularly at sea, the rateable values of the net fishings are likely to be radically reduced. As the net fishings now produce most of the income of the District Salmon Fishery Boards, the result will be that the rateable value of the Boards will diminish. The inevitable consequence will be that the fishery proprietors will be faced with very substantial increases in the Fishery Board assessments in order to finance the Boards' protection work, and in particular protection work at sea. The assessment may, in fact, reach such a level as may be fairly described as prohibitive.

Another method of dealing with the matter is, of course, to make it as difficult as possible for illegally taken fish to be sold without penalty either on the poacher or the person purchasing the fish. At the present time, because salmon is technically the property of the poacher, being *ferae naturae* (39), there can be no crime of reset of salmon. Accordingly, it is not difficult for the poacher to dispose of his illegally caught fish by direct sale to willing purchasers. Equally, if illegally caught salmon can be mixed with fish which have been legally taken, the poacher has no difficulty in disposing of his catch. It has been suggested that some means of identifying fish which have been legally taken and the licensing of fish merchants to deal in salmon might create so many difficulties for the poacher in disposing of his fish that illegally taken fish would be virtually unmarketable (40). The licensing powers are available to Local Authorities if they choose to put them into force, and a scheme for the tagging of legally caught fish has been proposed. However, there are difficulties in imposing such a scheme because special provision would have to be made for imported fish. This aspect appears to be causing considerable difficulties.

Those involved with the protection of salmon in Scotland are particularly concerned at the inroads into stocks of Scottish salmon made by the Greenland fishery, the Faroese fishery and the drift net fishery off the Northumbrian coast. It is alleged that a substantial proportion of the fish taken by the Northumbrian fishery are, in fact, Scottish fish. Drift netting for salmon is prohibited in terms of an Order under the Sea Fish Conservation Act, but the Northumberland fishery is specifically excluded from the provisions of this Order and indeed the Northumberland fishers are licensed by the Water Authority.

Drift netting for salmon at sea has, in recent years, been a source of great concern to the District Salmon Fishery Boards on the east coast of Scotland who are ill-equipped to finance the cost of patrols which would be essential to combat this particular problem. As far as the west coast is concerned, the vast majority of the Fishery Boards there are inoperative and the only curb on drift netting in that area is the effort made by the Fishery Protection Service of DAFS. The Service is concerned with the enforcement of various types of fishing, and the enforcement of salmon fishery legislation at sea forms only a relatively small part of its responsibility. Within the constraints imposed upon them, however, the Fishery Protection Service supplements the efforts of the District Salmon Fishery Boards, and in recent years their efforts have met with ever increasing success.

With the increase in the numbers of fish farms, it is perhaps surprising that the District Salmon Fishery Boards have virtually no control over such developments. The main cause of concern in a large number of cases is the amount of water which requires to be abstracted from a river to provide an adequate supply for the fish farm. In some cases, the abstraction reaches such a level that, in conditions of low flow, the volume of water in the main river is very seriously depleted to the prejudice of natural fish stocks. Further, District Salmon Fishery Boards ought to be able to require provision satisfactory to them to be made to prevent the ingress of wild stock to fish farms, particularly during the annual smolt run. Boards ought also to be empowered to ensure that adequate provision is made to prevent the escape of farm stock to the river, particularly during periods of spate or abnormally high water.

The primary concern of the District Salmon Fishery Boards is, of course, with those farms which are adjacent to rivers where there are natural stocks of salmon. Fish farms which are not dependent on rivers with a natural salmon population for their water supply would not ordinarily be of any great concern to the District Salmon Fishery Boards; and any powers given to District Fishery Boards would be used only where a Board was apprehensive of potential damage to natural fish stocks.

9 Conclusions

While the existing salmon fishery legislation has served its purpose in a manner which on the whole appears to have been found acceptable, it is clear that there is now an ever increasing body of opinion which requires that the whole concept of the statutory provisions for protecting salmon be re-examined with a view to substantial modernization.

The Report of the Hunter Committee points in one direction, and, if any Government of whatever political view had had the will to legislate along the lines suggested, the District Salmon Fishery Boards would today have had a modern statutory framework within which to operate.

It is becoming increasingly apparent that the funding of District Salmon Fishery Boards is a matter which requires urgent review. If the watching activities of the Board's staff are to be maintained at an effective level, then the organization and equipment of staff must be at least equivalent to that of those engaged in the illegal capture of salmon.

It may be necessary to extend the range of offences to take account of modern techniques employed in the illegal capture of salmon. Penalties may also require review so that existing anomalies between, for example, penalties which may be imposed under the Sea Fish Conservation Act and the Salmon and Freshwater Fisheries (Protection) (Scotland) Act 1951 are removed, and the penalties under the latter Act are increased to the extent where the penalties which are available to the Courts will truly act as deterrents.

In view of the ever increasing development of fish farms and the possible effects that the stock in such farms may have on the wild stock, it seems not unreasonable that the District Salmon Fishery Boards have some measure of control independently of Planning Authorities and River Purification Boards.

10 Summary

Statutory regulation of salmon fishing has its roots in Acts of the Scottish parliament passed in the reign of David I. Most of the early statutes were directed both to restricting the use of methods of catching salmon which were particularly effective at that time, and also to maintaining both the annual and the weekly close time.

The present administration of statutory salmon fishing law is bassed on the Salmon Fisheries (Scotland) Acts 1862 to 1868, under which the present system of District Salmon Fishery Boards operates.

The present Boards have a life of 3 years and are composed equally of proprietors of upper and lower stretches of the river concerned. Their main objective is to maintain, and if possible increase, the stocks of salmon within their District. This objective is achieved by creating various offences with regard to the legal capture of salmon, and also by positive measures to encourage the maintenance of salmon stocks.

Some fairly radical changes in the statutory control of salmon fishings were effected by the Salmon and Freshwater Fisheries (Protection) (Scotland) Act 1951 which basically created additional offences and increased penalties. Drift netting for salmon was prohibited in terms of an Order under the Sea Fish Conservation Act 1967.

Criticism is frequently made of the effectiveness of the legislation to prevent the illegal taking of salmon, and this is as much a criticism of the system of prosecution and sentencing as it is of the effectiveness of the District Salmon Fishery Boards. As long as the Boards are financed by the raising of fishery assessments, the financial constraints will restrict their activities.

It may be questioned whether Acts which are now over 100 years old are relevant to present-day considerations, and the whole question of salmon fishery legislation was investigated in some depth by the Hunter Committee, which reported as long ago as 1965. This Report was in some respects controversial, but there is general agreement that updating of the legislation is required, and those involved in the administration of the Salmon Fishery Acts have in recent years made unsuccessful efforts to have amending legislation introduced.

11 References

(1) 14 & 15 G VI C26 S24 (1)

(2) Stair Institutions of the Law of Scotland II.3.69

(3) 9 Geo IV C39

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(5) 9 Geo IV C39 S9

(6) 7 & 8 Vict C95 (repealed 14 & 15 G VI C26)

(7) 7 & 8 Vict C95 (repealed 14 & 15 G VI C26) S1

(8) 25 & 26 Vict C97

(9) 25 & 26 Vict C97 Ss3,4

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(11) 25 & 26 Vict C97 Ss15,16

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(13) 31 & 32 Vict C123

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(19) 31 & 32 Vict C123 S4

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(23) 14 & 15 G VI C26 S11

(24) 1976 C84 & SI 1973 no. 203 renewed SI 1983 no. 60

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(26) 14 & 15 Geo VI C26 S24(1)

(27) 14 & 15 Geo VI C26 Ss10/12

(28) 31 & 32 Vict C123 S15

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The biology of Scottish salmon

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1 Introduction

Probably no work has done more to make the life history of the salmon widely known than Henry Williamson's (1936) animal saga *Salar the salmon*. What better animal could be chosen for an epic guaranteed to rivet the attention of young and old than one whose life involves such long-distance return migrations from river to distant seas, with all the associated hazards! Here is a fish well adapted to both a marine and freshwater environment. The eggs are laid in gravel in fast-running rivers and streams, and develop there successively into alevin, fry, parr and smolt. Smolts migrate each spring to the sea where they feed voraciously, and eventually return as mature fish to their river of birth, where they fast. The timing and nature of their return are still something of a mystery. Why, for instance, do some fish return as grilse after only one year at sea, while others do not come back for 2 or 3 years?

The life cycle of the salmon (Figure 1) had, of course, been described in the scientific literature before Williamson's story. Hector Boece (1527) gave a correct outline of the history of the Atlantic salmon, while a 16th century priest, Peder Clausson Friis (1545–1614), surmized that salmon bred in fresh water, that the young fish spent a period in the river before migrating to sea, and that, once there, they grew rapidly and carried out extensive migrations. It is interesting to note that Willughby and Ray refer to the first description of the salmon in an old Latin folio *Salmo omnium autorum* (North 1840). There was, nonetheless, for some considerable time a misunderstanding about the juvenile life of the salmon, which arose because the parr is similar to a small brown trout and quite unlike a smolt which, having silvery scales, resembles a salmon. Indeed, the famous naturalist Agassiz considered the parr to be a variety of trout. However, some male salmon parr develop functional

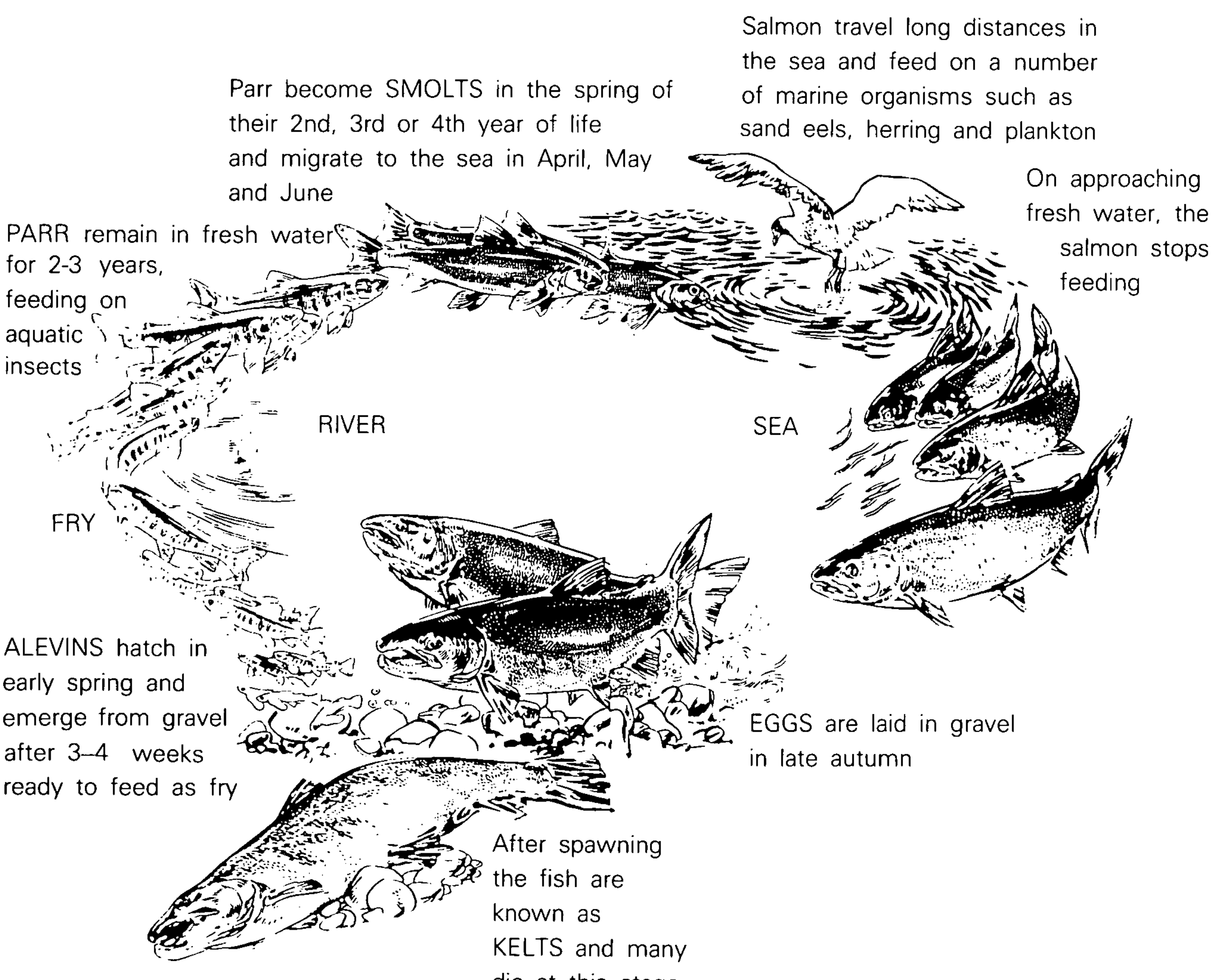

Figure 1. Life cycle of the salmon (source: Mills 1971, 1980)

testes, a phenomenon known as *paedogenesis*. It was therefore considered that the parr was a separate species, and it was given the specific name of *Salmo salmulus*, while the smolt was considered to be the fry of the salmon which went to sea in its first year of life.

The recognition of the parr as a separate species was promulgated for well over 150 years by such eminent naturalists as Ray and Willughby (1686), Pennant (1761), Davy (1832), Yarrell (1836) and Parnell (1840). It was not until Shaw (1836, 1840) carried out experiments and observations in ponds at Drumlanrig by the River Nith that it was confirmed that the parr was the young of the salmon. This fact was previously suspected by the angler Thomas Stoddart in *The Scottish angler* in 1831. Even so, Yarrell (1839), the famous ichthyologist, was not prepared to accept these findings. Although Andrew Young (1843) and Sir William Jardine corroborated Shaw's observations, the controversy was still raging in the 1860s, and was well documented by Flowerdew (1871). However, there was no doubt when the Salmon Fisheries (Scotland) Act was passed in 1868 that a parr was a young salmon as, in 1871, under this Act, a youth was charged with taking one parr, was fined one shilling plus ten shillings costs, and his rod and tackle were declared forfeited!

Agreement over the salmon's life cycle seems to have been reached in the late 1860s, and successive definitive works on its life history were subsequently produced over the next 100 years by Gunther (1864), Day (1887), Calderwood (1907), Malloch (1910), Hutton (1924), Menzies (1939), Jones (1959) and Mills (1971). A revised terminology list of definitions and terms designating the different life stages of the Atlantic salmon was produced in 1975 by Allan and Ritter.

2 *River life*

2.1 Spawning

Salmon spawn throughout the river system wherever there is a suitable substrate of clean, silt-free gravel with adequate aeration in which to 'cut' or dig their nests or redds. The greatest proportion of this type of substrate occurs in the upper reaches of the rivers and their tributaries where the flow is more turbulent, but spawning can sometimes also occur in the main channel immediately above tide level. A wide range of stone or gravel size can be used for egg deposition and no size preference is known for certainty, although probably very small gravel is normally avoided. Rantz (1964), in his list of criteria for favourable spawning conditions for king salmon, gives the optimum stream bed composition in terms of the weight fraction of silt, sand and stone size, and the majority of the stones measured 2.5–15.3 cm. Spawning salmon do seem to prefer certain water velocities and depths. According to Beland *et al.* (1982), female Atlantic salmon in the USA constructed redds in water with a mean depth of 38 cm, and the mean water velocity 12 cm above the substrate was 93 ± 1.3 cm s^{-1}. Mills (1984) found that the main factor limiting spawning by salmon in certain tributaries of the River Tweed was gradient, with gradients of less than 3% being favourable. Sea trout were found to spawn in streams with gradients of up to 4%. There is probably some overlap in the spawning requirements of salmon and sea trout, which may result in some competition between these 2 species for available spawning areas.

Spawning usually takes place from late October to December, but in some rivers, where late runs of fish occur, spawning may not be completed until the end of January, or even later. Unfortunately, few detailed observations of spawning salmon have been made in the wild. Once the net fishing and angling season is over, the salmon river becomes a closed book to all but the most dedicated biologist. Chapman (1924) attempted such a study on the River North Tyne, but it was unfortunately too anthropomorphic to be of any real value. River Authority and District Fishery Board bailiffs carry out redd counts which are of value in providing some assessment of spawning escapement (Hay 1984) and of potential egg deposition (Elson & Tuomi 1975), the fecundity of salmon being known within certain limits (Pope *et al.* 1961). However, while their smaller size makes it possible to distinguish redds made by smaller fish or grilse from those made by the larger salmon, there is no easy method of determining the distribution of redds of early-running (spring) and late-running (autumn) salmon. There has been a lot of speculation over the spawning distribution of various age classes in a river system, but the phenomenon requires further attention, as does the degree of spawning between fish from the spring, summer and autumn components of the stock.

There appear to be certain limiting factors to spawning which, while not documented for Scotland, have been recorded in Iceland (Einarsson, pers. comm.) and Greenland (Jonas 1974) where water temperature and river bed stability seem to limit spawning, and especially the subsequent survival of egg, alevin and fry.

2.2 Egg and fry survival

Water temperature seems to be the most important factor limiting the successful survival of salmon in fresh water. Power (1969) speculates that for northern Canada the survival of salmon may be reduced when there are fewer than 100 days in a year with a mean air temperature of at least 10°C. In Iceland, salmon only thrive in waters where temperatures are above 10°C for at least 3 months each year. Low water temperatures inhibit the development of the egg and result in a late hatch of the alevins. In some Icelandic streams, alevins do not emerge from the gravel until July, giving them a very short time to feed and grow before temperatures drop to a level at which feeding stops. In Scotland, this is only likely to occur in streams at high altitude and probably the factors most likely to limit egg survival here are low pH values and high concentrations of suspended solids. In Newfoundland, Chadwick (1982) found that survival from the egg to the fry stage was correlated with water temperature and discharge. He considered that the present recommended egg deposition of 2.4 eggs m^{-2} of parr-rearing habitat was inadequate for Newfoundland rivers. This finding seems to agree with the work of Buck and Hay (1984) on the Girnock Burn (in Grampian Region), who suggest a maximum egg deposition of 3.4 m^{-2}. On the Girnock Burn, this level of deposition gave an average production of 4000 juvenile migrants (0.07 m^{-2}) each season.

The survival of fry depends upon availability of space and food. During the first few weeks, there is usually a high mortality due to starvation, predation and competition for territories, which together result in the 'carrying capacity' of the stream. Studies of fry survival in Scottish streams (Mills 1964, 1969a; Egglishaw & Shackley 1977, 1980) have enabled useful recommendations to be drawn up for the stocking of streams with eggs and fry (Egglishaw *et al.* 1984).

2.3 Densities of fry and parr

The density and standing crop of salmon fry and parr in a stream depend, to some extent, on water temperature and the gross production of the stream, but also on the presence of other fish species and other environmental conditions such as stream bed stability, water velocity and water depth. Egglishaw and Shackley (1982), for example, showed that water depth, or some factor associated with water depth, can determine the suitability of a stream habitat for juvenile Atlantic salmon. Highest densities of 0+ age salmon were found in those sections of streams with a high proportion of shallow water. Trout of 1+ age, on the other hand, were found in their highest densities where there was a high proportion of deeper water.

Differences in densities of salmon within streams with widely varying physical characteristics can be as great as those between streams. Such differences may be due to food availability, river bed stability or water temperature. For example, on the Laxa i Kjos system in Iceland, the density of fry and parr in an upstream section of a tributary, the Bugda, immediately below a lake outfall, was several times greater than that in a downstream section of the same tributary a few hundred metres below its confluence with a coldwater tributary. While the resulting lower water temperature in the lower section would have some effect, the additional factor favouring the higher density of fry and parr in the upper section was a rich food supply of larval simuliids feeding on organic drift from the lake. Elsewhere, the differences may be more influenced by low spawning escapement, bird predation, pollution, land drainage, stream channel excavation or afforestation. The densities of fry and parr in some Scottish rivers have been recorded by Mills (1964, 1969a, 1969b), Mills *et al.* (1978), Mills and Tomison (1985), and Egglishaw and Shackley (1977). Table 1 shows the variation in the density and standing crop of juvenile salmon in a river system in Britain.

Table 1. The average population densities (no m^{-2}) and standing crops (gm m^{-2}) of juvenile salmon in 6 areas of the Tweed river system, 1984 (source: Mills & Tomison 1985)

River system	Number of sampling sites	Density (no m^{-2})	Standing crop (gm m^{-2})
Upper Tweed	42	0·25	2·3
Middle Tweed	9	0·14	2·5
Ettrick	10	0·59	4·8
Teviot	5	0·29	3·1
Lower Tweed	8	0·02	0·9
Till	5	0·08	1·1

2.4 Precocious male parr

A varying proportion of male parr attain sexual maturity, and Jones (1959) described their presence on spawning grounds in large numbers in November and December. From observations of the spawning behaviour of adult salmon and ripe male parr, Jones (1959) concluded that the presence of ripe male parr was an adaptation to ensure fertilization of the eggs in case of inadequate fertilization by adult males.

Parr have 2 main periods of movement, in spring and autumn/early winter. The autumn movement frequently consists mainly of ripe males (Pyefinch & Mills 1963). It had been thought that these fish might be the forerunners of the next year's smolt migration, or fish destined for the sea that autumn. Some ripe male parr were tagged at a trap on the River Meig, and one was subsequently caught 2 years later at the trap as a grilse, thus indicating that at least some parr were forerunners of the coming year's smolt migration. Shearer (1972, 1984b) records an autumn seaward movement of parr on the River North Esk, and Saunders and Bailey (1980) interpret downstream movement of parr in autumn as stock-specific behaviour developed to ensure timely arrival at sea the following spring.

It is suspected that not all ripe male parr go to sea, and probably many die while still in fresh water. In Newfoundland (Dalley *et al.* 1983), the incidence of sexual precocity in male salmon was examined in selected rivers from 1974 to 1977. The incidence was variable (12.3–100%), but generally high, particularly in eastern rivers (mean overall incidence was 72.7%). From smolt runs examined, it appears that too few precocious parr migrate as smolts to contribute to the grilse population. As a result of high mortality, rivers with a high percentage of sexually precocious males tend to have a correspondingly high percentage of adult females.

2.5 Smolt migration

The length of time that salmon parr spend in fresh water before going to sea as smolts in spring varies with the location of the river. In the Hampshire Avon, over 90% of the smolts were yearlings. In northern Scandinavia, parr stay in the rivers for 7 or 8 years, but not in Iceland, where smolts go to sea in their 3rd, 4th and 5th year. At the time of their seaward migration in Scotland, smolts are mostly entering their 3rd and 4th year (ie 2+ and 3+ years), with a few in their 5th year. On some rivers, there is a big variation in the age composition of the smolts, with older smolts tending to occur in greater proportions in the upper reaches of the river system (Table 2). Symons (1979) points out that, with the exception of the Ungava rivers, average smolt age in any particular river can be estimated from the number of days each year on which water temperature reaches or exceeds 7°C. The transformation from parr to smolt involves a number of morphological, physiological and behavioural changes which pre-adapt young salmon for life in the sea while they are still in fresh water (Hoar 1976). Saunders and Sreedharan (1977) consider that photoperiod is the environmental cue acting through the endocrine system to affect these changes. The timing of smolt runs appears to be influenced mostly by temperature (Mills 1964; Solomon 1978), with the run starting in earnest once the water temperature remains above 10°C. It is possible that there are stock-specific responses to the environmental cue for smolting and to those for triggering migratory behaviour.

Annual smolt production in Scotland has been estimated in only a few river systems. Through an intensive tagging programme on the River North Esk, Shearer (1984a) was able to estimate both annual smolt production and the number of adults surviving to return to home waters. His estimates of natural mortality suggest that smolt survival may be relatively high, with a total return rate between 16% and 46%. Mills (1964) estimated that the annual smolt production from releases of hatchery-reared unfed fry into the River Bran, in which no natural spawning occurred, was in the order of 18 000 smolts. This estimate implied a smolt-rearing capacity of approximately 4.2 100 m^{-2}. Assessments of annual smolt production from Scottish rivers as a whole will be of immense value in estimating survival rates to various stages in the adult life of salmon. Symons (1979) estimated the average maximum production of smolts per 100 m^2 as approximately 5 for 2+ smolts, 2 for 3+ smolts and 1 for 4+ smolts. The minimum egg depositions recommended for the production of these numbers of smolts are 220 100 m^{-2}, 165–200 100 m^{-2} and 80 100 m^{-2} for each age of smolt respectively.

Table 2. Age composition of salmon parr in the Tweed river system in 1984 (source: Mills & Tomison 1985)

River system*	Number in sample	Percentage of parr in their 2nd, 3rd and 4th year of life and destined to become smolts in the next year		
		1+	2+	3+
Upper Tweed	60	53·0	41·0	6·0
Ettrick and Yarrow	65	75·0	25·0	0·0
Middle Tweed	50	85·0	12·0	3·0
Teviot	90	90·0	10·0	0·0
Lower Tweed	45	97·5	2·5	0·0
Till	20	100·0	0·0	0·0

*Listed in order of distance from sea

Densities of smolts recorded for various river systems are shown in Table 3.

3 *Sea life*

3.1 Migration

Initially, little was known of the movements of post-smolts in the sea. With the advent of the high seas fisheries off west Greenland and the Faroes and in the Norwegian Sea, much more is now known. This increased knowledge is due not only to the recapture in some or all of these fisheries of tagged smolts and previously spawned adults or kelts from Canada, England, France, Iceland, Ireland, Norway, Scotland, Sweden and the United States, but also to the subsequent recapture in home waters of adult salmon tagged in some of the high seas fisheries. Recent studies of tagged Atlantic salmon have revealed their inter-continental migrations, with salmon tagged in the United Kingdom being recaptured in North America and salmon tagged in North America recovered off Norway and the Faroes (Reddin *et al.* 1984).

Post-smolts have generally eluded capture, and on the European side of the Atlantic there have been few records of this stage in the life cycle. However, a

Table 3. Densities of salmon smolts (no 100 m^{-2}) recorded for various river systems

River system	Density	Authority
CANADA		
Miramichi	4·7	Elson 1975
Pollet	6·0	Elson 1975
Big Salmon	3·9	Jessop 1975
Matamec	2·6	Gibson & Cote 1982
IRELAND		
Foyle	8·4	Elson & Tuomi 1975
NORWAY		
Orkla	4·1	Garnas & Hvidsten 1985
Vardnes	2·9	Berg 1977
SCOTLAND		
Bran	3·5	Mills 1964
Shelligan	10·0–22·0	Egglishaw 1970
Tweed	11·6	Mills *et al.* 1978
Girnock Burn	7·0	Buck & Hay 1984
SWEDEN		
Ricklea	1·9	Østerdahl 1969
USA		
Cove Brook	3·6	Meister 1962
WALES		
Wye	4·3	Gee *et al.* 1978

In most instances the smolts are 2–3 years old, with the exception of the Vardnes where the smolts are 3–4 years old considerable number of post-smolts, originally tagged as smolts in Maine, were taken off Nova Scotia, Newfoundland and Labrador (Meister 1984). No doubt their whereabouts in European waters will soon be located as other feeding grounds are mapped. Recently, a new feeding area for salmon was found to the east of the Newfoundland continental shelf (Reddin & Burfitt 1984). The sea age composition of the catch and the condition of the gonads indicated that some of these fish would have matured as grilse. This is the first record of grilse being caught at sea other than in coastal fisheries.

The mystery of how the salmon find their way around the ocean and eventually back to their parent rivers still needs to be solved. It is suspected that they may be able to sense the gradient in electric potential generated by the movement of an ocean current in the earth's magnetic field. Sensitivities close to that required have already been demonstrated in this species.

3.2 Feeding

Detailed information on the marine food of salmon has been obtained since the advent of the high seas fisheries. A wide range of planktonic organisms is included in the salmon's diet, as well as certain fish species, of which the capelin and Myctophidae are of considerable importance. Some concern has been shown recently for the possible effect on post-smolt salmon survival of a recent decline of capelin (Reddin & Carscadden 1982). Industrial fishing for other small fish species, such as myctophids, could also have some effect on salmon survival at sea.

3.3 Survival at sea

There is increasing evidence to show that climatic factors resulting in a change in oceanic conditions affect salmon survival at sea. Martin *et al.* (1984) presented evidence which suggests a possible link between the 1970s salinity anomaly in the eastern North Atlantic and Norwegian Sea and changes in salmon catch returns to Scottish rivers. Scarnecchia (1984) also demonstrated that climatic and oceanic variations affected the yield of Icelandic stocks of salmon.

There is considerable controversy concerning the importance of human predation in contrast to natural factors in exploring both short-term and long-term fluctations in salmon stocks. It should not surprise us that fish stocks respond to climatic factors and oceanic changes because, after all, they live their lives within a body of water which responds to these changes. Furthermore, the salmon's migration circuits are tied to hydrodynamic structures.

3.4 Sea age and time of return to home waters

Several authors have noted a possible relation between the river age at smoltification and the subsequent sea age at the return to fresh water. Calderwood (1925) commented that the oldest smolts tended to return soonest to fresh water. Hutton (1937) reached a similar conclusion, and propounded what he called *The inverse ratio theory of river and sea life*, which supposes that the total age (smolt age + sea age) at maturity tends to be constant. There has been much work tending both to support and refute this theory, and the subject is competently reviewed by Gardner (1976).

More recently, Shearer (1948b) has shown that on the North Esk there is a correlation between the calendar date when a fish returns to fresh water within its own sea age group and its river age, irrespective of whether the fish returns as a one sea-winter or multi sea-winter (MSW) fish. The longer the fish has spent in fresh water, the earlier it is likely to return within its own sea age group. Thus, few MSW fish derived from one-year-old smolts are caught before May and few grilse derived from one-year-old smolts are caught before July. In general, the monthly average smolt age of each sea age group decreases throughout its migratory season. Over the last 20 years, there has been a general decline in average smolt age. Shearer (1948b) found that the relationship between sea age and time of return is less well defined. However, few one sea-winter fish are caught before June and few 3 sea-winter fish are caught after June. In his review of factors which may influence the sea age and maturation of Atlantic salmon, Gardner (1976) considers the evidence for this timing being under either genetic or environmental control. The whole subject is still confused and much more work is required to unravel its complexity.

The time of entry of the main runs of fish varies from river to river. Some rivers such as the Aberdeenshire Dee, Tay, Tweed, Spey, Helmsdale and Brora have early (spring) runs of MSW fish while others, such as those on the west coast of Scotland, usually have very few spring fish and the first large runs of both grilse and MSW fish only start to enter the rivers in June and July. There are also rivers, such as the Annan, Nith and Tweed, which have a large run of fish in the late autumn and even early winter.

In a number of rivers, an increasing proportion of the run currently takes place outside the legal netting season. Shelton (1984) considers that the reasons may be linked with the decline in smolt age noted on the North Esk. Gardner (1976) suggested that, where the stocks are heavily exploited, natural selection would tend to favour winter-running fish which enter the river during the annual close time. However, there is evidence from the Tweed to suggest that this change from early-running to late-running stocks, and also in the alternating dominance of salmon and grilse, is cyclical (Figures 2 & 3) (Mills 1984).

3.5 Factors affecting upstream migration

Many factors are claimed to be responsible for the

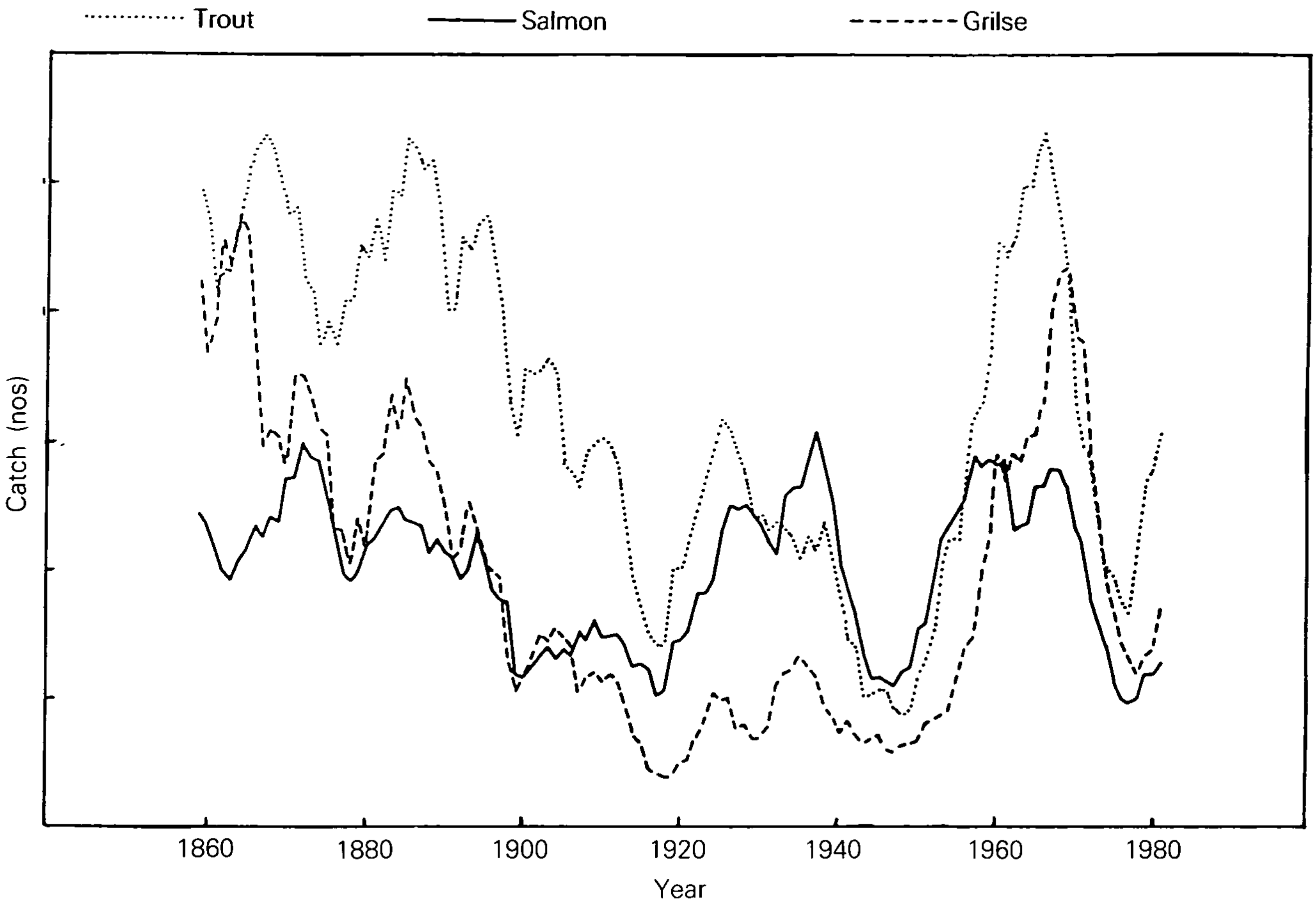

Figure 2. Commercial catch of salmon, grilse and sea trout by Berwick Salmon Fisheries Company (presented as 5-year rolling averages)

time of entry of salmon into rivers and their subsequent upstream migration. The importance of any one of these factors probably changes as the fish move upstream. Hayes (1953) found that fish move out of tidal waters into fresh water at dusk, and light change may be the controlling factor. He also had evidence that fairly strong onshore winds approaching 32 km h^{-1} induce salmon to concentrate in the river estuary and eventually ascend. Peaks in the tidal cycles representing daily increasing differences between high and low tides seem to be effective in concentrating salmon on the coast, and indicate the probability of a run into fresh water. Hayes (1953) showed that large natural freshets can initiate a major run of fish into the river, provided the winds and tides are favourable. In cases where these 2 other factors were not favourable, no run occurred.

Menzies (1939) describes how in dry weather grilse which are held up in tidal waters moved up the estuary just ahead of the tide, and fell back with the tide as it ebbed; but, during a spate, tidal movements were ignored and fish entered the estuary and moved directly and rapidly upstream. Almost 100 years earlier, Williamson (1843) writes: 'It is well known that salmon do not travel in dry weather. Before they ascend a river, they require a "leading water". They persist in hovering about the estuary, ascending with the tide, but, unless there be a fresh in the river, returning with it, and, what is very strange, however low the river may have sunk, no sooner does it become quickened by a heavy fall of rain, than they rush into it in shoals, run up with great vivacity, and are taken many miles from the sea in the course of a few hours. It is evident, therefore, that a dry summer, though fatal to fishes above high water mark, is eminently favourable to those below it; and the more so, the closer the approximation to the sea'.

Menzies (1939) has shown that water temperature is of great importance to fish movement in the spring, and until the water temperature reaches 5.5°C there is little upstream movement of fish over obstacles. Lindroth (1952) estimated that the average rate of travel upstream by adult fish ascending the River Indalsalven in Sweden was 10–20 km day^{-1}. It also seemed to him as if the salmon which entered the river last travelled furthest upstream.

Upstream migration is undoubtedly associated with endocrine activity as the salmon becomes sexually mature. Fontaine (1951) suggested that the alternating periods of activity and torpor which characterize the behaviour of ascending salmon may be due to variations in the activity of the thyroid gland.

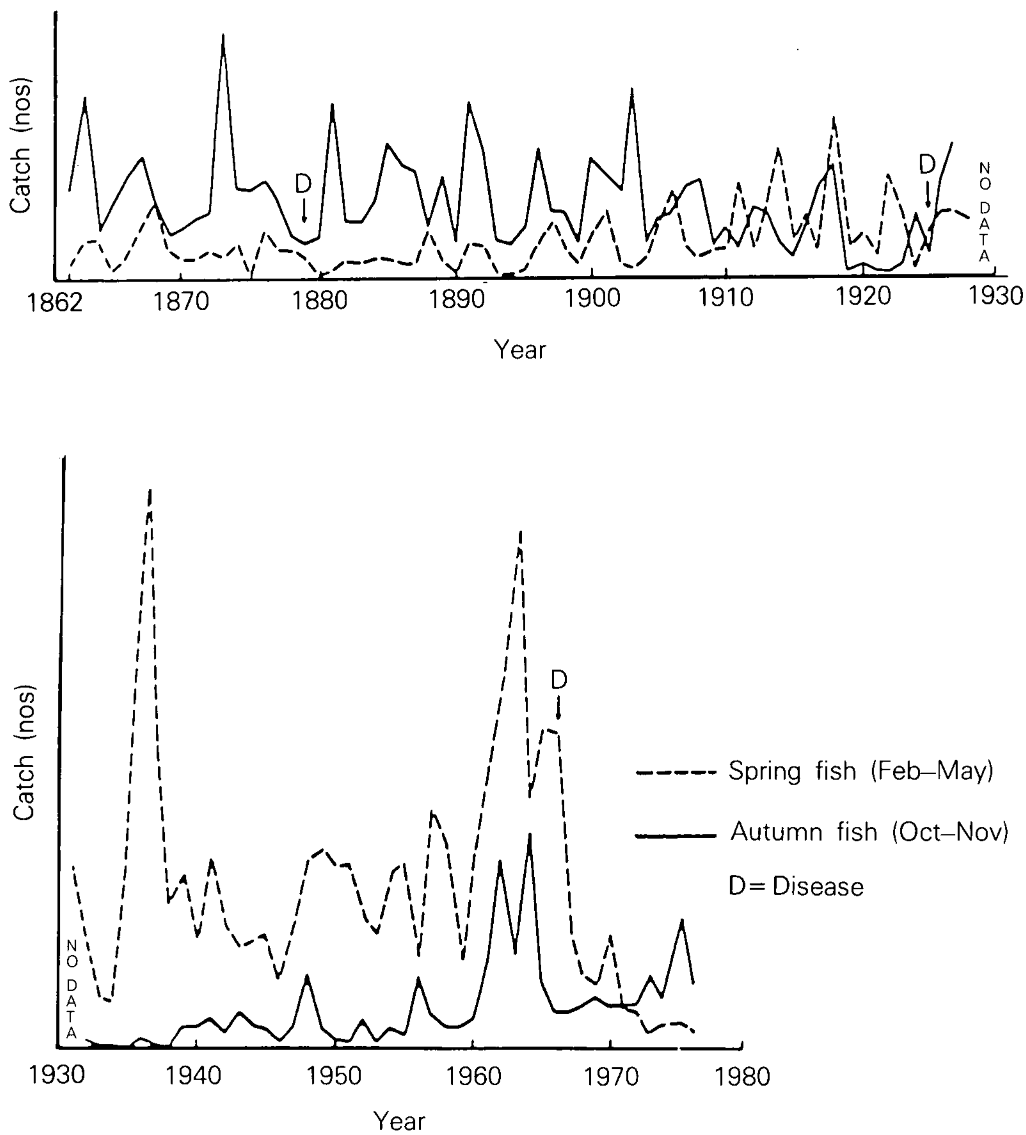

Figure 3. Annual spring and autumn rod catch of salmon on a lower beat of the River Tweed

There has been a great deal of speculation on the behaviour of salmon ascending rivers, much of it based on limited observations, unfortunately with little corroboratory scientific evidence (Banks 1969). Much more work on this important aspect of salmon behaviour is needed and, with several water abstractions schemes on the drawing-board in Scotland, where better to start than in the estuary?

4 Disease

The disease which has probably had the greatest impact on salmon stocks in recent years in Scotland is ulcerative dermal necrosis, or UDN. UDN is probably the same as the 'salmon disease' which occurred at the end of the last century. The pattern of spread of the disease is similar and the symptoms were remarkably alike. Some authorities (Stuart & Fuller 1968) believe that *Saprolegnia* spp. may be the causative organisms. The disease has been described fully by Pyefinch and Elson (1967) and Elson (1968), and investigated by Roberts (1969) and Roberts *et al.* (1969). Roberts considered that the microscopical appearance of the early lesions suggested that a virus was responsible, but that it was only the harbinger of the initial skin damage which allowed both loss of body proteins and attack of unprotected tissue by fungi.

Munro (1970) pointed out that many high annual catches were made over the period of the outbreak in the late 19th century, indicating that salmon were never in danger of extinction; indeed, the disease may have occurred as a result of an exceedingly large population. Munro considered that similar factors may have operated to start the outbreak in the late 1960s and through the early 1970s. There is also some evidence of a smaller outbreak of the disease on the Tweed in the mid-1920s when the salmon catches were 'reaching' a fairly high level, but this outbreak was not fully recorded.

It is not known what proportion of the annual total population of adult salmon was affected by the disease or what proportion survived. It is said that some kelts exhibited scar tissue, indicating that they had recovered from the disease. Unfortunately, Scottish rivers are so inadequately monitored that there are no reliable data from which to speculate.

5 *Kelts*

In recent years, kelts have received little attention from salmon biologists. It is generally agreed that the death rate after spawning is high, especially among male fish, and that only a small proportion (3–6%) of the kelts return to spawn a second time. However, a higher proportion survive for at least some months after spawning. At Torr Achilty dam on the River Conon, where both ascending and descending fish are counted, the average proportion descending was 26% of an average upstream run over 6 years of 2300 fish.

There has been some controversy over the value of previously spawned fish to the commercial and rod fisheries as they make up such a small proportion of the total stock returning, but according to Went (1964) their value should not be underestimated.

In recent years, with fish entering the rivers so late in the year and with some spawning occurring in the late winter months, the condition of kelts may be much better than previously. Unfortunately, as with so many aspects of the salmon's biology, we just do not know, and we will not know, until we get to know our rivers better, at all times of the year and not just during the fishing season.

6 *Summary*

6.1 Salmon spawn on clear, silt-free gravel with adequate aeration. They prefer gradients of less than 3%.

6.2 Water temperature seems to limit the survival of salmon. The survival limit may be reached when either the annual period with a mean temperature of 10°C falls below 100 days, or where water temperatures fail to reach 10°C for at least 3 months of the year.

6.3 The recommended optimum egg deposition is in the order of 3·4 m^{-2} and this can produce an annual average level of 0·07 juvenile migrants m^{-2}.

6.4 The density and standing crop of fry and salmon parr depend partly on water temperature and productivity, but also on competition from other fish, stream bed stability, water velocity and depth, and are affected by low spawning escapement, bird predation, pollution, land drainage, stream channel excavation and afforestation.

6.5 Older smolts tend to occur in greater proportions in the upper reaches of the river system. Most smolts migrating to the sea from Scottish rivers are entering their 3rd and 4th year of life (ie 2+ and 3+ years). Smolt survival may be relatively high, with a total return rate of 16–45%.

6.6 Recent studies of tagged salmon have revealed inter-continental migrations. New feeding areas are being found, but so far few post-smolts have been captured in European waters.

6.7 Salmon eat many planktonic organisms and some fish species, of which capelin and myctophids are important.

6.8 The longer a fish has spent in fresh water, the earlier it is likely to return within its own sea age group. An increasing proportion of the total annual run of salmon takes place outside the legal netting season, and may be linked to a decline in smolt age. A current change from early- to late-running stocks may be part of a cycle.

6.9 Water temperature is important to fish movement in early spring.

6.10 Pandemics of the salmon disease UDN have occurred at least twice in the last 100 years at periods of high salmon catches. The causative organism has not been isolated. The disease may spread as a result of high salmon density.

6.11 The death rate after spawning is high, especially among male fish, with only 3–6% of fish returning to spawn a second time.

6.12 Many management decisions are based on casual observations, limited data and speculation. More work should be done on whole river systems, monitoring fish stocks through the whole year.

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Changes in the timing and biology of salmon runs

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1 Introduction

This paper examines data on the Atlantic salmon population of the River North Esk to determine whether there have been changes in the biology and timing of salmon runs which could account, at least in part, for the recorded changes in salmon catches in this river. Although the data refer specifically to the North Esk salmon population, they may provide some insight into the factors affecting salmon populations elsewhere in Scotland.

2 Methods

The most complete set of biological data available for any Scottish salmon population was collected in the course of research into the relationship between estimated egg deposition and smolt production in the River North Esk over the period 1963–84. On one day each week throughout each net fishing season (16 February–31 August), every fish caught in the North Esk net and coble fishery was weighed, the fork-length measured, the sex determined from external characters, and a sample of scales removed for age determination and growth studies. The proportions of the catch sampled each year varied between 15% and 41% for grilse (one sea-winter salmon (1SW)), and between 19% and 49% for salmon (multi sea-winter salmon (MSW)). As the proportions of the total catch which were sampled varied within seasons, the biological characteristics of the salmon caught, such as age composition and length distribution, were obtained by weighting samples up to catch level. Three and 4 sea-winter salmon have become relatively scarce in the North Esk in recent years and so have been excluded in this analysis. The river and sea ages, ie the ages at which salmon first migrated to sea as smolts and returned from the sea as adults, of the salmon sampled were determined by scale analysis. To provide an index of the smolt age composition of the 1SW and 2SW salmon throughout the fishing season, the monthly age compositions of the salmon catches were used to compute monthly mean smolt ages.

The biological characteristics of the juvenile salmon emigrating from the North Esk were also examined from 1964 to 1984. Each year, the smolts which migrated to sea by way of Kinnaber Lade (Figure 1) were trapped, a proportion was tagged and a sample of smolts were scaled to provide age composition and growth rate data. Every smolt tagged was measured from the tip of the snout to the fork of the tail. Smolt production was estimated using a stratified mark and recapture technique (Schaefer 1951) which gave the numbers emigrating in each 5-day period, counted

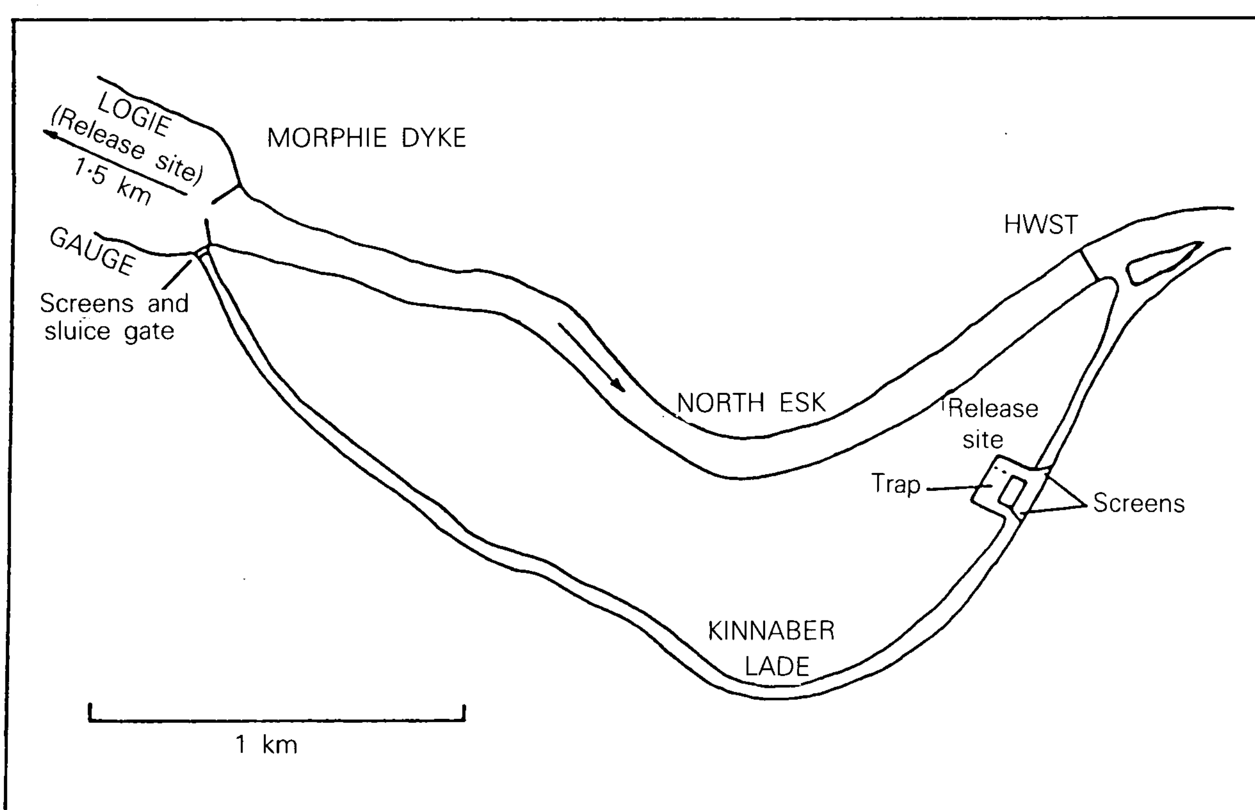

Figure 1. Site of Kinnaber Mill trap on the River North Esk

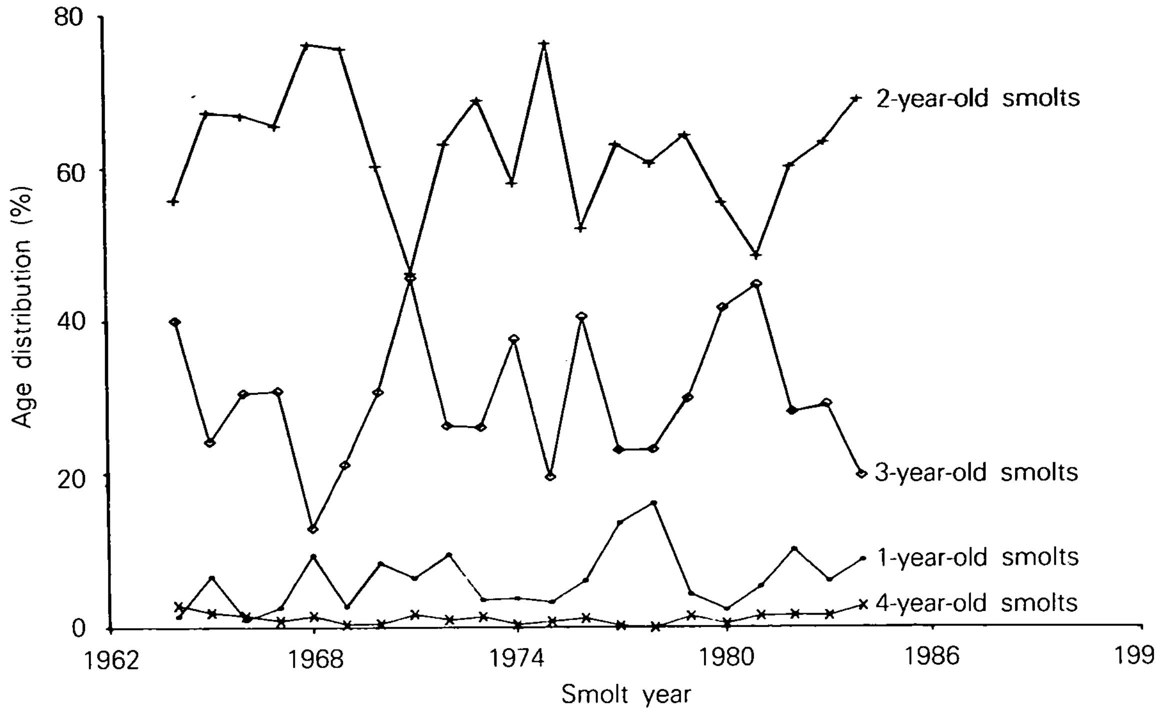

Figure 2. Age distribution (%) of smolts emigrating from the River North Esk

from 1 April, throughout the run. As the proportion of the emigrating smolts which was trapped varied throughout the smolt run each year, estimates of the age composition and length distribution of the emigrating smolts were obtained by weighting the sample data (from trapped smolts) from each 5-day period up to the level of the migrating population for the corresponding period. To provide an index of the smolt age distribution for each year, the mean age of the smolts emigrating was computed using the weighted figure. To provide an index of the timing of the smolt run each year, the data on numbers of smolts moving downstream in each 5-day period throughout the run obtained from the smolt production estimates were used to determine the 5-day period which included the day by which 50% of the smolts had migrated. High water levels during the springs of 1969, 1977–79 and 1983 precluded the estimation of smolt production in these years. In 1970, most of the smolts tagged were caught by sweep net as the Kinnaber Mill trap was under construction and, therefore, no smolt estimate was calculated.

In addition to providing data on the biological characteristics of the juvenile salmon and smolt production estimates, smolt tagging operations have allowed the mortality, both natural and fishing mortality, between the smolt stage and returning adults to be estimated for the North Esk salmon population (Pratten & Shearer 1981; Shearer 1984a).

Since 1980, an electronic counter has been operated on the North Esk at Logie. This equipment has provided counts of the number of adult salmon, including grilse, escaping exploitation in the lower reaches of the North Esk for the years 1981–84. These counts, together with the net and rod catches downstream, provide data on the number of fish which entered the North Esk and either were caught or passed upstream through the lower reaches.

3 Results

In the smolts emigrating to sea, 2- and 3-year-old fish formed the most important age groups. They accounted for 46–76% and 12–45% respectively of the smolts each year; few smolts emigrated after only one year in fresh water (1–16%) and only about 1% after 4 years (Figure 2). The mean smolt age (with 95% confidence limits) over the 21 years 1964–1984 was 2·29 ± 0·003 years and annual mean smolt ages ranged between 2·07 ± 0·03 in 1978 and 2·44 ± 0·01 in 1964 (summarized in Figure 3). There was no significant change in the mean age of the emigrating smolts over the years ($F_{1,19}$ = 0·167, P>0·1) but there were wide fluctuations between years. The aged sample of smolts each year was small relative to the total emigrating population (*c* 1%) and, because of the trapping methods involved, did not vary proportionately throughout the smolt run. Thus, any real changes in smolt age between years may have been obscured by sampling error. Smolt age appeared to decrease as the smolt run advanced. April smolts were older than May smolts which were, in turn, older than June smolts. However, no significant differences between the months could be found (P>0·1), again possibly because of the relationship between sample size and the size of the migrating population.

Two- and 3-year-old smolts formed the most important river age groups giving rise to the returning 1SW salmon, accounting for 45–84% and 15–52% respectively. One-year-old smolts formed 0·3–11% and

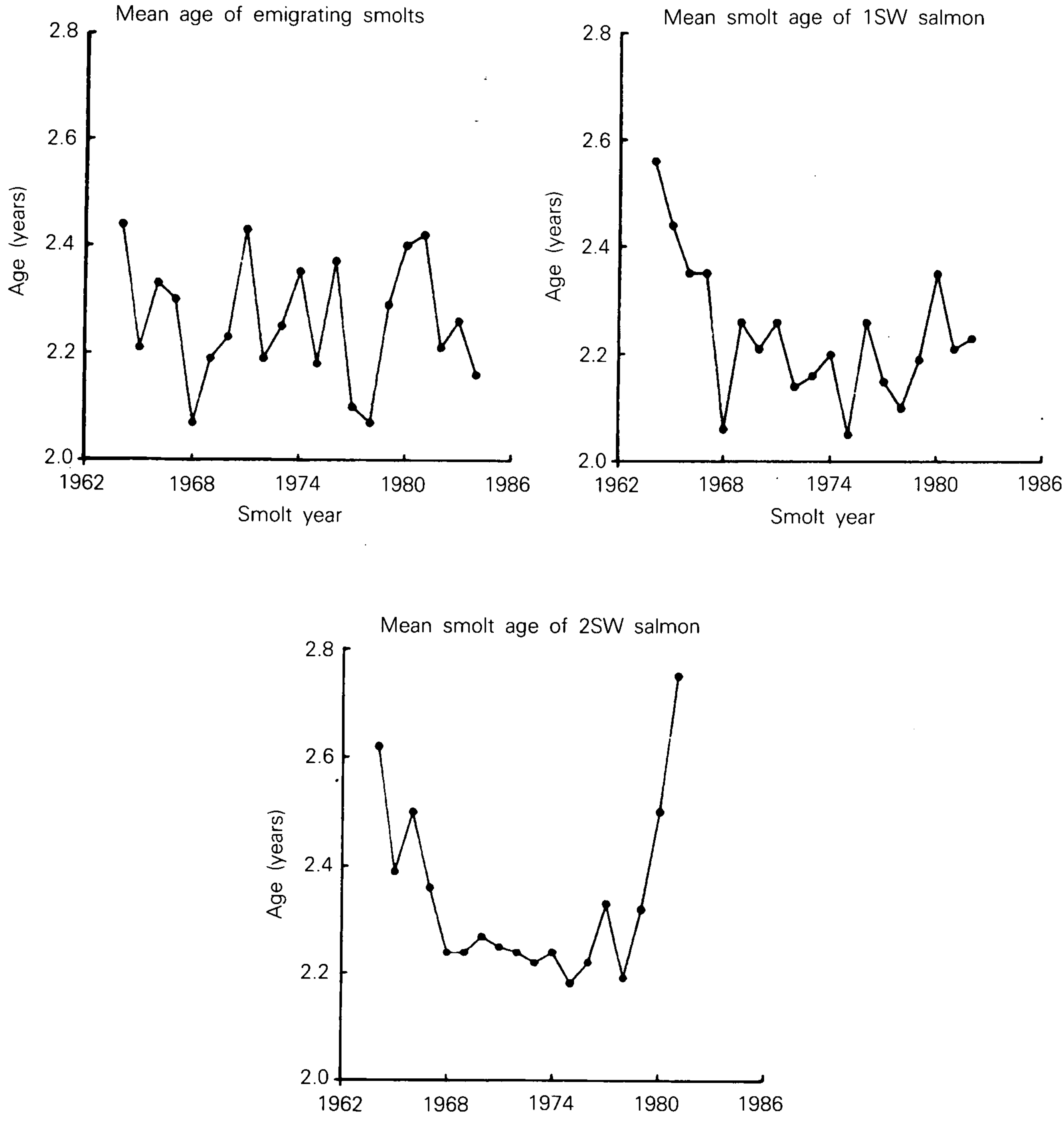

Figure 3. Mean smolt ages of emigrating smolts and returning 1SW and 2SW salmon in the River North Esk

4-year-old smolts 0–2·8% of the returning grilse (Figure 4). The mean smolt age of salmon returning after one winter in the sea from the smolt years 1964–82 was 2·24 ± 0·004 years, and annual means ranged between 2·04 ± 0·02 in 1975 and 2·55 ± 0·01 in 1964 (summarized in Figure 3). Over the period, there was a significant decrease in annual mean smolt age ($F_{1,17}$ = 5·004, P<0·05).

Two- and 3-year-old smolts formed the most important age groups in the returning 2SW salmon, accounting for 30–75% and 23–60% respectively of the returning salmon. One-year-old smolts accounted for between 0·3% and 7·7% of the returning salmon, while 4-year-old smolts formed 0·2–7·8% (Figure 5). The mean smolt age of these fish for the smolt years 1964–82 was 2·34 ± 0·004 years, and annual means ranged from 2·18 ± 0·02 in 1975 to 2·75 ± 0·03 years in 1981 (Figure 3). Over the total period, there was no significant change in mean smolt age ($F_{1,15}$ = 2·490, P>0·1) but, as with the 1SW salmon, smolt age increased from the 1979 smolt year onwards.

Over the period 1964–78, there was a significant

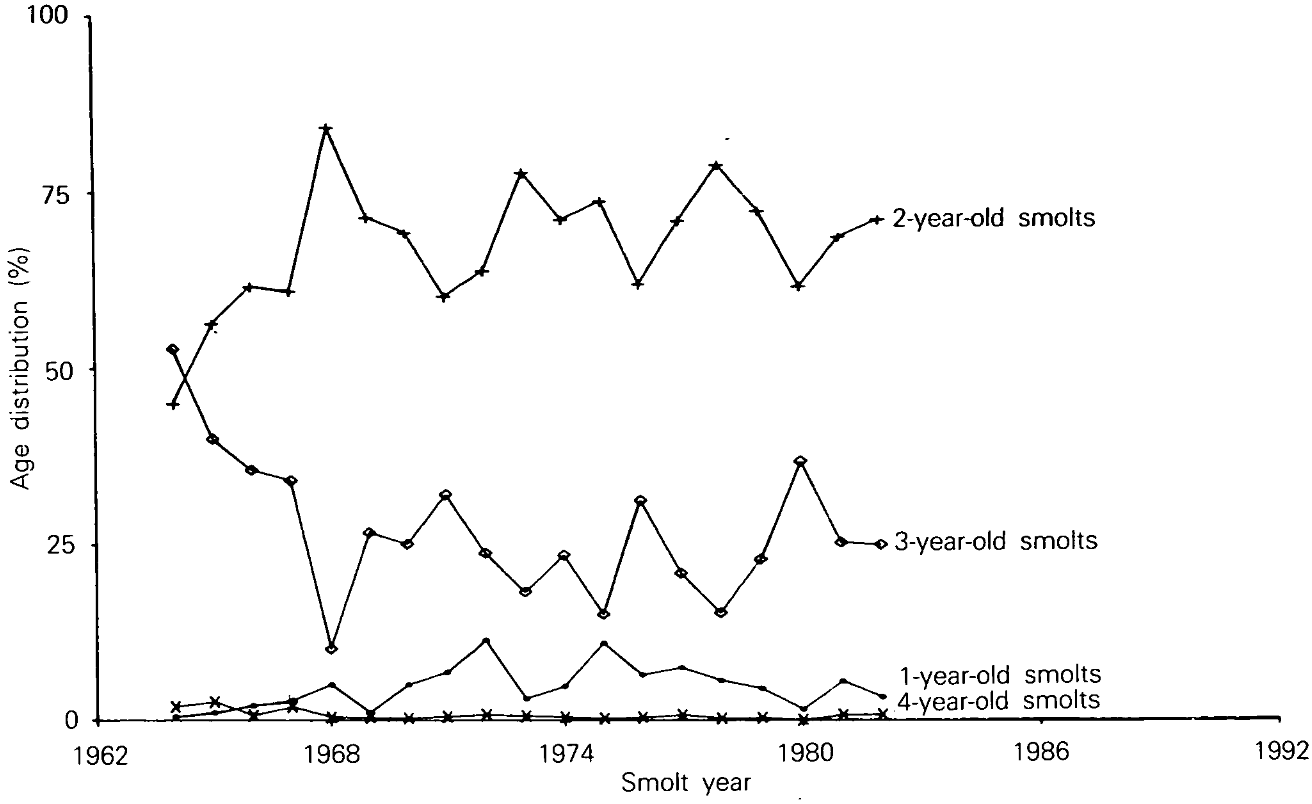

Figure 4. Smolt age distribution (%) of salmon returning to the River North Esk after one sea-winter

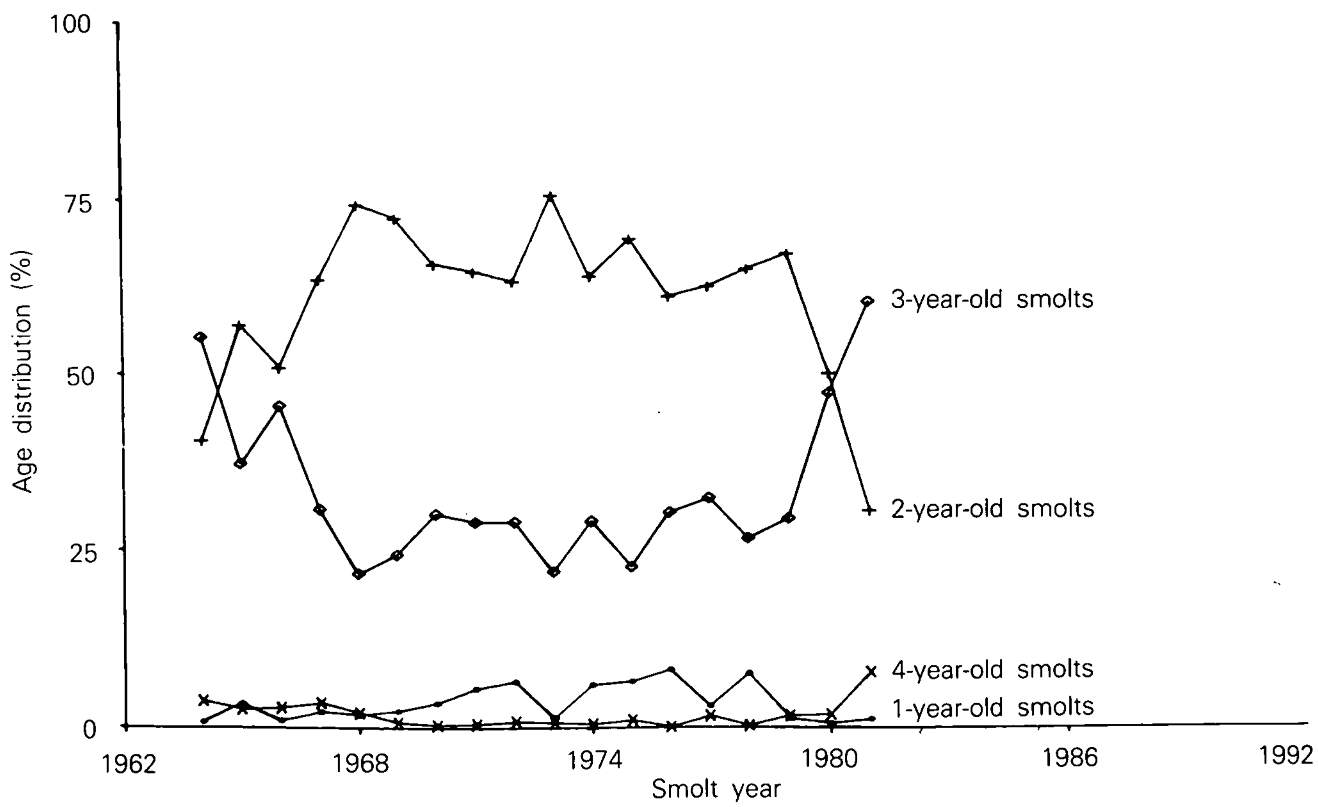

Figure 5. Smolt age distribution (%) of salmon returning to the River North Esk after 2 sea-winters

decrease in smolt age ($F_{1,13}$ = 14·115, P<0·005) and, in the latter part of the series, smolt age increased ($F_{1,2}$ = 95·569, P<0·05).

When the mean smolt ages of the smolts and returning 1SW and 2SW salmon were compared, it was found that the mean age of the emigrating smolts (2·29 ± 0·003 years) was significantly older (P<0·001) than the mean smolt age of the returning 1SW salmon (2·24 ± 0·004) and significantly younger (P<0·001) than that of the returning 2SW salmon. The mean smolt age of the 1SW salmon was significantly younger than that of the 2SW salmon (P<0·001). However, within the time series studied, there were individual years when this relationship did not hold; in the adults returning from the 1965 and 1969 smolt years, the mean smolt ages of the 1SW salmon each year were significantly older than those of the corresponding 2SW salmon (P<0·001).

An analysis of the monthly mean smolt ages of returning 1SW salmon showed that mean smolt age decreased between June and August each year (June>July, P<0·05; July>August, P<0·01). Similarly, in the 2SW salmon, the mean smolt age decreased between February and August, salmon returning in successive months having younger mean smolt ages (February>March, P<0·01; March>April, P<0·01; April>May, P<0·05; May>June, P<0·05; June>July, P<0·01; July>August, P<0·01).

The annual mean length of the smolts emigrating from the North Esk ranged between 12·18 ± 0·03 cm in 1979 and 13·52 ± 0·03 cm in 1967 (Figure 6). Mean smolt length decreased over the period 1964–84 ($F_{1,19}$ = 6·372, P<0·025).

The timing of the smolt emigration varied from year to year. The 5–day period which included the day by which 50% of the smolts had migrated ranged between 1–5 May in 1967 and 26–30 May in 1968. The first smolts were usually caught in the first week of April and continued until the end of June. In 1976–79 and again in 1982–84, occasional smolts were still being caught in mid-July. The annual variation in the timing of migration is likely to be largely attributable to annual variations in river levels and water temperature in April and May.

The proportion of the total returns of 1SW and 2SW salmon which returned as 1SW salmon ranged between 32·5% from the 1974 smolt year and 75·6% from the 1968 smolt year. There was a significant negative relationship (Figure 7) between the mean smolt age of 1SW salmon and the percentage of adults which returned as 1SW salmon ($F_{1,15}$ = 5·777, P<0·05), suggesting that there was a tendency for younger smolts to return as grilse rather than salmon. However, data from the smolt years 1974 and 1979 did not fit the overall pattern; in these years, a low mean smolt age coincided with a low percentage of grilse in the returning adults. There was no significant relationship between the mean smolt age of 2SW salmon and the proportion of adults which returned after 2 sea-winters, however.

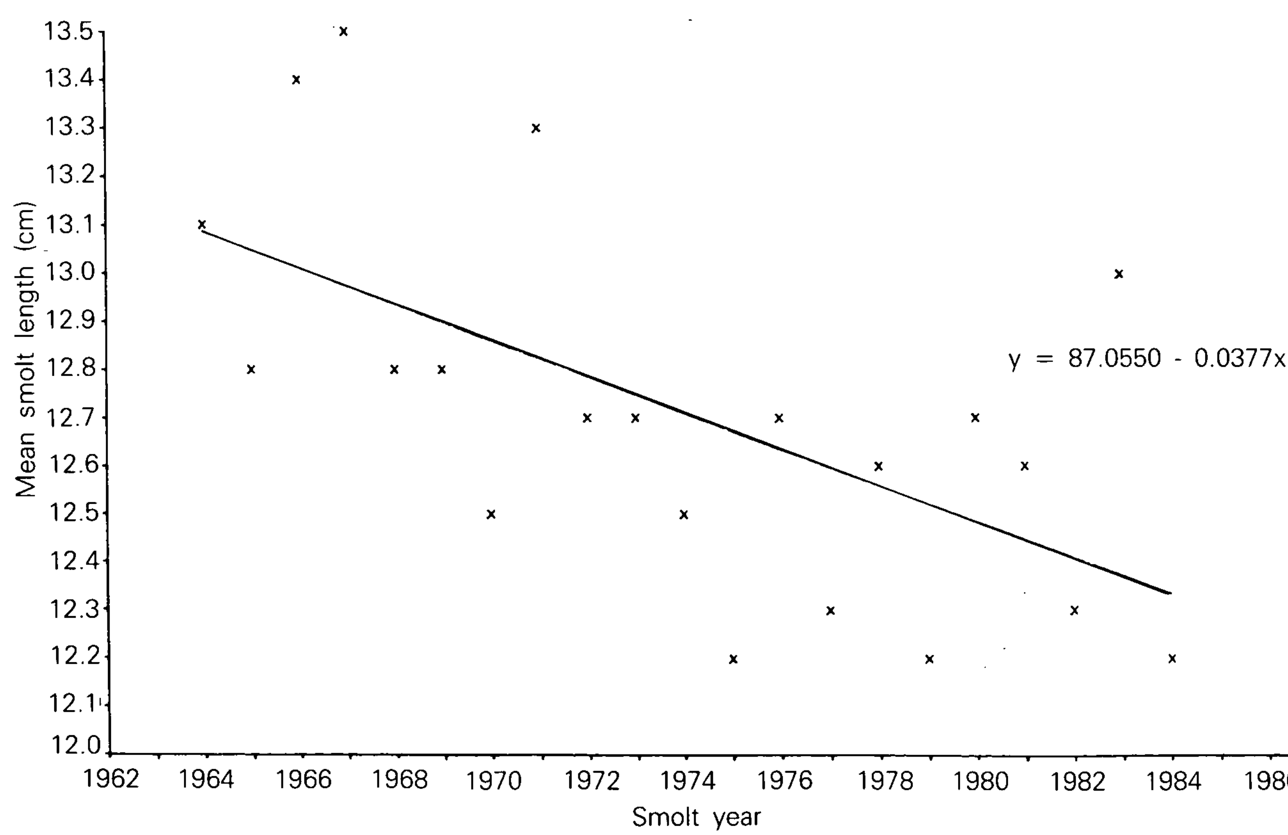

Figure 6. Annual mean lengths of smolts emigrating from the River North Esk in 1964–84

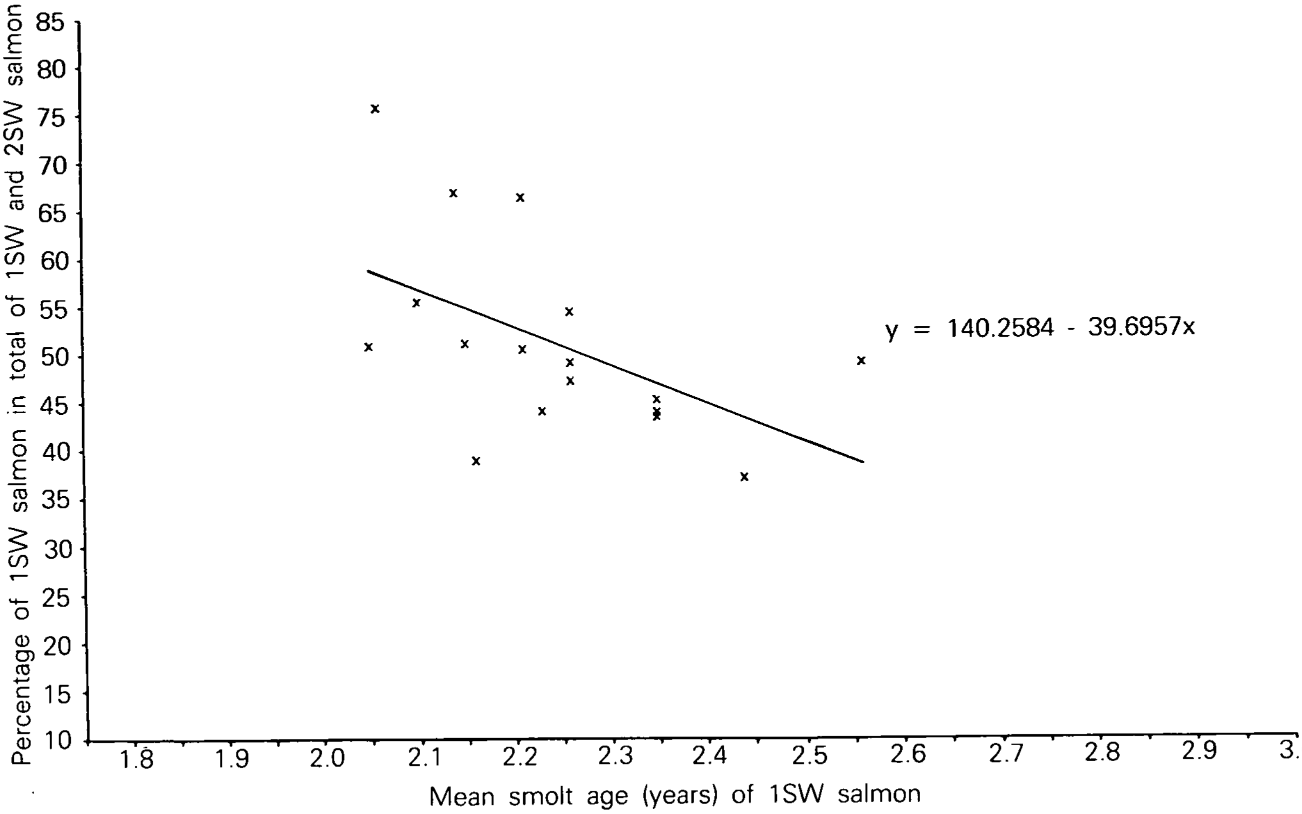

Figure 7. Relationship between mean smolt age of 1SW salmon and the proportion of 1SW and 2SW salmon returning after one sea-winter

In the years 1981, 1982, 1983 and 1984, some 23%, 33%, 41% and 44% respectively of the total number of fish which entered the North Esk, including net and rod catches in the lower reaches, did so after the end of the net fishing season (Figure 8).

4 Discussion

Using data from the North Esk, Shearer (1984b) showed that there was a relationship between both sea age and smolt age and the calendar date of return of adults. The older sea age groups tend to return earlier in the year, ie MSW salmon are present in catches from February onwards, while 1SW salmon are rarely caught in any numbers before May. The older smolt age groups in any particular sea age group tend to return earlier in the run. These findings are supported by the results of tests comparing the monthly mean smolt ages of returning 1SW and 2SW salmon. These ages were found to decrease throughout the year.

There may have been a slight decrease in the mean age of salmon smolts over the years, although there was so much fluctuation between years that no significant decrease could be demonstrated from the smolt samples. The mean smolt ages of the returning adults have also tended to decrease, but the mean smolt age of fish returning after 2 sea-winters was significantly older than that of grilse. However, the fish returning from the 1965 and 1969 smolt years did not fit this pattern, the mean smolt age of the 1SW salmon being significantly older than that of the 2SW salmon in these years.

In general, in those years when the majority of returning adults from a particular smolt year came back after one winter in the sea, the smolt age of these returning grilse was low but, in the 1974 and 1979 smolt years, low smolt ages were associated with low percentage returns as grilse. The reason for these anomalous results is not clear. There may be a connection with the mid-1970s salinity anomaly in the eastern North Atlantic (Martin *et al.* 1984). These authors found no statistically significant correlation between the salinity data and Scottish grilse catches, but, as in some years large numbers of 1SW salmon (grilse) are misrecorded as MSW salmon (salmon) because of their large size, the effects of this 'grilse error' may mean that a substantial proportion of the 'salmon' catches, which were correlated, were, in fact, grilse. In another analysis of the possible effects of environmental factors, Martin and Mitchell (1985) suggested that the sub-arctic sea temperature may have a marked influence on whether a fish returns as a grilse or as a salmon.

All 3 data sets, the smolts, 1SW and 2SW salmon, show increasing smolt ages in the late 1970s. There was no obvious change in smolt length during this period, but the timing of the smolt migration to sea was rather later than in earlier years. Shearer (1984a) showed that the sea mortality in North Esk salmon in

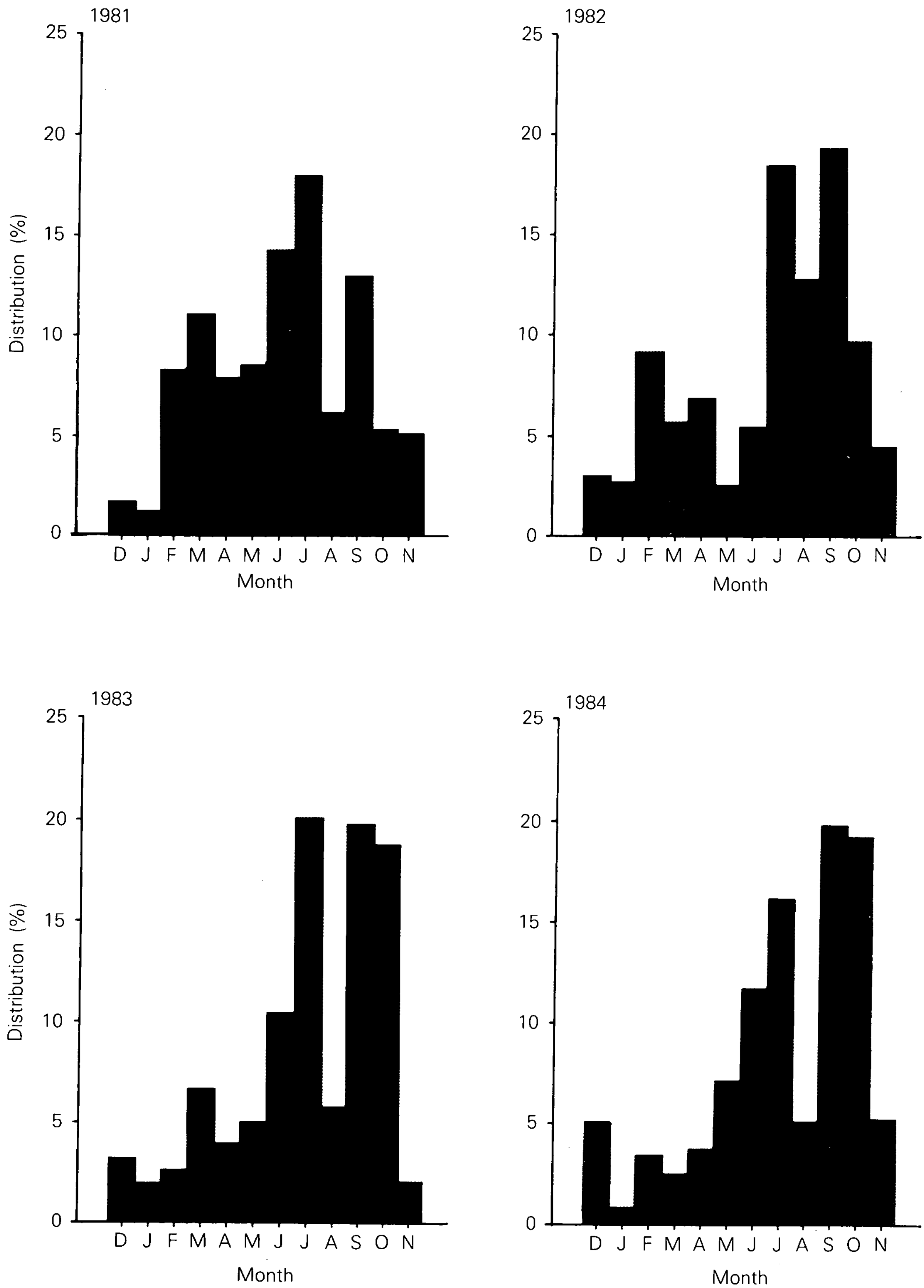

Figure 8. Monthly distribution (%) of salmon ascending the lower North Esk including fish caught by net and rod and fish crossing the fish counter at Logie

the late 1970s was among the highest in the time series he examined, starting in the early 1960s. Contrary to the earlier data, the older smolt ages recorded in the late 1970s did not result in increased MSW salmon runs as the adults derived from these smolts were largely grilse, although the effect has been an increase in the grilse: salmon ratio rather than an absolute increase in grilse numbers. It may be, therefore, that, rather than salmon returning at an earlier sea age, the fish which would have returned as MSW salmon are being removed from the population either by natural or fishing mortality.

The data resulting from the North Esk investigations can only apply specifically to the North Esk, but, if similar biological changes have also occurred elsewhere, the changes in salmon runs apparent in the salmon catch statistics (Shearer 1986) may be related to biological changes within salmon populations resulting from selective exploitation on the older smolt age groups or the adults derived from them. Substantial numbers of salmon and grilse may now be entering fresh water after the end of the netting season and may not be available to the rods for long enough for this gear to take advantage of their presence; recent studies undertaken on the River Spey have indicated this (Shearer, pers. comm.). The declining catches in recent years may not signify declining stocks, except within fishing seasons, and only then where effort has remained constant or increased. Having said this, the pressures on salmon are great and legion, and there is no room for complacency. There is a definite need for rational management of stocks in order to protect those stock components which appear to be in greatest danger, such as the spring salmon run, and those rivers supporting small populations of salmon which may be less able to 'absorb' the effects of these pressures.

5 Acknowledgements

I should like to express my gratitude to colleagues in both the Freshwater Fisheries Field Station, Montrose, and the Marine Laboratory, Aberdeen, for their help in the abstraction and examination of the data upon which this paper is based.

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Aspects of open sea exploitation of Atlantic salmon and the problems of assessing effects on Scottish home water stocks

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1 *Introduction*

This paper describes the main open sea fisheries which could affect Scottish home water stocks. It also discusses problems in assessing the impact of these open sea fisheries.

Until about 1959, the utilization of Scottish salmon resources was almost entirely a domestic matter in which privately owned or leased net and rod fisheries, operating within a framework of District Salmon Fishery Boards, exploited the returning fish at rates which experience suggested were sustainable. Long- and short-term variation in the composition of the returning populations and in the timing of the runs then seemed to be explicable mainly in terms of environmental influence (George 1982; Martin & Mitchell 1985). However, by the early 1960s, a number of rapidly expanding interception fisheries were established outwith Scottish waters, and this paper describes how salmon biologists attempt to estimate their short-term effects on home water stocks.

2 *The open sea exploitation of Atlantic salmon*

Strictly speaking, an interception fishery for a homing species is any fishery which takes place before the returning fish are fully separated into their respective spawning stocks. All Scottish fixed engine and some net and coble salmon fisheries would fit this definition. However, in this paper, coverage is restricted to major salmon fisheries outwith Scottish home waters but which include fish of Scottish origin in their catches. Of these fisheries, perhaps the best known is the pelagic net fishery at west Greenland.

2.1 The pelagic net fishery at west Greenland

Salmon were reported from the coastal waters of west Greenland as early as 1935 and 1936 (Jensen 1939, 1948), but serious exploitation dates from 1959 (Christensen & Lear 1980) when local Greenland fishermen began setting fixed gill (hang) nets for salmon within the fjords and around rocks and sea stacks. By the mid-1960s, an autumn (July–November) inshore hang net fishery extended from Julianehåb (60° 00′N) to Disko (70° 00′N), with occasional catches being taken at Upernivik (72° 45′N) and Angmagssalik on the south-east coast. In 1965, Faroese and Norwegian fishermen introduced offshore fishing with free-floating drift nets, and soon they were joined by fishermen from Greenland and Denmark. Like the hang net fishery, the offshore fishing with drift nets expanded rapidly. By 1979, it was also being practised over the whole of the west coast from Julianehåb to Disko up to a distance of 40 nautical miles (73 km) offshore.

Most of the drift nets now in use are made of monofilament nylon, but multifilament nylon nets are also becoming popular. Both types are normally made up in lengths of about 33 × 5 m. The top of each net is supported by floats or a buoyant rope, and a combined sinking and hauling rope is attached by strops to the foot rope. Nets are fished mainly in fleets of 100 (Christensen & Lear 1980). They are usually shot about sunset and, although hauling often begins before sunrise, it may not be completed until well into the following day.

Reported hang net catches at west Greenland first exceeded 100 tonnes (t) in 1961 (Table 1). By 1964, catches had reached 1539 t and, with the introduction of drift nets and the participation of Faroese and Scandinavian fishermen, catches increased further so that by 1971 the catch had risen to 2689 t. Fishing by non-Greenlandic vessels was phased out between 1972 and 1975, but the total catch remained around 2000 t until 1976, when a total allowable catch (TAC) of 1190 t was set. Since 1980, small adjustments in mesh size have been made (before 1980, some fishermen were using nets with a stretched mesh size as small as 130 mm; the current agreed size is 140 mm) in an attempt to equalize the exploitation rates in the fishery on salmon originating from Europe and on the slightly smaller fish originating in North America. Between 1981 and 1983, the TAC was altered to 1270 t to take account of small changes in the opening date of the fishery and to enable an equivalent number of fish to be caught later in their growth cycle. The new TAC was taken only in 1981. The 1983 catch (310 t) represented less than one quarter of the TAC, and in 1984 the TAC was reduced to 870 t. Preliminary reports suggest that the 1984 catch was only 297 t.

Apart from a small number of fish of Greenlandic origin, all salmon taken at west Greenland had spent one (90%) or more winters at sea. Females outnumbered males in a ratio of 3:1.

2.2 The long-line fishery at Faroe and in the northern Norwegian Sea

The current pelagic long-line fishery at Faroe dates from 1968. However, because northern Faroese waters are part of the Norwegian Sea, the Faroese fishery can be regarded as the southern component of a drift

Table 1. Nominal salmon catches at west Greenland, 1960–83 (tonnes round fresh weight) (source: Anon 1984)

Year	Origin of foreign fishermen Norway	Faroes	Sweden	Denmark	Gill net and drift net Greenland[4]	Total	Total allowable catch (TAC)
1960	0	0	0	0	60	60	
1961	0	0	0	0	127	127	
1962	0	0	0	0	244	244	
1963	0	0	0	0	466	466	
1964	0	0	0	0	1539	1539	
1965	[1]	36	0	0	825	861	
1966	32	87	0	0	1251	1370	
1967	78	155	0	85	1283	1601	
1968	138	134	4	272	579	1127	
1969	250	215	30	355	1360(385)[3]	2210	
1970	270	259	8	358	1244	2146[2]	
1971	340	255	0	645	1449	2689	
1972	158	144	0	401	1410	2113	
1973	200	171	0	385	1585	2341	
1974	140	110	0	505	1162	1917	
1975	217	260	0	382	1171	2030	
1976	0	0	0	0	1175	1175	1190
1977	0	0	0	0	1420	1420	1190
1978	0	0	0	0	984	984	1190
1979	0	0	0	0	1395	1395	1190
1980	0	0	0	0	1194	1194	1190
1981	0	0	0	0	1264	1264	1265[4]
1982	0	0	0	0	1077	1077	1253[4]
1983	0	0	0	0	310	310	1190[4]
1984	0	0	0	0	297	297	870

[1] Figures not available, but catch is known to be less than the Faroese catch
[2] Including 7 t caught on long-line by one of 2 Greenland vessels in the Labrador Sea early in 1970
[3] Up to 1968 gill net only, after 1968 gill net and drift net. The figures in brackets for the 1969 catch are an estimate of the minimum drift net catch
[4] TAC corresponding to specific opening dates of the fishery
Factor used for converting landed catch to round fresh weight in fishery by Greenland vessels = 1·11. Factor for Norwegian, Danish and Faroese drift net vessels = 1·10

net fishery which began in the early 1960s. Pelagic long-line techniques were introduced in 1966 by Danish vessels and a big international fishery developed. Landings peaked at 946 t in 1970, but subsequently the introduction of closed areas and the banning of long-line fishing for salmon by Norway restricted landings to one quarter or half of this figure. From 1976, only Danish vessels took part. This northern fishery is now closed under the terms of the North Atlantic Salmon Convention. In 1983, its last year of operation, landings were 383 t.

The Faroese fishery followed experimental long-line fishing cruises around these islands by the research vessel 'Jens Chn Svabo' in April 1968 and 1969 (Mills & Smart 1982). Early catches were dominated by small, young sea age fish, some in poor condition, but fishing later in the season and further north produced better results. The current fishery is centred on an area some 100 nautical miles (183 km) north of the islands, but may extend as far as the northern edge of the Faroese 200 mile (366 km) limit. Since 1979, the season has run from October to June.

The long-lines used in the fishery are made up from 10 'pins' of 80 size 3/0 Mustad hooks, baited with sprats and tied to 3.6 m monofilament snoods (Mills & Smart 1982). As in the case of the Greenland drift net fishery, catches tend to be best at low light levels, and especially at dawn and dusk.

Although the fishery began in 1968, it took several seasons to develop. Catches did not exceed 100 t until 2 years after the Faroese 200 mile Exclusive Economic Zone (EEZ) was established in 1977. The participation of Danish vessels (from 1978 to 1983), an increase in the number of Faroese vessels from 9 in 1977 to 44 in 1981, the extension of the fishing season, and the northward displacement of the fishery all contributed to the increased catches (Shearer 1984) (Table 2). By 1981, catches were estimated to be about 1000 t. From 1982, the Faroese government agreed to a voluntary quota system with a TAC of 750 t in 1982, decreasing to 625 t (25 boats each with a quota of 25 t) in 1983. Before the fishery moved to the northern sector of the Faroese EEZ, the catch consisted mainly of potential grilse (1 sea-winter fish) but in 1981, 1982 and 1983 mainly of multi sea-winter fish. For example, in 1981–82 and 1982–83, *c* 80% of the catch of virgin fish were 2SW. Samples of catches in 1981–82 and 1982–83 showed 84% and 71% to be female fish. In both seasons, catch rates and the proportion of female fish increased with latitude (Anon 1984).

Table 2. Reported nominal catches by boats from Denmark and the Faroe islands in the Faroese area long-line fishery, 1968–83 (tonnes round fresh weight, converted from gutted weight with a factor 1·11) (source: Anon 1984)

	Denmark		Faroes		
Year	Number of vessels	Catch	Number of vessels	Catch	Total long-line catch
1968	0	0	2	5*	5
1969	0	0	4	7	7
1970	0	0	5	12*	12
1971	0	0	0	0	0
1972	0	0	2	9	9
1973	0	0	5	28	28
1974	0	0	5	20	20
1975	0	0	6	28	28
1976	0	0	9	40	40
1977	0	0	9	40	40
1978	2	14	8	37	51
1979	2	75	7	119	194
1980	6	150	22	568	718
1981	6	100	38	1025*	1125
1982	6	74	31	606	680
1983	6	62	25	678	740

* A small part of the catch was taken more than 200 nautical miles (366 km) from the Faroese baseline

2.3 Other interception fisheries

The drift net fishery to the west of Ireland is also known to intercept some Scottish fish (mainly grilse). A steep rise in catching power followed the introduction of monofilament netting materials in the 1960s, so much so that drift netting now makes the largest single contribution to the Irish salmon catch. Because the statistics of this fishery are unreliable, and there is also no basis for dividing the catch between rivers of origin, the impact of this fishery on home water stocks cannot be assessed.

Similarly, the J-net and hang net fishery which has operated for over a century off the coast of north-east England was transformed in 1967 by the introduction of monofilament drift nets (Potter & Swain 1982). The consequent large escalation in effective fishing power has been only partly controlled by the introduction of a system of licensing by the Northumbrian and Yorkshire Water Authorities. Recorded landings in 1983 were *c* 226 t, and have been dominated throughout by grilse and summer salmon.

3 *Assessment principles*

Up to a point, the problems of identifying the origin of the fish at risk and assessing the yield of the new open sea interception fisheries were of a kind familiar to marine fisheries science with its well-developed theories of fishing. This similarity was reflected in the composition of the ICES/ICNAF Joint Working Party on North Atlantic Salmon, which first met in 1966 (Parrish & Horsted 1980) and which included a number of prominent population biologists experienced in sea fishery problems.

Hitherto, estimation of the effects of exploiting fish populations in the Atlantic had been geared to variants of 3 main life history strategies.

i. Multiple-spawning fish in which sexual maturation takes place early in the growth cycle.

ii. Multiple-spawning fish in which sexual maturation takes place late in the growth cycle.

iii. Fish which spawn at the end of the growth cycle and then die.

Many demersal fishes follow strategy (i). The individual weight of such fish may increase by as much as an order of magnitude (= × 10) in the years after they are first capable of breeding (Cushing 1980). Typically, these are highly fecund species in which the numbers of fish in different year classes may vary by as much as 2 orders of magnitude, often apparently independently of the size of the parent stock.

The rational management of many demersal fisheries has, therefore, to be aimed at reconciling the growth in weight of individual fish and the natural loss in numbers as the fish grow older. Ideally, this reconciliation is achieved by controlling the rate and pattern (the distribution of fishing mortality with age) of exploitation in such a way that yield per recruit to the fished stock is maximized. In practice, this ideal is rarely realized and high fishing pressure in combination with too low an age at first capture can lead to a state of 'growth overfishing'. Recruitment may not be endangered, but total yield is not maximized because too many fish are being caught too early in their growth cycle.

By contrast, in many pelagic fishes, sexual maturation takes place rather late in the growth cycle. A rate and pattern of exploitation appropriate to maximizing the yield per recruit may so reduce the size of the spawning stock that the supply of young fish in the next generation may be limited by egg deposition. A state of 'recruitment overfishing' is then said to exist, and unless firm management action is taken, the collapse of the stock may follow.

Finally, class (iii) includes marine organisms which grow rapidly to sexual maturity and then die. Many cephalopods and some pelagic fishes follow variants of this life history strategy. The Atlantic salmon approaches it in that some 95% die after spawning. Maximization of total yield of this kind of fish depends almost entirely on the rational management of recruitment. In anadromous populations of salmon, the situation is complicated by variation in age at sexual maturity, associated with both genotype and environment, in both the fresh (male) and sea water (both sexes) phases. However, as the home water fisheries for salmon by nets and rods are mainly on virgin adult fish returning at the end of sea feeding, the traditional harvest is of fish at maximum weight. The rate of exploitation is limited only by the need to leave adequate numbers of spawners for each component of the fished population.

With the development of high seas fisheries, the possibility of growth overfishing (ie catching too high a proportion of young fish) of salmon arises for the first time and, because high seas fisheries take place before the separation of homing units of fish, specific spawning stock components could suffer recruitment overfishing (Thorpe & Mitchell 1981). In this connection, the dominance of large females in the Greenland and Faroese catches gives particular cause for concern.

4 Attempts at assessment

Attempts to estimate the effects of the high seas fisheries began in 1966 with the setting up of an ICES/ICNAF Joint Working Party on North Atlantic Salmon, chaired by J A Gulland. The task of this Working Party and its successor, the ICES Working Group on North Atlantic Salmon, was to monitor and assess the west Greenland interception fishery and later those in the northern Norwegian Sea and off the Faroe islands.

The problem at west Greenland was stated originally as follows (Anon 1967).

> 'The effect of the Greenland fishery can be considered in 2 parts: first, the effect on the numbers and weight of fish returning to, and caught in home waters, and secondly the effects on the numbers and composition of the spawning stock and hence on the subsequent production of smolts.
> The first part, the effect on the numbers and weight of fish returning to home waters and the catches there, will depend on,
> (a) the proportion of the original population that visits Greenland,
> (b) the proportion of those that are caught at Greenland,
> (c) the proportion of those fish which avoid capture at Greenland which survive to return to home waters,
> (d) the growth of the fish between the times of the Greenland and home water fisheries,
> (e) the proportion of the returning fish caught in home waters.'

It was realized from the beginning that, in the absence of comprehensive data on rivers of origin, only the first part of the problem could be tackled for any of the international open sea fisheries and further that, as home water exploitation was a matter for states of origin, assessment could be based only on short-term effects on the stocks available for exploitation in home waters.

4.1 Home water origins

Although comprehensive data on rivers of origin have yet to be obtained for any of the open sea interception fisheries, it has sometimes been possible to estimate home water origins by area. Tagging experiments have shown that more than 95% of the fish taken in the Northumberland drift net fishery were en route to Scottish east coast Fishery Districts, from the River Tweed to the River Bervie (Potter & Swain 1982). Similarly, tagging results suggest that the fish taken in the former international fishery in the northern Norwegian Sea were primarily of Norwegian origin, with smaller contributions from other Scandinavian countries and the USSR (Meister 1983).

For the west Greenland fishery, which, apart from a few fish of local origin, is remote from rivers of origin, establishing home water contributions by area was far less straightforward. Tagging experiments were attempted both at the site of the fishery (Horsted 1980; Møller Jensen 1980a) and in home waters (Møller Jensen 1980b; Ruggles & Ritter 1980; Swain 1980). Despite a series of small-scale experiments in 1965–71 and a big effort in 1972 involving 5 research vessels and 8 commercial drift netters, the numbers of fish tagged (2293 in 1965–71 and 2364 in 1972) were too low to estimate home water origins quantitatively or the size of the feeding population at west Greenland. Post-tagging mortality and local differences in reporting rate were the principal reasons for low apparent recapture rates both at Greenland and in home waters. In the 1972 experiment, only 164 tagged fish were recorded at west Greenland, 12 in North America and 44 in Europe. This and the earlier experiments were valuable, however, for the proof they provided that at least some of the fish feeding at west Greenland would afterwards return to rivers on both sides of the Atlantic.

Relatively few smolts tagged in home waters were subsequently recorded (Table 3). However, they also provided evidence (Møller Jensen 1980b) that fish from both Europe and North America were contributing to the fishery in west Greenland and that early-running MSW fish of Scottish origin may make the largest single contribution to the European component, followed, not necessarily in order, by fish from the rest of the United Kingdom, France and Ireland.

An attempt to use the occurrence of parasites as clues to the origin of salmon at west Greenland failed (Pippy 1980), but Child (1980) and Payne (1980) were able to show that serum transferrin polymorphism could be used as a guide to continent of origin. So far, the most straightforward method of determining the continent of origin of fish caught at west Greenland, and the method adopted by successive ICES Working Groups, has been discriminant analysis of scale characters (Lear & Sandeman 1980). The method is ultimately based on differences in the growth characteristics of fish from each continent. Experience has shown that the method is generally reliable, subject to periodic updating of home water reference standards, and that,

Table 3. Recaptures at west Greenland in 1972 by tagging vessels (TV) and other vessels (OV) of salmon tagged in countries outside Greenland (source: Møller Jensen 1980b)

Tagging country	Tagged as smolts: Before 1971, Recaptured TV	Before 1971, Recaptured OV	In 1971, Recaptured TV	In 1971, Recaptured OV	Total recaptured	Tagged as adult: Recaptured TV	Recaptured OV
Canada	6	37	40	192	275	2	9
USA	4	15	12	70	101	0	3
North America	10	52	52	262	376	2	12
Scotland	2	19[1]	29	112[2]	162	0	0
England	0	2	8	23	33	0	0
France	0	4	1	7	12	0	0
Norway	0	1	1	3	5	0	0
Sweden	0	1	1	2	4	0	0
Iceland	0	0	0	2	2	0	0
Ireland	0	1	0	0	1	0	0
Faroes	0	0	0	0	0	0	1
Europe	2	28[1]	40	149[2]	219	0	1
Total (N America & Europe)	12	80	92	411	595	2	13

[1]2 tags included
[2]1 tag included
(3 recaptures are included in this Table, but not in the estimation of the reporting rate and in the analysis of the distribution)

over the history of the fishery, the origin of the Greenland catch is almost evenly divided (50–60% European) between the European and North American continents.

Except for small numbers of Canadian fish taken in the northern part of the fishery, the Faroese catch is entirely derived from European rivers (Anon 1984). It has not yet been possible to specify broad areas of origin quantitatively, but feasibility studies for major tagging experiments are in progress and discriminant analysis of scale characters shows some promise. Results to date suggest that Scottish fish contributed to the grilse-dominated fishery around the Faroe islands and latterly to the northern fishery which is largely on potential MSW fish. Other European countries known, from home water tagging experiments, to have contributed at some time include England and Wales, Ireland, France, Denmark, Iceland, Sweden and Norway. Sampling in the fishery suggests that the total age of the fish, and therefore the likelihood of Norwegian origin, increases with latitude.

4.2 Estimation of total losses to home water stocks

All estimates by ICES of total short-term losses per unit weight (LF) to home water stocks have been based on simple mathematical models of the general form:

$$LF = \frac{WH}{WS} \times e^{-Mt} \times \frac{1}{1-N}$$

where,

WH = mean weight of salmon on return to home water;

WS = mean weight of salmon landed in the fishery;

M = the instantaneous mortality rate per month;

t = time in months between leaving the site of the high seas fishery and arrival in home waters;

N = non-catch fishing mortality expressed as a proportion of the total fishery-induced mortality. This term includes the estimated effects of all unreported fishing and increments to total mortality caused by encounters with fishing gear which do not result in capture.

For most assessments, it is necessary to estimate losses separately (Anon 1981, 1984) for each smolt age class returning to home waters at different ages, so that the expression for total short-term losses becomes:

$$LF = \frac{1}{1-N} \sum_{ij} (WR_{ij} \times PW_i \times PN_{ij} \times S_{ij})$$

where the subscript 'i' refers to sea age classes of salmon taken in the high seas fishery (any discard being treated as a separate sea age class) and the subscript j refers to the sea age classes of the same stocks on their return to home waters. Parameters are then defined as follows:

N = non-catch fishing mortality expressed as a proportion of the total fishery-induced mortality;

WR_{ij} = ratio of the weight of each sea age class in home waters to their mean weight in the high seas catch;

PW_i = proportion by weight of each sea age class relative to the total nominal catch;

PN_{ij} = estimated proportion of the fish of each age class in the fishery returning in the same and subsequent years;

S_{ij} = survival rates of different sea age classes between the high seas fishery and home waters.

All assessments using mathematical models of this kind have been limited by the difficulty of obtaining adequate input data (Anon 1984). Estimating natural mortality rates is a difficulty common to all fish stock assessments, but in salmon it is compounded by the large differences in size between post-smolts and maturing adults. In some assessments, estimates of natural mortality have therefore been based on the hypothesis that its rate varies inversely with total weight for the whole of the marine phase or at least its first year. The application of this hypothesis requires more complete growth data than are commonly available.

It is also difficult to estimate accurately non-catch fishing mortality, and the collection of the weight parameters is impeded by the fact that the high seas populations are not homogeneous and home water destinations, and hence appropriate sampling sites, are not fully known.

The 1984 report of the ICES Working Group on North Atlantic Salmon (Anon 1984) gives a useful summary of the likelihood of error in the separate input parameters for a major assessment (the 1984 assessment of the Faroese fishery) and the relative effect of errors on results. A list of the main possible errors follows.

'(a) Discards
The discarded fish contribute only 2% of the total loss estimate, and the discard rate (5·5%) is thought to be well estimated. Thus, errors in this parameter are expected to have virtually no effect on the assessment. However, any change in the discard rate is likely to be related to a change in the age composition of the catch, which would itself have a greater effect on the result.

(b) Non-catch fishing mortality (N)
This parameter (a nominal value of 0·1 was assumed by the Working Group) has a proportional effect on the total assessment. Thus, if N is assigned a value of 0·15, the estimate of total loss is increased by 6% of the estimated value; and if N is assigned a value of 0·05 the estimate of total loss is decreased by 5%.

(c) Proportion by weight in each sea age class (PW_i)
The estimates of PW_i for the 1982–83 season are based on extensive sampling and are thought to be well estimated. Changes may occur in the age composition of the population in the fishery area in different years. However, even a substantial change from a catch comprising 5·6%, 78·4% and 15·8% of one, 2 and 3 sea-winter fish to one of 30%, 65% and 5% respectively gives only a 5% increase in the assessment result.

(d) Proportion returning in the same year (PN_{ij})
It was suggested that the serum steroid sampling method used to estimate this parameter (at 78%) was more likely to underestimate than overestimate the true value. Using the value of 90% derived from the tagging experiments in the early 1970s reduces the estimated loss by 6%.

(e) Weight ratios (WR_{ij})
There was considerable variation (up to ± 15%) in the values used to give the average weight ratios for each sea age class. In the unlikely event that all values are biased in one direction, the final assessment will be increased or decreased by the same proportion. Errors in the weight parameters for the 2 sea-winter fish will have a disproportionate effect on the assessment.

(f) Survival (S_{ij})
The model previously used to estimate monthly M is based on very limited data and may be inaccurate. A value of 0·01 was assumed for all sea age classes assessed. If M is increased to 0·015, the estimated loss will be decreased by 3%. If M is decreased to 0·005, the estimated loss will be increased by 3%. Alternatively, a 5% additional natural mortality on homing fish, caused by straying or predation in home waters, will decrease the assessment by 5%.'

Subject to the limitations imposed by the estimation of input parameters, current estimates of home water losses for every tonne intercepted are:

i. Northumberland, 1 t;
ii. Greenland 1·29–1·75 t (Europe), 1·47–2·00 t (North America), combined, 1·37–1·85 t;
iii. Faroe, 1·59 t.

The estimate of home water loss for the Northumbrian fishery assumes that no natural mortality takes place between the site of this fishery and those in home waters. This assumption would lead to an overestimate if predation in coastal waters by seals were significant. However, it is likely that this estimate is more than balanced by the further assumption that non-catch fishing mortality can be ignored. The estimates for Greenland and Faroe are those published in the latest report of the ICES Working Group on North Atlantic Salmon (Anon 1984).

It is interesting to speculate on possible interactions between these interception fisheries.

Because of its proximity to Scottish east coast rivers, the Northumbrian catch may include some fish returning from Greenland and Faroe but, because it is primarily a summer fishery, it is likely to intercept a higher proportion of fish returning from Faroe than from Greenland. However, because the Northumbrian fishery contains a high proportion of grilse, much of the catch will be derived from fish which have not passed through either the Greenlandic or Faroese fisheries.

Possible interactions between the Faroese and Greenland fisheries were considered at the 1984 meeting of the ICES Working Group on North Atlantic Salmon. The following points were noted.

'Tagging of salmon at sea close to the Faroes between 1969 and 1975 produced evidence that the Faroese fishery harvested salmon that would otherwise be available to the west Greenland fishery. Three of the 91 recoveries from the 1751 fish tagged in Faroese waters were made at west Greenland. There has been no tagging at sea at the Faroes since 1975.

In recent years, the fishery at the Faroes has moved north where it now harvests more than 90% 2 sea-winter and older fish, of which over 50% will be maturing. The age composition of the present catch at Faroe is older than that of both the catch in earlier years and the fish which were tagged. This change in age composition is attributed to the recent northward movement of the fishery. The age composition of the present Faroese catch resembles that reported for the 1971–73 Danish long-line fishery in the Norwegian Sea situated north of latitude 68°.

On the basis of the differences in maturity status and sea age composition of the catches in the Faroese and Greenland fisheries, the Working Group concluded that the Faroese fishery does not harvest significant numbers of salmon that would otherwise be available subsequently to the west Greenland fishery. It was noted, however, that the Faroese fishery may be harvesting salmon on their return migration from west Greenland to European rivers. Further, the Faroese fishery may be impacting on spawning stocks which contribute to both Faroese and Greenland fisheries.'

Without comprehensive data on home water exploitation rates, it is not possible to say for certain whether current rates and patterns of exploitation in the open sea interception fisheries increase or decrease total salmon yield per recruit in the North Atlantic area. The highest home water losses occur when fish of young sea age are intercepted which would have matured a year later, and the least when older sea age fish are harvested which would have matured and returned to home waters the same year (Anon 1984) (Table 4). However, taking the interception fisheries together, the overall exploitation pattern is clearly biased toward older fish and, as current home water exploitation rates are well below the rate of post-spawning mortality, the net effect of the interception fisheries is likely to increase total salmon yield in weight per recruit for the North Atlantic as a whole.

Note that this does not necessarily imply an increase in total yield. The fisheries at west Greenland and Faroes are heavily biased in favour of large female fish, so it is possible that, for some stock components on both sides of the Atlantic, egg deposition is now limiting recruitment. In attempting to explain the recent low catches in the west Greenland fishery, it was noted (Anon 1984) that 'reduced stock abundance in Canada and reduced abundance of the spring-run component in Scotland' could well have been contributory factors. Other factors were reduced fishing effort and the possible effects of low sea temperatures on availability, natural mortality and maturation.

Throughout this paper, no attempt has been made to assess the effects of interception fishing on total economic yield. Such an assessment has rarely been achieved convincingly for any marine fishery. In the case of salmon, such an analysis would be especially difficult because, in addition to estimating the normal economic parameters, it would also be necessary to

Table 4. Assessment of the relative effects on returns to home water of harvesting salmon at different stages of their migration routes (source: Anon 1984)

Age at catch	Age at home	Weight at home / Weight in fisheries	Adjustment for mortality not due to capture (ie to non-catch fishing mortality) (1/1-N)	Survival	Relative loss
1	1	1·64	1·11	0·97	1·77
1	2	3·19	1·11	0·88	3·12
2	2	1·30	1·11	0·97	1·40
2	3	2·24	1·11	0·88	2·19
3	3	1·30	1·11	0·97	1·29
3	4	1·50	1·11	0·88	1·47

N = non-catch fishing mortality

estimate the numbers of fish in excess of spawning requirements which are required for consistently successful angling. A general lack of good quality data on angling effort is a major impediment to progress in this area.

5 *Conclusion*

Open sea interception fishing has posed new assessment problems for Atlantic salmon biologists. Solutions have been sought within the context of existing theories of fishing. The utility of this approach suffers all the limitations associated with the management of complex mixed stock fisheries, with additional complications created by fishery and environmentally induced changes in a flexible anadromous lifestyle. The ICES Working Group on North Atlantic Salmon has been able to provide useful estimates of short-term losses to home water stocks and has identified some of the deficiencies in data which currently limit their refinement. However, the key biological problem of measuring the long-term effects of interception fishing on specific homing units of fish remains unsolved as, for the time being, must the political problem of quantifying, and ultimately controlling, the effects of open sea interception fishing on Scottish salmon stocks.

6 *Summary*

6.1 This paper describes the main open sea fisheries for Atlantic salmon which may affect Scottish stocks. These fisheries became important from the early 1960s and are off west Greenland, north of the Faroe islands, to the west of Ireland and off north-east England.

6.2 Annual catches in the pelagic net fishery at west Greenland first exceeded 100 t in 1961 and had risen to 2689 t by 1971. A total allowable catch (TAC) of 1190–1270 t applied to the fishery from 1976–83. This figure was reduced to 870 t in 1984. Annual catches in 1983 and 1984 were only 310 and 297 t respectively.

6.3 The Faroese long-line fishery dates from 1968. Annual catches first exceeded 100 t in 1979 and rose to over 1000 t in 1981. A TAC of 750 t was imposed in 1982, reducing to 625 t in 1983. Between 1978 and 1982, Danish vessels also participated in this fishery and (since 1967) in an international fishery further north in the Norwegian Sea. Landings in 1983 (its last year of operation) were 383 t.

6.4 The pelagic net fishery off north-east England became important from 1967, when nylon drift nets were introduced. Recorded landings in 1983 were 226 t. The Irish drift net fishery has a similar history but reliable statistics are lacking.

6.5 The salmon taken off Greenland are all potential MSW fish, with females outnumbering males by 3:1. The Faroese catch at first consisted mainly of grilse, but from 1981 mainly of MSW fish, again mostly females. The Irish and English interception fisheries take mainly grilse and summer salmon.

6.6 With the exception of the north-east English fishery, which is largely (> 95%) based on fish returning to Scottish rivers, the home water origins of the intercepted stocks are known only by broad area. The origin of the Greenland catch is almost evenly divided (50–60% European) between Europe and North America. Tagging results suggest that fish of Scottish origin may make an important contribution to the European component. The Faroese fishery is based almost entirely on European fish. The size of the Scottish component is unknown. The Irish fishery intercepts an unknown proportion of Scottish fish.

6.7 Subject to the stated limitations imposed by the estimation of input parameters, current estimates of short-term home water losses for every tonne intercepted are:

i. Northumberland, 1 t;
ii. Greenland 1·29–1·75 t (Europe), 1·47–2·00 t (North America), combined, 1·37–1·85 t;
iii. Faroe, 1·59 t.

6.8 Because all of the open sea interception fisheries exploit mainly salmon and/or grilse late in their growth cycles, and because home water exploitation rates tend to be low relative to the high (*c* 95%) post-spawning mortality of salmon, the overall effect of open sea exploitation is to increase total yield per recruit for the North Atlantic area as a whole. Other countries than the ones where the fish originated get the gains. However, for some stock components, it is possible that the exploitation prior to the pre-spawning separation of homing units of fish limits recruitment, and therefore total yield.

7 *Acknowledgements*

I am greatly indebted to Dr B B Parrish CBE, General Secretary of the International Council for the Exploration of the Sea, for permission to quote from ICES documents, and to Mr W M Shearer, principal Scottish member of the ICES Working Group on North Atlantic Salmon, for much helpful advice and discussion.

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The exploitation of Atlantic salmon in Scottish home water fisheries in 1952–83

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1 Introduction

This paper estimates exploitation rates of Scottish Atlantic salmon in their native rivers or in nearby home waters. Some fisheries exploit mixed stocks from several rivers (mixed stock fisheries). Other fisheries exploit stocks from only one river (single stock fisheries). The exploitation rates are estimated from recapture rates of fish tagged at 14 places widely distributed on Scottish coasts and rivers. The marking sites on rivers were in the North Esk in 1967–83 and near the mouth of the Spey (1983 only).

Most fixed engine fisheries exploit fish originating from more than one river system and are, therefore, referred to as mixed stock fisheries. On the other hand, net and coble fisheries within estuarial limits tend to exploit a single stock, the stock native to the river in which they operate.

2 Regulations and practices

2.1 Fishing regulations

In addition to an annual close time which, for the majority of nets, extends from the end of August to roughly mid-February, there is a weekly close time from noon on Saturday until 0600 h on the following Monday morning. The rods can normally begin fishing earlier in the year and cease fishing later in the year than the corresponding nets. Depending on the Salmon Fishery District, the rod fishing season begins between 11 January and 25 February, and ends between 30 September and 30 November. The weekly close time for rods is Sunday. Fishing by rod and line is permissible throughout the length of the river including the spawning burns. In most rivers, all legal methods (spinning, fly and bait fishing) are allowed without restriction during the fishing season.

The minimum permissible mesh size of any net used to catch salmon is 178 mm all round when wet, but there is no legal limit to the length and depth.

2.2 Fishing practices

The fishing effort along the coast varies widely as, with one notable exception (Solway Firth), the number of nets which can be fished at a station is not fixed by statute. Most netting stations now limit their fishing effort to the second half of the permissible netting season. Since about 1950, there has been a general reduction both in the number of netting stations fished and the length of the season fished. Net and coble fisheries are not operated in all rivers. The Rivers Don, Deveron, Nairn and Ness are among the exceptions.

3 Materials and methods

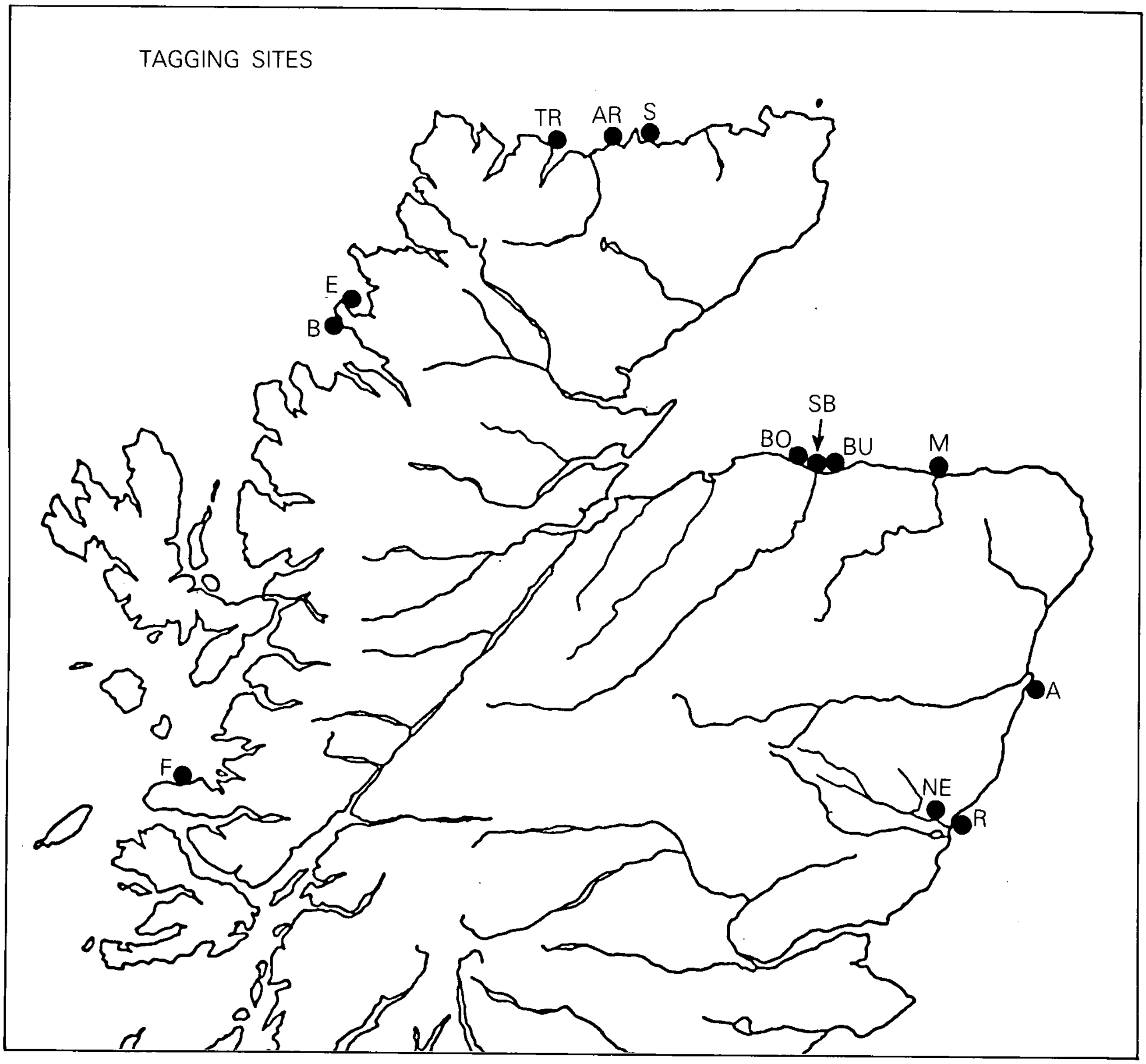
3.1 Material

Between 1952 and 1955 and in 1977–83, fish caught in bag nets at 12 sites (Rockhall, Altens, Macduff, Buckpool, Boar's Head, Strathy, Armadale, Talmine and Rabbit Island, Enard and Badentarbat Bays and Fascadale (Figure 1)) were bought from the fishermen and tagged before release. In addition, between 1976 and 1983, salmon caught in a trap (Kinnaber Mill) in the lower reaches of the North Esk were also tagged. These fish were released downstream from the principal net and coble fishery which operates throughout the fishing season (river conditions permitting) on the river. In 1983, a similar experiment began on the Spey, fish for tagging being obtained from a jumper net operated just outside the river mouth.

At Altens (near the River Dee, Aberdeen), only salmon were tagged. At Rockhall (near the North Esk) in 1954, 1955 and 1978, at Kinnaber Mill trap (N Esk) in 1976–83, at Buckpool and Boar's Head (both near the Spey) in 1983 and at the mouth of the Spey, both salmon and grilse were tagged. At all other sites, only grilse were tagged. This decision was taken on economic grounds (2–3 grilse could be tagged for the price of one salmon). However, earlier results had shown that there was little difference between the overall rates of recapture of these 2 sea age groups when both were tagged at the same time and coastal site. Further experiments in 1983 confirmed this finding.

3.2 Methods

Fish tagged at the coastal sites were taken individually from the net, measured and sexed. A sample of scales was removed from the appropriate area. Two types of tags were used. At Altens in 1952, a Lea's hydrostatic tag was attached by a length of stainless steel wire in front of the dorsal fin of each fish tagged. At Rockhall in 1954, 1955 and 1977, 2 Lea's hydrostatic tags were attached in a similar manner to each fish before it was released. At all other sites, including both Kinnaber Mill trap and the mouth of the Spey, serially numbered yellow or orange plastic Floy tags were inserted just below the dorsal fin by means of a Dennison tagging gun. As the results from previous experiments had indicated that salmon were more susceptible to disease if they were handled soon after they had entered fresh water, great care was taken not to handle the fish when tagging them. Salmon were removed from the trap at Kinnaber Mill by means of a specially designed heavy-duty plastic bag, the mouth



A - Altens
AR - Armadale
B - Badentarbat
BO - Boar's Head
BU - Buckpool
E - Enard Bay
F - Fascadale
M - Macduff
NE - North Esk
R - Rockhall
S - Strathy
SB - Spey Bay
TR - Talmine and Rabbit Island

Figure 1. Sites where grilse and salmon were tagged in 1952–83

of which was held open by a triangular-shaped frame (Figure 2). Once the fish had been coaxed into this bag, the frame was removed and the neck of the bag was held closed. In this way, a quantity of water was retained with the fish as it was lifted from the trap. The fish was then manoeuvred within the bag until its dorsal fin protruded through a slit in the side, and tagging was achieved through this slit. Tagged fish were released into the main river through a plastic pipe running from the trap the full distance to the river. The pipe was kept lubricated by passing water through it. The method adopted for tagging the fish at the mouth of the Spey was similar and again did not involve handling the fish. In this case, the fish were released directly from the net into the sea.

In order to measure tag loss, all fish tagged at Kinnaber Mill trap since 1982 were pan-jetted at the same time as they were tagged, leaving a small blue spot which was easily recognized during normal sampling of the catch in the fish house. Because it was important that the tagged fish were undamaged, they were not

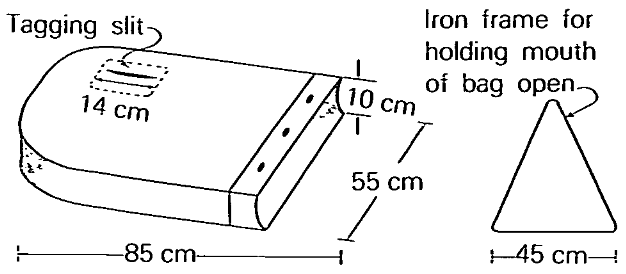


Figure 2. Bag used for holding salmon for tagging

measured, sexed or scaled before release at either site. Furthermore, only fish which showed no external disease or damage were tagged. As the fish caught in bag nets were free swimming in the trap section of the net, a high proportion of the catch at each fishing was suitable for tagging. Apart from the experiments at Altens, Kinnaber Mill and the mouth of the Spey, the period of each experiment was chosen to coincide with maximum fishing effort. No tagging was done at the coastal stations after early August. A minimum of 15 days (the period which had been shown necessary for the bulk of the fish to migrate beyond the netting zone) was allowed to elapse before the end of the netting season.

4 Results

4.1 Recovery of tags

Once the fish had been tagged and released, the success of this experiment depended upon receiving details of all recaptures. Posters were displayed at appropriate sites around the country, netting stations were regularly visited, and random checks for the presence of tagged fish were made on catches in fish houses. In addition, dealers who handled the sale of rod-caught fish were requested to look for tagged fish and to report them. In general, fewer tagged fish were reported by anglers than by netsmen. However, the tagging experiments and the instructions for returning tags were well publicized, and it is not considered that the anglers generally failed to return tags.

4.2 Tag loss

Regular sampling of the net and coble catch from the North Esk has resulted in the recovery of only one (0·1%) fish with a blue spot and no tag. All other fish with a blue spot had a tag *in situ*. In addition, tagged fish were caught after a lapse of several months between tagging and recapture, and a small number of fish were recaptured in the year following that in which they had been tagged with the tag still in place; these fish had spawned in the interval. The conclusion is that tag loss was negligible.

4.3 Tagging

Analysis of the tagging and recapture data showed that there were no statistically significant differences between the recoveries of fish tagged on different days of the week or in different months at the same site in the same year. Therefore, the data have been pooled to provide a single estimate of exploitation rate by each fishing method on tagged fish. Table 1 shows

Table 1. Tagging sites and year of tagging

Area	Tagging sites and year
East coast	Rockhall (1954, 1955, 1977, 1978) Altens (1952)
Moray Firth	Macduff (1978, 1979, 1980, 1981) Buckpool (1981, 1982, 1983) Boar's Head (1982, 1983)
North coast	Strathy and Armadale (1977, 1978, 1979) Talmine and Rabbit Island (1977)
North-west coast	Enard and Badentarbat Bays (1979, 1980, 1981)
West coast	Fascadale (1981, 1982, 1983)

the 5 areas (east, north, north-west and west coasts and Moray Firth) into which the coastal sites were grouped, and the year of tagging. Additional fish were tagged each year from the North Esk trap and from the jumper-net near the mouth of the Spey in 1983.

4.4 Recapture sites

4.4.1 East coast (Figure 3)

Few fish tagged at Kinnaber Mill were recaptured outwith the North Esk system. Of the fish marked at Altens, 30% were caught in the Dee, and 23–43% of the fish tagged at Rockhall in 1954, 1955, 1977 and 1978 were caught in the North and South Esks. From Altens, fish were also caught in the Don and Tay, and from Rockhall also in the Nairn, Spey, Don, Dee, Tay and Tweed.

4.4.2 Moray Firth (Figure 4)

Recaptures from these stations occurred on the coast between Helmsdale and Montrose, and in the Rivers Helmsdale, Conon, Findhorn, Lossie, Spey, Deveron, Ythan, Don, Dee, North and South Esks, Tay, Tweed and Aln (Northumberland). In different years, about 19–44% were caught in the Spey and Deveron, the 2 major salmon-producing rivers nearest to the tagging sites.

4.4.3 North coast (Figure 5)

Recaptures occurred over much wider areas, and on coasts bounded by the River Ayr (west) and River Tay (east) and in the Rivers Laxay, Grimersta and Barvas on Lewis and the Rivers Laxford, Dionard, Hope, Thurso, Berriedale, Shin, Beauly, Spey, Dee, North Esk and Tay on the mainland. In 1977, 1978 and 1979, 40–56% were recaptured in the Naver and Halladale, the 2 major salmon-producing rivers nearest to the tagging sites. Two other fish were caught in Ireland in the same year as that in which they had been tagged.

4.4.4 North-west coast (Figure 6)

Grilse tagged on the north-west coast at Enard and Badentarbat Bays were recaptured on the coast between Ardnamurchan and Aberdeen (including Mull, Skye and Lewis) and in the Rivers Carron, Luing, Balgy, Ewe, Gruinard, Broom, Ullapool, Garvie, Inver, Laxford, Naver, Halladale, Thurso, Shin, Spey, Dee and North

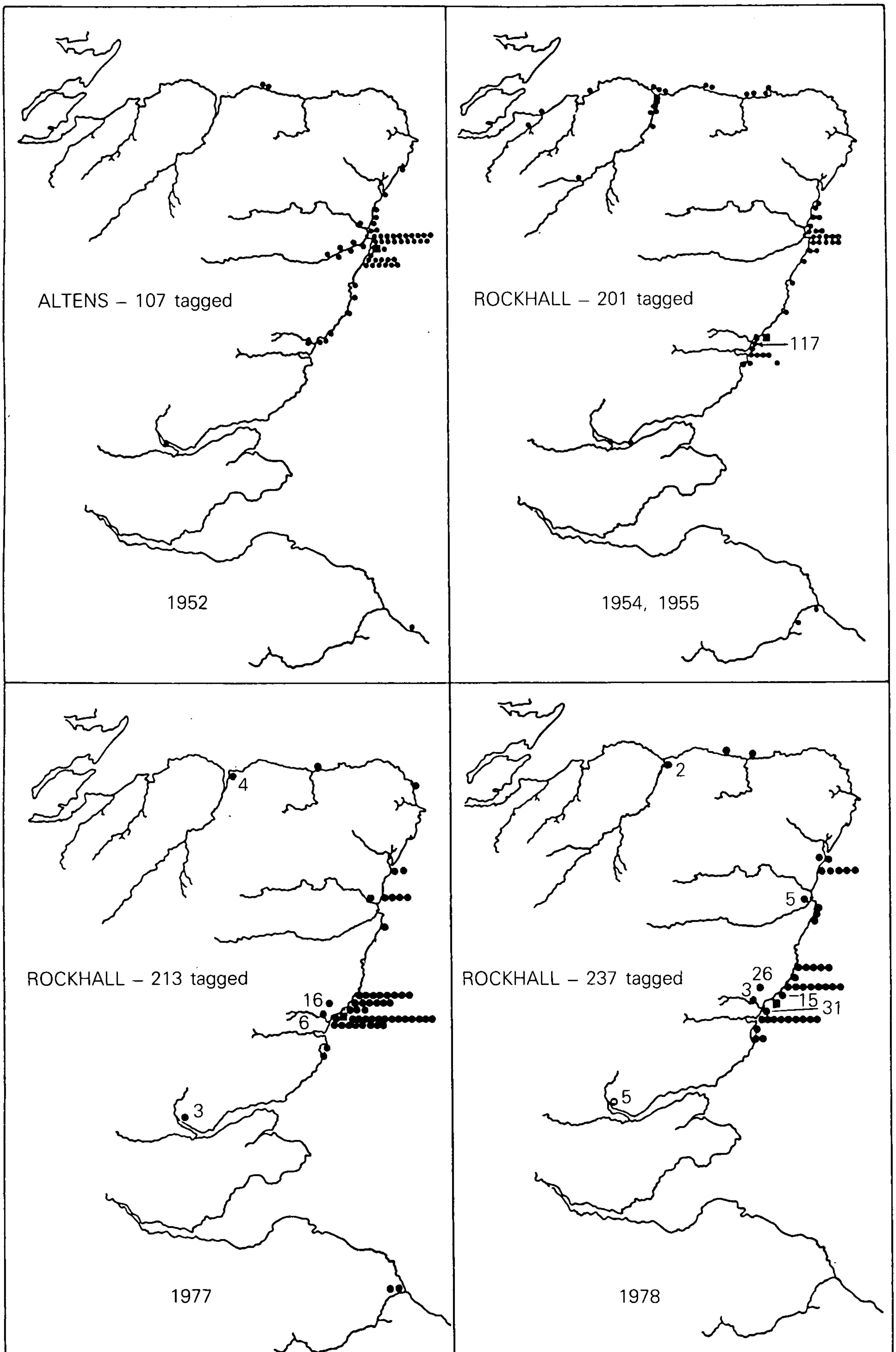


Figure 3. Recapture sites of salmon tagged from coastal nets on the east coast in 1952–83

Esk. In each year, recaptures in fresh water tended to be single fish at each site, so that there was little evidence of stocks from particular rivers making major contributions to this fishery. This finding was different from that at most other sites, where fish from neighbouring rivers featured prominently in the list of recaptures.

4.4.5 West coast (Figure 7)

Fish tagged at Fascadale were recaptured on coasts and rivers between the Solway Firth and Montrose (including, Mull, Arran, Islay and Skye), and in the Rivers Awe, Lochy, Spean, Shiel, Morar, Inverie, Dee (Aberdeenshire) and Tay.

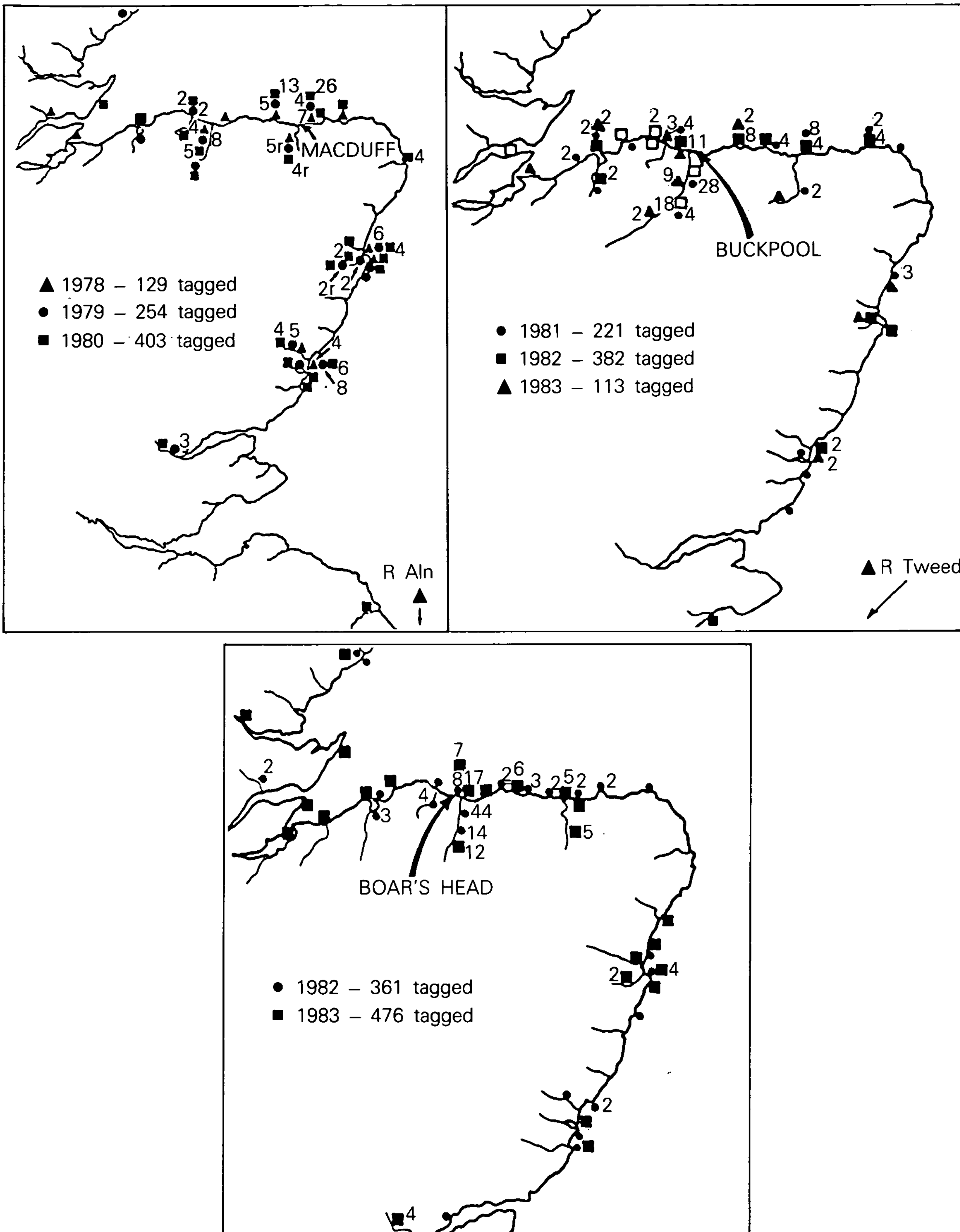


Figure 4. Recapture sites of salmon tagged from coastal nets in the Moray Firth in 1978–83

4.4.6 Kinnaber Mill trap

Most recaptures came from within the River North Esk, the majority from the net and coble fishery some distance above the trap.

4.4.7 Spey (Figure 8)

Eighty per cent of all recaptures were within the Spey Salmon Fishery District and 60% within the River Spey. Others were on the coast between Nairn and Montrose. Tagged fish were also caught in the Kyle of Sutherland, and in the Rivers Alness, Nairn, Findhorn and Cowie.

4.5 Estimated exploitation rates

4.5.1 Mixed stock fisheries

In this context, exploitation rate has been taken to mean the proportion of the assumed available tagged fish which were removed by each of the gears.

Most (*c* 90%) recaptures by nets occurred within 15 days of tagging, and few fish were caught again in the net from which they had been released. From the number of fish tagged in each area and the number of fish subsequently recaptured by commercial nets and rod and line, the rate of exploitation was calculated for each area. The rate was calculated by 2 methods:

A. assuming that all tagged fish were available equally to all fishing methods;
B. assuming that fish caught by fixed engine were unavailable to net and coble and rod and line fisheries, and those caught by fixed engine and net and coble were unavailable to rod and line fishermen.

Exploitation rates calculated using methods A and B for one sea-winter fish and for MSW fish for each year and area of the coast are summarized in Tables 2–5. In each experiment, fish recaptured by methods other than the 3 specified types of gear were deducted from the original number tagged.

Except on the north coast, the fixed engine fisheries usually caught a significantly higher proportion ($P<0{\cdot}001$) of the grilse tagged than the net and coble fisheries (Table 2). Irrespective of the method used to calculate the exploitation rates, these experiments showed that the level of exploitation varied greatly

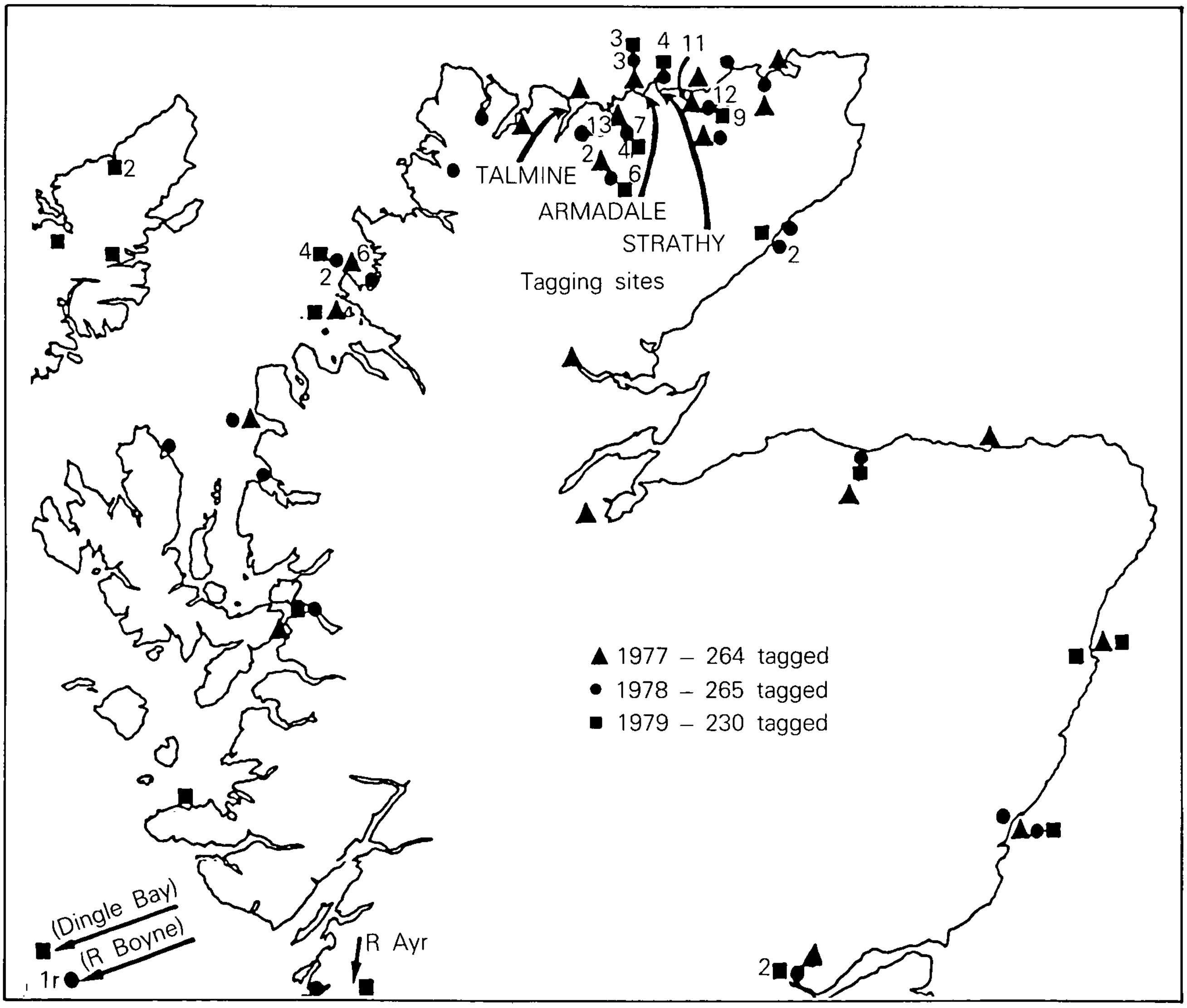


Figure 5. Recapture sites of salmon tagged from coastal nets on the north coast in 1977–79

between different areas of Scotland, but tended to remain markedly similar between years at any individual site. Whereas the mean exploitation rate by all nets of grilse tagged on the east coast was 48% (Table 2), the corresponding values for the Moray Firth, north, north-west, and west coasts were 19%, 16%, 9% and 7% respectively. As might have been expected, the level of exploitation around the coast was directly correlated with the densities of nets fishing. The proportion of tagged fish taken by rod was generally no greater than 5%, suggesting that on the north and east coasts, including the Moray Firth, angling removed a relatively small proportion of the fish escaping the nets. However, on the west coast where the density of nets at each fixed engine station was lower and the stations were more widely spaced, the exploitation rate by rods was similar to or greater than that of either of the netting methods.

When salmon and grilse were tagged in the same year at the same site (Moray Firth 1983, east coast 1954, 1955, 1978), the rates at which the one and multi sea-winter fish were exploited by the different gears were similar, and the corresponding total exploitation rates were not significantly different from each other ($P<0{\cdot}001$) (Tables 2 & 3).

Exploitation rates for fixed engine fisheries were the same irrespective of which method was used for their calculation, but for the other 2 types of gear the rates obtained by using method B were the same or greater than the corresponding values calculated by method A (Tables 2–5).

4.5.2 Single stock fisheries (North Esk and Spey)

The coastal tagging experiments mainly involved mixed stock fisheries and did not allow any assessment of exploitation rate for the stock migrating into individual rivers. Data on exploitation rates by single stock fisheries came from tagging adult salmon at Kinnaber Mill trap (N Esk) and at the mouth of the Spey. For this paper, it is assumed that the proportion of non-native fish in these 2 rivers was negligible.

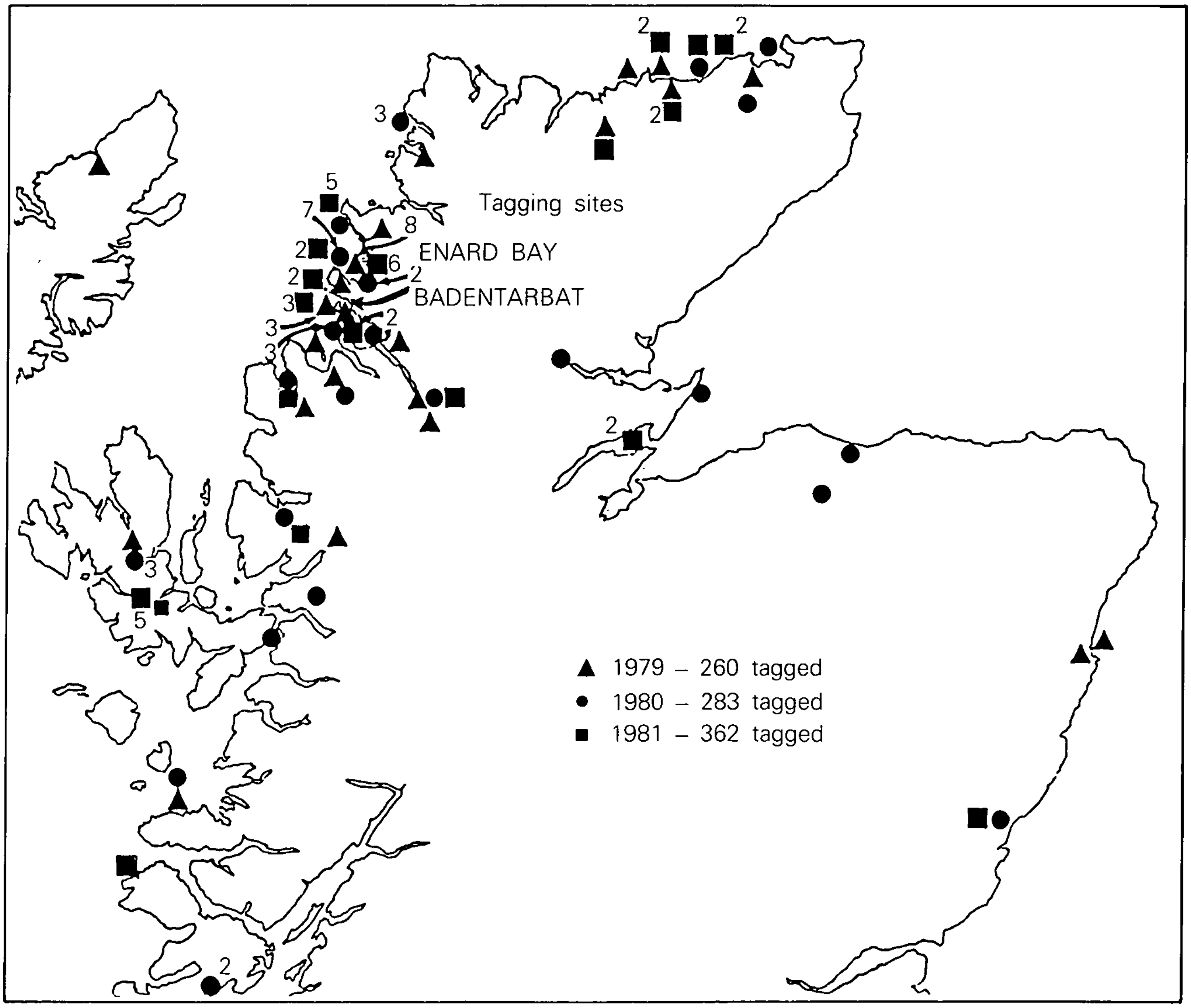


Figure 6. Recapture sites of salmon tagged from coastal nets on the north-west coast in 1979–81

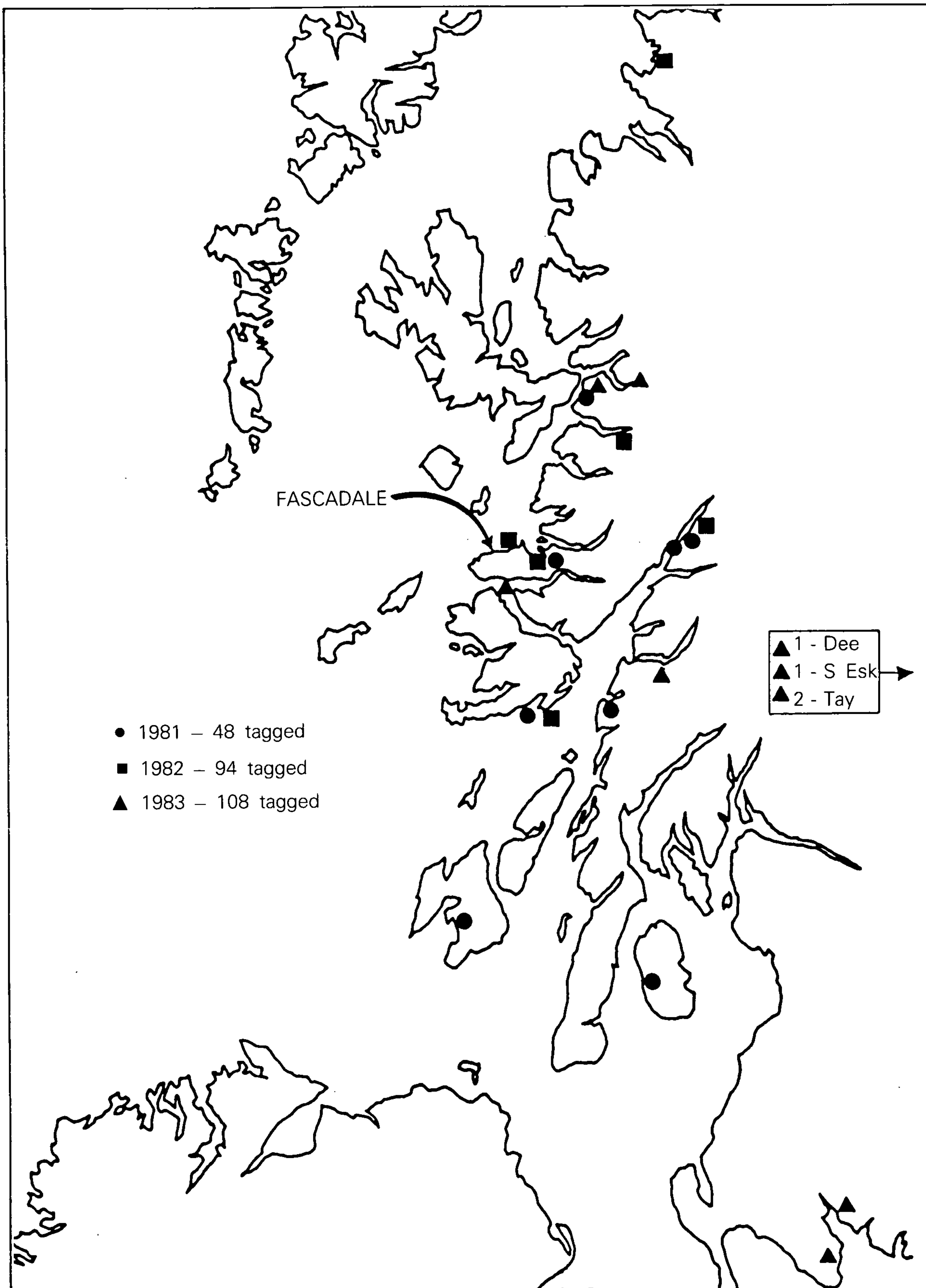


Figure 7. Recapture sites of salmon tagged from coastal nets at Fascadale in 1981–83

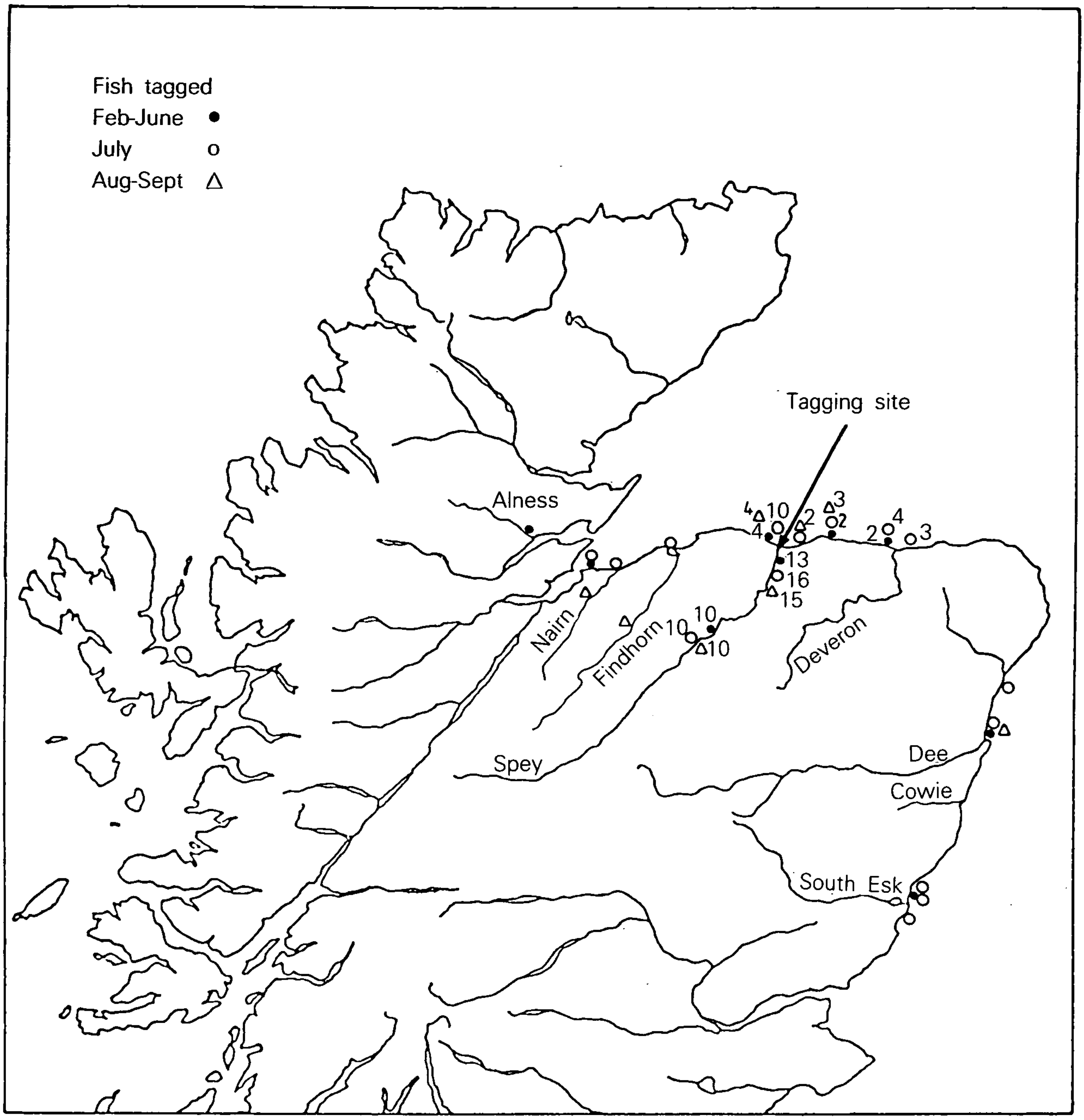


Figure 8. Recapture sites of salmon tagged from a net near the mouth of the River Spey in 1983

4.5.2.1 North Esk

The catch and recaptures in the North Esk net and coble fishery were used to estimate the exploitation rate by this fishery on grilse and salmon migrating into the river in 1976–83 (Table 6). The population passing through the main fishing area during the netting season was estimated using a stratified mark-recapture method (Schaefer 1951), incorporating a small adjustment for tags taken outside the river. The numbers of fish which ascended the river but were not caught in the commercial fishery during the netting season (the escapement) were then calculated by subtracting the catch at the principal netting site from the estimated number of salmon and grilse available to that fishery. The netting season exploitation rates were then estimated, knowing the escapement of salmon and grilse and the total river catch of these 2 sea age groups. These rates were 39%–53% for grilse and 39%–63% for salmon (Table 6). These 2 exploitation rates fluctuated independently. Accurate data from the rod fishery in this river are not available, but an estimate of 5% suggests that for practical purposes the catch is negligible.

4.5.2.2 River Spey

As, on any day, fish tagged from the net could contain significant numbers of fish of non-Spey origin which would not be available to either of the 2 methods of fishing within the river system, it was necessary to allow for this factor before calculating the exploitation rates on fish of Spey origin (Shearer 1984). In brief, the method used to calculate this allowance assumes that the relative levels of exploitation on fish of Spey and non-Spey origin in the tagged groups were the same.

Table 2. Exploitation rates (U) on one sea-winter salmon tagged at coastal netting stations in 1952–83, expressed as percentages (Method A)

Area	Year	Number tagged	Fixed engine		Net and coble		All nets		Rod and line		All methods	
			U	CI	U	CI	U	CI	U	CI	U	CI
West coast	1981	48	2	–	4	–	7	–	13	–	20	± 11
	1982	94	4	–	–	–	4	–	3	–	7	–
	1983	108	4	–	4	–	9	± 5	3	–	11	± 6
	Overall	250	4	± 2	3	–	7	± 3	5	± 2	11	± 4
North-west coast	1979	260	7	± 3	2	–	8	± 3	4	± 2	12	± 4
	1980	283	8	± 3	4	± 2	11	± 4	2	–	13	± 4
	1981	362	6	± 2	3	± 2	9	± 3	1	–	10	± 3
	Overall	905	6	± 2	3	± 1	9	± 2	2	± 1	12	± 2
North coast	1977	264	6	± 3	9	± 4	16	± 4	3	± 2	19	± 5
	1978	265	5	± 3	10	± 4	15	± 4	2	–	17	± 5
	1979	230	7	± 3	9	± 4	17	± 5	3	± 2	20	± 5
	Overall	759	6	± 2	9	± 2	16	± 3	3	± 1	19	± 3
Moray Firth	1978	129	13	± 6	4	–	17	± 6	2	–	19	± 7
	1979	254	11	± 4	8	± 3	19	± 5	3	± 2	22	± 5
	1980	403	15	± 4	3	± 2	19	± 4	2	± 1	21	± 4
	1981	221	13	± 4	13	± 4	25	± 6	4	± 3	29	± 6
	1982	743	9	± 2	13	± 2	22	± 3	5	± 2	27	± 3
	1983	398	7	± 2	7	± 3	14	± 3	4	± 2	18	± 4
	Overall	2148	11	± 1	8	± 1	19	± 2	4	± 1	23	± 2
East coast	1954	286	28	± 5	25	± 5	53	± 6	–	–	53	± 6
	1955	105	27	± 8	15	± 7	42	± 9	–	–	42	± 9
	1977	207	23	± 6	14	± 5	38	± 7	1	–	35	± 7
	1978	188	37	± 7	16	± 5	53	± 7	1	–	54	± 7
	Overall	786	29	± 3	19	± 3	48	± 3	1	–	48	± 3

CI 95% confidence limits

Table 3. Exploitation rates (U) on multi sea-winter salmon tagged at coastal netting stations in 1952–83, expressed as percentages (Method A)

Area	Year	Number tagged	Fixed engine		Net and coble		All nets		Rod and line		All methods	
			U	CI	U	CI	U	CI	U	CI	U	CI
Moray Firth	1983	191	8	± 4	6	± 3	13	± 5	3	–	17	± 6
East coast	1952	127	29	± 8	11	± 5	40	± 9	5	–	45	± 9
	1954	209	24	± 6	28	± 6	52	± 7	2	–	54	± 7
	1955	96	32	± 9	17	± 7	49	± 10	–	–	49	± 10
	1978	49	27	± 12	20	± 11	47	± 14	–	–	47	± 14
	Overall	481	27	± 4	20	± 4	48	± 4	2	± 1	50	± 4

CI 95% confidence limits

The estimated rates at which the net and coble and rod and line fisheries exploited the Spey stock throughout the season were 11% ± 3% and 7% ± 3% (ie much less for the net and coble fishery than in the North Esk).

5 Discussion

5.1 Sources of error

As recaptured fish showed no evidence of damage and few dead tagged fish were picked up in the North Esk where they would have been readily seen, particularly in summer, tag-induced or tag-related mortality is thought to have been negligible. In addition, because few tags have been returned by merchants who regularly buy salmon, and because sampling the catches at fishing stations around Scotland has revealed no evidence of tags not being returned, it has been assumed that Scottish fishermen recognize and report the tagged fish taken in their catch. The results from Kinnaber Mill trap in 1982 and 1983 showed tag loss to be negligible. The construction and method of attachment of the Floy tag, in particular, are such that, in itself, the tag is unlikely to render the fish more susceptible to capture, although the physiological and psychological effects of tagging cannot be assessed. It is not known whether the

Table 4. Exploitation rates (U) on one sea-winter salmon tagged at coastal netting stations in 1952–83, expressed as percentages (Method B)

Area	Year	Number tagged	Fixed engine		Net and coble		Rod and line	
			U	CI	U	CI	U	CI
West coast	1981	48	2	–	4	–	14	–
	1982	94	4	–	–	–	3	–
	1983	108	4	–	5	–	3	–
	Overall	250	4 ±	2	3	–	5 ±	3
North-west coast	1979	260	7 ±	3	2	–	4 ±	3
	1980	283	8 ±	3	4 ±	2	2	–
	1981	362	6 ±	2	4 ±	2	2	–
	Overall	905	6 ±	2	3 ±	1	2 ±	1
North coast	1977	264	6 ±	3	10 ±	4	4 ±	2
	1978	265	5 ±	3	10 ±	4	3	–
	1979	230	7 ±	3	10 ±	4	4 ±	3
	Overall	759	6 ±	2	10 ±	2	3 ±	1
Moray Firth	1978	129	13 ±	6	4	–	2	–
	1979	254	11 ±	4	9 ±	4	4 ±	3
	1980	403	15 ±	4	4 ±	2	3 ±	2
	1981	221	13 ±	4	15 ±	5	5 ±	3
	1982	743	9 ±	2	15 ±	3	6 ±	2
	1983	398	7 ±	2	8 ±	3	5 ±	2
	Overall	2148	11 ±	1	9 ±	1	5 ±	1
East coast	1954	286	28 ±	5	35 ±	7	–	–
	1955	105	27 ±	8	21 ±	9	–	–
	1977	207	23 ±	6	19 ±	6	2	–
	1978	188	37 ±	7	25 ±	8	1	–
	Overall	786	29 ±	3	26 ±	4	1	–

CI 95% confidence limits

Table 5. Exploitation rates (U) on multi sea-winter salmon tagged at coastal netting stations in 1952–83, expressed as a percentage (Method B)

Area	Year	Number tagged	Fixed engine		Net and coble		Rod and line	
			U	CI	U	CI	U	CI
Moray Firth	1983	191	8 ±	4	6 ±	4	4	–
East coast	1952	127	29 ±	8	16 ±	7	8	–
	1954	209	24 ±	6	36 ±	7	4	–
	1955	96	32 ±	9	25 ±	10	–	–
	1978	49	27 ±	12	28 ±	15	–	–
	Overall	481	27 ±	4	28 ±	5	4 ±	2

CI 95% confidence limit

Table 6. Exploitation rates by North Esk net and coble fishery during the commercial netting season expressed as percentages

Year	One sea-winter	Multi sea-winter
1976	52	55
1977	51	43
1978	44	51
1979	42	45
1980	39	39
1981	50	57
1982	50	63
1983	53	39

tagged samples represented a random sample of the salmon populations examined. In view of this and the other sources of bias described, any estimates should be regarded as approximate rather than precise.

In each year, a small proportion of the salmon migrating upstream which were tagged at Kinnaber Mill trap were subsequently recaptured outwith the North Esk. In addition, smolts tagged in the Dee were regularly caught as adult fish in the North Esk. The number of these tagged Dee fish suggests that a significant proportion of the MSW component of the

North Esk catch consists of fish of Dee origin. However, although this bias results in an overestimate of the total fishing mortality rate, it is not thought to be important for the one sea-winter component of the North Esk net and coble catch.

The assumption that the relative rates of exploitation on fish of Spey and non-Spey origin in the tagged groups were the same can introduce 2 types of bias into the analysis. First, if the exploitation rate on tagged fish of non-Spey origin was greater than that on fish of Spey origin, the exploitation rates on native Spey fish would have been overestimated. On the other hand, if the reverse had been the case, the rates of exploitation on fish of Spey origin would have been underestimated. Fish of Spey origin, having reached the Spey Project net, were unlikely to encounter fixed engines in significant numbers as they proceeded into the Spey, so that fishing pressure on them was mainly restricted to the net and coble and rod and line fisheries within the river. However, tagged fish of non-Spey origin could have encountered a significant number of fixed engines on the coast, in addition to the fisheries in the rivers which were their final destinations. For example, captures from the coastal tagging experiments at Macduff, approximately 50 km to the east of the Spey, in 1978–80 demonstrated that the majority of the fish tagged there were unlikely to have originated in the Spey. Nonetheless, the recapture rate of 21% obtained from this experiment was very similar to the level calculated in the Spey Project (20%). As a result, I assume that the exploitation rates on fish of Spey and non-Spey origin tagged in the Spey Project net were of the same order.

Although the coastal tagging experiments coincided with the period of maximum fishing effort, the exploitation rates reported for coastal fisheries could be minimal because the fish may have been available for capture in these fisheries prior to tagging. Local exploitation rates within river systems whose stocks are heavily exploited will be underestimated by averaging with rivers which have lower exploitation rates. However, the figures refer to exploitation rates within the fishing season, and the exploitation rates on the total stocks will be reduced by escapement during the close season. Nevertheless, in only one area (east) did the estimated level of exploitation approximate 50%. The levels of exploitation in the North Esk and Spey net and coble fisheries were markedly different. However, the Spey data refer to a single year so that it would be unwise to place too much weight on them.

5.2 Conclusions

The exploitation rates by nets estimated in this paper may, in general, not be so high as to reduce the number of spawners to a level which would limit juvenile production. Buck and Hay (1984) showed that large variations in the number of female spawners in the Girnock Burn each year (range 28–127) produced smaller annual variations (range 2900–5600) in the number of juvenile migrants. However, as the net fisheries were exploiting mixed stocks, a rate which could be borne by the stocks from large rivers could deplete smaller stocks from less productive rivers. Similar considerations have led to proposals for a 'river harvest' system of management, whereby the exploitation of salmon is confined to its river of origin. The management of mixed stock fisheries requires a knowledge of the river of origin and the proportion of each river's stock being exploited. Discriminant analysis of scale samples has proved useful in Canada in determining the river of origin of Atlantic salmon in the mixed stock Newfoundland fishery (Reddin, pers. comm.), and it may be possible to use similar techniques for Scottish fisheries.

Firm conclusions about the rod fisheries cannot be drawn without more precise data, particularly because there could be differences between the rates at which grilse and MSW fish are exploited by anglers. Nevertheless, the present values for exploitation rates suggest that, in general, the rods catch only a small proportion of the fish available to them. For example, on the Spey the results suggest that, for every 100 fish of Spey origin which entered the Spey between February and August 1983, angling removed about 4–10 fish. The number escaping the net and rod fisheries, less losses due to natural mortality and poaching, would be potential spawners.

6 Summary

6.1 This paper describes the rates at which salmon returning to their rivers of origin were estimated to have been exploited in Scottish home water mixed stock fisheries.

6.2. Estimates are given of the rates at which grilse and salmon were exploited in the net and coble fishery in the River North Esk in 1976–83 and in the net and coble and rod and line fisheries in the River Spey in 1983.

6.3 Fish tagged at coastal tagging sites around Scotland were recaptured from Innerwell (Solway) to the River Aln (Northumbria) and Ireland.

6.4 Exploitation rates of multi-stock fisheries varied from *c* 11% to 48% between areas, but were similar between years at the same site.

6.5 Grilse and salmon tagged at coastal sites appeared to be exploited at similar rates.

6.6 Exploitation rates in the single stock North Esk net and coble fishery varied from 39% to 53% for grilse and 39% to 63% for salmon.

6.7 At present, there is insufficient information to determine whether the rod and line catch in the North Esk and/or the annual smolt production could be increased by reducing the present rate of exploitation by the net and coble fishery.

6.8 The exploitation rate in the Spey by angling was estimated at 7% ± 3% and by net and coble at 11% ± 3%

7 Acknowledgements

None of this work would have been possible without the help and encouragement of many netsmen, including Messrs Joseph Johnston and Sons Ltd, Montrose, Messrs J & D R Sellar Ltd, Macduff, the late Mr T R Paterson, Strathy, Mr W Muir, Achiltibuie, and Mr R A MacLeod, Fascadale. To them all, I record my grateful thanks.

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Recent changes in fishing methods

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1 Introduction

The content of this paper is tempered by whatever meaning one wishes to place on the word 'recent'. If it is to be taken to mean the last 30 or so years, then it coincides with the passing of the 1951 Salmon and Freshwater Fisheries (Protection) (Scotland) Act, and perhaps from my own point of view the period of time when I am able to recall some of the changes. However, in order to try and understand why we have reached the position we are in today, to explain the methods and why we use them, it is advantageous to look back a little further into history.

In his opening chapter on the law of fishing, Stewart (1892) states that, 'As the air is common to all men, and incapable of appropriation by individuals, so is the sea common to mankind for fishing and navigation'. This basic premise has, of course, been modified but it remains a fact that fishing for white fish (this does not include salmon) is for the good of the lieges or, in other words, a public right. That right has, of course, been modified by law in the interest of 'preservation of fish', as it was termed. Various controlling authorities were set up, such as the Board of British White Herring Fishery, established in 1809, followed by the Fishery Board for Scotland, and right up to the present District Fishery Board System. It is interesting to note from Stewart that, in talking about conservation, the history of British Fisheries is 'far from being one of uniform success'. Here we are today some 90 years on, and I wonder if we have not all heard that comment being made in the last few years with regard to both white fish and salmon fisheries.

2 Salmon fishing rights

What, then, happened to salmon and salmon fishing rights? According to feudal law, all lands and real rights in Scotland were vested in the Crown and the right to fish for salmon was treated as an heritable estate. Thus, all salmon fishings originally belonged to the Crown and were made available to favoured individuals by either permanent grant or temporary lease. Crown grants were issued by the Barons of the Court of Exchequer in Scotland until 1832 when the Commissioners of Woods and Forests took over that responsibility. Until 1832, the main interest concerned the salmon fishings in rivers rather than in the sea, so that fewer of the coastal fisheries were disposed of by the Crown. The right of salmon fishing is exclusive and is founded on a written title and conveyed from one party to another in the same way as heritable estate. The owner of that right has the exclusive right, therefore, to fish for salmon himself or to lease that right exclusively to another individual. This is quite different from the public fishery which remains in being in England and it is important to emphasize this basic fact. There are, of course, many other facets of the law of title and rights of salmon fishing, but these need not concern us presently.

The Crown made grant of salmon fishings for 3 particular natural situations or localities, namely in rivers, in estuaries and in the open sea. However, the way in which that right may be exercised varies and has been modified according to the locality of the grant. Today, generally, the only legal methods of fishing are by rod and line, net and coble and by fixed engine. There are some exceptions such as the haaf net and poke net fisheries in the Solway. However, the curiosity and ingenuity of man have ensured that where there are salmon to be caught legally there are also methods of catching them illegally.

3 Early methods

If, first of all, we look at the situation in rivers today, the only methods available are rod and line and net and coble. However, one only needs to delve into the stories of rural life in Scotland of some centuries ago to realize that, formerly, there were many methods of catching salmon in rivers by the use of movable implements or by fixed engines. As early as the 9th and 10th centuries, leisters, or salmon spears as they are known, are recorded as being used by the iron workers for poaching salmon. A leister is simply a pronged, barbed implement shaped like a garden fork, which could either be thrown into the water by itself or was attached to a wooden shaft perhaps some 5 m long and used in the manner of a spear. Leistering was most prevalent in the headwaters of rivers at spawning time when the fish were in shallow water and at their most vulnerable, although not of best quality.

This method of catching fish depended on the clarity of the water, but it soon became known that it was possible to catch more fish by this method with the aid of a bright light at night. Indeed, burning the water in the 17th and 18th centuries was commonplace. A burning torch was made of dried heather, and tarred sacking or staves from old tar barrels, which created great light in the dark. A further development saw the emergence of the crusie, which was an iron cage about 30·5 cm deep and 20 cm wide, filled with combustible materials. With these bright lights at night, it was possible to see fish very readily. Those who have used a bright torch at night will know what is meant. It was also possible to use a leister to great effect on a very bright sunny day, but the day-time implement was much smaller than the night-time version. It is interesting to note that leistering was forbidden in England in 1533, in Scotland in 1601, and in Ireland in 1714. Of course, that does not mean that it stopped immediately. I am quite sure that there are up-to-date versions of the leister to be found today.

Other more effective methods of catching fish migrating upstream were developed, of which the cruive is probably best known. Fishing by cruive was forbidden by the 1951 Act, but the remains of many of these structures are still to be seen today on the River Don and on the River Conon for example. Old maps show the position of cruives on many of the rivers of Scotland. A cruive was simply a structure or series of structures, usually built of stone, placed across the width of the river. An inscale on the downstream side of the structure chanelled the fish into a chamber from which they were removed. It was mandatory to leave a space in the centre of the structure to allow an escapage of stock upriver.

The cruive was a fixed engine legalized by special right but it was also the cause of much contentious litigation within river systems.

Strict rules governing the operation of cruives were enacted as long ago as 1318. It is clearly stated that all cruives set in fresh water, where the sea fills and ebbs, which destroy the fry of all fishes, be destroyed and put away for evermore. Later in 1478, the following was added to that regulation—'under the pain of five pund for ilka cruive'. Cruives in estuaries were forbidden. There were many regulations governing the six foot (1·83 m) free gap in the structure and, finally, there was a reminder that they keep the laws 'anent Saturday's slap'. We still have this today.

In tidal waters, where cruives were illegal, fish dams or yairs were often built. These were stone or sometimes wickerwork structures whose purpose was to entrap fish within the structures as the tide was falling and so strand them in shallow water where they could be easily removed. This method of fishing was not popular, but some examples of derelict yairs remain, particularly on the west coast of Scotland where salmon, sea trout and flat fish were all taken.

4 Rod and line fishing

Rod and line fishing, with which we are all probably familiar, sounds straightforward, but there are ways and means of fishing with rod and line which do not always comply with the law. Rod and line fishing or angling takes place almost entirely within river systems, although there are locations on sea shores, mainly at the mouths of small rivers such as the Bervie or Lossie, where fish are sometimes taken legally. More often than not in these areas, fish are caught illegally by using rather large hooks, heavily weighted on the end of very strong nylon line, itself heavily weighted. By using a violent jerking motion or ripping, fish can be impaled on the hook and wound ashore. When approached, the fisherman is inevitably 'fishing for white fish', and it is extremely difficult and time-consuming to gather sufficient evidence for prosecution. Set lines with baited hooks are also forbidden in rivers. However, set lines tried by some foreign fishing boats in the Moray Firth some years ago were not illegal, but neither was the method very fruitful.

Angling today is very much changed from the angling of 10 to 15 years ago. Many more people are interested in angling; better transport allows people to reach what were formerly inaccessible rivers or parts of the highlands; more holiday time allows more people to pursue their hobby on the rivers and lochs. The bigger the demand for angling, the higher the price the angler is asked to pay. The higher the price, the keener the angler is to catch fish to cover the rent by fair means or by foul. Angling today, in a great many instances, is as commercial as netting. No longer the greenheart rods and the expert casting the fly in exactly the right lie to tempt and tease a fish to take his lure; the modern technology of carbon fibre, glass fibre, and nylon is used to plop the minnow ceaselessly into today's much changed rivers to catch his 10 black fish for the day to offset the rent.

Of course, it is not all like that. There are still experts who can defy everyone and take a fish in the most apparently impossible conditions, and be happy and content at their one victory of the day. Changes there have been, and I would simply query 'are they for the better?'

5 Net and coble

Net and coble, or sweep netting as it is sometimes called, is the only other method of catching salmon which is permissible within the river and its estuary. As its name suggests, a net and a boat are used. The net is carefully stowed on the stern of a small boat which may be rowed or it may have a small outboard or inboard engine. A rope attached to one end of the net is held by a fisherman on the shore, while the boat moves out from the river bank and in a semi-circle to arrive on the same bank at a point further downstream. While the boat has moved downstream, the fisherman on the bank has also moved downstream pulling the net with him. In essence, a semi-circle has been formed, and within that semi-circle fish are trapped as the net is pulled fully ashore. All this explanation sounds very simple and absolutely fatal to the existence of salmon at all. Not unnaturally, rules and regulations qualify the use of net and coble fishing in rivers. For example, the minimum mesh size, but not the length or depth of the net, is stipulated; there is a weekly and an annual close season, and one is not allowed simply to leave a net across the river waiting for fish to swim into it. The size and shape of the river, the current in the river, and the landing places all determine the length of net, the depth of the net, and the shape of the shot or sweep that are used at any particular time. For example, when a river is at a high water level, it is just not possible to handle a sweep net properly as the crew are unable to hold the net when it swings with the current. Even if the net were held, the ground rope, which is normally weighted with sinkers or has a lead core, rises off the bottom and the fish escape under the net. In this instance, a shorter net may be partly effective. In real flood conditions, straw, branches of trees and other debris preclude the use of a sweep net altogether.

It may appear that a sweep net is 100% efficient, but fish are very adept at finding an escape route round the end of the net, under the ground rope, or simply by falling back downstream in front of the net. There is inevitably a delay between shots and there is a period when there is no net in the water. Often, particularly during the grilse run, a crew may be netting a pool and fish are seen running upstream out of the pool having passed the nets. Contrary to some beliefs, there is an escapage of fish even in low water conditions. Sweep netting may also be carried out on a suitable shallow coast line, mainly in areas having a sizeable run of sea trout. This method is known as beach seining.

Although the materials used in sweep netting may have changed, the method has not. But, as in all commercial salmon fishing, the number of stations and the duration of fishing have declined dramatically.

6 Fixed engines

Outwith river estuaries, the fixed engine fishery becomes the predominant method used. But, first of all, how are estuaries defined? In the 1864 Act, a schedule is set out which determines the limits of the estuaries of all but the smallest rivers in Scotland. Where there is no annual movement in the mouth of the river these definitions still apply, but where the confluence of the river and the sea is very mobile, such as the North Esk where the mouth of the river has migrated over 0·8 km northwards in the last 20 years, a method of annual measurement was devised in 1864. Each year at low water at equinoctial spring tides in, March, each river is surveyed at its mouth. From that survey, a plan is drawn up giving the limits of the estuary for that year. This is a complicated but necessary procedure in order to prevent fixed engines being placed across river mouths. It is a fine example of how the legislators of that time went into great detail to regulate the catching of salmon and ensure the survival of local stocks.

In general, 2 varieties of fixed engines are used to catch salmon. Fly or stake nets are used in shallow water where the tide recedes and the structures dry out, and bag nets are used in deeper water. These nets are floating but moored and normally identifiable by brightly coloured floats.

6.1 Fly or stake nets

The fly net is designed to divert adult salmon, grilse and sea trout homing to their rivers of origin into a trap from which the fish can be removed alive and in good condition. The whole essence of fixed engine fishing is to catch salmon which have not been meshed and are in top quality. The entire structure is one of wooden poles or stakes, *c* 5·5 m long, planted in the sand and supported by rope guys and pins. The arm of the structure is at right angles to the shoreline and ends in a triangular-shaped trap. This trap may have a further arm going seaward to another one or 2 traps and the whole structure may extend 275 m from high water mark. On the arm is fixed a curtain of netting about 3·7 m deep, called the tiering. The purpose of this netting is to lead the fish from shallow to deeper water, and thus into the trap. The trap is made in 3 sections, an outer, middle, and inner or fish court. It has netting on the top and the bottom as well as the sides and is shaped in the manner of an inscale. There is a footrope 2·5 m off the ground and a hand rope about 0·6 m from the top of the stakes. The net is fished at about half ebb tide when there is about 0·6 m of water in the trap. The fisherman walks out along the arm on the footrope on to the top of the trap, holding the hand rope as he goes. He unlaces a few meshes of the top netting and uses a dip net to catch and lift out the fish before killing them. These nets are fished according to the tides at 12-hour intervals in both daylight and darkness, so one can well imagine the difficulty facing the fisherman in the early hours of a stormy March morning in the dark and in a biting wind.

The whole structure is very vulnerable to the effects of violent seas. Often the complete woodwork can be knocked down by severe weather and even carried away completely. Severe weather also causes strong cross-currents which can move 1 m or more of sand in a matter of hours and loosen all the pins. The stakes are then without support and collapse or break. The netting can be covered with debris, seaweed or even jellyfish in the calmer waters of summer time. The netting can be torn from top to bottom, if it is blanketed in debris and there is a current running through the netting. Considerable fishing time can be lost until repairs are carried out.

There are variations and modifications to the nets which have been described. For example, in Aberdeen Bay the jumper net is more common. The principle of fishing is exactly the same, but the net is not fished by a man climbing out on the structure, neither is there a leader supported by stakes throughout its entire length. It is fished from the ground as the net dries out on the ebbing tide. The trap is supported by stakes, and the leader which is attached at the shore end is allowed to float. On the Solway Firth, traps, or pockets as they are called locally, are of a more complicated nature and probably developed in that way because of the strong tidal currents in the area. There is no legal limit on the number of stake nets or jumper nets which may be set or on their position, except that they must be outwith estuaries. Obviously there comes a point where it is uneconomical to set up more of these expensive structures. However, regulations on the Solway define how many and where each net may be positioned. With rapidly shifting sand banks in the Solway estuary, some net positions are totally unworkable but they may suddenly become workable again as the physical features change.

6.2 Bag nets

Where the water is too deep for fly or stake net fishing to take place or the shoreline is of a rocky nature, bag net fishing is carried out. These nets are used round the whole of the coastline of Scotland. They are a floating version of the fly net, set seawards of the fly net and at right angles to the shoreline. The net itself is secured by 3 anchors, one to seaward and 2 at an angle towards the shore. The leader is streamed out towards the shore and is also secured by a fourth anchor or perhaps a large bolt or eye fixed into a rockface. The whole net floats and is supported by corks and floats on the mooring lines. Because the whole net floats, it has to be serviced by a boat, normally a flat-bottomed salmon fishing coble, 5·5–8·2 m long, with a crew of 3–6 people depending on the number of nets and the distance between them. The net has 3 poles which keep the net open and standing. The headpole is important as it takes the seaward strain, and when it is released the net collapses with the side walls forming a bag into which the fish are manoeuvred and boarded on to the boat. Hence the name bag net.

6.3 Modern improvements

Bag nets and fly nets probably came into being in the early 1800s and in their infancy were very complicated pieces of equipment. Over the years, they have become simplified and, while the size of the net and the method of fishing remain the same, the main change has occurred in the materials used. Whereas, in the years gone by, cotton nets dipped in archangel tar and supported with cork floats and oak casks were in common use, today's synthetic materials such as nylon, courlene, polypropylene and fibrefilm have taken over. The main difference is that the old cotton nets were very heavy to handle, required a lot of flotation and were easily damaged in a storm. Often they would sink to the bottom and become completely wound up in a huge ball of net, moorings and anchors, which, after recovery, necessitated a considerable amount of repair. Sometimes the complete gear would have been dragged away in the current during a storm for a distance of up to 3 km, and occasionally never recovered. Nowadays, all the synthetic materials float and are stronger than cotton twine and manilla ropes; consequently, storm damage is much more limited. Modern nets will fish in harsher sea conditions than previously. One man can lift the netting of the modern day, whereas 4 men were required to lift a heavy, dirty, cotton bag net. A recent development has been the fashion to set up double-headed bag nets where the leader runs into 2 bag nets set opposite each other at the seaward end. This system seems to have advantages in deeper water and fishes quite well. No doubt there are more permutations to be tried in the future.

Mechanization has improved the lot of the salmon fisherman. No longer must the 6-oared rowing boat be rowed 5–6 km into a stiff breeze. The day of the outboard engine, the inboard engine, the winch and the powerblock has arrived and has taken a lot of the backache out of the salmon fisherman's life. The tractor surpasses the horse and cart on the beach, the mechanized blondin does away with the toil of carrying heavy gear and catches up cliff paths, and the number of men required for a station has decreased. Cars have taken the place of bicycles; bothies are seldom used as sleeping accommodation, but are now rest places during the day. Electricity has succeeded paraffin lamps and stoves. Water pumps are used to plant stakes on the beaches where before hard labour did the job. Manpower has been reduced at many salmon stations and, sadly, many stations have closed. In my own Company, 8 stations employing about 50 people have closed in the last 20 years, and the remaining 5 boats are not operating throughout the full salmon season.

7 Illegal methods

Not all these modern devices have necessarily brought good. We have seen the tremendous increase in the use of illegal hang and drift nets following the invention of monofilament nylon, with the resultant damage caused to the fish themselves and the huge interception of homing fish on the high seas and nearer home. Despite the attentions of all sorts of law-enforcing agencies, illegal fishing still persists. Monofilament twine has been used in leaders of nets and, as a result, more fish are often enmeshed in the leader than are trapped in the bag itself. This method is of doubtful legality and has no place in sensible fishing practice.

8 Conclusions

Thanks to the efforts of the legislators of 100 years ago, a balance has for many years been struck between the number of salmon taken by commercial methods, those available for angling, and those which escape to form the spawning stock of future generations. However, if the methods of catching are improved to a highly efficient state through the development of finer netting, electronic aids, and all the other scientific devices on man's side, this balance is liable to be upset. Furthermore, the development of high seas fishing away from rivers of origin has put further pressure on the returning salmon.

Currently, the tendency has been for more coastal netting stations to close rather than open. The legal netting effort both at sea and in rivers and, conseqently, the catches have diminished remarkably in a short time. The fisheries are therefore tending to become concentrated nearer river estuaries, and pure economics may well be bringing about what the Hunter Committee (Committee on Scottish Salmon & Trout Fisheries 1965) set out to do by law.

The history of the salmon fishing industry is full of ups and downs in catches and alterations in the timing of seasonal runs, and no doubt these trends will continue. As the runs have changed, so have the regulations and methods of fishing, but what we must all ensure is that there are salmon for generations to come.

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The management of a rod and line and a commercial fishery

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1 Introduction
Let us begin by asking ourselves what constitutes 'management' when the term is applied to a salmon fishery resource. In general, it must comprise all actions designed to ensure the maximum production, exploitation, continuance and improvement of the resource and the co-ordination of these, sometimes conflicting, aims. Let us take these aims one by one.

2 Maximum production
This aspect is really only within control of a fishery manager whilst the fish are below the smolt stage. After the smolt age, they are his concern in a general sense, but control passes out of his hands and, in so far as it passes into those of anyone else, it passes into the hands of the politicians. Maximum production consequently means ensuring the maximum possible smolt run from a river. To achieve maximum production, therefore, a fishery manager must have an eye to 4 factors, ie the stock, the spawning, distribution of fry, and rearing conditions.

The stock must be adequate but there is little point in it being more than adequate, and indeed there might even be disadvantages. An overcrowded redd is probably less productive than one which is adequately stocked, or even slightly understocked. Nonetheless, the stock must not be less than adequate. The difficulty is that there is really no way of describing or defining 'adequacy'. I do not think that there will ever be, even though the Hunter Committee (Committee on Scottish Salmon & Trout Fisheries 1965) did seem to think that it would be possible.

Nature has equipped the salmon with the capacity to reproduce itself many thousand-fold, and not without reason. There are so many obstacles to the survival of the species in nature, and so many predators taking their toll, that this reproductive capacity may well be needed. However, nature has included the safety measure, to stop the salmon species expanding infinitely, of death by disease, or starvation of fry, if the stock gets too great.

It follows, therefore, that the harvest which we are entitled to take from a wild stock is that proportion which nature has over-provided in the final stage of spawning return. We control our harvest by imposing close seasons, and we can also do so to some extent by making the smaller upper waters and tributaries into sanctuaries which are not fished, especially later on in the season. We assess our success by keeping careful records and examining them over long cycles.

It is important, in my view, not to get too excited by short-term fluctuations. Most people tend to make the mistake of interpreting one or 2 bad years as a disaster, or else of regarding one or 2 exceptional years as the norm. It would be bad practice for a fishery manager to do so. He must keep a cool head and accept that all his actions must be judged over a period of years.

That is why in my view great care should be taken not to muck about with close seasons, certainly in the short term. It is tempting to think that, if one closed a river early, in the light of one or 2 years' poor catches, the stock in the river would at once start to increase so that catches in following years would be bigger; but that would not necessarily be so.

For instance, experience on the Thurso has shown me that to cease netting the estuary early does not necessarily add greatly to the spawning stock. In the war years 1940–46, also, when rod fishing effort was very low and sea fishing almost non-existent, the average catch taken by rods on the Thurso was a mere 282 fish per annum. This low catch was due to lack of fishing effort. But in 1947–51, the average only rose to 678, at least 200 fish lower than the long-term average and 300 lower than the 5 years 1979–83.

However, I do believe that it is important to give the spawning stock sanctuary in the upper waters as the spawning season approaches. Spawning success is perhaps the most vital contribution to maximum production, especially the natural spawning of pairs of fish in the small upper tributaries of a river.

Maximum production, therefore, involves making sure that salmon have access to all tributaries of a river and that these tributaries are clean, unobstructed and healthy. This may mean that it would be advisable to provide fish passes to get fish into the upper tributaries, or, where this is not feasible, stocking those tributaries with ova or fry from a hatchery. It may equally mean guarding against erosion, or acidity caused by forestry, or watching out for thoughtless pollution.

In attempting to achieve maximum stocking, care has to be taken not to overstock. Account has to be taken of the rearing capacity of the water if one is to get the correct distribution of fry. One of the most elementary mistakes a fishery manager can make is to introduce artificially reared fry into waters which are already adequately stocked. The only result of so doing must be to kill off some of each lot of fry until the stocking level decreases to what it was when the fry were introduced, and this may well mean a dilution and possibly a weakening of the natural stock.

The rearing conditions needed to achieve maximum production also include waters free from undue competition and predation. One of the greatest obstacles to maximum production of salmon smolts in Scottish rivers is the brown trout population. Trout both compete with and predate parr, and in the rearing areas of a salmon river they usually have little or no sporting (and therefore no commercial) value. It would, however, be a Herculean task to try to eliminate them from a river system. The best one can do is to see that they are thinned out as much as possible from those areas which one intends to stock with fry.

On the Thurso, we do this by electrically fishing those stretches of burn intended for stocking. The trout taken out are then put into selected lochs where they grow well and provide some commercial return in the form of trout fishing.

After trout, the next greatest danger to salmon in the rearing stage is from birds, particularly mergansers. Recent legislation has made more complicated the task of ensuring that predation by birds does not reach an unacceptable level. My observation on the upper waters of the Thurso suggests to me that mergansers are on the increase rather than on the decline, as are cormorants and shags in the river estuary. All of these birds can do great damage to stocks. None of them were being greatly reduced by normal methods, but nevertheless they have been granted protection by the Wildlife and Countryside Act of 1981.

3 Maximum exploitation

There are, of course, 2 ways to exploit a salmon resource, and they are not necessarily mutually exclusive. First, the fish can be caught by net or trap and exploited as a food source; second, they can form the basis of sport fishing.

In my view, maximum exploitation can only be achieved through the use of both methods at the same time. The danger of over-exploitation by net or trap is obvious. One could kill a river stone-dead in 5 years with 100% efficient estuary fishing. The same does not apply to a rod fishery. The rods could never catch enough fish, by fair fishing methods, to damage a stock, unless fishing were to be carried on late in the year and into the spawning season, or on the redds.

As rod fishing gives more employment than net fishings, but the net gives us most of the salmon which we so enjoy eating, it is obvious that a mixed exploitation of a salmon resource is desirable. In order, therefore, to allow enough fish to get into a river to provide decent and continuous sport, it is necessary for nets to be fished in such a way as to allow the continuous escape of a proportion of returning fish so that some fish will continuously run up the river.

We must remember that salmon present themselves at the mouth of a river, ready to run up it, in every month of the year, which is convenient for the angling resource because, by and large, it is fresh-run fish which provide the sport. It is better to have a few fish run into the river every day than a lot of fish on one day and then none for a fortnight.

The present arrangement of weekly close times is good from this point of view, and the fact that most estuary nets can only fish for part of the day and not at night is also a safety valve which over the last century has prevented real damage to stocks. In other words, a mildly inefficient coastal netting industry has ensured an adequate angling and spawning escapement.

However, increasing efficiency of both legal and illegal sea fisheries is threatening this delicate balance. If we are to restore the balance, we have to address our minds to this problem, and I suggest that we should not only crack down hard on illegal fishing but also take a hard look at what legal methods are to be allowed.

For instance, drift netting should be classed as an illegal method throughout our waters. It is just plain pusillanimous to allow it to take place off the coast of Northumberland. At the same time, we should take an equally critical look at our fixed engine netting stations. Whilst it is commendable in any business to strive for maximum productivity, in the salmon netting business it is doubtful whether it is desirable to carry such efforts to their logical conclusion. By all means increase productivity by using faster boats so that 2 adjacent netting stations can be worked by one crew; but it is not the same thing to seek an increase in productivity by increasing the size and number of nets on an existing netting station.

What we need is agreement on the type of net which gives the sort of mild inefficiency that is desirable, and we must then produce a clear definition of this engine and how it is to be fished, so that the law can be enforced without dubiety. Perhaps we should do this by positive rather than negative identification. That is, instead of making it illegal to use a monofilament drift net, we should say that it is only legal to use a courline bag net of such and such dimensions, set in such and such a manner with leaders of such and such length. If we achieve this mild inefficiency of fishing method, in my view it would be safe to allow netsmen to employ it without further interference. In other words, it would not be necessary to limit them in other ways, for instance by messing around with close seasons.

Once in the river, fish can only be exploited by providing conditions in which they will take. This means providing the maximum number of lies which salmon can occupy over the longest possible time. On the Thurso we have tackled this by 2 means. First, by providing a dam on Loch More as a reservoir of fishing water, so as to prolong the effects of spates and rises of water, and second by constructing pools. About half the pools on the Thurso are man-made.

Other than making pools and storing surplus spate water, the only thing one can do to get maximum angling exploitation is to be good to the anglers. There are 4 things one can do that anglers appreciate.

i. Treat them fairly. We do this by operating a rotation system and being scrupulous in drawing lots to see which rotation each angler gets allotted. Every angler is offered his last year's dates for the following season, and waiting lists are scrupulously kept for favourite periods.

ii. Look after the banks. We try to keep stiles in good order and banks tidy and firm, with bridges over ditches and duck boards over boggy areas.

iii. Offer them shelter. We provide luncheon huts where anglers can get out of the wind and rain for a smoke or to eat their sandwiches.

iv. Let them know that you care about them. We always have someone to meet anglers, whether they employ a ghillie or not, to give them help, advice or just news. This person is usually the River Superintendent who also gets their return of fish caught, and is thus able to keep in touch and collect a lot of information.

It is very important to a river to be well and fully fished. It is easy to get a bad name but hard to keep a good one. Unless a river is well and fully fished, it will never show its true potential. The only people who can make this happen are faithful and contented regular anglers.

4 Management

Having set the stage for maximum production and optimum exploitation, how does one get it to continue? The answer, in a phrase, is by eternal vigilance. Stocking must be regularly attended to, repairs must be anticipated and carried out, watch must be kept for poachers, anglers even must be watched to see that nobody cheats, and netting stations must be inspected regularly to see that leaders are slapped for weekly close times. In short, it is all very like running any other successful business. It is a matter of regularity, attention to detail and staying one jump ahead of regular problems.

So, then, what can one do to improve a river? Assuming that one is doing all that one can to achieve maximum production and exploitation, the first thing to do is to look at the resource to see what part of it is being underutilized. Look at the upper waters first, to see if there are areas which breeding fish do not reach and to see whether these areas can be used, either by finding a way to get breeding fish up there or by stocking them artificially.

Next, look at areas of water which could be added to the river, eg lochs which are not valuable for trout fishing but which could be cleared and stocked with fry. We have done this successfully on the Thurso by clearing a loch called the Grassy Loch by poisoning, and now we stock it every second year with fry.

Then look at the rearing areas of the river to see if you can set up a programme to reduce competition and predation. Also consider whether these areas could be improved by habitat engineering (eg see Solomon 1983).

Finally, if it is possible and economically feasible, see if there is a part of the river system where spate water can be stored. Such storage has 2 benefits. First, by releasing the stored water gradually, the lies created by a spate are kept in existence for longer than normal. Second, while there is some water stored over a wide area, the efficiency of the whole catchment area is increased.

I am sure that there is much scope for all these kinds of improvement on salmon rivers all over Scotland. The problem, however, is not only whether they can be financed, but, more particularly, whether enough agreement can be reached amongst owners of fishings, first to carry such measures out and then to manage them properly to full advantage.

I have often been complimented on the way in which we manage the Thurso, and, although I am always pleased to get compliments, and so too are the rest of the river staff, I am very well aware that there is nothing magic or superhuman about us, and the bailiffs and ghillies know this too. We are just doing an ordinary job in an informed and common-sense way. We do, however, have one great advantage not shared by all rivers. We have a unified management from source to sea, and indeed right out to estuary limits.

Though there is nothing to stop owners of fishings on a multi-ownership river getting together to carry out improvements or to enjoy joint management, they would have to set up some sort of structure. This structure would require long-term stability because the work it would be called on to do would essentially have a long-term nature. That is why the District Fishery Board structure has served so well over the 100 years or more of its existence. The Board remains, though its members change from time to time.

5 The future

I passionately believe in the development of Scottish salmon fisheries, and I also believe in the District Board as the agency which should carry it out. As a representative body of both rod and netting interests, it can fairly look to the good of the river rather than merely to the good of one user section. However, this structure needs to be modernized, and to examine how this might be done I now have a Bill before parliament.

Whether my Bill or some other Bill is the one which parliament finally chooses to enact, any Act designed to modernize the management of Scottish salmon rivers will have to take account of 2 things. These are the following.

5.1 The just representation of users of the resource

At the moment, Boards only legally represent owners. However, in order to obtain the authority which they require and to maintain the consensus which is desirable, tenant anglers and tenant netsmen must also be represented.

I do not think that the roughly equal balance between netting and rod fishing interests should be disturbed, neither should existing representation of owners, whose views should by nature be more conservationist and long term than that of users, be swamped by newly enfranchised tenants.

I am also very opposed to outside, regional or national bodies being given any sort of representation on District Boards. Boards should be representative of owners and tenants who use and exploit the river resources which they administer and not of bodies with no direct interest in those resources. The representation of a tenant should be personal to the resource which he regularly exploits. In other words, this is the other side of the slogan 'No taxation without representation' which might be stated as 'No representation without contribution'.

5.2 Finance

Boards must be sufficiently strong financially to carry out the tasks which are allotted to them. They have to be able to hire and keep staff, and perhaps carry out improvement operations which can prove costly. The money for these tasks can only come from the users. It is unrealistic to hope that money is available from any other sources, which is why amalgamation of existing River Boards may be desirable, and also why District Boards should be empowered to levy direct from tenant netsmen and anglers.

On the other hand, it is not unreasonable to seek to stop the drain directly resulting from rating and taxation on the money generated from the resource by the users. On the Thurso, one fifth of the money taken from anglers as rent has to be used to pay Local Authority rates. The Local Authority then takes another series of bites and nibbles out of the angler's pocket by rating the hotel he stays at, the garage where he fills his car, the shop where he buys his tackle, and so on. All the angler gets back is the use of the roads for which he is already paying through his road fund tax and petrol taxes.

Nearly all of the rest of the money taken from anglers goes to pay for the sort of management which I have described. In fact, the average amount available from angling rents to transfer from the Rod Fishings Account to the General Account as a contribution to office and management expenses over the last 5 years has been a mere 1.9%. All the rest has gone in repairs and improvements, apart from the large slice which went to rates and this amount, of course, would never have paid for the cost of running the office even in the most profitable years.

Had it not been for the contribution from the estuary net, it would have been impossible to offer anglers the level of management which we do without a considerable increase in rents, and even then I doubt if they would have been willing to pay.

It can be seen therefore that, with the best will in the world, it will be difficult to provide the quality of management which Scottish salmon rivers need and deserve, unless we first provide them with a sound and representative structure, and secondly leave enough money in the hands of that management to enable them to do a decent job. It is indefensible to allow Local Authorities to continue draining river managements of their life-blood just because some people think that anglers are rich people. Anglers are not rich people; they are a cross-section of society, ranging from the very rich to the very poor, but most are somewhere in the middle. On the other hand, it is unrealistic to expect angling to be de-rated. However, something must be done and done soon to limit the effect of rates.

It is important to get the new structure of District Boards right and, in my view, there is one all-important consideration which should be paramount in shaping the new Boards. They should be made up of people directly interested in the river systems which they seek to serve. They should not have on them appointees of other bodies. They should keep, but bring up to date, the elective principle by which they are constituted, and they should broaden their franchise to include all users, both upper and lower income brackets, whilst maintaining a balance between the rod and net interests.

We shall never get absolute consensus, but it should be possible to reach agreement on some of the most important principles. Let us hope we do, because legislation is already 20 years overdue.

6 Summary

This paper aims to show that:

i. the first concern of a fishery manager is to maximize his smolt run, which calls for particular attention to the spawning and rearing areas of the river;
ii. a fishery manager should think of himself as serving both the sea netting and rod fishing interests of a river; and

iii. to achieve these 2 objectives successfully, a fishery manager requires control throughout a river system, with support from all the interests involved.

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The effect of the competition of farmed salmon in the market place on the present state of commercial salmon fisheries

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1 Introduction
This paper deals with the supply of and demand for Atlantic salmon over the last 25 years. It considers some of the main requirements for the successful marketing of wild and farmed salmon. It goes on to deal with the effect that the marketing of farmed salmon has had on the marketing of wild salmon, and the future significance of this relationship.

2 The general marketing situation
A review of salmon marketing has first to deal with the general supply and demand situation which provides the framework to that market. Table 1 indicates the general supply position for 1960–85. Of course, many of the figures are approximations, especially the wild catches for 1983–85 and some of the early farmed figures; nonetheless, they do give a fair overall picture from the marketing point of view.

The main facts about the supply of Atlantic salmon over the last 25 years are clear. There was an increase from about 10 000 t in the early 1960s to an expected 40 000 t in 1985. This increase was at first gradual, but accelerated rapidly since 1982 when the supply of farmed fish first overtook the wild catch.

The demand for salmon is not so easy to quantify as the supply. However, price is a measure of supply and demand, so the prices of the last 25 years reveal the trends in demand. Table 2 shows the ex-Montrose average prices of wild and farmed salmon and grilse for 1960–84. These figures, too, must be regarded as approximate, because so much depends upon size distribution, seasonal distribution, the supply of comparable commodities, currency fluctuations and many other factors. To assess the level of demand, it is essential to reduce these prices to a common level.

Table 1. Supply of Atlantic salmon in 1960–85 (tonnes) (source: ICES published catch statistics and personal information)

	Place of capture in the wild						
Year	Canada & USA	Baltic	Other European home countries	Feeding grounds	Total	Farmed	Total (wild and farmed)
1960	1638	2265	5575	60	9 538		9 538
1961	1585	2908	4819	127	9 439		9 439
1962	1721	2441	6763	244	11 169		11 169
1963	1863	2096	6296	466	10 721		10 721
1964	2071	2980	7198	1539	13 788		13 788
1965	2118	2884	6498	861	12 361		12 361
1966	2361	2424	6114	1370	12 269		12 269
1967	2865	2781	7554	1678	14 878		14 878
1968	2113	2930	6168	1535	12 746		12 746
1969	2204	2521	6288	3128	14 141		14 141
1970	2325	2283	5944	3104	13 656	10	13 666
1971	1994	2044	5640	3177	12 855	60	12 915
1972	1760	2162	6471	2628	13 021	350	13 371
1973	2437	2601	7315	2902	15 255	700	15 955
1974	2540	2928	6938	2310	14 716	850	15 566
1975	2487	3001	7053	2533	15 074	1 200	16 274
1976	2507	3045	5176	1504	12 232	1 800	14 032
1977	2547	2631	5205	1652	12 035	2 400	14 435
1978	1549	1995	4921	1159	9 669	3 500	13 124
1979	1289	2137	5040	1707	10 173	4 650	14 823
1980	2685	2506	5320	2067	12 578	5 650	18 228
1981	2443	2651	4827	2602	12 523	9 300	21 823
1982	1804	2157	4344	2350	10 655	13 450	24 105
1983	1425	2327	4831	1433	10 016	19 900	29 916
1984	1500	2300	4500	1500	9 800	26 450	36 250
1985	1500	2300	4500	1500	9 800	30 700	40 500

Table 2. Prices of Atlantic salmon in 1960–84 (£ kg^{-1}) (source: ex-Montrose)

Year	Average price wild salmon and grilse	Average price farmed salmon and grilse	Overall average price	Overall average price wild salmon and grilse converted to 1982 prices	Overall average prices converted to 1982 prices
1960	0·95		0·95	6·13	
1961	1·04		1·04	6·52	
1962	0·75		0·75	4·56	
1963	0·86		0·86	5·07	
1964	0·82		0·82	4·65	
1965	0·84		0·84	4·61	
1966	0·97		0·97	5·09	
1967	0·82		0·82	4·10	
1968	1·01		1·01	4·90	
1969	1·04		1·04	4·76	
1970	1·08		1·08	4·74	
1971	1·28		1·28	5·12	
1972	1·50		1·50	5·60	
1973	1·48		1·48	5·07	
1974	1·65		1·65	4·87	
1975	2·20		2·20	5·25	
1976	3·97		3·97	8·09	
1977	3·77		3·77	6·64	
1978	3·97	3·30	3·92	6·46	6·39
1979	5·53	3·77	5·16	7·92	7·39
1980	4·83	4·04	4·59	5·89	5·60
1981	4·06	3·15	3·86	4·41	4·21
1982	4·47	3·56	4·01	4·48	4·01
1983	4·18	4·06	4·10	3·97	3·90
1984	4·63*	4·30*	4·45*	4·21*	4·06*

* The 1984 figures are estimates

Otherwise, inflation makes it impossible to gauge their relative standing. The common denominator chosen is that of the 1982 price level. In column 5, the average price of wild salmon is multiplied by the inflation factor in order to convert all prices to the 1982 level. In column 6, the overall average price of wild and farmed salmon is similarly converted.

The first 16 years, 1960–75, represent a period of stability; there was a steadily increasing supply from 10 000 t to 16 000 t. Demand must have almost kept pace with the increasing supply. This trend would have reflected a rising standard of living, and the average prices of the first 5 years at £5.38 kg^{-1} (1982 prices) and of the last 5 years £5.18 kg^{-1} are little different. The little difference that exists is accounted for more than adequately by the change to early maturing fish that occurred between these 2 periods.

The last 5 years have been subject to some strong pressures. The current trend of decline in wild catches began in 1976 and was reflected by a much higher price of £8.09 (adjusted to 1982 level). A new high price phase lasted 4 years until 1979. But, in 1980, increased farmed production and the start of the Faroese fishery had a lowering effect. This trend continued in 1981 for the same reasons. However, the last 4 years seem to presage a period of greater stability. The price decline has halted and the average price for the 4 years 1981–84 (at 1982 levels) was £4.26.

In other words, salmon in the 1960s and early 1970s was priced at the same level as best beef steak. It is now much cheaper, at about the same level as leg of lamb, and is within the reach of a wider section of the population. The great question for those marketing salmon today is how much wider is this section of the population. The price stability in 1984 in face of a supply increase of 6000 t was most encouraging for salmon salesmen. It seems that a lot of new people are buying salmon, are liking it, and are buying more.

3 The marketing of wild salmon

Traditionally, salmon were something of a seller's market. Supplies were strictly limited; there were always plenty of people eager to buy and no great effort was required to dispose of the fish. It was well appreciated, however, that treatment was important and that the price depended on careful handling and getting the fish on ice and to the market as quickly as possible.

Originally, Scottish salmon were salted and packed in barrels; they were pickled and placed in kitts; and finally they were iced and packed in boxes (Stansfeld 1981). It is said that George Dempster, Laird of Dunnichen, first packed salmon in ice somewhere towards the end of the 18th century (George 1983). The main requirements for handling the wild fish were well defined (Holmes 1982). They involved careful removal from the net to prevent scaling, a quick blow between the eyes, immediate placing in a box to prevent soiling, drying or injury, icing at the earliest possible moment, careful handling and grading at the packing station, and immediate despatch to the customer.

The 2 principal sections of the Atlantic salmon market are the 'fresh trade' and the 'salmon smokers'. No Atlantic salmon is canned and all canned salmon is Pacific in origin. There are differences in the handling requirements of the 2 sections of the trade. Fresh salmon is best ungutted until a few hours before it is to be cooked; the fatty oils of the salmon flesh start to oxidize when they are exposed to the air. Gutting is therefore inclined to give fresh fish a rancid taste. Smokers prefer to have their fish gutted and also like them to be 'bled' (Davies 1984). The greatest enemy of the salmon smoker is blood. Blood turns black in the kiln whether in a bruise or in broken blood vessels. Gutting as soon as possible after death, and in particular removal of the kidney, allows the blood vessels in the belly to drain. This process is assisted by washing out the cavity with very cold water, causing the veins to contract and expel blood.

On the whole, Scotland has tended to specialize in producing fish for the fresh market, while Norway has specialized in producing salmon for the smokers. Scotland enjoys an advantage through being closer to the market. Distances make the gutting of Norwegian fish essential and their larger size also makes them popular with smokers. They tend to be appreciably cheaper than Scottish salmon and the rancid taste disappears in the smoking process.

In addition, there is a small market for frozen salmon, which is satisfied mainly by supplies from Greenland and the Faroes; not much Scottish salmon is frozen.

4 Special features affecting the marketing of farmed salmon

The most important special feature of farmed salmon from the marketing point of view is that they can generally be killed when needed so that they are available all year. It follows that the salesman will have a very fair idea of the proportions of the component size selections in each harvest. He is therefore able to approach his customers with some confidence in advance, negotiate a price, and should deliver his correct order to the customer on time. All this is very different from the 'hit and miss' affair of marketing wild salmon.

The price of wild salmon has been fixed each morning in accordance with prices prevailing in the country's main markets and the supply of fish expected that day. The price of farmed salmon can be fixed for a week at a time and can be notified to customers a week before the fish are due to arrive. This obviously has great advantages to both salesman and customer.

Some fish farmers have gone much further and have contracted to supply agreed quantities of farmed salmon at an agreed price months in advance. However, such speculating in commodity futures is a risk. It often ends in tears. It is seldom possible to foresee the market price and, when the contract comes to fulfilment, someone is likely to feel aggrieved. If there is a large divergence of price in favour of the supplier, the customer can be put out of business. He has contracted to buy expensive fish at a time when his competitors are buying at the cheap market price. He is likely to do eveything he can to break his contract.

The salmon farmers' association has produced a quality standard specification for farmed Scottish salmon (Anon 1982). The main requirements of the association's quality standard are straightforward, ie starving to empty the gut effectively, and icing within 2 hours of killing. If the fish are gutted, this must be done as soon as practicable and all internal organs including the heart and kidney should be removed. The belly cavity must be washed with clean, cold water and the salmon held in clean, iced water for at least 30 min to allow the blood to drain out. Gutted fish are to be packed ventral side down, ungutted fish with the belly up.

5 Effects of farmed salmon on the marketing of wild salmon

The first effect of farmed salmon on the marketing of wild salmon has been a price change. The best way to detect and evaluate this price change is to convert the average wild salmon prices in Table 2 into 1982 values. It can then be seen that the average price for the stable period 1960–75 was £5.07. The first 4 years of the period of declining wild catches were offset by an average price in 1976–79 of £7.28. Wild salmon producers were shielded by this real rise in prices and did not fully appreciate the change of circumstances until 1980 which was a year of transition. The average price of the last 4 years 1981–84 has been £4.26, and it does seem possible that it will stabilize again around this level.

The second great pressure brought to the marketing of wild salmon by the advent of the farmed variety is the quality standard being practised by many of the salmon farmers. It was always customary to grade out secondary fish from the catch and to send them to the auction markets and not to regular buyers. However, many salmon companies did not grade their fish into size selections, but would pack salmon 8–15 lb (3.6–6.8 kg) and grilse 3–8 lb (1.4–3.6 kg) and insist that any buyer took a full range of sizes. The large fish of 15 lb (6.8 kg) and over were usually sold separately to smokers. This practice has largely ceased and most salmon companies now grade their catch into the following size selections: under 2 lb (0.9 kg); 2–4 lb (0.9–1.8 kg); 4–6 lb (1.8–2.7 kg); 6–8 lb (2.7–3.6 kg); 8–10 lb (3.6–4.5 kg); 10–12 lb (4.5–5.4 kg); 12–15 lb (5.4–6.8 kg); and large (over 15 lb (6.8 kg)). There is some pressure to change to the equivalent kilo grades, but there is a lot of resistance to this conversion especially among retailers and wholesalers, and it is not likely to come about in this country in the immediate future.

The grading into size selections is only the tip of an iceberg so far as quality control is concerned. Intelligent netsmen are appreciating that the whole system of handling salmon after they are caught must be put under an exacting review, if they are to compete with the farmed salmon. The killing must be done more carefully. Service boxes must be clean and hygienic. The fish must be placed in them and iced as soon as they are caught. In summer, the sea is a warm environment and it is essential to ice up the fish within half an hour of landing them. At the packing station, they must be graded conscientiously and handled gently as bruising can occur until rigor sets in. If the fish are going on a long journey, polystyrene boxes should be used as their insulating qualities are superior.

The marketing fundamentals have changed for the netsmen; it is no longer a seller's market and, if a buyer does not like someone's fish, he can get plenty more elsewhere.

Other changes in the wild market have also been brought about by the farmed salmon. Prices are much more stable. The great fluctuations that used to occur are a thing of the past. The market is stabilized by a constant supply of farmed salmon that is sensitive to market conditions; it can increase to meet an increased demand such as at Easter or before a holiday. Many people are prepared to pay more for a good quality wild fish, but not so very much more.

Another major change is the shrinking of the trade in frozen salmon. A lot of grilse and summer salmon were frozen to meet demand in the close season and at times of scarcity during the season. Farmed salmon are now always available. Most people prefer fresh farmed salmon to frozen wild fish and the trade in frozen salmon has collapsed.

Prices of sea trout have been affected at the same time as those of wild salmon. It is hard to say whether this has happened because of the regrettable practice of calling rainbow trout reared in sea water 'sea trout', or whether the early marketing of small farmed grilse has had something to do with it. It is an offence to describe rainbow trout (*Salmo gairdneri*) as sea trout (*Salmo trutta*), but this has not prevented the ruthless and the ignorant from doing so.

6 Future prospects for the marketing of farmed salmon

It is certainly unwise to gaze into the crystal ball and predict the future of farmed salmon. Nevertheless, it is an entrancing prospect and temptation is not easily resisted.

It seems likely that farmed salmon are here to stay and that their supply will increase greatly. The harvest of 1985 is now relatively clear and is predicted at about 30 000 t. The great question is how far will the supply increase thereafter. The best sites for fish farms are now occupied and it is becoming more difficult to find new ones, and these are riskier and more expensive to operate. It is still fairly safe to predict a steadily increasing supply over the next few years, but it is not possible to predict the level at which supply will stabilize. It is likely that some outside factor such as increased food prices or disease might step in and call a halt. At that stage, producers would have to consolidate their position and supplies might decrease again.

The market is being greatly widened. People who have never seen salmon before are now eating it; this may be because of geography, for financial reasons, or just because there weren't enough salmon. But European salmon are going to the Americas, to the Mediterranean countries and to people on housing estates who thought salmon only came in tin cans. Salmon are soon likely to be exported to the Middle East and to Africa. This widening of the market greatly increases demand and is the reason for recent stability in the face of steadily increasing production. The probabilities are that demand will keep pace with supply and may even outstrip it and cause prices to rise again. All the indications are that there is a very large market indeed.

The market is completely dependent upon transport. Scottish producers are still slow to appreciate this factor, and when there is more co-operation to secure better transport facilities, demand and prices can be expected to increase.

Packaging for air freight is another art still in its infancy. Fresh fish travelling on ice are not viewed favourably by airlines. Nevertheless, the Norwegians have produced new packaging that lays the American market at their feet. A visit to Fulton Market in lower Manhattan demonstrates the extent of this penetration. This area of packaging will be very important to the future, and the successful marketing of salmon in distant places will depend upon the technical standards reached with packaging materials.

Grilse are another problem area for salmon farmers. Fish maturing at the end of their first sea year must be killed. Unfortunately, the fish are small, they appear at a time of glut, and they are coloured. Prices for them are poor and seldom equal the cost of producing them. They are generally sold at a loss. Needless to say, salmon farmers are trying hard to reduce the proportion of their fish that mature as grilse. Scientists have produced numerous ingenious schemes for eliminating early maturation, including castration, chromosome adjustment, sex change and sterility. However, selective breeding is slowly eliminating the problem. It appears that there is an inherited element in the grilse characteristic, and careful breeding from late-maturing fish is reducing grilse numbers to an acceptable level. This achievement is a good sign for the future.

It may be possible to improve handling further. In Norway, farmed fish are made torpid by CO_2, or very cold water, and killed by bleeding. When the fish are split for smoking, there is virtually no blood at all. Smokers report that the cleanliness of these fish visibly and bacteriologically is impressive (Davies 1984). It is not likely that this practice will be copied in Scotland where humane killing methods are favoured, but technical advance should allow humanity and hygiene to co-exist.

7 Future prospects for wild salmon

There has been a lot of loose talk about the effect of farmed salmon on the market for wild fish. Some simplistic journalists have suggested that massive supplies of farmed salmon will make netting wild salmon uneconomic and eliminate poaching by destroying the financial incentive. Such assertions are as wide of the mark as those of traditionalists who ignore farmed salmon and want life to go on as before.

The truth of the matter lies between these extremes, and it is not easy to judge the level at which things will settle down. The analysis of the situation in this paper suggests some answers to the question. The average price for wild salmon at 1982 levels is settling down around £4.25 kg^{-1}, and this figure compares with an average price of £5.07 before 1975. The difference is substantial, and it has already had an effect upon the netting industry. Marginal stations which tend to be a distance from rivers have closed and other stations work a shorter season. This means that the netting effort has reduced considerably and so has its catch. It has also resulted in a greater concentration of the netting effort around each individual river. Both these factors reflect the recommendations of the Hunter Committee (Committee on Scottish Salmon & Trout Fisheries 1965, paragraphs 56 and 82).

It does not seem likely that prices will fall further, and they may even recover to some extent. The recovery will depend upon the ability of netsmen to improve their quality control and fish handling methods.

If we pass on to the effect of farmed salmon on anglers, we see there must be a new opportunity. A substantially lower proportion of the returning fish will be caught by netsmen and a larger proportion will be available for anglers.

There has not been much sign of this change so far, because for every legal netsman who has closed down, 2 or 3 illegal drift netters have appeared in his place. As the legal netsmen made a large contribution to Fishery Board law enforcement and the drift netters do not, the end result has been worse and not better. The anglers have an opportunity to catch more, but it will only be realized if they are prepared to pay at least as much as the netsmen who have been displaced. The fishery assessment method of revenue raising is subject to the crippling double rating of rod fishings at present operating in Scotland, and if this system cannot be ended, it seems that the only way to raise the replacement revenue would be through rod licensing.

The other major effect of farmed salmon on anglers is the possibility of 'put and take' salmon angling. There have been some successful experiments already. The supply of wild salmon angling can hardly increase, but 'put and take' salmon angling could provide a new angling opportunity for many who are unable to afford the increasing prices being paid for the wild sport.

The belief that salmon farming will discourage poachers is a complete illusion. Prices will never fall to such a level that it will not be a temptation to reap a harvest at very small expense. Poachers will always be with us. Talk to the contrary is damaging because it encourages a 'do nothing' attitude. It is essential that Fishery Boards should be reformed so that effective law enforcement runs the length and breadth of Scotland.

Salmon farming does offer one very great opportunity for the future. This opportunity is the ranching of Atlantic salmon. The bottleneck in wild salmon production is feeding space in fresh water. The rivers of Scotland are only able to produce the number of smolts for which they have food available. This bottleneck can be bypassed through salmon culture. Smolts can now be produced in rearing units cheaply and easily. Salmon ranches could increase enormously the supplies of wild salmon. Alas, government inaction closes the door to this great opportunity for investment and employment in the future. It allows intercepting fisheries such as that of north-east England to reap a harvest sown by others. On the other hand, the government will not modernize Scottish Fishery Boards responsible for law enforcement, with the result that poachers flourish. No-one can invest in salmon ranching until they can see a legal framework that will protect their investment and give them a reasonable chance of obtaining a return.

8 Summary

The supply of Atlantic salmon in 1960-85 has been tabulated and compared with average prices adjusted for inflation over the same period. A period of stability is apparent in 1960–75, followed by a time of fluctuating supply and price in 1976–81. Since 1981, supplies of farmed salmon have increased rapidly but prices have stabilized again at a level about 15% lower than during the period 1960–75. These lower prices have contributed towards a contraction in the salmon netting industry and more competition has resulted in higher quality standards. The full potential of salmon culture is not being realized, owing to political failure to legislate for the new opportunities.

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Salmon farming and the future of Atlantic salmon

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1 Introduction

In this paper, we detail some of the recent findings from studying farmed salmon. We discuss how some of these findings could be applied to the management of wild stocks. We accept that the interests of those involved in salmon culture or wild salmon management are different. On the one hand, fishery managers operate hatcheries to produce fish for stocking, while, on the other, commercial methods are applied to produce an animal for the table. Magazines read by anglers and fishery managers seldom mention fish farming, while those for farmers usually acknowledge the existence of wild fish only in the section relating to market prices.

Salmon farming has become a commercial reality in the last 20 years. More than 15 M Atlantic salmon were harvested from over 400 sea farms in Scotland and Norway in 1984, and output in Scotland is expanding at some 50% a year (Figure 1). This new industry has given a major impetus to research into Atlantic salmon. Much has been learned about growth patterns, survival and maturity simply by observing and establishing the precise requirements of salmon throughout their life cycle. This knowledge is now successfully used in commercial salmon rearing but the rapid growth and development of the industry have not been fully documented in the scientific literature.

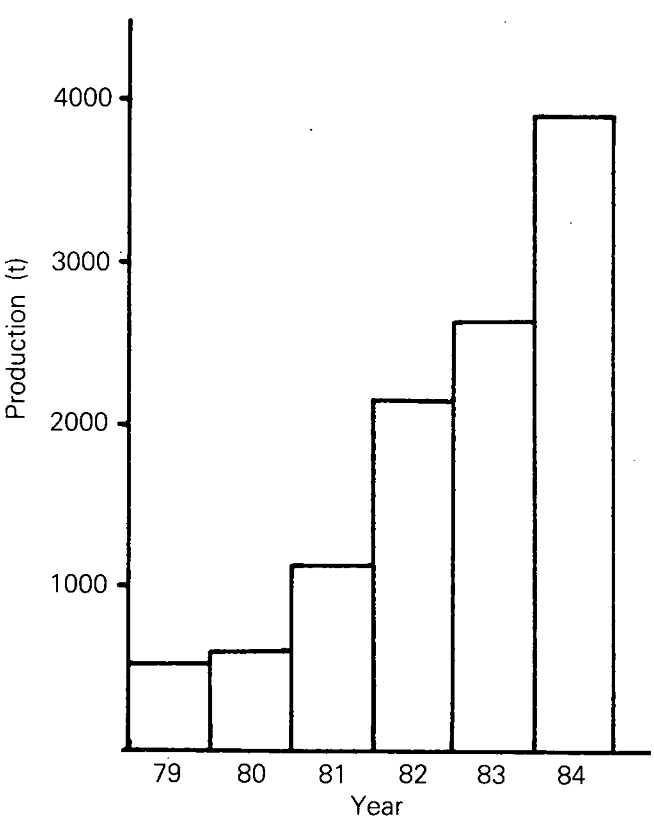

Figure 1. Production of farmed salmon in Scotland (source: original data)

2 Shared resource: genes versus environment

At the start of salmon farming, both parties had to co-operate. Initially, all farmed salmon were grown from ova stripped from wild fish. Now, over 80% of farmed fish are bred from ova derived from farmed broodstock, because the broodstock needs to be certified free of certain disease agents that can be readily picked up in the wild. Also and more importantly, quantitative strain differences are being recognized that need to be either retained or bred out in the farmed animal.

For example, Gjedrem (1979, 1983) found big growth differences in offspring derived originally from over 100 Norwegian rivers. The demonstrable fast-growing strains from rivers like the Namsen and Alta are proving extremely valuable on Norwegian salmon farms. Ova that originated some 3 or 4 generations ago from farmed broodstock from these better strains fetch a premium.

In Scotland, growth differences between strains have not been studied with such precision, though some results are available. In 1970–71, Unilever Research found that in fresh water salmon hatched from ova from the River Shin grew faster than those from the River Helmsdale. Indeed, Shin stock are still highly favoured amongst Scottish salmon farmers. Growth differences between strains also exist when these are reared in sea water. At Landcatch in Argyll in 1983, fish of Shin origin grew faster than those from the North Esk.

In the light of these differences, most fish farmers who operate hatcheries as well as sites in sea water are developing their own 'in house' strains, although the origins of the strains become less and less certain with each succeeding generation.

Gjedrem and Aulstad (1974) have found differences between strains in the ability of salmon to resist vibrio disease in sea water. Disease resistance in salmonids is well understood following the studies of Snieszko and colleagues in the USA on furunculosis in the brook trout (Snieszko *et al.* 1959). Also, while Norwegian strains of Atlantic salmon imported to Scotland are susceptible to the condition known as proliferative kidney disease (PKD), native Scottish strains reared alongside Norwegian strains on 2 Scottish salmon farms have so far remained resistant to the disease. The species most susceptible to this disease is the

Plate 1. Electro-fishing for salmon parr in a typical highland nursery stream. Collectively, streams like this are of major importance to salmon production in Scotland
(Photograph DAFS)

Plate 2. Each of these 4 m tanks at a salmon farm in north-west Sutherland contains about 5000 smolts in winter. In early spring, they are transferred to sea cages
(Photograph J Johnston & Sons Ltd)

Plate 3. Angling for salmon on the River Dee, Aberdeenshire. Except for seine netting, this is the only permitted method of catching salmon within estuarial limits in Scotland
(Photograph DAFS)

Plate 4. Fishing for salmon by net and coble (seine netting) in the estuary of the River Dee at Aberdeen
(Photograph DAFS)

exotic rainbow trout, which in both Scotland and the south of England can suffer mortalities of some 75% of total stocks in 2 months.

Coupled with variations in growth and susceptibility to vibrio disease, Gjedrem has also noted differences in the ability of various strains to take up carotenoid pigment in their flesh.

In Scotland, Thorpe and co-workers at Pitlochry have isolated strain differences in growth in fresh water, and in the percentage of first and second year smolts and precocious male parr (Thorpe 1977; Thorpe & Morgan 1978; Thorpe *et al.* 1980). It is hoped that, as with brown trout, strains tolerant to low pH will be identified and used to advantage on both salmon farms and for stocking waters affected by acid precipitation.

The most important strain differences to be found on salmon farms concern the proportion that mature after one year in the sea, ie grilse. This is normally termed the grilse rate:

$$\text{Grilse rate (\%)} = \frac{\text{Number of grilse}}{\text{Total surviving stock}} \times 100$$

Information on the grilse rate of different strains is crucial to the salmon farmer because farmed grilse are harvested at the same time as wild grilse, when prices are at a minimum.

Despite evidence that the grilse rate is genetically determined, environmental influences can largely over-ride the inherited characteristics of a stock. For example, in Irish salmon farms, salmon of any origin or parental maturity characteristically produce a 95–100% grilse rate, whilst in Norway the grilse rate of fish from the same stocks is generally between 5% and 10% (Naevdal 1983). On the other hand, some stocks of Norwegian origin reared alongside Scottish strains in Scotland will give grilse rates as low as 1% compared with 35% from the Scottish. Grilsing rates are also influenced by the smolt age, 2-year-old smolts (S2) giving higher grilse rates than one-year-old smolts (S1). This rate might be sex-related as both S2 smolts and grilse are predominantly male: up to 90% of farmed grilse may be male.

Table 1 shows (i) that salmon which originated from ova from the River Thurso had the highest grilse rate,

Table 1. Proportions of grilse (%) in batches of 800 farmed salmon (source: unpublished data; Alderson, pers. comm.)

River of origin	1980 Site A	B	1981 C	D	1982 E	F
Thurso	16	40	42	36	43	39
Shin	10	15	17	23	–	36
Don	1	13	10	9	22	21
Spey	8	18	18	12	–	–

and (ii) that ova from the River Don produced the lowest proportion of grilse at different sites in 3 different years. However, in stocks from both Don and Shin, higher proportions of grilse were produced in 1982 than in 1980 and 1981. It might be concluded that there were differences between years, 1982 being a higher 'grilsing year' than 1980.

Against this background of overall population characteristics, individual parents influence strongly whether offspring become grilse or salmon. Table 2 gives results of experimental crosses (Alderson, pers. comm.). Two sea-winter (2SW) fish produced offspring with a low grilsing potential. Grilse crossed with grilse produced populations with a far higher grilsing potential. Most importantly, the use of a grilse male on a salmon female produced half as many grilse as from a crossing of grilse with grilse.

Table 2. Effect of grilse or salmon parentage on grilse percentage (using S1 smolts) (source: original data)

Parent Male	Female	Site (same year) C	D
Salmon	Salmon	4	7
Grilse	Salmon	20	18
Grilse	Grilse	43	44

Some evaluation and identification of stock characteristics, such as disease resistance, growth, and timing of maturity, are being carried out in the process of searching for the ideal farmed fish. This new information, particularly on the grilsing character of strains or individuals, is helpful in relating to wild stock management. A major problem in controlling the exploitation off wild stocks is that of apparent population fluctuations which may be caused by year-to-year variations in grilse rates. When the degree of genetic control and the precise environmental influences can be established in artificial culture, unnderstanding the relative abundance between years and stocks of wild grilse and salmon will improve.

3 Life cycle studies

During the 2 centuries since Jacobi first fertilized and incubated salmon eggs in 1763, knowledge gained from captive fish has been applied to the better understanding of salmon in the wild. In the early part of the 19th century, one of the biggest problems facing those concerned with the preservation of salmon and trout was the confusion over the relationship between the salmon parr (also known as a samlet) and the returning grilse and adult salmon. Some writers held that the samlet was a separate species and that its conservation would be of no benefit to the salmon stocks. What came to be known as the 'parr question' was resolved through the culture of eggs taken from adult salmon and reared to the smolt stage by Mr Shaw of Drumlanrig (Shaw 1836). From this experiment, the importance of unobstructed passage for spawning adult salmon to areas of spawning and nursery ground where the parr were found came to be understood.

3.1 Eggs and alevins

Concerned at the poor return of adult salmon from hatchery-reared smolts compared with wild ones, Marr experimented, first at the DAFS Freshwater Fisheries Laboratory, Pitlochry, and later at Unilever, on the development of artificial rearing conditions to produce large salmon fry with a high survival rate (Marr 1967). From his and subsequent work in other hatcheries, the following factors have been shown to be important.

3.1.1 Egg size

Large eggs are produced by female salmon of 2 or more winters in the sea. A high proportion of the smolts developing from the smaller eggs produced by female grilse will become smolts a year later than those derived from large eggs, ie they will be S2 smolts rather than S1 smolts.

3.1.2 Surface

Eggs should be incubated on a rugose surface with an up-welling current. The surface is usually perforated metal or corrugated plastic which enables alevins to rest on their sides. At this stage, growth is entirely based on conversion of yolk into body tissue. If activity is minimized, less energy is used to maintain position and more yolk is converted into body tissue. Marr found that incubation on a rugose surface increased weight by up to 20% at the end of the yolk sac phase (first feeding), compared with controls on a smooth surface.

3.1.3 Incubation

Incubation in the dark also reduces energy wastage and increases weight at first feeding. Alevins, which in the wild would be in the dark under gravel, are highly active if their incubation trays are not protected from the light. They are negatively phototaxic and actively try to swim away from the light, searching for refuges in the dark.

3.1.4 Water temperature

The basic degree-day concept relating development to water temperature has been refined, and it is now known that fewer degree-days are required for development at low temperatures. An optimum pattern of change in temperature during incubation has been developed to produce first-feeding fry in February from eggs stripped in November. The optimum temperatures are 8°C for green eggs, 10°C for eyed eggs, and 12°C for alevins.

Over-heating the water at the time of first feeding can have the unwanted effect of producing precociously maturing 0+ male parr.

3.2 First feeding

The transition from endogenous to exogenous nutrition used to be carried out in shallow hatching troughs. Mortalities from starvation in excess of 40% were experienced. Then 1 m^2 tanks were introduced and mortalities were reduced to around 15%. By feeding in circular tanks up to 4 m diameter with a water depth of 0·6 m, mortalities can be reduced to less than 1%.

This highlights the need for information on the precise environmental requirements of Atlantic salmon fry. Survival is high if abundant food is carried to the fish on fast currents (equivalent to one body length s^{-1}), but any divergence from optimum conditions results in death from starvation. Mortality rates in the wild are thought to be as high as 90%. The farm successes indicate that all the lost fry are potentially viable. Fry being put into a river for stocking operations should be carefully placed in riffles and not, as is often the case, simply tipped into the stream off the most convenient road bridge! It is likely that the main cause of poor survival from stocking unfed fry is starvation, or, more precisely, predation by pool-dwelling fish such as large brown trout on fry weakened by starvation.

3.3 S1:S2 ratio

Eggs from an individual hen fish show little variation in diameter. Size differences between siblings which give rise to the bimodal distribution observed in the length of parr are apparent at or shortly after first feeding. However, manipulation of environmental conditions can result in wide variations in the numbers of fish from a given batch of eggs, which end up in the faster or slower growth mode, and consequently as S1 or S2 or even older smolts. Factors tending to produce low numbers of potential S1 smolts include inadequate feeding, high stocking densities, cool summer weather and generally poor husbandry and holding facilities (Saunders *et al.* 1983). In optimum conditions, 95–100% of parr can become S1 smolts. Ideally, the water flow and depth should be kept constant in the smolt rearing tanks, and grading and thinning should be carried out to keep the biomass approximately constant and to enable food of the appropriate particle size to be supplied. Salmon parr prefer to feed just below the surface, and delivery of food in precisely the right place can greatly enhance growth performance.

3.4 Precocious parr

During the early days of commercial rearing, it was discovered that, when 'forcing' eggs and fry in heated recirculating water systems, up to 20% of parr in a tank would mature at 0+ age. These were always male fish. In the second year, after grading out the S1 smolts from the tank, up to 70% of the remaining parr would be precociously mature males, indicating that the majority of S1 smolts were female. Under natural conditions of temperature and photoperiod, maturity at 0+ is very rare. Although precocious parr appear to smolt normally, some do not fully smolt until later than normal smolts and will not survive early transfer to sea water.

3.5 Requirements for growth in fresh water

The optimum conditions for growth in fresh water are continually being studied. So far, the main information available is in response to light and flow conditions. For example, light requirements have attracted some attention. Salmon maintain station in mid-water in as little as 0·2 lux light level but may require 50 lux to see food. Two tank environments can be provided, a dark area for the fish to lie in and a lighted area where the food is given. Peak feeding times are around dawn and dusk.

Care is taken to produce stocking and flow conditions where the fish will 'stack' in mid-water in a 3-dimensional shoal. In a 3–6 m diameter tank with an operating water depth of 1 m, a flow of 4 l s^{-1} is ideal. This reduces growth differences between the largest and smallest in a tank and also minimizes aggression and fin rot. Up to 6000 healthy smolts can be produced in a 3–6 m diameter tank of 1 m depth. In the wild, an area of stream bed the size of a smolt tank (approximately 10 m^2) might produce one or 2 smolts. However, the occupation of water volume is not usually considered in estimates of the potential of streams for smolt production. It is interesting that most strains of brown trout remain on the bottom in tanks and cannot be made to stack in the same way as salmon (Walker, pers. comm.).

3.6 Transfer to sea water

From this stage in the life cycle onwards, commercial farming gives us totally new information for use in salmon management. In the wild, smolts disappear for 1–5 years to sea where little is known of their day-to-day behaviour, diet, feeding habits and diseases. Experience has shown that, provided conditions in fresh water have been adequate, smolts can be transferred directly from fresh water to sea water at any time between mid-April and the end of June, the time during which wild smolts enter sea water. The rapid pre-smolt growth in fresh water, which begins when water temperatures pass 6°C, continues at the same rate in sea water. The time of transfer in the period between mid-April and the end of June has no effect on the size the fish attain at the end of September. Death following the failure of osmoregulation after transfer is often associated with temperatures of less than 8°C.

From the beginning of the rapid growth phase in fresh water, smolts are susceptible to any disease associated with physical damage. Scales are easily removed by handling or abrasion during transfer, resulting in diseases such as fin rot. *Saprolegnia* infections and furunculosis occur secondarily to the skin damage. In the wild, predators such as mergansers, cormorants and terns may damage salmon smolts which die later from such diseases. Although tagging of smolts has provided almost all the information available on wild salmon at sea, it involves handling. The returns of adult fish marked with microtags have been shown by Icelandic scientists to be higher than the returns of fish marked with Carlin tags (Isaksson & Bergman 1978). It appears that any reduction in handling can reduce mortality.

3.7 Growth in sea water

Through July, August and September, a normal post-smolt salmon will double its weight every month; for example, a salmon smolt which weighs 40 g when it enters the sea in mid-June can weigh around 350 g by the end of September. At this stage, the salmon are not laying down any fat. The fat content of smolts is about 4% and does not begin to increase until September. A useful indicator of when fat storage begins is retention of carotenoid pigment from the diet. The pigment, which is derived from crustaceans in the food, colours the flesh pink as fat content increases. Where no fat is stored, no pigment is retained and the flesh remains pale in colour. In the wild, young salmon caught in spring, a year after smolting, are pink-fleshed, although at this time they are feeding on fish. It is therefore likely that their autumn diet was crustacean, giving them their pink flesh while fat was being deposited.

The observation that smolts have extremely low fat reserves at a time when metabolism is highly active, following introduction to sea water, indicates that the migration in the wild must be accomplished along routes where the food supply is abundant.

Sensitivity to light is maintained through smolting into the sea water phase of the life cycle. Where salmon are raised in sea water ponds on land, the salmon will seek any shade or cover available in preference to open areas. In cages in the sea, salmon will only pass into the top of the water column when actively feeding. It seems that salmon avoid the sea surface. However, as cage facilities rarely exceed 6 m depth, it is doubtful if cage rearing tells us anything about preferred depth at sea. Farmed smolts released into the sea appear to go down immediately out of surface waters, but this is a common alarm response of any fish upon release into a new environment and may be related to the possibility of predation.

Growth of post-smolts in sea water slows down in the autumn with decreasing water temperature. By the year end, the fish should average more than 800 g, with a size range of between 100 g and 2 kg. At this point, there is no evidence of a bimodality separating potential grilse from potential salmon. At water temperatures as low as 2°C, they continue to feed. It appears that the biggest fish entering the winter months will feed and grow better during the winter than the smaller ones. By the end of winter, 2 groups can be separated by weight, the heavier fraction being the potential grilse.

After one year of growth in sea water, the weight of farmed grilse varies between 0·5 kg and 4 kg, averaging around 2 kg, as shown in Figure 2. The largest farmed grilse do not quite reach the 6+ kg weight of the largest wild grilse, though the overall mean weight is close to the wild.

In sea water, deaths occur through failure of the holding facilities rather than through disease. Most farms harvest the fish which have not become grilse after their second winter, irrespective of their state of maturity at the time. However, where salmon are kept for longer, it has been noted that, in populations where grilse proportions are low, maturity of 2SW fish is also low, with a relatively high proportion maturing as 3 or more sea-winter fish. After 2 growing seasons in the sea, the largest fish can weigh 10 kg, with maturing fish larger than non-maturing. Mature fish decrease their food intake while still in sea water but do not cease feeding until 2–3 weeks before gonad maturation is complete.

4 Water quality

Most salmon farms are situated in waters containing natural stocks of salmon. The requirements for high water quality standards are the same for the farmed and wild stocks. Equipment monitoring water quality (pH, dissolved oxygen, and silt), designed to protect the substantial investment of the fish farmer, may also help protect the wild stocks by rapid identification of the onset of any pollution. Potential adverse interactions between captive and wild stocks need to be carefully controlled.

Mortalities in hatcheries can occur in spate conditions when suspended solids rise to levels exceeding 500 ppm. In heavy rain, particularly after periods of drought and especially at snow melt, the acidity of the water supply can suddenly drop below pH 5 in areas where the natural buffering capacity of the water is poor. At this level, hatching is impaired and mortalities exceeding 50% can occur perhaps by inactivation of the hatching enzyme. As a result, it is now routine practice at some salmon hatcheries to add lime continuously to the water to hold the pH above 6. Also, addition of calcium ions buffers out much of the toxic aluminium that may be the cause of the problem.

Acidity and high aluminium also affect parr and smolts. There can be severe damage to gill epithelium and a

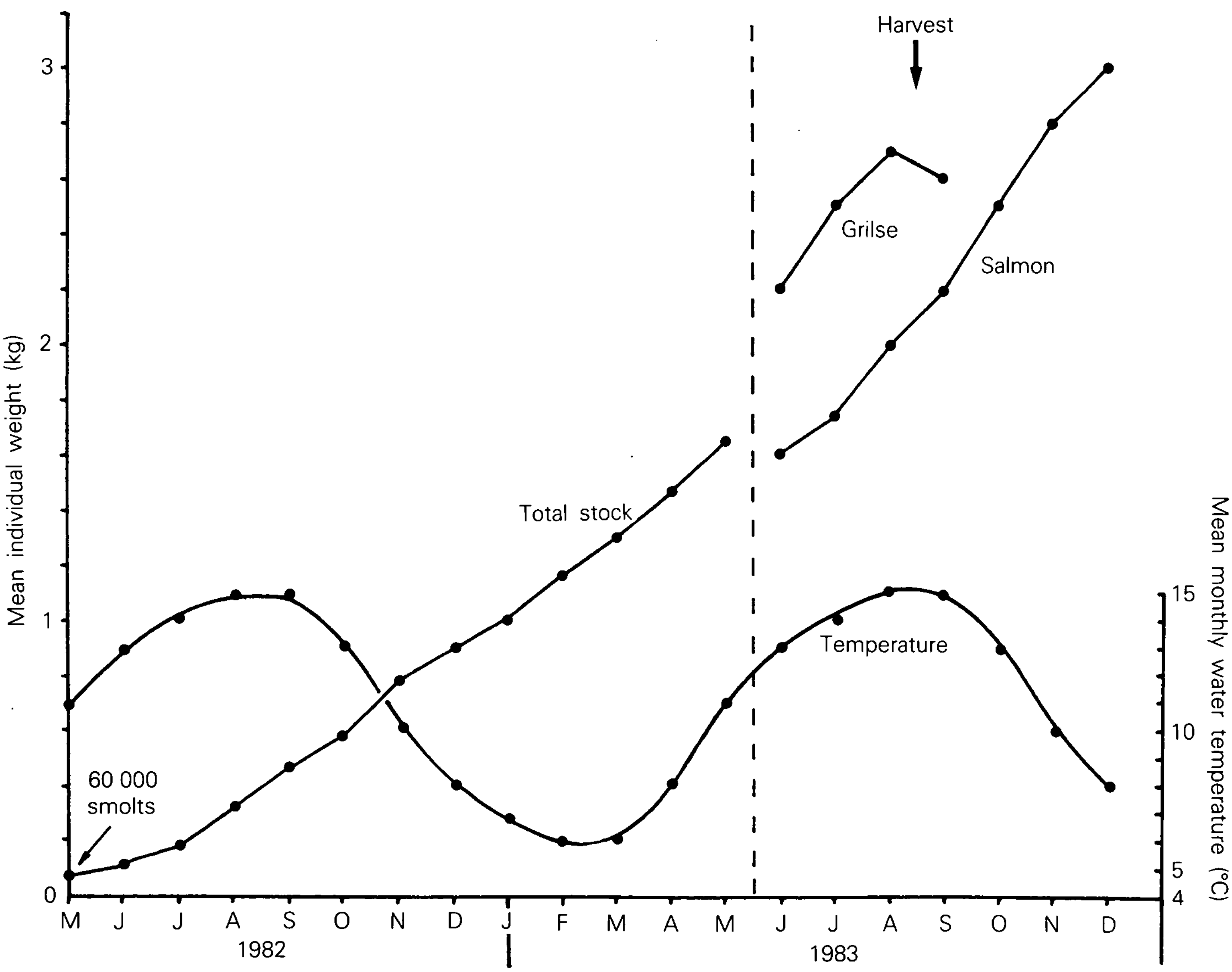

Figure 2. Growth of salmon in sea water tanks (source: original data)

consequent failure of smolts to osmoregulate satisfactorily on entering sea water.

Both suspended solids and low pH may affect the eggs and other freshwater stages of wild salmon. So far, the effect on salmon stocks is unquantified. Many fish farms continually monitor pH, and the Scottish National Farmers' Union has proposed that fish farmers should co-operate with DAFS and the River Purification Boards (Burns *et al.* 1984) in building up a picture nationwide of the effect of acid precipitation on salmonids. After all, the salmon farm is an ideal natural monitor of water quality and should be used as such.

5 Salmon farming and wild salmon

The new commercial fish culture technology, which developed to provide a high-quality fish directly to the table market, is now influencing approaches to production of eggs and fish for augmenting or sustaining wild stocks where natural recruitment has declined. Increasingly, some farmers are specializing in production of high-quality smolts which are sold for on-growing in farms and for ranching and supplementing of wild stocks. We anticipate a close relationship developing in the future between salmon farming and management of wild stocks through such activities.

It is interesting to observe that in Sweden and Scotland 2 totally different approaches were taken to mitigating the effects of the hydro-electric dams. In Scotland, an immense amount of effort and money was expended on building fish passes to give the fish the option of passing upstream to their spawning areas. As many spawning areas were now flooded and therefore useless for spawning, the riparian owners were compensated financially.

In Sweden, the approach was to build hatcheries wherever possible. Indeed, the successful development of hatchery technology in Sweden laid the foundations of salmon farming in Scotland and Norway. Through controlled and successful smolt releases on a large scale in the Baltic, the salmon fishing there has been sustained: 50% or more of the Baltic salmon population is now maintained by hatchery rearing (Larsson 1980).

In Iceland, salmon stocking policies were taken further. Gudjonsson (1978) reports that rod catches in the 250 rivers increased until the end of the 1970s. In 1897–1909, the average catch was approximately 5000 salmon. From 1910 to 1950, there was a steady increase, with the annual catch averaging about 15 000 due to a near total ban on netting at sea and in the estuaries, and to increased fish cultural facilities. The rod catch of Icelandic salmon continued to increase, with the annual average for 1970–75 reaching 64 000. This big increase was ascribed to the practice of releasing fed parr and smolts rather than unfed fry in the rivers and to the opening of new areas of rivers for spawning. However, despite the 12-fold increase in catches, it must be remembered that records of rod catches may not relate directly to stock levels because of changes in fishing effort from year to year.

In contrast, the advances in salmon culture pioneered in Sweden and Iceland have not been applied to any great effect in Scotland, although they are now used to great commercial advantage in the salmon farming industry overseas. Stocking policies in Scotland have barely changed this century. In some cases, there is mutual suspicion between farmed and wild salmon interests where instead there should be co-operation.

Salmon ranching has not been successful in Scotland. At both Ormsary in Argyll and in North Uist, fishing returns of farmed smolts in 1984 were less than 1% of fish released. In Scotland, a 40 g smolt currently costs at least £1.00 to purchase. Grilse prices are about £2.50 kg^{-1}. In order to break even at these prices, a ranch must harvest at least 40 kg for every 100 smolts released. Assuming an average grilse weight of 2·5 kg, that is 16 fish. To be profitable, consistent returns above 20% of fish released must be assured. The high price of smolts may be determined by current high demand from farms, but a shift to ranching is unlikely as long as more reliable profits can be made by growing fish in captivity.

Therefore, the fears that many genetically foreign smolts will be released into the sea off Scotland are as yet unfounded. It is just not commercially realistic even though it is legal, as demonstrated at a recent test case in North Uist.

On the other hand, salmon farming is here to stay. In 1986, it is expected that 10 times more salmon will be produced on farms in Scotland and Norway than will be fished and netted from the wild. The demand for salmon continues to expand ahead of supply. Fish farmers and people interested in wild salmon should be working together. After all, it has to be in every conservationist's interest that the bulk of commercial salmon is raised on farms rather than hunted by nets, particularly those operating on mixed populations of salmon where there is no possibility of regulating the exploitation of individual breeding stocks. It has to be good news for wild salmon that farmed salmon dominate this expanding market and set their own prices all the year round.

6 Summary

6.1 This paper describes some of the main features of the growth and requirements of salmon learned from salmon farming that could be applied to the management of wild stocks.

6.2 Big differences in growth rate have been found in offspring derived from different Norwegian and, to a lesser extent, Scottish rivers. These differences, and also differences in susceptibility to some diseases, are genetic. There are also 'strain' differences in the taking up of carotenoid pigment, in the proportions of S1 and S2 smolts, of precocious male parr, and possibly in tolerance to low pH.

6.3 However, environmental influences largely override inherited characteristics, particularly in 'grilse rate'. This rate is typically low in Norwegian stocks and high in some Scottish and Irish stocks. S2 smolts give a higher grilse rate than S1 smolts. Experimentally, 2SW fish produced offspring with a relatively low grilsing potential.

6.4 Small eggs produced by female grilse tend to become S2 smolts. Large eggs are produced by 2+ sea-winter fish. In optimum hatchery conditions, > 95% of parr can become S1 smolts.

6.5 Mortality rates of fry in the wild may reach 90% but in farms are less than 1%.

6.6 Smolts which are heavier in late autumn after transfer to sea water tend to become grilse. In captive stocks where grilse proportions are low, maturity at 2SW is also low, with most individuals maturing as 3SW or older fish.

6.7 In Sweden and Iceland, fishing of 'wild' salmon has been maintained or increased at least partly due to releasing parr and smolts, a practice now known as ranching.

6.8 Salmon ranching has been unsuccessful in Scotland, where it is more profitable now to grow smolts in captivity than to release them. The release of unfed fry into rivers in many Scottish systems may be wasteful, with large numbers of fry dying from starvation.

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The potential impact of fish culture on wild stocks of Atlantic salmon in Scotland

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1 Introduction
This paper reviews the potential threats to wild salmonids from current fish culture practices, and suggests improved codes of practice among those concerned. Historically, salmon occurred all round the coast of Scotland and elsewhere in the British Isles, and were found in virtually every river as far upstream as they could migrate until prevented by waterfalls or other obstructions. The exact number of salmon rivers in Scotland is debatable. Mills (1980) says that there are in the region of 200, but the number originally holding salmon is likely to have been greater. Smith and Lyle (1979) have shown that there are 387 river systems of stream order 2 in size or larger entering the sea, and almost all of these are potential salmon waters, each with its individual stock of fish.

In many of these systems, of course, former salmon stocks are now extinct; these include the Rivers Carron (Lothian), Leven (Fife) and, until recently, Clyde (Strathclyde), and their many tributaries. In addition, the populations in many other rivers have been depleted by hydro-electric developments, water abstraction and the effects of various forms of land use (eg afforestation). The development of salmon hatcheries and the introduction of stock to all these systems have long been regarded as an entirely beneficial activity, but this may not always be the case.

The paper is concerned primarily with the more direct biological effects of salmon culture and stocking on wild populations, but it should also be remembered that there is a relatively new type of pollution which is associated with modern fish farms. A number of farms have been implicated in pollution incidents, usually involving high levels of suspended solids. In addition, a variety of therapeutic and prophylactic chemicals is used on these fish farms and much more information is needed on their effect after discharge to natural systems, especially where drinking water supplies are involved. A recent application to develop a cage fish farming system in Loch Lomond was turned down because of potential damage to water quality there.

2 Salmon stocks
Following a great number of recent international conferences (FAO 1981; Fetterolf 1981), it is now widely accepted that most species of fish are subdivided into more or less genetically isolated stocks. A stock can be defined as a group of organisms which share a common gene pool and a common environment (Ihssen 1977). Within these stocks, adaptive as well as non-adaptive changes can occur and lead eventually to genetic differentiation among them. When these genetic processes become substantially influenced by man's activities, irreversible loss of genetic material may start to take place. In order to counter this loss, it is essential to understand the way various activities can affect the genetic processes. The ideal is eventually to be able to predict the impact of man's activities on fish stocks, and this knowledge can only be acquired through an understanding of the processes and interactions involved.

It is believed that human activities can influence the gene composition of individual fish stocks through the operation of any one of a combination of the following 4 genetic processes:

i. migration rate, which is affected by the mixing of 2 or more genetically distinct populations;
ii. selection, where there is differential success of genotypes contributing to the genetic structure of succeeding generations;
iii. inbreeding, which results in a reduction in heterozygosity;
iv. drift, in which gene frequencies change at a rate dependent on the size of the genetic variation, but in an unpredictable direction.

The number of individual stocks of Atlantic salmon is uncertain. Saunders and Bailey (1980) estimate 2000 is a conservative number of stocks in Europe and North America. Power (1981) suggests that in Newfoundland and the Quebec-Labrador peninsula alone there are more than 500 stocks in a natural, vigorous state. The 74 stocks in the British Isles identified by Thorpe and Mitchell (1981) are likely to be a minimum number, and indeed in Scotland alone each river system, at least originally, seems likely to have possessed a stock with individual genetic traits developed over 5-10 000 years since the last glaciation. If this is so, then it would be reasonable to conclude that there could be up to 400 stocks in Scotland.

Thorpe and Mitchell (1981) have shown that not all Atlantic salmon in the North Atlantic belong to a common stock. There are differences between the North American and European stocks in transferring gene frequencies, chromosome numbers and scale circuli. In Europe, there are western, northern and Baltic components, and the western group subdivides into Icelandic, French and British/Irish subpopulations. Even within the latter, it is possible to define a further 2 units, the Boreal and Celtic races. Additionally, circumstantial evidence for the separate identity of 74 river stocks in the British Isles, on the basis of differences in age structure at smolt and adult stages and size at return to river, is supported by evidence from tagging, heritability of growth and developmental traits, and other features. Thorpe and Mitchell (1981) point out that 'the existence of such discrete stocks of Atlantic salmon implies the need for management on a stock-by-stock basis. Current national and international regulations do not achieve this goal'.

Most stocks of Atlantic salmon which have been studied show a number of stock-specific traits. These traits have been reviewed by Saunders and Bailey (1980) and include the following characteristics: fecundity, egg size, survival rates, growth, precocious sexual maturity, seaward migration, behaviour at sea, return migration, spawning frequency, resistance to disease, resistance to low pH, tissue protein and enzyme specificity. Only in some cases has experimentation been able to distinguish between genotypic and ecotypic effects, and considerable important breeding and rearing work remains to be done. However, the evidence so far shows that many of these characteristics are controlled by genes and they are likely to respond rapidly to selective breeding in fish farms.

3 Salmon culture

3.1 General

Among the earliest homing experiments carried out on fish farms anywhere were the classical tagging trials on the River Tay in 1905 and 1906 by Malloch (1910). Smolts were marked on their downstream migration by passing loops of silver wire through the thick flesh in front of the dorsal fin. Menzies (1939) carried out further work on homing behaviour and claimed that: 'the existence of separate types of salmon in individual rivers is too well known to require either emphasis or proof'. He based this on the fact that the runs in some rivers commence in summer and autumn, and in others in spring, and that in some rivers the fish may be predominantly large, while in others grilse may form the bulk of the catch.

Historically in Scotland, and elsewhere, although increasing numbers of salmon were brought into culture during the 19th century, they were kept there for a short time only; in effect, the progeny were used for enhancement (see below). Usually adult fish were caught in the autumn, stripped on the river bank in twos and threes, and the fertilized eggs taken to appropriate hatcheries. Sometimes these eggs were returned soon to the river and planted in gravel as eyed ova, but more commonly they were hatched and subsequently released as fry, parr or smolts. Although these eggs and young fish were often returned to their own river, there was often (and still is) a great deal of indiscriminate transfer of stock from one river system (and even one country) to another. By the beginning of this century, there were about 18 salmon hatcheries in Scotland (Netboy 1980).

The culture of Atlantic salmon, as presently practised in Scotland and elsewhere, is divided into 3 types of approach, ie (i) *enhancement*, where the objective is to augment wild stocks in individual systems (for both anglers and commercial fishermen) by the release of eggs, fry, parr or smolts to the wild; (ii) *ranching*, where the fish are reared and released to the wild as smolts at a specific point near the sea to which it is hoped they will return and be captured commercially as adults; and (iii) *farming*, where the whole life cycle is undergone in captivity, the young in fresh water, and the maturing adults in cages in the sea from which they are taken, and marketed at appropriate times.

3.2 Enhancement

In general, it can be said that the majority of salmon enhancement procedures carried out within Scotland operate at the level of the 106 District Salmon Fishery Boards or within them at riparian ownership level. Though full statistics are not available, there are many small and medium-sized hatcheries and rearing facilities in different parts of the country which are used to supplement wild recruitment in various local waters. In addition, there are a number of commercial hatcheries which will supply stock (at almost any stage between egg and smolt) to agencies in any part of Scotland (or abroad) for introduction to local systems.

The procedures for obtaining and handling broodstock and their progeny have been well documented (eg Jones 1961). They include a variety of important principles between selecting the site and water supply for the hatchery and handling the final eggs or young to the release point. Egglishaw *et al.* (1984) have recently outlined the principles and practice of stocking streams in Scotland with salmon eggs and fry. In addition to actual culture procedures, they stress the need for an assessment of whether or not artificial stocking is desirable or relevant and they discuss the ecological criteria on which a decision may be based.

Although salmon enhancement techniques are widely practised in Scotland, it is not clear on what scientific basis, if any, they are operated.

3.3 Ranching

Thorpe (1979, 1980) has provided recent reviews of salmon ranching abroad and in Britain. Both Pacific salmon (*Oncorhynchus* spp.) and Atlantic salmon are involved in this form of culture, especially the former. The number of fish concerned is enormous. Altogether some 2·8 billion young Pacific salmon were released in the North Pacific area in 1978, and it appears that about 50-10 000 t of Pacific salmon originate each year as hatchery fish (ie some 20–30% of the total world catch (Thorpe 1979)).

No full-scale salmon ranches exist in the British Isles. However, the DAFS Freshwater Fisheries Laboratory, Pitlochry, is developing a small pilot ranch at the mouth of the River Lussa, near Campbeltown, Kintyre. The unit is designed to produce about 30 000 smolts for release directly to the sea via a release pool at the head of a short fish ladder. This ranch will be used to evaluate the biological and economic viability of such schemes in the UK. Further, it is hoped that the release of fish through a device to which they will home and from which they will be harvested will keep the ranched stock separate from any local wild stock, as far as genetic mixing is concerned.

3.4 Farming

Almost all the early research and development work in salmon culture was either to increase knowledge of salmon biology or to enhance wild stocks, either locally or abroad. Practically no attention was given to the main growth and adult phases in salt water, and indeed, prior to about 1960, very few people believed that the rearing of adult Atlantic salmon in the sea would ever be possible.

The earliest successes with the sea phase came during the 1960s when the Vik brothers in Norway started rearing salmon right through to the adult stage in cages in sheltered fjords on the west coast. Subsequently, the salmon farming industry started to grow rapidly in Norway, and considerable research was initiated into salmon genetics so that the best stock could be selected for breeding in farms. During one 4-year period, wild broodstock from 40 rivers in Norway were sampled and subsequently reared in various fish farms.

In Scotland, the considerable advantages of the numerous sea lochs on the west coast for salmon farming were quickly realized, and several firms developed experimental cage farm facilities in these lochs in the early 1970s. These were immediately successful and salmon farming developed very rapidly as an industry in Scotland. Already all the most favourable sea loch sites have been utilized and the total production of farmed salmon is already several times the total catch of wild salmon in Scotland.

4 Cultured fish and wild stocks

One of the major problems in attempting to assess the impact of releasing cultured fish among wild stocks is that, although many thousands (possibly hundreds of thousands) of different releases have taken place, only rarely have adequate data been recorded to compare the subsequent performance of cultured and wild fish or possible changes which may have taken place in the wild stock. In general, it is true to say that, certainly within Scotland, the great majority of new species introductions which have been attempted have failed totally (Maitland 1977).

In a series of stocking experiments with brook charr, Flick and Webster (1964, 1976) compared the performance in the wild of 2 domestic (ie fish reared in hatcheries through several generations) and 3 wild stocks. Survival, growth and longevity were superior in the wild groups.

Fraser (1981) has compared the success of domesticated and wild (or hybrid) brook charr released annually in 9 small natural Canadian lakes over a period of 5 years (1973–77). Recoveries were made annually by gill netting and/or angling during subsequent years (1974–80). In 3 lakes, recoveries were similar, but in 6 lakes the wild strain was recovered at 2–4 times the rate of the domesticated one. Most domesticated trout were caught in the first year following planting, whereas wild strains were caught over a period of 3–4 years afterwards. Each 1·0 kg of domestic strain planted yielded 0·8 kg from the lakes, whereas each 1·0 kg of wild strain yielded 5·6 kg.

Ricker (1981) has reviewed several studies concerning stocking with Pacific salmonids in various waters. In general, young fish reared in hatcheries but stocked in their native streams returned in greater numbers as adults than the same stock placed in a different stream. In addition, stock from streams close to the test streams and planted there returned better than stock from more distant streams.

Ricker (1981) suggests that attempts to transplant various stocks of Pacific salmon have often proved unsuccessful because the new stock was unable to home correctly, and the same belief is expressed for Atlantic salmon by Saunders and Bailey (1980). In one experiment, stocks of female pink salmon from distant rivers were crossed with males from the local river system; as a result, adult returns 10 times greater than from the pure transplanted stock in the same river were recorded. The increased success was due to improved homing ability.

Altukhov (1981) has presented genetic data on the influence of indiscriminate stocking on wild populations of chum salmon in the River Naiba in northern USSR. In 1964–71, over 350 M fertilized eggs of chum salmon from the River Kalininka were transferred to the Naiba. By 1970, the genetic characteristics of the Naiba stock had shifted towards those of the donor stock. However, the return rates of the Kalininka stock in their new river reached only about 10–20% of that expected, whilst the composite return rate fell from a mean of 0·5% (for the original Naiba stock) to a new mean of less than 0·2%. The population size fell from 650 000 spawners in 1968 to about 35 000 in 1980, thus indicating the adverse consequence of massive genetic migration of non-adapted genotypes.

There are very few studies concerning any changes which may have taken place in wild stocks kept in hatcheries for short periods but not retained as brood-stock over more than one generation. Studies of Atlantic salmon have indicated that hatchery-reared fish are recaptured less often than wild fish (Carlin 1966), and Ryman (1970) believes this could be the result of inbreeding during hatchery procedures.

Atlantic salmon stock from the Big Salmon, Miramichi and Restigouche Rivers were planted as smolts by

Jessop (1976) in the Big Salmon River. All 3 stocks returned to this river, but the Big Salmon adults came back in greater numbers than the other 2 stocks. Ritter (1975) has shown lower survival rates for hatchery-reared Atlantic salmon stocks released in various rivers than those stocked in their native streams.

5 Discussion

Several benefits have resulted from the development of salmon culture. These have been spectacular over the last decade in Scotland in the field of salmon farming, where the number of farmed fish marketed is now several times that of wild fish (Laird & Needham 1986). This trend is likely to continue and there will probably be major developments in farm management techniques, including the selection of strains of fish particularly suited to farming. Many observers feel that the salmon farming industry stands now where the poultry industry stood some 50 years ago, and a bright future is indicated.

Salmon ranching, as far as the Atlantic salmon is concerned, is still in its early stages, though the prospects seem good and developments in Scotland seem likely. Stock enhancement has a long tradition in many areas and, often in spite of little evidence of benefit, seems likely to continue. It is certainly true that in some areas, usually those where salmon stocks have been eradicated or severely depleted, stocking has increased (or re-established) salmon populations. For example, in the Connecticut River in New England, salmon runs which were decimated by the construction of dams and other barriers during the last century are responding to a restoration programme. Starting with one fish returning in 1974, 3 in 1975, 2 in 1976, 7 in 1977, 90 in 1978, 58 in 1979, 175 in 1980, 530 in 1981 and so on, the project seems to have been successful. However, in a recent report commissioned by the Association of River Authorities of England and Wales (Harris 1978), it was emphasized that little tangible benefit resulted from artificial propagation as a means of maintaining and increasing salmon stocks, despite a widespread and heavy commitment to the use of hatcheries and culture stations.

In the British Isles and other parts of western Europe, many hundreds of individual stocks of Atlantic salmon have been wiped out by the pollution and damming of major rivers. The Rivers Clyde and Thames are good examples of systems containing large runs of salmon which disappeared completely following industrialization and gross pollution. Several other species disappeared with them, including sea lamprey, river lamprey, eel and flounder. The recent decades of improvement in water quality in both rivers have resulted in some spectacular biological recoveries and an interesting contrast in their salmonids. The steady recovery and reappearance of numerous fish in the lower Thames have been well documented by Wheeler (1979), and from being completely fishless over 40 species now occur there. However, the Atlantic salmon has not recovered naturally (there are no populations in nearby rivers), and an expensive programme of stocking is at present in progress. In the River Clyde, in contrast, even though there is still some pollution in the upper estuary, there is already a significant run of adult salmon into the river. This is apparently a completely natural recovery, presumably from fish derived from the River Leven (Loch Lomond) which enters the upper estuary of the Clyde. This stock and that of the Clyde may well have been part of one continuous population at one time, and thus the ideal one to use in recovering the stock in the River Clyde.

Apart from the definite evidence of pollution from salmonid culture in some river systems, caution should be exercised in relation to other types of damage to wild stocks, particularly that resulting from genetic mixing and change. In developing certain strains of salmon more suitable for domestic purposes, they are made less suitable for the wild. One of the primary aims of the scientific management of stocks (from the point of view of fish culture) must be to keep wild and farmed strains separate. This division is not being done at present. At a recent meeting of the Atlantic Salmon Trust, it was suggested that each large salmon farming unit in Scotland (there are about 30 companies operating now) 'would have something in the region of hundreds of thousands of fry available for disposal' every year. Some of these fish appear eventually to be used for stocking in the wild.

In the general field of salmon conservation, most of the problems concerning habitat alteration are understood and their resolution is more a question of resources than absence of methodology. In a number of rivers where appropriate recovery measures have been undertaken, the results have been spectacular. However, with many aspects of fishery management related to culture and stocking, not only are the techniques not available, but many of the problems are not yet fully understood. From the examples given above, it is clear that (i) the total wild gene pool is the basic resource for future fishery management, (ii) the population as a whole is divided into numerous local stocks, (iii) when non-native fish are introduced, they perform less well than the wild fish, and (iv) where very large numbers of non-native fish are introduced, they may swamp native fish and the whole stock performs poorly.

Apart from their scientific value, the economic importance of maintaining diverse stocks of wild salmon may be demonstrated by examples from other organisms which have long been in cultivation. Some of the most important natural resources brought into domestication are the various varieties of grain grown today throughout the world. An enormous amount of research and genetic selection has gone into producing a wide spectrum of varieties suitable for the different soils and climates in different countries. However, these triumphs of modern science and inbreeding have collapsed on many occasions, particularly in relation to various fungal epidemics. Recovery has only proved possible by the introduction of new genetic diversity from the wild, often from obscure countries and habitats (Harlan 1981). Nevo *et al.* (1979) showed that there was more genetic diversity in wild barley in Israel than in a composite cross involving 6000 cultivars from all over the world.

Because of the importance of diverse wild stocks of Atlantic salmon, their conservation should always remain a high priority among fishery managers, yet this is very rarely the case. The first objective in any geographical area is to identify the status of the wild population and the individuality and importance of local stocks. Guidelines for establishing status have been given by Utter (1981), Maitland (1985) and others.

Once wild stocks have been assessed, consideration must be given to their conservation if they are threatened. Three major conservation options are available, ie habitat restoration and preservation, selected translocations and, as a last resort, captive breeding. These options have been discussed in a recent paper by Maitland and Evans (1986) who emphasize the importance of integrating all 3 measures in any conservation management plan.

The use of fish culture techniques will continue to form an important, and probably increasing, part in the management of Atlantic salmon fisheries. Obviously, too, considerable research still needs to be carried out in this area, particularly on the long-term effect of stocking on the performance of wild populations.

However, in view of the theoretical and practical information already available, it is possible to draw up some preliminary guidelines which should be considered carefully by all those involved in the handling of salmonids in captivity and their subsequent release to the wild. The fish farming industry has already shown some interest in such guidelines (Needham 1984).

Some of these topics have previously been discussed by Helle (1981) and Maitland (1985). The main points are as follows.

i. Some pristine stocks should be maintained and conserved in each geographical area. Stocking and hatcheries in these areas should be strictly controlled.

ii. The necessity or purpose of stocking any river system should be clearly demonstrated.

iii. Broodstock for hatcheries used for stock enhancement should be obtained regularly from the wild; indeed, where possible each broodstock should not be kept in captivity for more than one generation.

iv. Local fish, from the area of intended eventual release, should be used for broodstock.

v. Surplus young from fish farms should not be used for stocking in the wild simply because they are available.

vi. Unconscious selection in taking wild broodstock should be avoided, for example in connection with size, place of capture, season of capture or spawning.

vii. Conditions in hatcheries should be kept as close as possible to those in nature (eg in terms of ambient temperatures, oxygen levels, current speed, etc) and selection procedures (eg size grading, etc) should be reviewed carefully.

viii. Large numbers of adults should be used as broodstock to avoid 'bottleneck' effects and genetic drift. Franklin (1980) argues that a minimum effective size of 500 is needed to preserve useful genetic variation within any stock.

ix. Much more research is needed on the success of introductions from captivity to the wild and on the genetics and other characteristics of the wild stock.

The importance to wild stocks of the role of the fishery manager, especially his culture techniques, has been emphasized in many recent publications. Not surprisingly, the same problems have been discussed in relation to many other types of wildlife management. Greig (1979) recognized the importance of genetic conservation in relation to wildlife management in southern Africa and offered a number of guidelines. Two recent symposia (FAO 1981; Fetterolf 1981) also dealt thoroughly with the subject as far as fish stocks are concerned, and included numerous suggestions and guidelines for fishery managers and others concerned with the future of fish stocks. In addition, various national (eg National Council on Gene Resources 1981) and international (Maitland *et al.* 1981) groups have developed to stimulate greater interest in the problems associated with the culture of salmonids.

If sensible guidelines are developed and followed, then the risks to the wild stocks of Atlantic salmon will be minimized. The philosophy is one of commonsense. As with the growing of wheat and many other domestic varieties, so it is likely to be necessary to return regularly to the wild stock to obtain new genes to counteract problems arising in domestication. If this stock is conserved in as intact and genetically diverse a condition as possible, then all best interests are served and the future of the Atlantic salmon will be more secure.

6 Summary

The various ways of culturing the Atlantic salmon are reviewed, with particular reference to their impact on wild stocks in Scotland. There are 3 main types of objective in culture: enhancement (to augment wild stocks in individual rivers), ranching (to release young fish at a point to which they will return and be recaptured as adults), and farming (to rear entirely in captivity). Salmon farming has been a spectacular success in recent years, whereas ranching is still at the experimental stage. Enhancement, though it has been widely practised for many decades, is of uncertain value and, though it may have given benefits in some systems (where salmon stocks were absent or depleted), it could have caused damage in others. The evidence for adverse and beneficial effects on wild stocks is considered and conclusions are drawn. In general, the objectives of farming (and to a lesser extent ranching) are incompatible with those of the enhancement of wild stocks. Future management techniques should ensure that the release to the wild of fish which have gone through more than one generation in captivity should be avoided.

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The data on salmon catches available for analysis in Norway

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1 Introduction

This paper describes the Norwegian salmon fishery. The official catch figures are discussed together with changes in the structure of the salmon fishery, and estimates of the rate of exploitation on some stocks are presented.

In Norway, Atlantic salmon are found in rivers along the coast from the border with the USSR southward to the border with Sweden. In recent years, several salmon populations have been wiped out by pollution, particularly in southern Norway where several important rivers now lack salmon because of the effects of acid rain (Jensen & Snekvik 1972; Leivestad *et al.* 1976).

Presently there are between 400 and 500 rivers and streams in Norway populated by salmon. The morphology and life history patterns vary considerably between the different populations, and reflect the great variability between river systems.

Salmon have probably been exploited in Norway since earliest times, starting in the rivers, where the salmon could be caught easily. In recent years, there has been a strong development towards mixed stock exploitation.

2 The salmon fishery

Fishing for salmon has been of great importance to the people living in those areas where salmon could be exploited. In the past, the exploitation of salmon in Norway was limited to the rivers and estuaries. However, as gears which could catch salmon efficiently in the fjords and coastal areas became available, the fishing intensity in these areas increased.

Many different types of gears have been used to exploit salmon. Drift nets, bend nets, bag nets and stationary lift nets are the most common legal gears used in salt water, while rod and line fishing is the most common method in rivers. Table 1 shows the number of each type of fishing gear annually in use since 1966 in the Norwegian home water sea fishing.

Drift nets are mainly manufactured from monofilament twine and can be operated between the national baseline and the 12 mile (22·2 km) limit. All other gears operate inside the baseline, and the materials used include spun nylon for bag nets and lift nets and monofilament nylon (mostly) in bend nets. The legal minimum mesh size is 58 mm knot to knot (116 mm stretched mesh), and most bag nets and lift nets are made of this size. The mesh size of bend nets can vary, and more than 70% of drift nets have mesh sizes of 65–70 mm knot to knot.

Table 1. Number of fishing gears used in the Norwegian home water salmon fishery, 1966–83 (source: Anon 1984a)

Year	Seine net	Set net	Bag net	Bend net	Stationed lift net	Drift net
1966	–	–	7101	–	55	–
1967	–	4607	7106	2827	48	11 498[1]
1968	345	4817	6588	2613	36	9 149
1969	307	3959	6012	2756	32	8 956
1970	309	4006	5476	2548	32	7 932
1971	288	3980	4608	2421	26	8 976
1972	436	4798	4215	2367	24	13 448
1973	477	5443	4047	2996	32	18 616
1974	409	5616	3382	3342	29	14 078
1975	349	5877	3150	3549	25	15 968
1976	260	4775	2569	3890	22	17 794
1977	303	4074	2680	4047	26	30 201
1978	301	4433	1980	3976	12	23 301
1979	–	–	1835	5001	17	23 989[2]
1980	–	–	2118	4922	20	25 652[2]
1981	–	–	2060	5546	19	24 081[2]
1982	–	–	1843	5217	27	22 520[2]
1983	–	–	1735	5428	21	21 813[2]

[1] Inclusive of seine nets
[2] Number of drift nets at start of the season

Drift and bend net fishing is permitted during the period 1 June to 5 August, and bag nets and lift nets may operate from 15 May to 5 August. There is a weekly close time for all nets extending from 1800 h on Friday to 1800 h on the following Monday. The drift net fishery also requires a licence to operate, and in 1983 a total of 632 licences were issued. The number of drift nets which can be fished per licence is restricted to 20, 35 and 50 in vessels, with 1, 2 and 3 fishermen respectively. Bend, bag and lift net fisheries belong to the owners of the adjoining land, and at present do not require a licence. The river fishing is carried out mainly with rod and line. With few exceptions, river fishing can be carried out from 1 June till 1 September. The fishery belongs to the owners of the river.

3 The official salmon statistics

In Norway, systematic collection of data from the different salmon fisheries began in 1876. Fewer than 100 rivers were included in the first year, and the sea fishery data were very incomplete. Although the reliability of the data has improved, obtaining reliable figures still presents problems.

The country is divided into 33 Salmon Districts, each one with its own Salmon Board. The Board compiles data from the fishermen and summarizes figures for its own District. Until 1979, all catch statistics were based on this source, but after that date drift net fishing was regulated by licence, and from that time the drift net fishermen had to keep a record of their catches. These data are now sent directly to the Central Bureau of Statistics which is responsible for preparing and publishing all the catch data (see Anon 1984a). The collection of catch statistics is a legal requirement under Norwegian law.

The quality of the statistics is somewhat uncertain (Anon 1984a). Fishermen have to pay a tax based on catch and this could result in poor quality information or the complete lack of it in certain geographical areas.

A sample survey was carried out by the Central Bureau of Statistics in 1977 (Anon 1984a). The survey indicated that actual salmon catches were, in most instances, larger than the figures issued by the Boards. A study based on River Gaula confirmed this fact (Gjøvik 1981).

Even though the official statistics seriously underestimate the actual catch, it is generally accepted that the data describe the fluctuations in catches and the

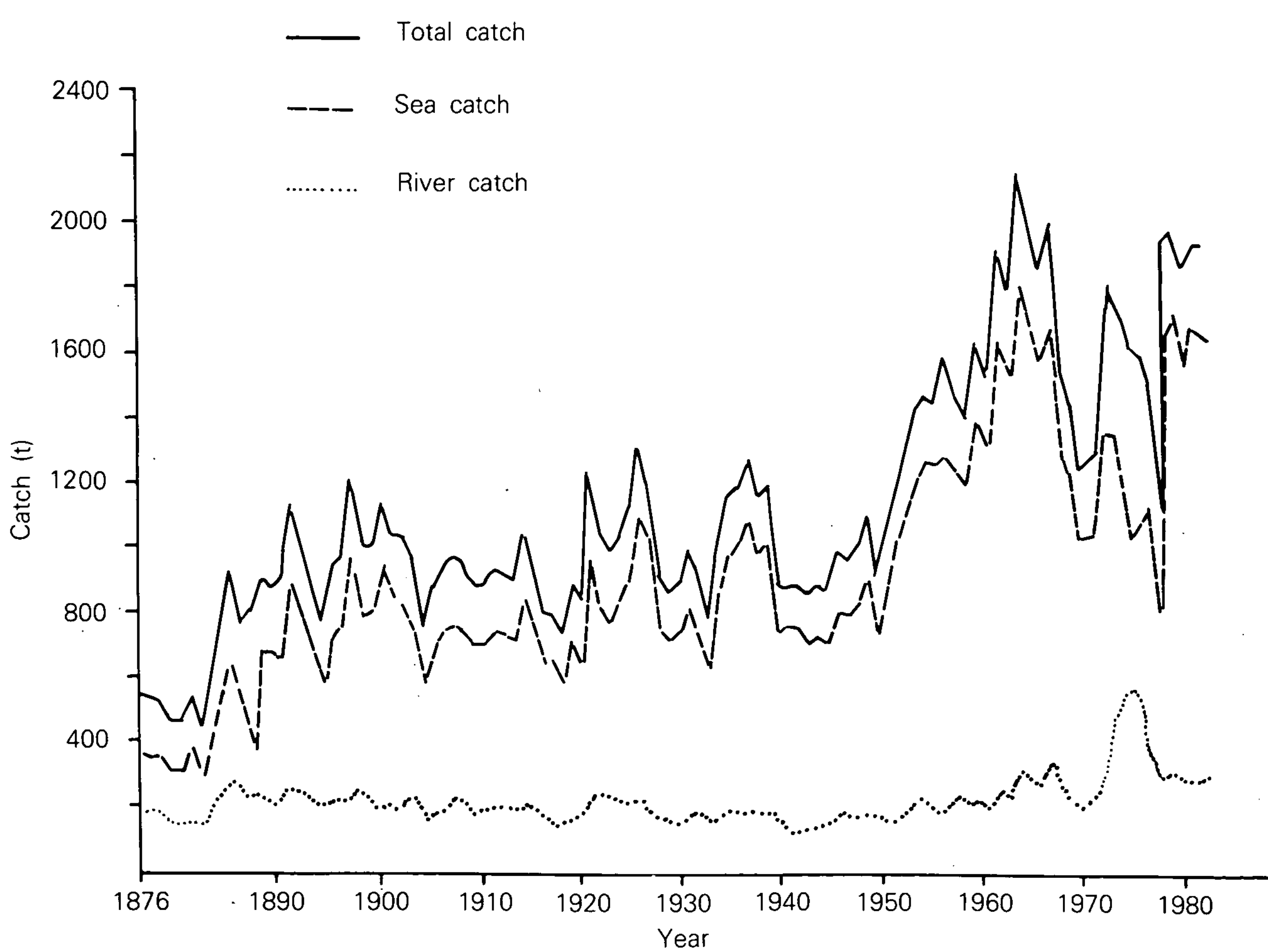

Figure 1. The reported catch of Atlantic salmon in Norway from 1876. Salmon caught in the northern Norwegian Sea by Norwegian fishermen are included

development in the fisheries (Rødstøl & Gerhardsen 1983; Anon 1984a).

Figure 1 shows the river catch, sea catch and the total catch of salmon in Norwegian home waters from 1876. The catches show great variations between years. Initially, total catches increased, but between 1900 and 1950 they were remarkably stable. However, from the beginning of the 1950s, the total catch increased considerably and reached a peak in the middle of the 1960s. This increase was probably due to a combination of several factors, including improved catch statistics, increased abundance of salmon due to stock enhancement, and an increased fishing effort. Towards the end of the 1960s, catches declined despite improved statistics. The downward trend may have been caused by natural factors, but it may also indicate that a smaller proportion of the Norwegian salmon run did not return to home waters because of the development of a long line interception fishery in the Norwegian Sea. In addition, there is some evidence to suggest that there could have been an overexploitation of salmon in home waters, and a subsequent reduction in smolt production.

Catches by the different gears are shown in Figure 2, which illustrates the development and decline of the different fishing methods in recent years. The decline in the bag net fishery is very pronounced, and its replacement by drift and bend nets. The reported increase in catches by drift nets after 1978 was probably partly due to the introduction of a licensing system (which required log books to be kept) and the resulting improvement in catch statistics.

4 Exploitation

Norwegian salmon stocks are heavily exploited, and a high proportion of the salmon ascending rivers throughout the whole country are net marked (Hansen 1980). However, the rate of exploitation on each stock is difficult to estimate.

In 1981, as part of a large sea ranching programme, hatchery-reared salmon smolts from River Isma stock were released during spring at the Research Station for Freshwater Fish at Ims, near Stavanger, southwest Norway. At the same time, wild descending smolts were caught in a smolt trap at the river mouth and were tagged with Carlin tags (Carlin 1955). Many of the tagged fish were subsequently recaptured as adults in the Norwegian Sea, in Norwegian home waters and in the fish trap at the mouth of the River Imsa. These recapture data were used to calculate exploitation rates (Anon 1984b,c).

Table 2 shows the number of smolts released, the estimated number of fish available to the Norwegian Sea and the Norwegian home water fisheries, and the estimated exploitation rates. The methods used are described in Anon (1984c).

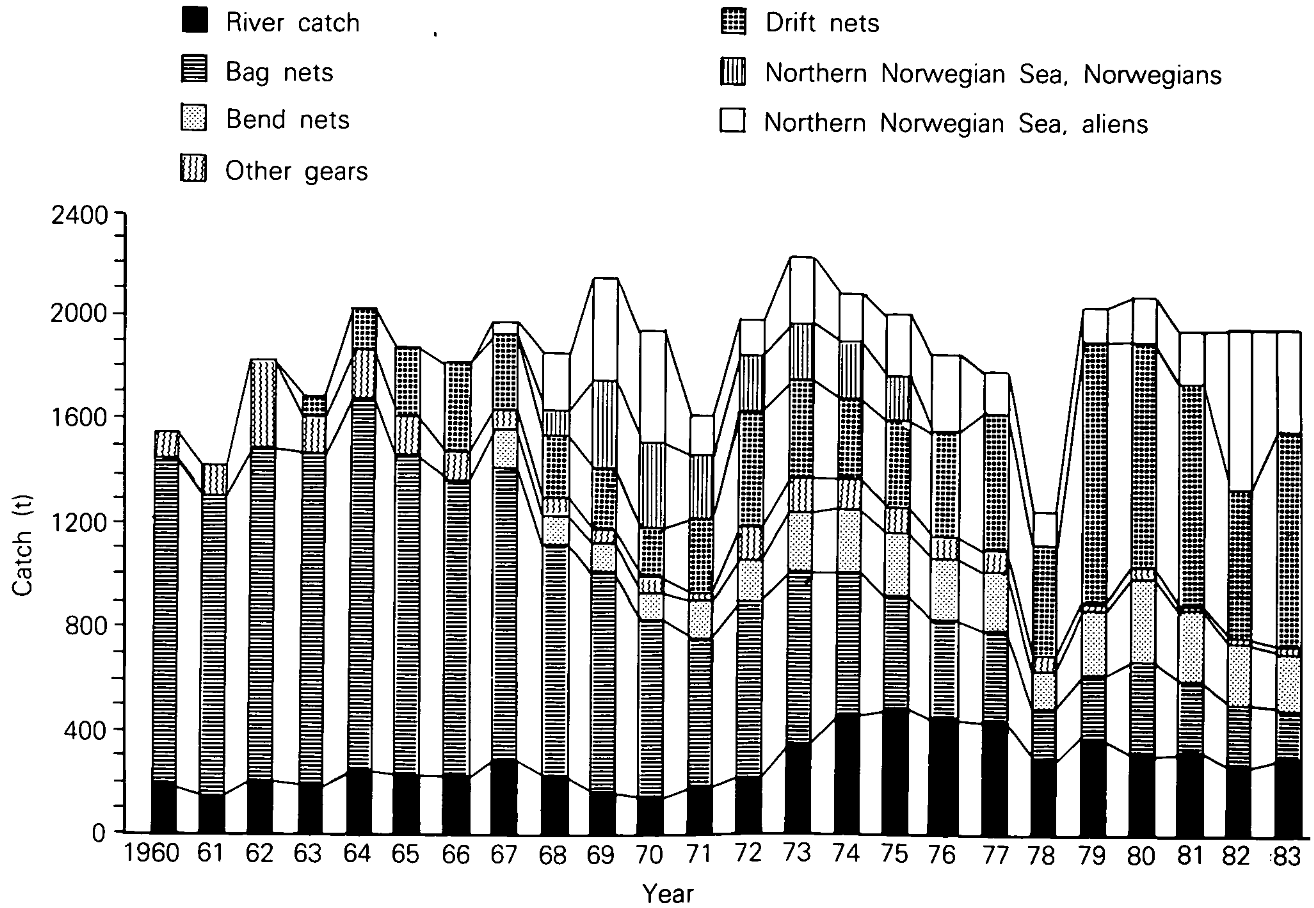

Figure 2. The reported catch of Atlantic salmon by different gears from 1960

Table 2. Estimated number of 1SW and 2SW salmon of the River Imsa stock available to the Norwegian Sea and Norwegian home water fishery, and estimated exploitation rates. The number of salmon caught in the River Imsa trap is considered to be the total river escapement. The smolts were released in 1981 (source: Anon 1984c)

		1SW					2SW				
		Norwegian Sea		Norwegian home waters			Norwegian Sea		Norwegian home waters		
Smolt type	No tagged	No of fish available	Expl rate	No of fish available	Expl rate	No in trap	No of fish available	Expl rate	No of fish available	Expl rate	No in trap
1. R Imsa wild	3214	776	0·00	555	0·88	66	177	0·25	127	0·93	9
R Imsa 2+	5819	757	0·01	586	0·80	114	125	0·38	74	0·92	6
2. R Imsa wild	3214	592	0·00	416	0·84	66	142	0·32	93	0·90	9
R Imsa 2+	5819	596	0·01	452	0·74	114	105	0·46	55	0·89	6

1. 75% tag reporting rate at Faroes, 50% tag reporting rate in Norwegian home waters
2. 75% tag reporting rate at Faroes, 70% tag reporting rate in Norwegian home waters

The following assumptions and approximations were made.

i. All survivors which are not caught return to the River Imsa.

ii. The monthly instantaneous natural mortality coefficient has been taken to be 0·01 after the fish became available to the fishery.

iii. The mean dates of capture in home water fisheries and in the trap have been taken to be 15 July and 15 September respectively.

iv. The mean date of capture in the Norwegian Sea has been taken as 15 March.

v. Non-catch fishing mortality was assumed to be negligible.

vi. Tagged and untagged fish were assumed to be equally vulnerable to the fishing gears.

vii. Exploitation rates for the home water fisheries were calculated for 2 assumed levels of tag reporting efficiency of 50% and 70%.

To calculate the actual number of tags taken in the Norwegian Sea area, the reported numbers have been adjusted using an estimate of efficiency of tag recovery of 75% calculated for the 1982–83 fishery (Anon 1984b). Because of an increased effort by the Faroese laboratory to collect tags during the 1982–83 season, the efficiency of tag reporting was probably higher in 1982–83 than in 1981–82. Therefore, the estimated number of one sea-winter fish taken in the 1981–82 Norwegian Sea fishery will be a minimum figure. There are no reliable figures from Norway on tag reporting efficiency, but rough estimates based on adult salmon taggings indicate that between 50% and 70% of the tags are reported by the fishermen (Rosseland 1973).

Lakhani (1986) argued that the very action of the removal of fish on the high seas materially alters the biological circumstances (ie prevailing fish density, crowding, competition, etc), and therefore the parameters of the fish population are not necessarily trustworthy estimates of these parameters if the exploitation had not occurred. There are no data available on density dependent mechanisms regulating the number of salmon at the feeding grounds in the North Atlantic. However, due to the small total stock of salmon in the North Atlantic relative to other fish species present in the area, it does not seem likely that possible effects of density-dependent mechanisms are of great importance. The heaviest mortality is probably taking place at the post-smolt stage during migration from the rivers to the feeding areas. Because the present exploitation model has been built up from the total returns of tagged fish, the estimated exploitation rates are independent of the mortality which occurs before the fish become vulnerable to the fisheries. Due to the several assumptions of the parameters in the model, the estimated exploitation rates are rough. The increase of the tag reporting rate in Norwegian home waters from 50% to 70% increased the estimated exploitation rates in the Norwegian Sea and decreased the Norwegian home water exploitation rates. However, the total rate of exploitation in the sea on salmon which migrated as smolts from the River Imsa in 1981 was very high, and probably exceeds 0·90. This figure agrees well with previous estimates from the Rivers Lærdal and Eira, in west Norway, suggesting the total exploitation rates on these stocks to be at least 0·80 (Rosseland 1979; Jensen 1979, 1981).

5 Summary

Catch data from the Norwegian salmon fishery have been systematically collected from 1876. Because the methods of collecting have varied, the reliability of the statistics has been questionable. The methods used at present were described and discussed, and it is concluded that the reported catch seriously underestimates the actual catch. Long-term catches of salmon in Norway are described and discussed in light of recent developments in the structure of the home water fishery. A smolt tagging experiment in the River Imsa, south-west Norway, in 1981 demonstrated that the rate of exploitation on this stock is very high. It is also high for other Norwegian salmon stocks.

6 Acknowledgements

Financial support for my participation in the ITE symposium was received from the British Council which is gratefully acknowledged.

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The data available for analysis on the Irish salmon stock

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1 Introduction
This paper describes how catch statistics for salmon are collected in Ireland, and assesses recent changes and the use of the statistics for management.

2 Legislation and management
According to Went (1970), measures were taken in the year 1220 to control the operation of salmon fishing weirs in Ireland. There is no record of how successful this legislation was in controlling salmon fishing, but legislation introducing measures to protect Irish salmon stocks is still being enacted.

Salmon fishing protection and development in Ireland is organized by 7 Regional Fisheries Boards, co-ordinated by a Central Fisheries Board. All these Boards are responsible to the Department of Fisheries and Forestry which enacts appropriate legislation and approves general policy for the management of salmon stocks. In 1981, the Central and Regional Fisheries Boards replaced the former Boards of Fishery Conservators and the Inland Fisheries Trust.

The power of legislation is restricted to the Department of Fisheries and Forestry, but the law is enforced by the Regional Fisheries Boards. The main thrust of the legislation as it relates to conservation and management of salmon is towards allowing the free passage of fish to their natal rivers and upstream to spawn. The main provisions are as follows.

i. Salmon fishing is banned outside 12 miles (19.3 km) from the baselines, in accordance with an EEC Regulation.

ii. Annual close seasons are prescribed for both commercial and sport fishing.

iii. Commercial salmon fishing is banned over weekends.

iv. Regulations prescribe the length and depth of nets, the type of material, the size of mesh, the type of boat allowed, and the size of the free gap in fishing weirs.

v. The maximum number of commercial salmon fishing licences permitted is restricted under the Control of Fishing for Salmon Orders 1980 and 1982, the Control of Fishing for Salmon by Drift Net (Kerry Fishery District) Order 1982 and the River Shannon Tidal Waters (Issue of Fishing Licences) Regulations 1935, as follows:

Drift nets	917
Draft nets*	629
Snap nets	132
Loop nets	33

In addition, there are about 57 private draft net operations, bringing the total of draft nets to approximately 686. Went (1964) describes the fishery for salmon and the various methods of capture.

vi. Under the Statistics Acts 1926 and 1956, holders of licences are required to make a return of the numbers of fish caught.

vii. A person dealing in salmon must have a salmon dealer's licence. A requirement of the licence is the keeping of a register of fish bought and sold. The format of the register is shown in Figure 1.

* Draft net: an encircling net hauled on to a bank or into a boat.

3 Biological aspects
The fishery is composed mainly of one sea-winter fish. Table 1 shows the proportion of one and 2 sea-winter fish caught in 1972–83. The grilse run is quite precise in timing from year to year. They start to appear in the catch towards the end of May and quickly replace 2 sea-winter fish. Salmon caught at the riverine trap at Galway have been examined since 1980. Scale readings show that the run there is composed exclusively of 2 sea-winter fish up to the end of May and one sea-winter fish after 12 June (Browne unpublished). The drift net fishery begins in mid-June and so exploits mainly grilse. There are 3 smolt ages (1–3). The 2-year-old class predominates so that the main cycle lasts 3 years, 2 years in fresh water and one year at sea.

4 Statistics collection
The Fisheries Division compiled statistics on the catch of salmon every second year from 1927 to 1943, and annually from 1945 onwards. Statistics were based on the returns made by licence holders. Since 1969, however, the returns from licence holders have been adjusted following an examination of the dealers' registers.

The published figures (Anon 1927–83) are shown in Figure 2. The reported catch can fluctuate greatly. With minor exceptions, however, there was a sustained increase from 1962 to 1975. From 1975 to 1984, there has been a decline in reported catch, with the exception of 1983.

SCHEDULE

Register of Purchases, Receipts, Sales, Exportations, Disposals and Removals of Salmon (including sea trout) or Trout (including rainbow trout) under Section 163 of the Fisheries (Consolidation) Act, 1959 as amended.

Name of holder of salmon dealer's licence (*a*) ______________ Address at which holder of salmon dealer's licence is authorised to sell salmon or trout (*b*) ______________

Record of Purchases and Receipts of Salmon (including sea trout) or Trout (including rainbow trout).

(1)	(2)	(3)	(4)	(5)			(6)			(7)			(8)		
				Salmon			Sea Trout			Rainbow Trout			Brown Trout		
Date	Name and Address of person from whom purchased	Name and Address of person from whom received	Fishing Licence Number (only in the case of salmon or sea trout not purchased from a licensed salmon dealer)	Number of Salmon	Weight in kilograms or pounds		Number of Sea Trout	Weight in kilograms or pounds		Number of Rainbow Trout	Weight in kilograms or pounds		Number of Brown Trout	Weight in kilograms or pounds	
					kg	lb		kg	lb		kg	lb		kg	lb

Record of Sales, Exportations, Disposals and Removals of Salmon (including sea trout) or Trout (including rainbow trout)

(1)	(2)	(3)			(4)			(5)			(6)		
		Salmon			Sea Trout			Rainbow Trout			Brown Trout		
Date	Name and Address of person to whom sold, exported, or disposed of or place to which removed	Number of Salmon	Weight in kilograms or pounds		Number of Sea Trout	Weight in kilograms or pounds		Number of Rainbow Trout	Weight in kilograms or pounds		Number of Brown Trout	Weight in kilograms or pounds	
			kg	lb		kg	lb		kg	lb		kg	lb

Figure 1. Data which have to be recorded in the salmon dealers' registers

Table 1. Nominal catches of salmon in Ireland in 1972–83 (tonnes round fresh weight) (source: Department of Fisheries and Forestry, Dublin)

Year	Salmon	Grilse	Total	% Grilse
1972	200	1604	1804	89
1973	244	1686	1930	87
1974	170	1968	2138	92
1975	274	1942	2216	88
1976	109	1452	1561	93
1977	145	1227	1372	89
1978	147	1082	1229	88
1979	105	922	1027	90
1980	202	745	947	79
1981	164	521	685	76
1982	63	930	993	94
1983	150	1506	1656	91

Before 1962, the stock may have had a higher proportion of 2 and 3 sea-winter fish. The increase in 1962 was in the grilse component of the stock. It is reported (Anon 1963) that the grilse run arrived early and continued late in that year with an increase in the size of grilse. Scale reading confirmed that the average weight of returning grilse was about 3·1 kg. The increase in catch over this period resulted from a higher survival rate in the sea (Anon 1965). The 2 sea-winter components of the catch also increased. A large increase in the grilse catch was also reported from Great Britain, the continent and Canada in 1962.

The figures collected prior to 1969 based solely on returns of licences were considered to underestimate the catch by Whelan *et al.* (1974), who pointed out that the export figures at times exceeded the published catch figures. They re-estimated the figures for the period 1952–68 (Figure 3).

The re-adjusted estimates show high and low adjustments based on export figures and home consumption of Irish-caught salmon. Only the low estimates are given in Figure 3. The other changes or events which have affected the collection of the data or the size of the stock have been included. In many cases they are not quantifiable and are not scaled.

It is difficult to arrive at a figure which accurately reflects the national catch. Therefore, how useful are the catch figures in judging the health of the stock? Two elements must be considered. The first is how accurate and constant is the collection of the data. The second is whether the data on catch can relate to stock.

A number of changes have directly affected the collection of the data. Some Regional Boards found it more difficult than others to collect catch data because of the size of the region and the diversity of sales outlets. The major change occurred in 1969 when the dealers' registers were used as a basis for the catch figures in addition to the licence returns.

In 1951–83, the proportion of fish caught by the various engines changed dramatically (Table 2), mainly due to an increased catch at sea. There were also a number of minor changes, the magnitude of which is not measured. The advent of freezing facilities made the inspection of dealers' premises more difficult and also complicated the recording of purchases and sales. The advent of home freezers coupled with a raised standard of living greatly increased the local purchase of salmon. Other influences which have affected the collection of the statistics have included the re-structuring of fishery management in 1980, the introduction of a 3-day close season from 1977 to 1980, and the existence of a salmon levy from 1980 to 1982.

As a result, a number of fluctuations in efficiency of collection are superimposed on the data, in addition to the natural fluctuations expected in a salmon stock which could be reflected in the catch.

With regard to relating the catch figures to the stock, a further set of problems arise; these include such factors as the effect of the Greenland and Faroese fisheries and an increase in pollution.

5 Stock

There is no measure of the effort in Irish fisheries, and therefore the catch cannot be used as a measure of

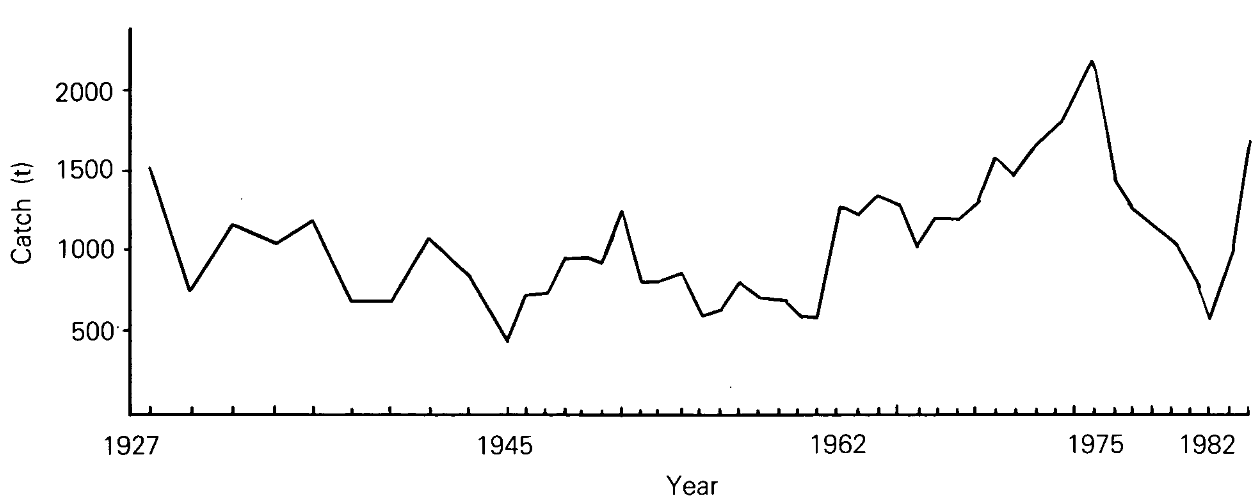

Figure 2. Official catch figures for Ireland in 1927–83 (source: Anon 1927–83)

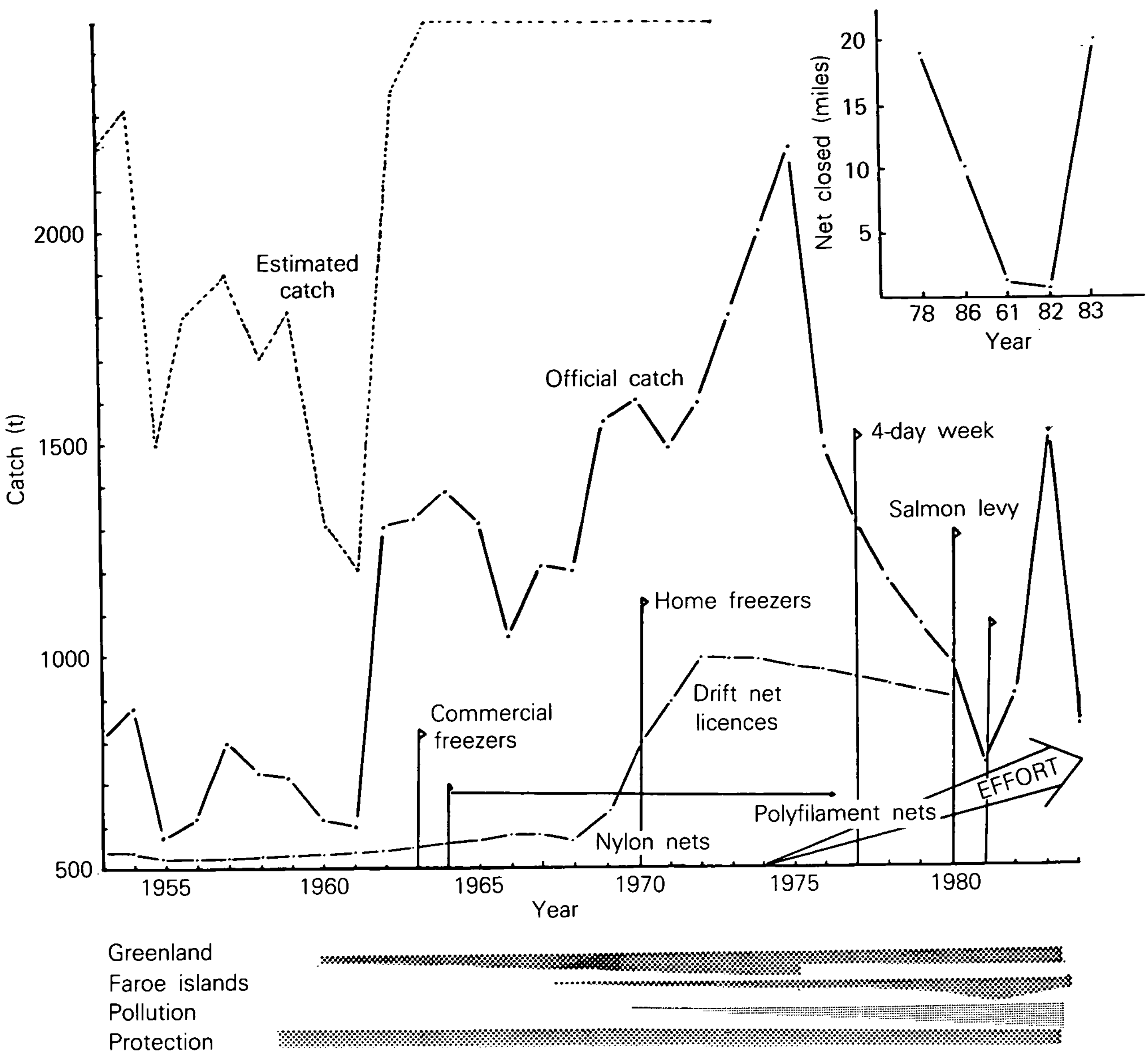

Figure 3. Amended catch figures showing some changes that have affected the collection of statistics or the effort in the fishery

stock abundance. The abundance of a stock will obviously be reflected in the catch, but the effort used in catching plays a major part in determining the numbers caught. The weather plays a major role in both marine drift net and riverine fisheries, but establishing the effect of weather is difficult. The number of fishermen, the size of nets and the time spent fishing are, perhaps, the most crucial measures of effort. This information is relatively simple to determine in estuaries but difficult in drift net fisheries. The level of protection also has a direct bearing on effort. The effort in the fishery has changed due to both an increase in drift netting and the efficiency of nets (Figure 3).

Illegal fishing must also be taken into account. It is suspected that most of the salmon caught in this manner are disposed of other than through the normal channels and are not recorded.

6 Escapement into fresh water

Counts of returning adults are available from a number of rivers. On the Rivers Shannon and Erne, which are affected by hydro-electric schemes (Tables 3 & 4), relatively complete counts of the numbers of adult salmon returning are available. In the Burrishoole River (Table 5), complete counts of upstream and downstream migrants have been done since 1970 at fish traps operated by the Salmon Research Trust of Ireland.

The figures from the Rivers Shannon and Erne show a large increase in catch in 1962 and generally high levels in the period following. The picture in the River Erne is complicated by a particularly high incidence of ulcerative dermal necrosis (UDN) after 1969.

In the Burrishoole River, runs increased until 1973 and started to decline in 1975. Apparently the catch

Table 2. Proportion of catch taken by various engine (source: Department of Fisheries and Forestry, Dublin)

Year	Drift nets	Draft nets	Other nets	Rod and line
1951	20	56	15	9
1952	23	45	20	12
1953	20	48	20	12
1954	24	47	14	15
1955	19	48	14	19
1956	17	50	15	18
1957	17	56	10	17
1958	17	47	13	23
1959	22	53	9	16
1960	19	51	13	17
1961	16	55	14	15
1962	21	57	13	9
1963	24	49	15	12
1964	25	50	12	13
1965	28	44	14	14
1966	32	41	14	13
1967	37	39	14	10
1968	38	39	13	10
1969	49	35	10	6
1970	49	36	11	4
1971	50	36	10	4
1972	64	24	7	5
1973	66	23	6	5
1974	72	20	5	3
1975	68	24	6	2
1976	70	20	7	3
1977	75	17	5	3
1978	71	22	4	3
1979	82	12	2	4
1980	72	19	5	4
1981	75	12	7	6
1982	76	15	5	4
1983	83	11	3	3

increased from 1962 to 1975 due to increased survival of the fish in the sea phase and was sustained subsequently by an increase in effort in the drift net fishery.

The reasonably large escapement into all 3 rivers up to 1975 suggests that the apparent decline thereafter was due to factors affecting survival in the sea. With an indiscriminate drift net fishery, it is not possible to determine whether the Shannon and Erne stocks are declining or whether they are being exploited in a different manner. However, it appears that the Burrishoole stock is declining because both the numbers of returning adults and smolts are falling.

It is generally agreed that the fishing effort in the drift net fishery has not decreased in recent years and is probably increasing. Even allowing that the numbers of fish caught annually and not recorded may be increasing, the Irish stock of salmon appears to be declining.

There are at least 2 possible explanations: either the level of fishing may be too high or the survival rate of fish in the sea may have decreased. There is some evidence to suggest that the survival rate changed from year to year. Tagging in the River Lee at Carrigadroghid in 1973 and 1975 showed huge differences in returns which could only be explained by a change in survival at sea (Browne & Doyle 1979).

It is apparent that major changes in the stock of Irish salmon have occurred, and the data suggest that a further change is taking place. The statistics available on the catch, however, do not allow a detailed analysis of these changes. The shortcomings of the system are as follows.

i. It is generally agreed that a full count of the fish landed is not achieved and that this would be difficult to obtain.

ii. Where data on escapement into rivers are available, they must be linked with estuarine and sea catches, which is not possible at present.

iii. Catch can be used as a measure of abundance only if effort is measured. No information is available for the catch per unit effort exerted in salmon fisheries including the drift net fishery.

iv. The effort is continually changing in the drift net fishery so that comparison between years is not possible.

At present, the whole question of the collection of salmon catch statistics and measures of conservation is being reviewed. There is a general awareness that a better system of judging the health of the stock will have to be developed. It is probably timely for the various interests concerned (fishermen, buyers, management and research) to outline their requirements from salmon catch statistics so that a comprehensive system suitable to all needs can be introduced.

Work is in progress to provide population models for 3 river systems, the Corrib, the Burrishoole and the Erriff. The bases for these models are upstream and downstream counts for adults and estimates of the catches in the drift net and draft net fisheries based on micro-tag returns.

It is hoped that the results from these 3 river systems can be translated into other systems in the country, river by river, to provide a better basis for determining the health of our salmon stocks than relying on catch statistics.

7 Conclusions

7.1 The published catch figures are subject to inaccuracies and do not provide a proper basis for comparison from year to year.

7.2 The present system of collection is not adequate to monitor the fluctuations in the stock and to give definite answers on whether it is increasing or decreasing.

7.3 A more reliable method of recording catch data is essential.

Table 3. Counts of salmon stocks in River Shannon (source: Electricity Supply Board, Dublin)

Year	Numbers caught: Estuary nets	Numbers caught: Stake weir catch	Numbers caught: Thomond weir	Numbers counted: Thomond weir escapement	Total run
1950	17 359	2 551	4 224	10 560	34 694
1951	21 827	4 051	3 888	10 103	39 869
1952	14 283	3 461	2 946	7 610	28 300
1953	13 153	3 043	4 873	12 558	33 627
1954	12 366	3 929	3 772	10 148	30 215
1955	7 096	2 372	2 448	6 475	18 391
1956	7 317	2 008	3 597	9 402	22 324
1957	2 128	2 361	3 647	9 480	17 616
1958	12 870	2 270	3 001	8 980	27 121
1959	16 715	1 715	3 002	8 516	29 948
1960	13 590	1 780	2 467	6 094	23 631
1961	14 175	3 333	1 425	4 030	22 963
1962	31 326	5 431	5 128	15 992	57 877
1963	26 246	4 516	4 745	18 577	54 084
1964	20 021	2 812	3 538	10 459	36 830
1965	20 664	4 229	5 258	14 446	44 597
1966	15 348	2 867	2 767	8 105	29 087
1967	31 468	4 973	4 527	15 040	56 008
1968	33 222	3 713	4 653	12 699	54 287
1969	26 505	5 011	5 625	14 970	52 111
1970	31 745	3 545	3 407	9 933	48 630
1971	32 000	2 734	3 698	9 180	47 612
1972	30 000	2 982	3 285	10 100	46 367
1973	33 035	3 999	4 247	11 773	53 054
1974	21 766	5 770	2556	6 978	37 070
1975	28 728	6 130	4 184	11 016	50 058
1976	26 050	1 809	1 465	4 253	33 577
1977	16 728	909	1 453	3 956	23 046
1978	12 131	806	795	2 307	16 039
1979	12 325			No count	12 325
1980	7 442			8 595	16 037
1981	4 293			4 305	8 598
1982	2 072			3 429	5 501
1983	6 185			1 818	8 003
1984	2 822			558	3 380

Table 4. Yearly escapement of salmon in the River Erne (source: Electricity Supply Board, Dublin)

Year	Total count
1960	5 056
1961	4 574
1962	9 802
1963	5 101
1964	8 715
1965	9 885
1966	10 936
1967	6 036
1968	8 690
1969	5 262
1970	6 865
1971	2 724
1972	2 875
1973	2 484
1974	1 210
1975	1 733
1976	2 075
1977	801
1978	297
1979	445
1980	433
1981	660
1982	678
1983	578
1984	561

Table 5. Escapement of salmon into the Burrishoole River in 1970–83 (source: Anon 1971–84)

Year	Salmon	Grilse	Relevant smolt migration
1970	0	1 088	
1971	5	740	14 637
1972	21	1 369	13 915
1973	23	1 676	14 081
1974	25	855	11 282
1975	52	824	9 972
1976	50	797	14 650
1977	43	607	16 136
1978	31	375	6 232
1979	6	914	9 998
1980	49	637	8 276
1981	64	326	11 208
1982	21	445	9 434
1983	29	545	–

8 Summary

This paper gives the catch statistics for salmon in Ireland since 1927, together with a resumé of the enforcing regulations and background on the biological composition of the stock. The shortcomings of the systems and the problems of using the figures for statistical analysis are discussed. The main conclusion is that the present data are inadequate for monitoring fluctuations in the salmon stock.

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An evaluation of the data available to assess Scottish salmon stocks

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1 Introduction

This paper describes the various sources of data which are available to assess the status of Atlantic salmon stocks in Scotland. These sources include the national catch statistics, historical catch records and counts of fish at North of Scotland Hydro-Electric Board (NSHEB) dams. In addition, the annual smolt production figures for the River North Esk for 15 years from 1964 are compared with roughly comparable data from the Girnock Burn, a tributary of the Aberdeenshire River Dee (Hay, pers. comm.).

In addition to an annual close time which, for the majority of nets, extends from the end of August to roughly mid-February, there is a weekly close time from noon on Saturday until 0600 h on the following Monday morning. The rods can normally begin fishing earlier each year and cease fishing later each year than the corresponding nets. Depending on the Salmon Fishery District, the rod fishing season begins between 11 January and 25 February and ends between 30 September and 30 November. The weekly close time for rods is Sunday.

2 Material

2.1 National catch statistics

Before 1952, there was no statutory obligation to make catch and effort data available to the Department of Agriculture and Fisheries for Scotland (DAFS). However, since then, this information has been provided annually, in confidence, to the Department as a statutory requirement under the Salmon and Freshwater Fisheries (Protection) (Scotland) Act 1951. Catches, divided between salmon, grilse and sea trout, are recorded by number, by weight and by method of capture (fixed engine, net and coble, and rod and line). In addition, net and coble fisheries are requested to supply the minimum and maximum number of netting crews and persons engaged in netting operations each month, and fixed engine fisheries are also asked for the minimum and maximum number of traps operated each month. Operators of fixed nets are also requested to give some additional details of gear used. For example, bag, fly, jumper and stake net fishermen are asked to supply details of the maximum number of bags or pockets fished in any month. Poke net (Figure 1) fishermen are asked for the maximum number of

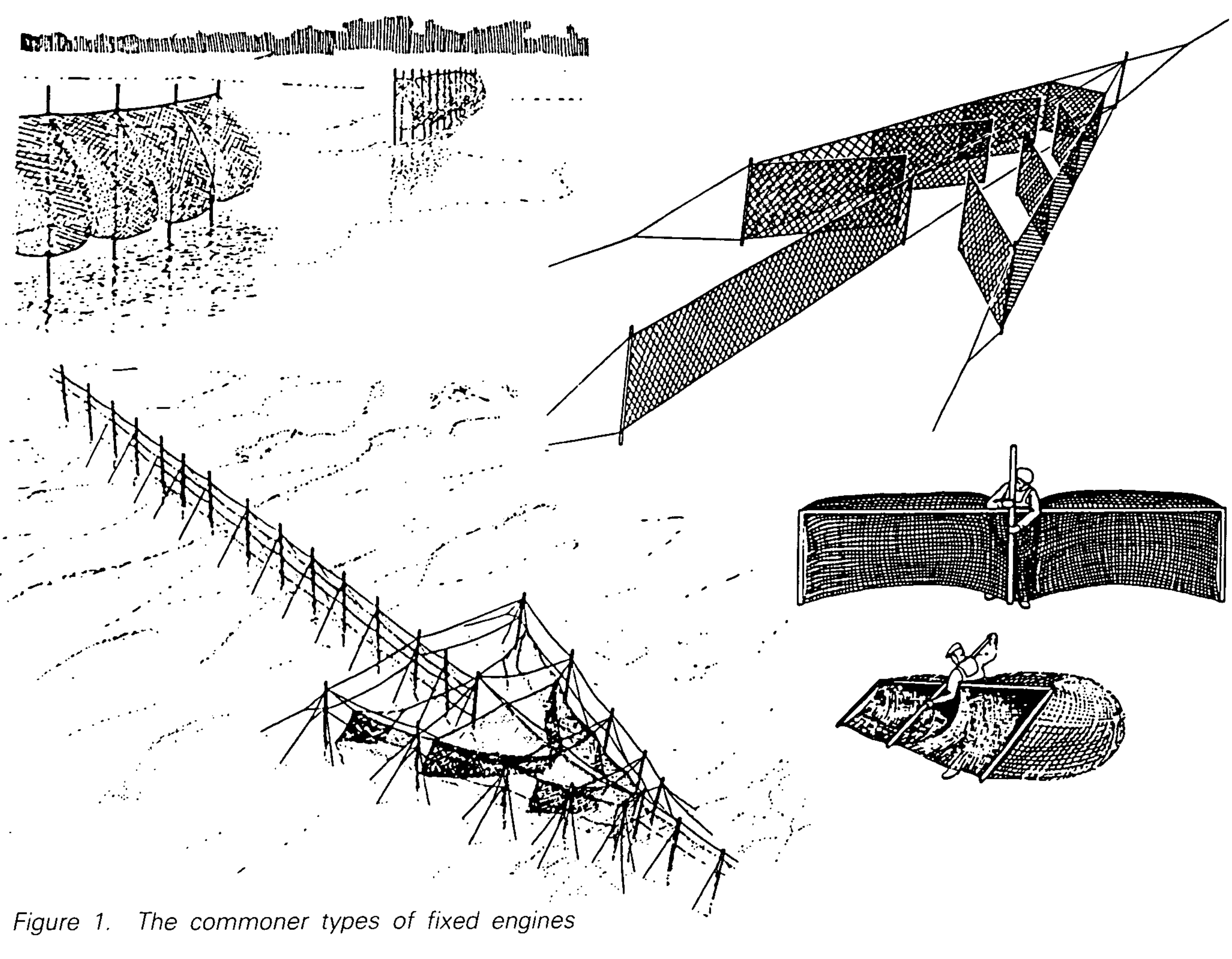


Figure 1. The commoner types of fixed engines

pokes, and haaf net fishermen for the total number of permits. Whoever makes the return to DAFS is also required to state as accurately as possible the exact location of each fishery covered by the return, including limits of the fishery, and, in the case of river and estuary fisheries, whether on right or left bank. The grid reference(s) is also required. Although at one time a separate form had to be completed for each fishery, operators of more than one fishery in the same Fishery District can now combine their returns on one form (Appendix A).

The Act also provides that the resulting statistics can be published to show the catches made by rod and line fishing, by net and coble fishing within estuary limits, and by net fishing outside estuary limits in any Salmon Fishery District. There is also a saving proviso to ensure that information on the number of fish caught in any one fishery during the previous 10 years is not disclosed.

Brief summaries have been published each year giving the reported catch for Scotland as a whole, divided

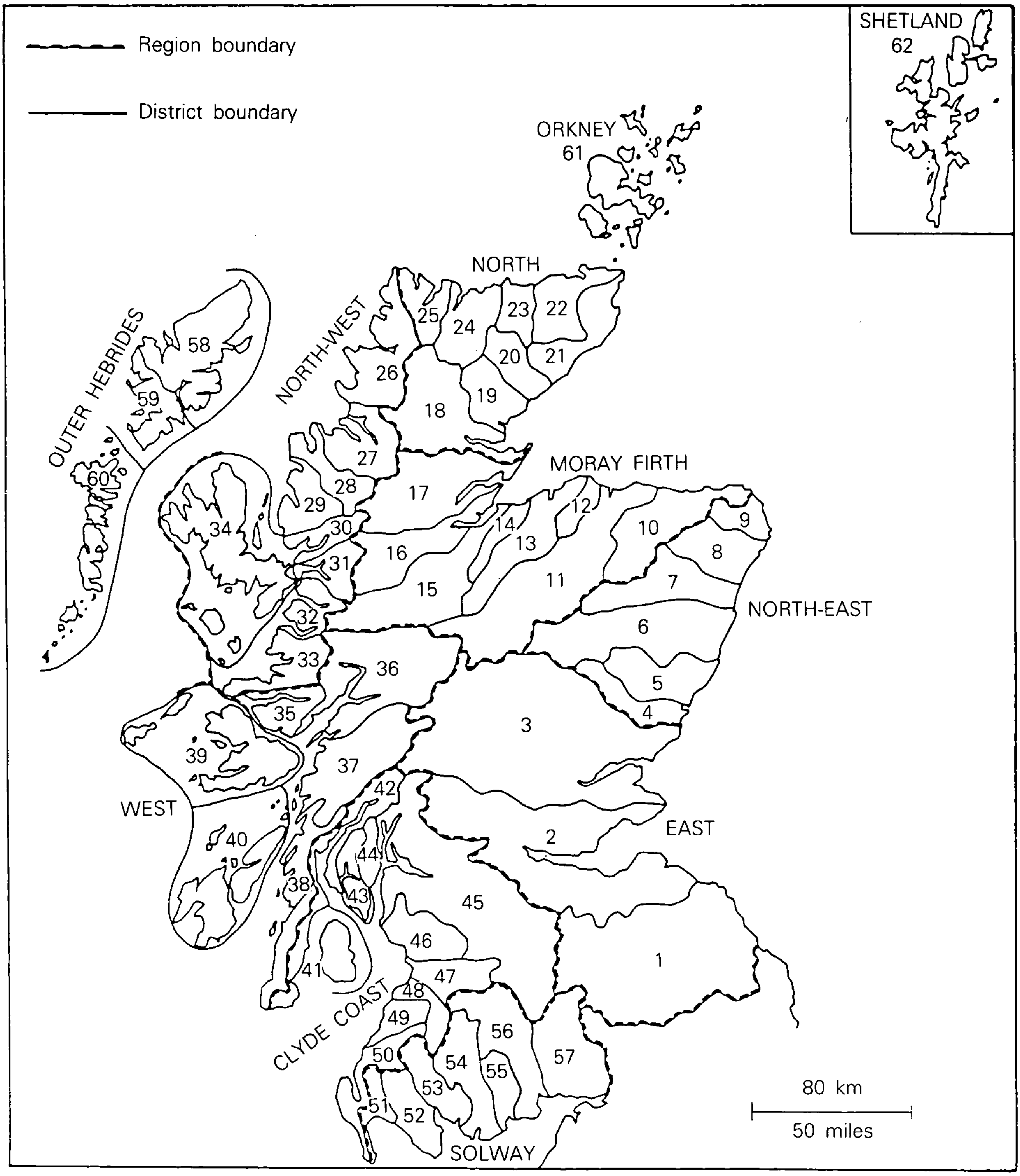


Figure 2. Regions and districts defined for the analysis of catch statistics of salmon in Scotland

both between salmon, grilse and sea trout and between rod and line, net and coble and fixed engine. Following requests for the salmon catch statistics to be available in greater detail, it was agreed that more detailed statistics would be made available on a regular basis from 1982 (Anon 1984a, 1985) and that a compendium would be published for the years 1952–81 (Anon 1983, 1984b).

2.1.1 Collection of the statistics

The catch return form (Appendix A) is sent out at the end of each fishing season to the owners and occupiers of salmon fisheries in Scotland, with a request that it be completed and returned not later than 31 December.

2.1.2 Statistical areas

The 1951 Act provides that catch figures can be published for each Fishery District. However, some of the smaller Districts have been amalgamated to give 62 statistical districts in all. These are grouped into 11 regions for recording catches, according to the method of capture (rod and line, net and coble, and fixed engine) (Figure 2).

2.1.3 Summary tables

Catches taken in each statistical district are summarized by years (and for each year by statistical districts and regions), total weight, and numbers of fish, and the all-method catch into spring salmon (fish caught up to and including 30 April), summer salmon (fish caught on or after 1 May), total salmon (spring plus summer), grilse, salmon plus grilse, and sea trout. Another set of tables shows the total catch in each region, first by all methods (ie the total) and then by rod and line, net and coble, and fixed engine fisheries. The final set of tables describes the 'all-Scotland' catch by year and by method divided between spring, summer, total salmon, grilse, salmon plus grilse and sea trout.

The 30 April is the demarcation line between spring and summer salmon because most salmon caught in May have open bands at the edge of their scales rather than the closed bands which characterize spring fish. However, this technique probably underestimates the number of rod-caught spring fish, as some fish taken after 30 April could have entered the river earlier.

2.2 Historical catch records

Many private estates and old established commercial fishing companies, including the Crown Commissioners, the Aberdeen Harbour Board and the Berwick Salmon Fisheries Co Ltd, who operate the net and coble fisheries on the Rivers Spey, Dee and Tweed, have long series of catch records. The information recorded varies widely, but most records give the date, number of salmon, grilse, and sea trout caught at each station or on each beat, and their weight. Many angling records also recorded the daily water height and the identity of the angler who caught the fish. No measure of effort is given. Although the anglers who caught fish were recorded, there is no mention of those who fished but caught nothing.

2.2.1 Published catch records

Published catch records, particularly after the mid-1850s and before 1952, are fragmentary. The growing secrecy of net fishing proprietors and lessees stemmed from a hostility between the netsmen and proprietors of rod and line fisheries. The monetary value of leased fishings, which periodically came up for renewal, imposed further restrictions on the free exchange of information. Nevertheless, catch figures from widely separated fishings are scattered throughout the annual reports of the Fishery Board for Scotland. Additional catch data were published in the reports of the various Salmon Commissions which heard evidence in the 19th and early 20th centuries. Prior to 1952, estimates of the total Scottish catch each year were based mainly on the returns provided by the railway and steamship companies of the weight of salmon and trout carried by them. These were useful in making comparisons between years, but they did not record the real catch figures because (i) the weight of ice and boxes was included; (ii) there was double counting in that fish consigned from the place of capture to a Scottish wholesale market were often sent on to another place; (iii) there was no differentiation between salmon and sea trout; and (iv) the number of fish was not recorded. A number of correction factors have been suggested, and in the annual report of the Fishery Board for Scotland for 1931 the Inspector of Salmon Fisheries, in addition to recording the tonnages transported between 1894 and 1931, suggested that a deduction of one third had to be made for the weight of the boxes and ice and a further 12% for double counting.

More recently, George (1982) has examined and commented on the catches taken between 1790 and 1976 by anglers and net fisheries fishing within Fishery Districts stretching the length and breadth of Scotland.

2.3 Counts at North of Scotland Hydro-Electric Board dams

Although the majority of fish counters are sited at NSHEB dams, there is one (Tongland, Dee (Solway)) in the area of the South of Scotland Electricity Board (SSEB) (Figure 3). Within the NSHEB area, counters are presently installed at sites on more than 20 rivers, each one recording the upstream and downstream movement of salmon. These counts are published annually in the annual report of the NSHEB. In some instances (Pitlochry Dam), the time series extends back more than 30 years. The counts at 2 dams (Pitlochry, River Tummel, and Aigas, River Beauly) were chosen to illustrate the type of data that are available.

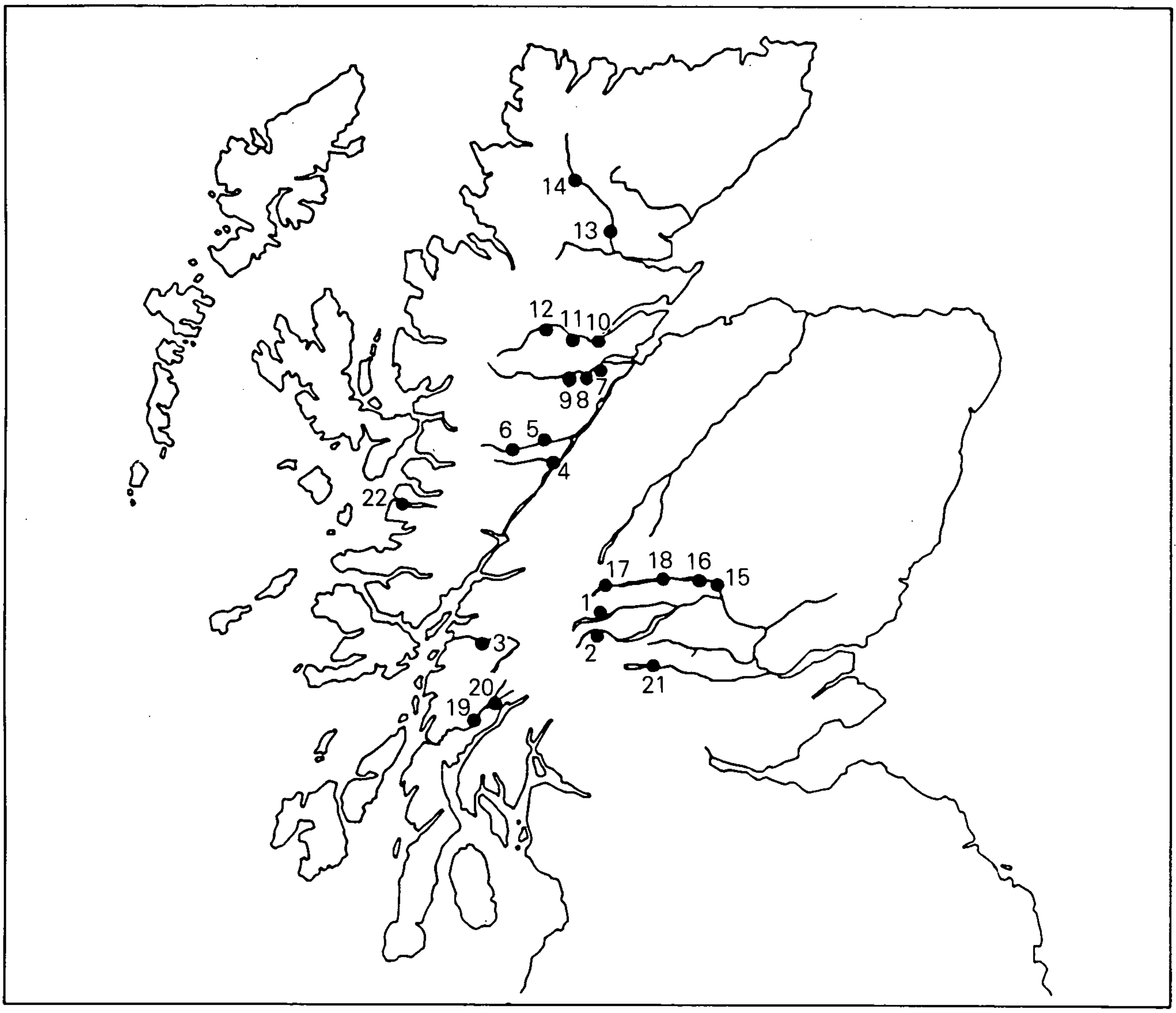
2.4 Smolt production (River North Esk and Girnock Burn)

In most years since 1964, the smolt production of the North Esk has been estimated using a stratified mark-recapture method (Schaefer 1951). Breaks in the run of data were the result of too few smolts being caught in Kinnaber Mill trap because of above-average flows, particularly during the early part of the smolt migraton season. Figures for smolt production from the Girnock were the actual numbers of smolts passing each spring through a trap sited a short distance above the confluence with the Dee.

2.5 Biases in the data

2.5.1 Relationship between catch and stock

Salmon runs do not necessarily conform with fishing seasons. In 1981–84 (the years for which data are available), an increasing percentage (over 40% in 1984) of the fish which returned to the North Esk moved upstream over the Logie fish counter (3 km



1 Stronuich Dam - R Lyon
2 Lochay Falls - R Lochay
3 Awe Barrage - R Awe
4 Invergarry Dam - R Garry
5 Dundreggan Dam - R Moriston
6 Mucomir - R Moriston
7 Kilmorack - R Beauly
8 Aigas - R Beauly
9 Beannachran Dam - R Farrar
10 Torr Achilty Dam - R Conon
11 Luichart Dam - R Conon
12 Meig Dam - R Meig
13 Lairg Dam - R Shin
14 Onchally Weir - R Cassley
15 Pitlochry Dam - R Tummel
16 Clunie Dam - R Tummel
17 Gaur - R Gaur
18 Dunalastair Dam - R Tummel
19 Add - R Add
20 Tunns - R Tunns
21 Loch Earn Weir - R Earn
22 Morar - R Morar

Figure 3. Locations of fish counters operated by the North of Scotland Hydro-Electric Board

upstream from the sea) after the end of the net fishing season. Fish which arrive on the coast and enter rivers after the end of the netting season contribute neither to the fixed engine catch nor to catches taken by net in the rivers. Changes in the timing of runs could bias estimates of annual stock abundance based solely on catch data in the fishing season. Furthermore, it is unlikely that the fishing effort, or the rate at which the stock has been exploited, has remained constant throughout a fishing season, from one season to another, or from one area to another (Shearer 1986). In addition, as netting in rivers decreased in the last quarter of the 19th century, coastal fisheries first increased and then declined. The decline began in the late 1950s and has continued. Not only has the number of sites fished decreased but also the length of the season fished at many of these sites has diminished.

Fishing seasons (rod and net) have changed. In 1852, for example, the season on the Dee lasted from 1 December to 20 September and in 1902 from 11 February to 26 August (nets) or 31 October (rods) (Grimble 1902). More recently, the rod fishing season was reduced by one month to 30 September.

The fish caught may not be typical of the stock. Differences could occur for various reasons, including gear selectivity or differing levels of exploitation on different components of the stock. Shearer (1984a) demonstrated a relationship between both river and sea age and the calendar date when fish belonging to particular cohorts returned to fresh water. The age composition of the catch will be biased towards those age groups which return in greatest proportion during the fishing season. The rod catch could be particularly sensitive to physical changes in the river system, which could include the gravelling of pools, and changes both in the patterns and rates of discharge and temperature. Changes in the sea age composition of the stock could also be important as they would alter the timing of the runs and the availability of catchable fish.

2.5.2 Limitations of the data

2.5.2.1 Annual fluctuations in catches

Most data examined refer to reported catch figures, with additional data from fish counters and from the North Esk and Girnock. Fluctuations occur in annual catches for a number of reasons. A low catch in a particular year must not be assumed to be evidence of a decline in salmon stocks, though increased catches may usually be related to an increase in the numbers of catchable fish. The spawning escapement (ie the proportion of returning salmon that is not caught by nets and rods) cannot be estimated directly from the numbers of fish caught, because a large number could enter the river after the end of the fishing season having made no contribution to catches.

2.5.2.2 Grilse error

In the catch returns submitted to DAFS, lessees and owners of salmon fisheries, with few exceptions, have separated their catches into salmon and grilse on the basis of weight. Fish weighing less than 3.6 kg have been classed as grilse and the rest as salmon when fish in both sea age groups are present. In 1952–83, the proportions of fish classed as grilse varied because of changes in the growth rate of grilse in the sea. Furthermore, as grilse generally increase in weight as the season advances, the magnitude of this reporting error does not remain constant throughout the fishing season. In August and September, 'salmon' catches will contain relatively more over-weight grilse than in June and July. In general, those years when grilse were most abundant were also characterized by above-average proportions of over-sized grilse. In 1850–1950, the relative number of over-weight grilse classed as 'salmon' was probably less than in more recent times because grilse tended to be on average lighter and market requirements were less rigidly tied to weight.

3 Results

3.1 National catch statistics

The reported catches from 1952–83 have been summarized into 6 groups, the first 25 years into 5 groups each containing 5 years and the remaining 7 years (1977–83) into the sixth group. Grouping the catches in this manner masks the wide fluctuations in annual catches (Figures 4–6).

3.1.1 Total reported Scottish catches by all methods (Figure 4)

3.1.1.1 Total reported grilse (one sea-winter) catches)

In the period 1952–83, reported Scottish grilse catches increased to a peak 5-year mean of 283 000 fish in 1967–71, since when they have declined. Nevertheless, the mean catch in 1977–83 was some 50 000 greater than the corresponding figures in 1952–56.

3.1.1.2 Total reported salmon (multi sea-winter (MSW) fish) catches

Apart from the increase in the Scottish salmon 5-year mean catch in 1962–66, catches of MSW fish declined in 1952–83 from a mean of 231 000 fish in 1952–56 to a mean of 151 000 fish in 1977–83.

3.1.1.3 Total reported spring salmon catches

Total catches of spring salmon in 1952–83 declined steadily throughout the time series, from a mean of 88 000 in 1952–56 to a corresponding value of 28 000 fish in 1977–83. The rate of decline was faster in 1952–71 than in 1972–83.

3.1.1.4 Total reported summer salmon catches

Catches of summer salmon averaged over 5-year periods peaked in 1962–66. Subsequently, they have declined. The mean catch in 1977–83 was 19 000 less than the corresponding catch in 1952–56.

The rates of decline were not constant throughout these series of data. Whereas the decline in the 5-year

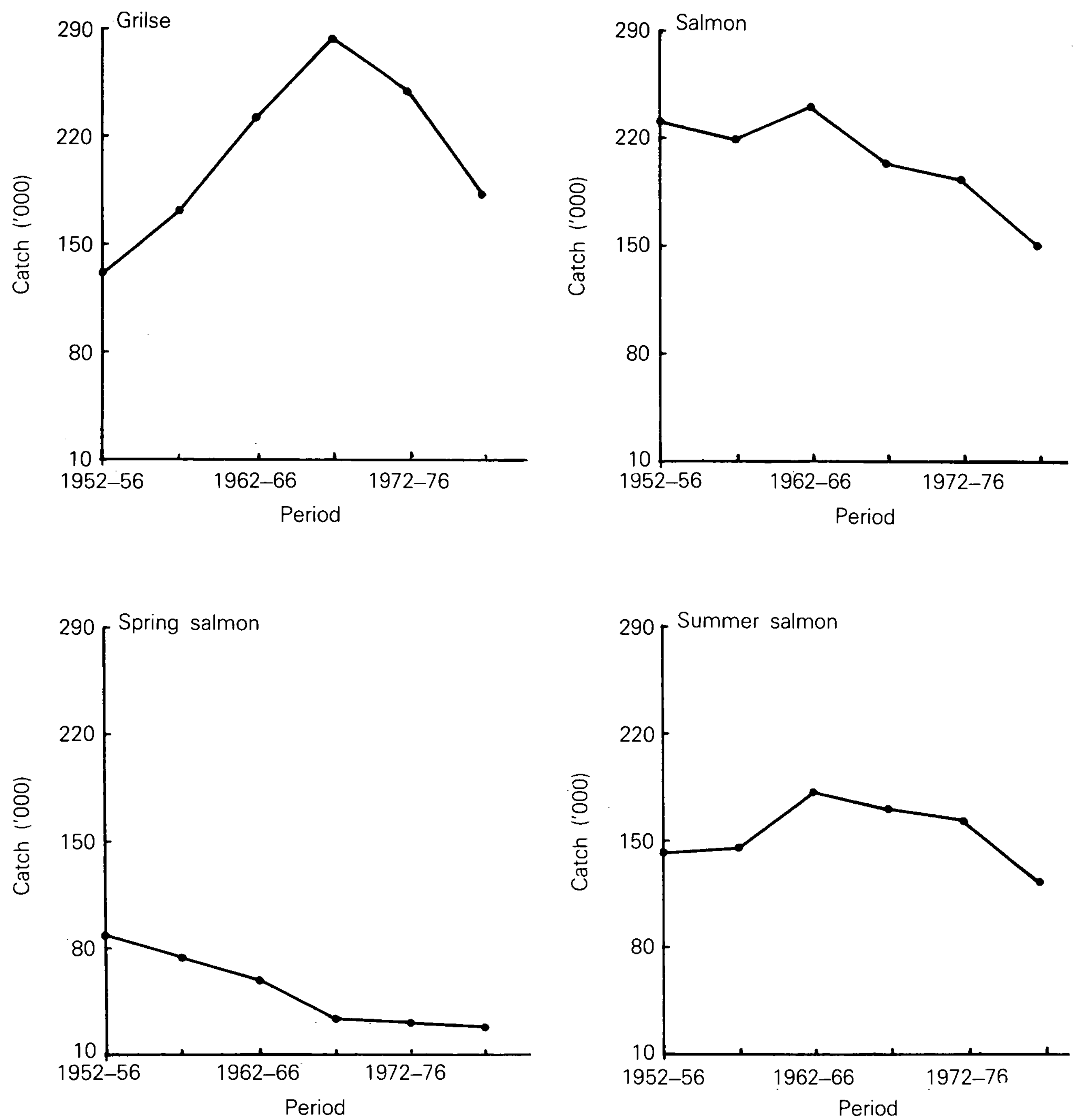


Figure 4. Reported Scottish catches of grilse and salmon in 1952–83, expressed as 5-year means

mean numbers of spring salmon in each period was marked and continuous (88 000–28 000), the decline in the mean numbers of summer salmon was less marked and did not begin until 1967–71.

3.1.2 Total reported Scottish catches by different fishing methods (Figure 5)

In 1952–83, fixed engine and net and coble catches were approximately the same, varying between about 110 000 and about 280 000 in different years, but the corresponding angling catch rarely exceeded 80 000. The trends in catches by the different gears differed from each other, with most of the decline borne by the net fisheries.

3.1.2.1 Total reported catches by fixed engines

The 5-year mean catch by fixed engines increased from 169 000 in 1952–56 to 199 000 in 1962–66, with a slight drop in 1957–61. Five-year mean catches continued at this level in 1967–71 and 1972–76, since when they declined rapidly to a mean of 141 000 fish in 1977–83.

3.1.2.2 Total reported catches by net and coble

The net and coble catch rose steadily from a 5-year mean of 143 000 fish in 1952–56 to a maximum mean of 224 000 fish in 1967–71. Then, mean catches rapidly declined to 123 000 in 1977–83. The decrease between each of the last 2 5-year periods was approximately the same (40 000 fish).

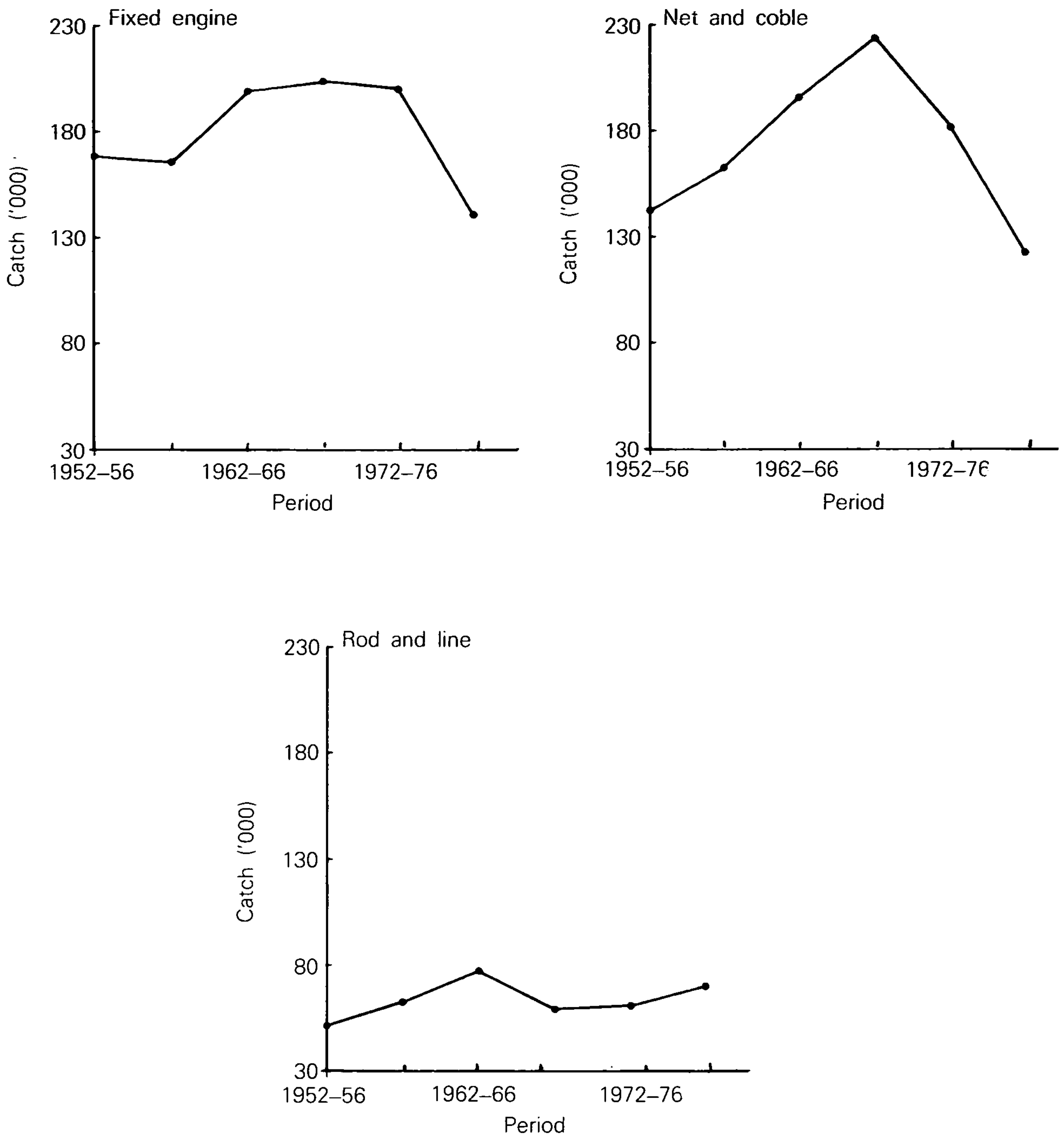


Figure 5. Reported Scottish catches by different gears in 1952–83, expressed as 5-year means

3.1.2.3 Total reported catches by rod and line

The rod and line and net catch patterns were rather different. The angling catch rose from a mean of 51 000 fish in 1952–56 to a maximum mean of 77 000 fish in 1962–66, before dropping to a mean of 70 000 fish in 1977–83. The latter value was 19 000 fish more than the corresponding value in 1952–56.

3.1.3 Reported Scottish catches of grilse and of spring and summer salmon by net and rod and line in 1952–83 (Figure 6)

In 1952–83, catches of grilse and spring and summer salmon by net and by rod and line fluctuated independently.

3.1.3.1 Catch of grilse by net and by rod and line

Grilse catches by net increased from a mean value of 126 000 in 1952–56 to a maximum mean of 273 000 fish in 1967–71, and then decreased to a mean of 169 000 fish in 1977–83. The pattern of rod catches of grilse, on the other hand, was rather different. Apart from the drop in the mean rod catch of grilse in 1972–76, catches of grilse by angling have increased steadily over the time series examined, from a mean of 6000 fish in 1952–56 to a mean of 13 000 fish in 1977–83.

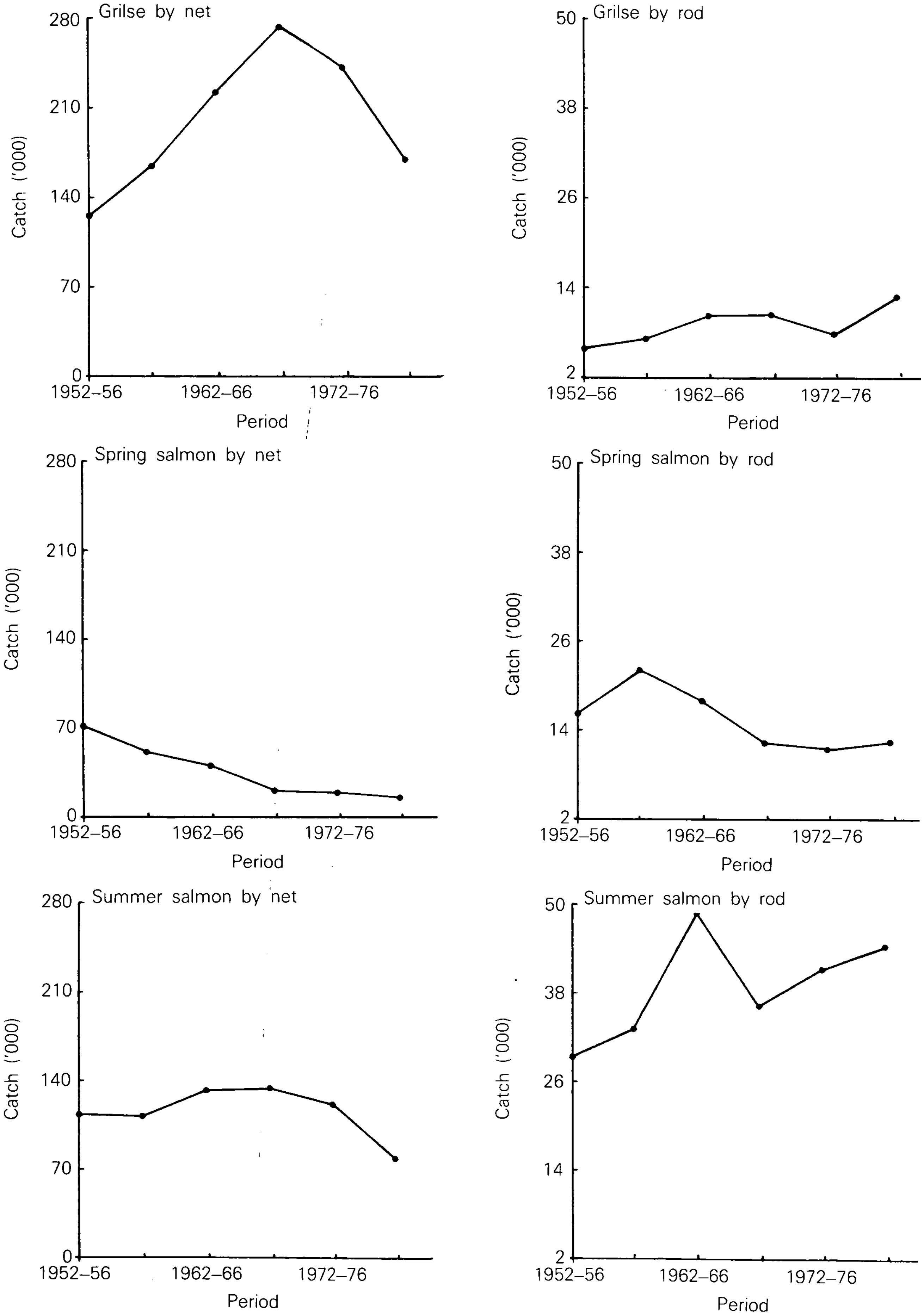


Figure 6. Reported Scottish catches of grilse and spring and summer salmon by different gears in 1952–83, expressed as 5-year means

3.1.3.2 Catch of spring salmon by net and by rod and line

Catches of spring salmon by net and by rod both declined, but the rate of decline was different in each case. Whereas net catches steadily declined from a mean of 72 000 fish in 1952–56 to a mean of 15 000 fish in 1977–83, the comparable rod catch peaked in 1957–61 (22 000) and subsequently dropped to 12 000 in 1977–83. Thus, the net catch was reduced by 80% and the rod catch by 45%.

3.1.3.3 Catch of summer salmon by net and by rod and line

Mean rod and line catches of summer salmon peaked in 1962–66 at 49 000 and, although they declined to a mean of 36 000 fish in 1967–71, mean catches in 1972–76 and 1977–83 both exceeded 40 000 fish (ie 11 000 more than the mean catch in 1952–56). On the other hand, catches of summer salmon in nets peaked in 1967–71 at a mean value of 134 000. However, they have since declined to a mean catch of 79 000 in 1977–83. This mean catch was some 34 000 less than the corresponding value in 1952–56.

3.1.4 Ratios of salmon to grilse in catches reported by fixed engine, net and coble and by rod and line fisheries

Expressed as percentages, the grilse proportion of the total fixed engine, net and coble, rod and line, and fixed engine and net and coble catches combined varied much more between net and rod catches than between fixed engine and net and coble catches.

Fixed engine catches contained the highest proportion (44–68%) of grilse, and rod and line catches the lowest (11–18%). The proportions of grilse in the catches by all 3 gears increased in 1952–83.

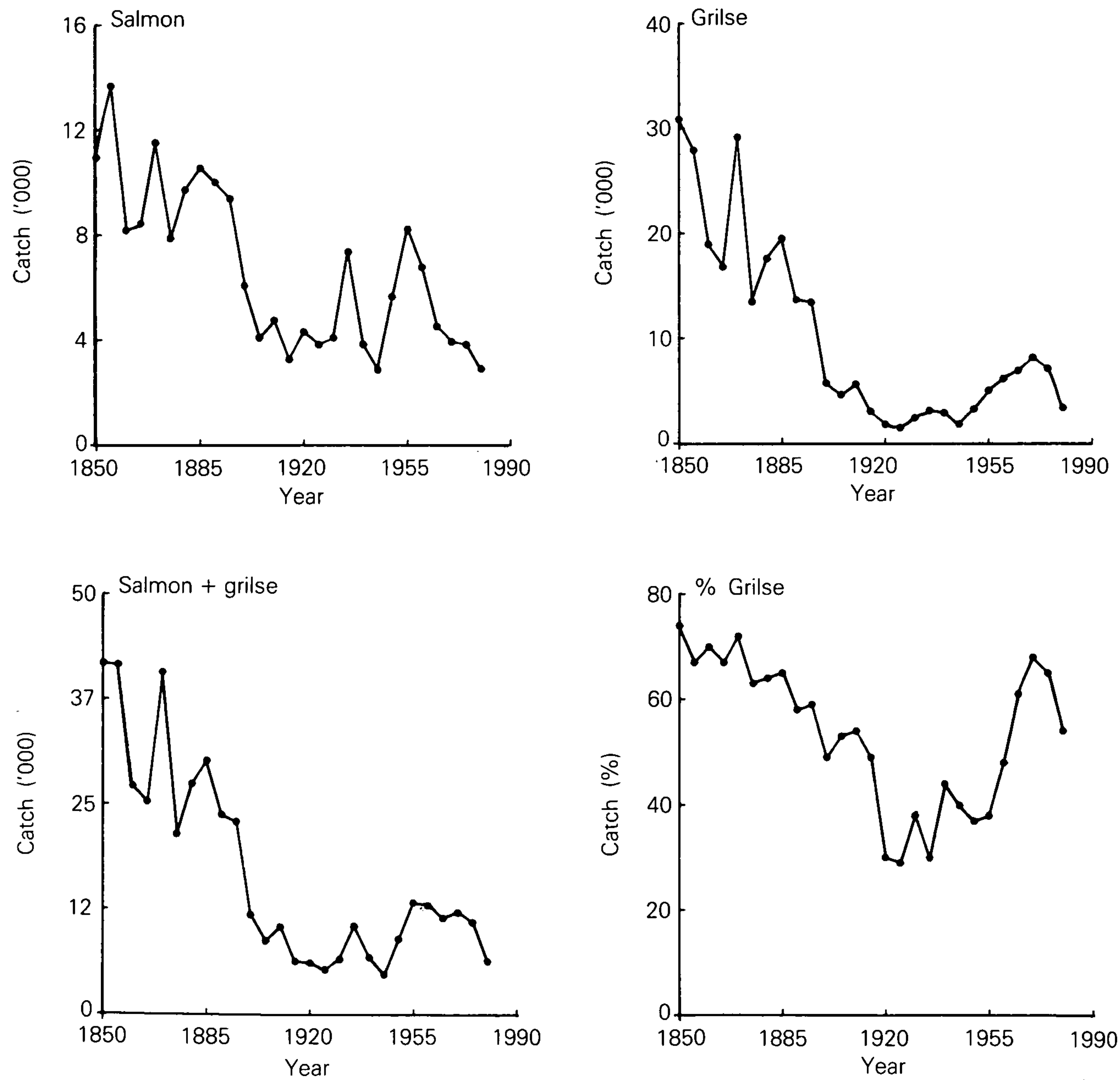


Figure 7. Net and coble catches in the River Spey in 1851–1983, expressed as 5-year means

3.1.5 The division of catches between rods and nets

In 1952–56, the proportions of the total Scottish catches of spring salmon, summer salmon, total salmon, grilse and salmon plus grilse taken by angling were 18%, 21%, 20%, 4% and 14%, whereas in 1977–83 the corresponding values were 45%, 36% 40%, 7% and 21%. The rod and line share of the total Scottish catch for each of these groups therefore increased over the period 1952–83, in some cases by more than 50%.

3.2 Historical catch records

3.2.1 Long-term trends

Particularly in the Spey, catches of salmon and grilse fluctuated widely. There were differences in the relative magnitude of the changes in the catches of grilse and MSW fish in the Spey and Dee. Underlying catch trends in the Spey differed from the Dee in a number of important respects (Figures 7–8).

3.2.1.1 Salmon catches

i. River Spey Catches of salmon in the Spey in 1850–1983, averaged over each 5-year period, fluctuated widely (Figure 7). From 1850 to 1889, the 5-year mean ranged between 7877 and 13 682 fish with no trend evident. From 1890 to 1909, mean catches averaged for 5-year periods rapidly declined from 10 010 to 4080. Thereafter, excepting peaks in 1935–39 (5-year mean 7364 fish) and 1955–59 (5-year mean 8224 fish), the more recent catches have fluctuated around a 5-year mean of 4671 fish.

ii. River Dee The trend of catches in the Dee (Figure 8) differed from that in the Spey. Excepting declines in mean catches in 1945–49 and 1970–75, the underlying trend in 1870–1983 was upwards. The 5-year mean catch peaked in 1925–29, 1935–39, 1950–54 and in 1980–83.

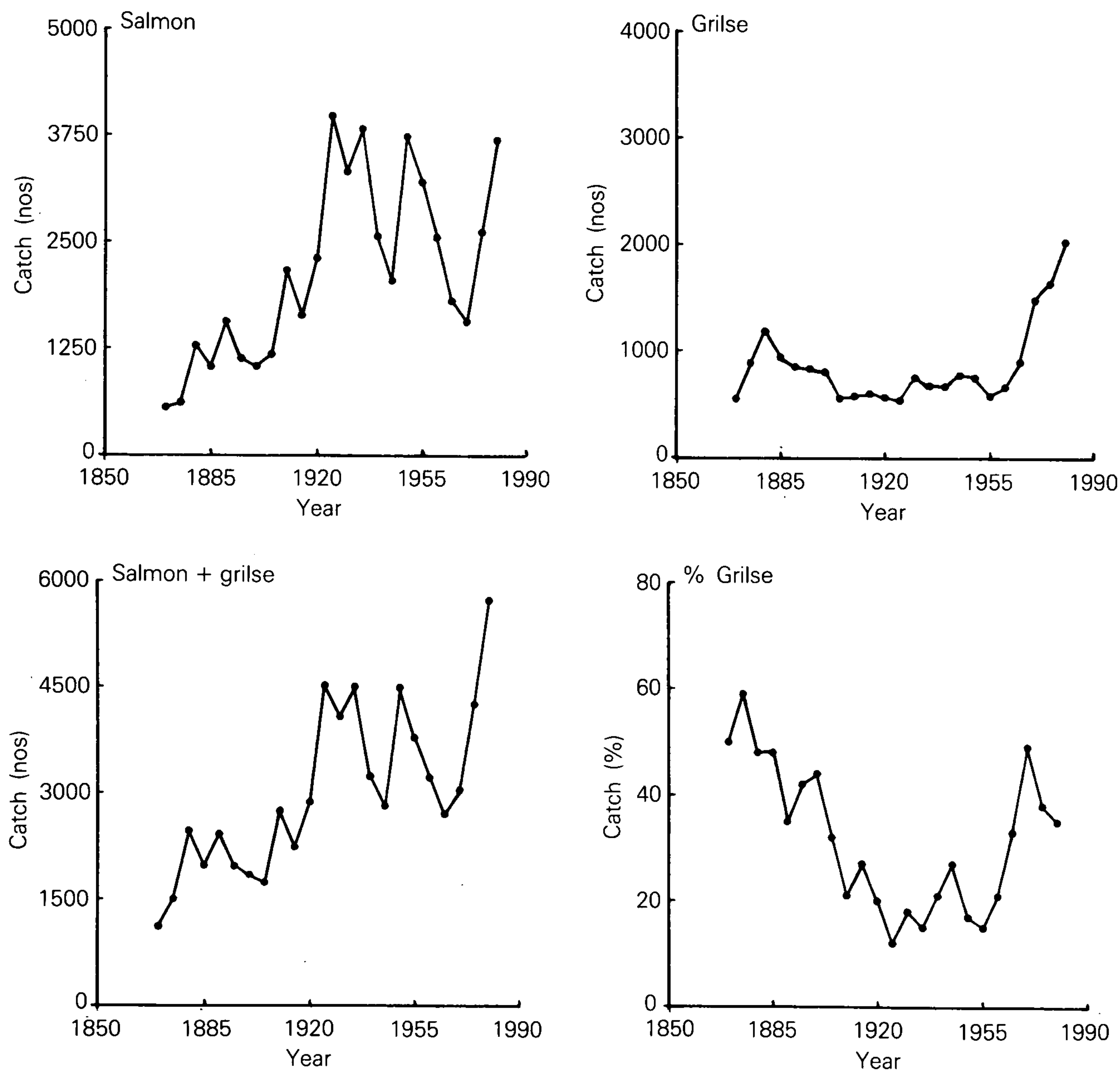


Figure 8. Net and coble catches in the River Dee in 1872–1983, expressed as 5-year means

The smallest mean catch since 1915–19 occurred in 1970–75. In 1870–1983, the 5-year mean catch increased from 560 in 1870–74 to 3700 in 1980–83.

3.2.1.2 Grilse catches

i. River Spey The Spey grilse catch trend between 1850 and 1929 was downward, the 5-year mean declining from 30 873 fish in 1850–54 to 1531 fish in 1925–29. The decline was not continuous as peak means occurred in 1870–74 and 1885–89. After 1925–29, 5-year mean grilse catches improved and the underlying trend was upward. Apart from a drop in 1945–49, this improvement lasted until 1970–74. As a result, there was a 5-fold increase in the 5-year mean catch between 1925–29 and 1970–74. In comparison with the 1970–74 mean catch, the corresponding catch in 1975–79 was less, and this decline continued in 1980–83.

ii. River Dee The Dee grilse catch trend differed from the Spey. Instead of a decline followed by an increase, Dee grilse catches remained remarkably stable until 1960–64, since when they too have shown a steady increase, and there was no evidence of a decline in 1980–83. The increase in the 5-year mean catch between 1870–74 and 1980–83 was approximately 4-fold (552–2027).

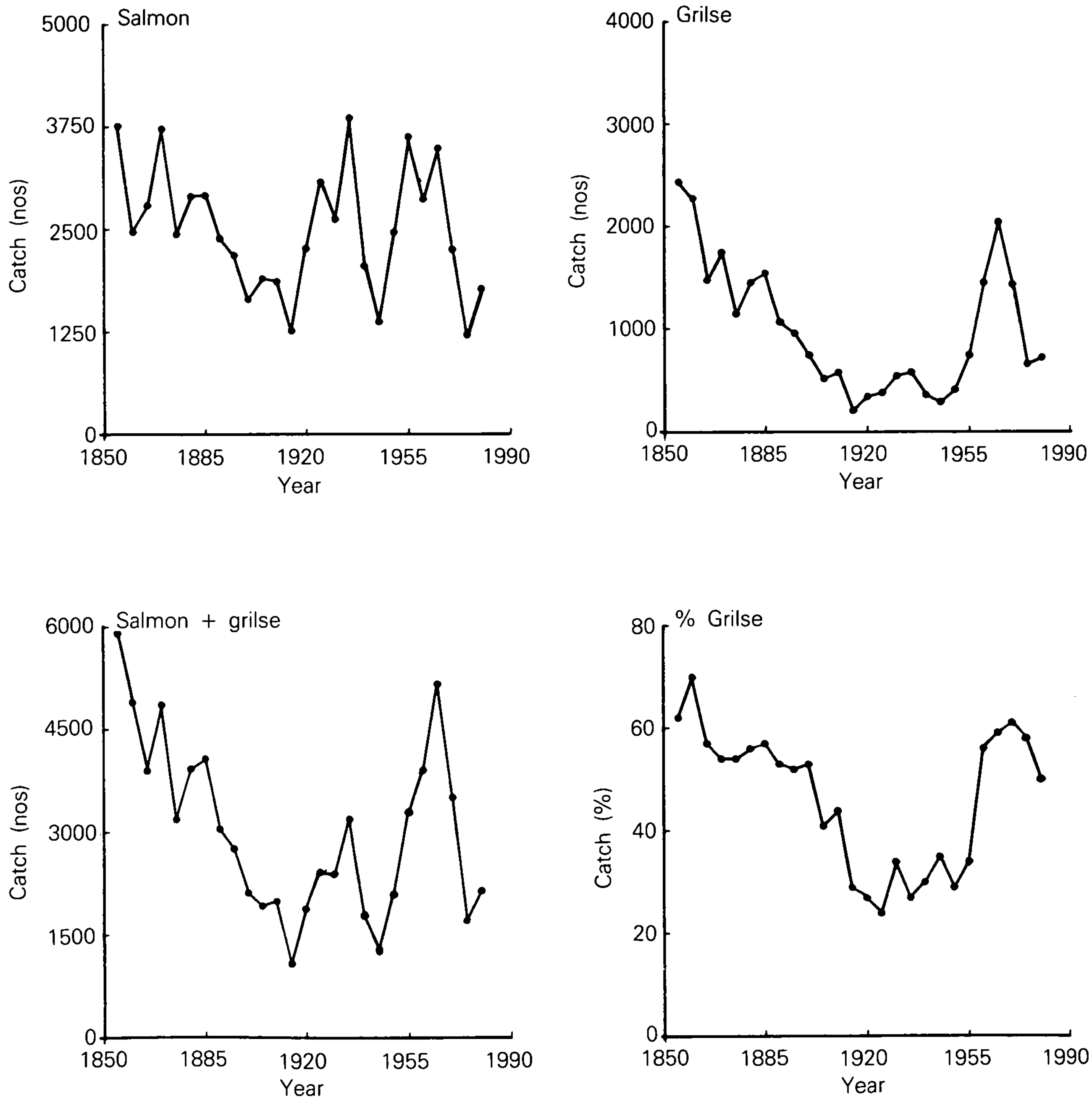


Figure 9. Net and coble catches in the River Tweed in 1857–1983, expressed as 5-year means

3.2.1.3 Salmon plus grilse

Trends for salmon plus grilse catches in the Spey closely followed those for grilse. In contrast, the trend for the combined salmon plus grilse catch in the Dee closely followed the trend for the salmon only catches, and illustrates the much greater importance of MSW fish to Dee catches than to the Spey.

3.2.1.4 Salmon to grilse ratio

Expressed as percentages, the grilse proportion of the total salmon plus grilse catch varied widely. In the catches for these 2 rivers, the proportions of grilse declined until the second half of the 1920s. Subsequently, they increased almost to the level of the late 1880s. However, since 1975 in the Dee and since 1980 in the Spey, the trend has again been downward.

3.2.1.5 Catches of salmon and grilse in the River Tweed

Catches in the Tweed of salmon and grilse showed the same general pattern as the Spey rather than the Dee. They declined from the late 1850s until about 1920. Thereafter, catches of both salmon and grilse showed some recovery, but not to the high level of the early 1850s (Figure 9).

3.2.2 Returns from rail and steamship companies

Records of the weight of salmon carried in 1894–1931 by the rail and steamship companies (Fishery Board for Scotland 1932) also illustrate the wide fluctuations in salmon catches. During the relatively short period 1894–1931, the weight of salmon and sea trout carried fluctuated between 5-year means of 1650 tonnes in 1914–18 and 2830 t in 1894–98, with no evident underlying trend. After adjustment for weight of ice and boxes and double counting, these figures become 907 t and 1557 t respectively. The average weight of salmon (including sea trout) reported caught in 1979–83 was 1325 t, which lies almost mid-way between these 2 values.

3.3 Counts at NSHEB dams

Counts at Aigas and Pitlochry Dams (Figure 10) were chosen to illustrate the data. Trends for upstream migrants could be different between these 2 sites as a result of differences in the sea age composition of the fish which passed these counters each year. Whereas most fish passing Aigas Dam were likely to be grilse, the bulk of the fish passing Pitlochry Dam were probably MSW fish. Although the counts at Aigas Dam fluctuated between 12 748 in 1967 and 4300 in 1968, no overall trend was evident in 1963–84 after an initial decline in 1963–68. The counts at Pitlochry Dam also fluctuated widely, ranging between 3045 in 1983 and 11 977 in 1973. Between 1951 and 1978, the underlying trend was slowly upward, but after that date the count in each succeeding year was less than its predecessor. However, the accuracy of resistivity counts can change, as the pre-set trigger level alters as the conductivity of the water changes, ie when the conductivity of the water decreases, the counter will count smaller fish. The reverse will occur when the conductivity of the water rises. As changes in conductivity are unlikely to be the same from year to year, or for the same duration, any error is unlikely to be constant between years. These problems have been largely circumvented at Logie by installing another module in the standard counter. This module compensates for changes in the electrical resistance between the electrodes. In addition, the counters at Logie are calibrated twice daily. Dunkley (1986) discusses the counts of fish at Logie.

3.4 Smolt production from the River North Esk and Girnock Burn

3.4.1 River North Esk

The estimated production of smolts from the North Esk fluctuated widely in 1964–84, between 93 000 in 1976 and 275 000 in 1964 and with no apparent trend (Figure 11). Also, estimates of the juvenile salmon densities in the major tributaries in the 1970s and again in the 1980s indicated no evidence of a sustained downward trend.

3.4.2 Girnock Burn

In 1967–84, the smolt production from the Girnock fluctuated widely between 1440 in 1968 and 3679 in 1977 (Figure 12). The underlying trend was upward. This increase occurred during a period when the numbers of female spawners were declining. The numbers of smolts migrating each year from the North Esk and Girnock fluctuated independently.

4 Discussion

4.1 Main features of the data

Scottish catches increased in 1962 and this new catch level was maintained until about 1975. Since 1976, total catches have declined and recent figures are among the lowest since 1952. The decline was largely confined to net fisheries with little change in numbers caught by rod.

Catch trends differed between different components of the salmon stock. Whereas the total catch of spring fish dropped steadily from a mean catch of 88 000 in 1952–56 to a mean of 28 000 fish in 1977–83, the all-method catch of summer fish peaked in 1962–66 at a mean value of 182 000, before declining to a mean catch of 123 000 (19 000 less than the 1952–56 mean) in 1977–83. The total grilse catch trend was somewhat similar to that of summer fish, rising from a mean of 132 000 fish in 1952–56 to a peak mean value of 257 000 in 1967-71. Although it had declined to a mean of 182 000 fish by 1977–83, the grilse mean catch was still 50 000 more than the comparable figures for 1952–56.

The main feature of Scottish catches since 1952 has been a decline over the last 20 years in the catch of spring salmon and an increase followed by a decrease in the catches of one sea-winter fish.

The rod and line share of the total catch has increased.

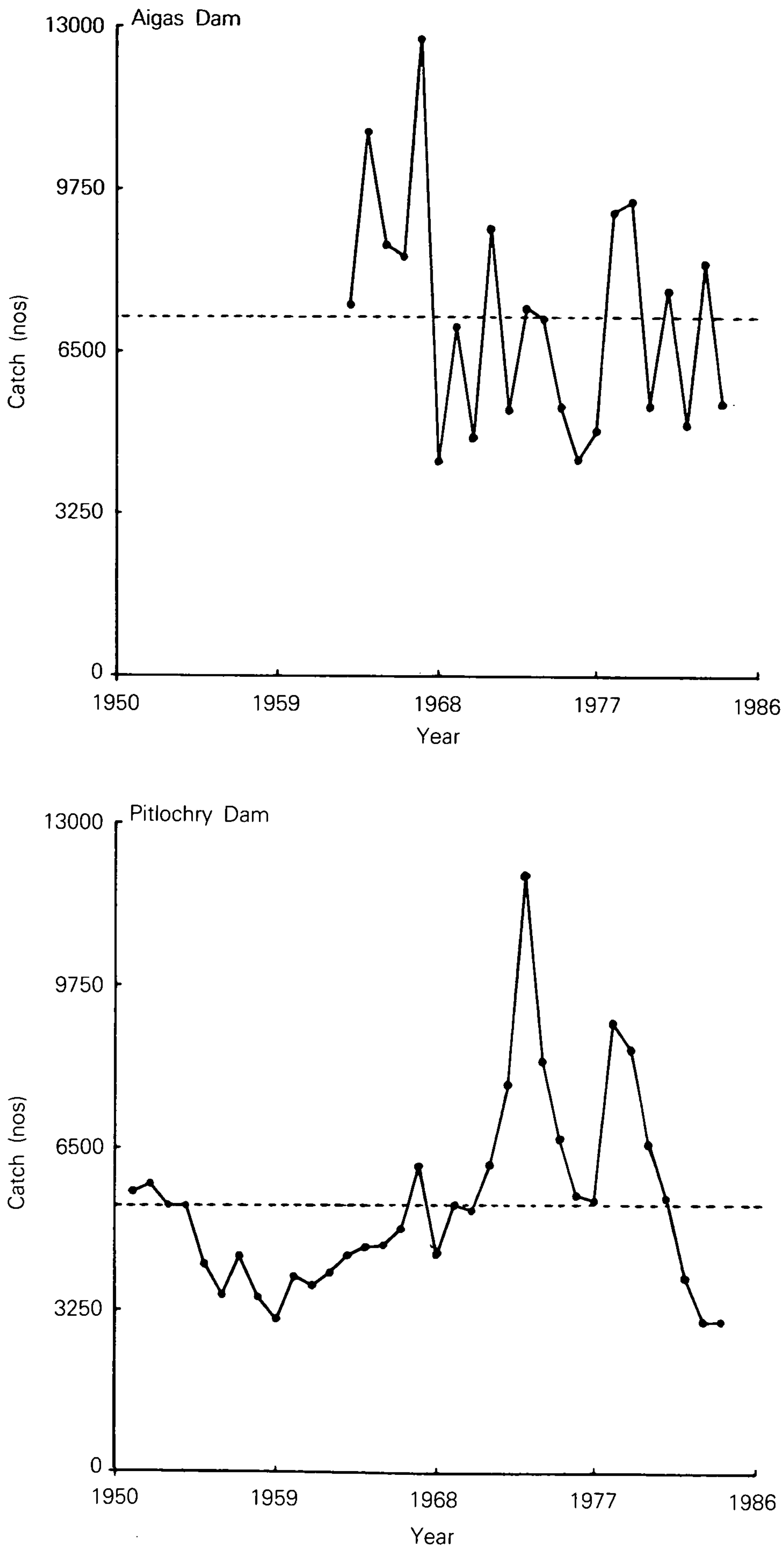


Figure 10. Fish counts at Aigas and Pitlochry Dams

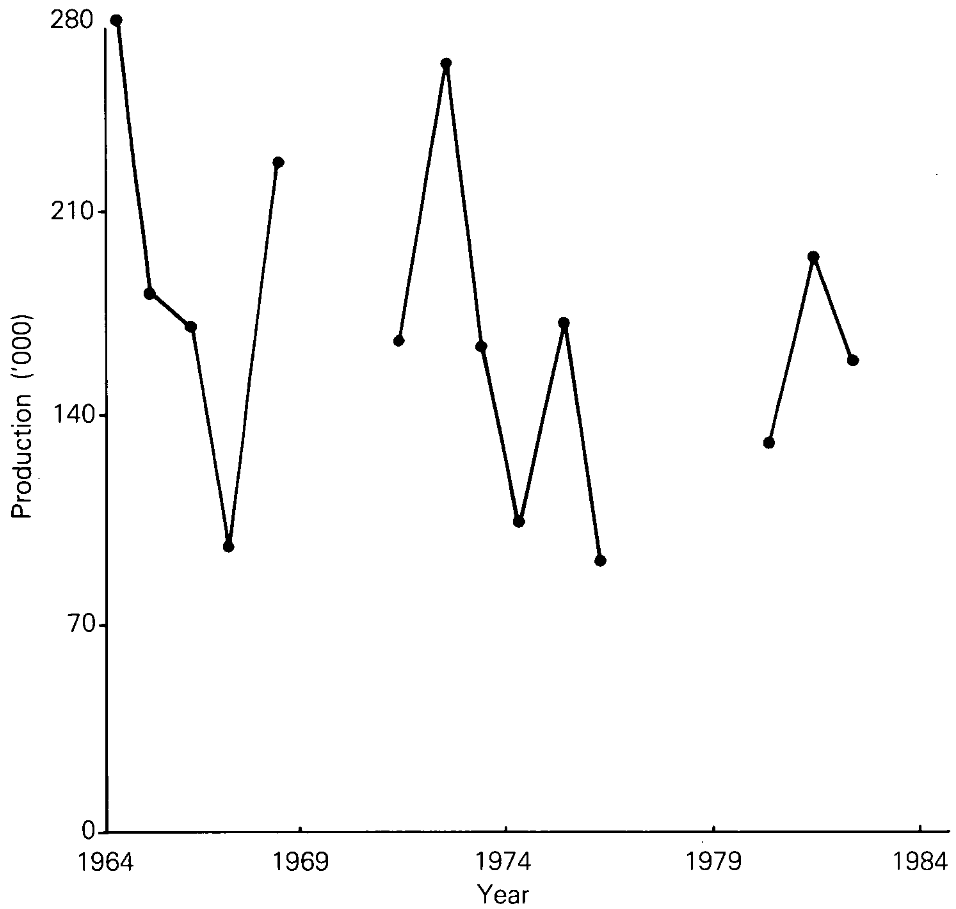


Figure 11. *Estimated annual smolt production in the River North Esk, 1964–84*

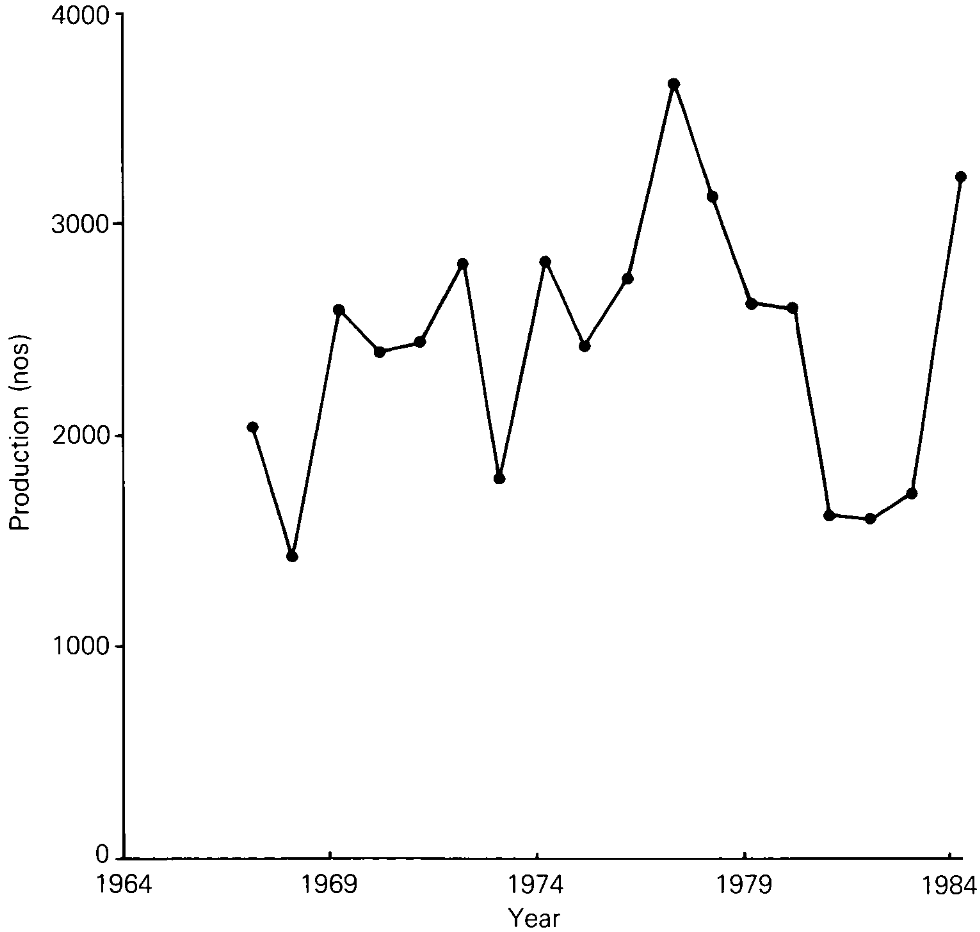


Figure 12. *Annual smolt production in the Girnock Burn, 1967–84*

Catch trends for the River Spey for 1850–1983 differed from the pattern for the River Dee over the same time period in several respects.

On the Spey, grilse and MSW fish catch trends for 1850–1983 fell into 3 patterns, downward until the 1920s, then upward, and downward again from the 1970s. In contrast, the catches of MSW fish from the Dee showed an upward trend from the late 1800s and the grilse catches remained remarkably stable until 1960–64, since when they too have shown a steady increase.

Although catches of salmon and grilse in the Spey recovered after the 1920s, they did not reach the former high level of catches in 1850–70.

In the catches from both rivers, the proportion of grilse first declined, but from about 1925 increased to about the same level as previously.

Grilse are less important to the Dee fishery than to the Spey and Tweed fisheries.

Catches of salmon and grilse in the Tweed showed the same general pattern as the Spey.

Assuming that the weight of fish (adjusted for the weight of ice and boxes and double counting) transported by the rail and steamship companies in 1894–1931 was an index of the total Scottish catch during that period, the data illustrate that not only did catches fluctuate widely but also that the level of catches was not substantially different from those taken at the present time.

Omitting the counts in 1979–84 at Pitlochry Dam and in 1963–68 at Aigas Dam, the counts at neither dam indicated a sustained downward trend in the number of potential spawners in either river system. The counts at these dams and the reported catches of grilse and MSW fish fluctuated independently. The possibility of a major difference between the counts and the actual number of salmon passing each counter site should not be discounted.

Smolt production figures for the North Esk and Girnock Burn over the last 20 years fluctuated widely but show no evidence of a sustained downward trend. Such data as are available are insufficient to determine what effect possible changes in the age composition of the smolts might have on their survival at sea or time of return to the rivers.

4.2 Stock genetics

Not every river and tributary contains spring salmon, summer salmon and grilse. In those that do, the proportions of these components can vary both between rivers and between years. At present, we do not know whether these groups are genetically distinct or whether the distinction is based on environmental or other factors to which the fish are exposed, either as juveniles in fresh water or later in the sea. There is some evidence that at spawning time there may be some separation of the stock components. Spring salmon are normally found in tributaries which join main rivers nearer their source. They also tend to spawn earlier than summer salmon and grilse.

4.3 Effort

Variation in effort presents a major difficulty in interpreting the data. It is not clear whether the trends observed in catch data were correlated with the availability of fish or with the effort put into catching them. Neither, with the data available, is it possible to quantify the effect which observed reductions in net fishing effort have had on total catches. Similarly, it is not possible to quantify the effect which changes in the materials used to manufacture nets have had on their catching efficiency, or whether the catching efficiency of net and coble crews has altered with the change to motor cobles and powered winches. The stations which stop fishing tend to be those with lowest catch rates. Therefore, reductions in total catch due to the closing of fishing stations may not be directly proportional to the number of stations which have been closed. No data describing the effort from rod fisheries are available. Even if the numbers of rod days were known, it cannot be assumed that all anglers and tackle are equally efficient.

4.4 Location of net and coble fisheries

During the period for which long-term catch records are available, not only have the number of sites fished by net and coble within the Spey, Dee and Tweed Fishery Districts decreased but, what is equally important, the area fished has also been severely restricted.

For example, no net and coble fishing now occurs on the coasts adjacent to the mouth of the Spey. Apart from a reduction in the actual number of nets fishing, this change could markedly decrease the number of salmon of non-Spey origin occurring in the Spey net and coble catch.

4.5 Effects of interception fisheries

Prior to the 1950s, the salmon-producing nations, with several notable exceptions, had complete control of the exploitation and management of their stocks. Now, there are fisheries at sea, including some where countries other than the producing nations are fishing. Fish of known Scottish origin are presently being exploited off Greenland and the Faroes and off the coasts of Ireland and north-east England.

4.5.1 Effects of the Greenland and Faroese fisheries

The Greenland fishery began in the early 1960s and catches reached a peak (2689 t) in 1971. They have since declined, particularly in the last 2 years. On the other hand, catches in the Faroese long-line fishery did not exceed 100 t until 1979, and since 1982 catches have been limited by a quota of 750 t in 1982, reduced to 625 t in 1983. Although there may be other marine feeding grounds for salmon besides Greenland and Faroe, it is possible to estimate the total losses to European home water stocks for each tonne landed from the Faroese and Greenland fisheries (Anon 1984c). Estimating these losses at the individual country level presents greater difficulties. As both these fisheries exploit potential MSW fish rather than grilse, any effect on the stocks native to individual countries is likely to depend on the proportions of grilse and salmon in the national stocks. Similarly, any effect of the Greenland and Faroese fisheries on river stocks within countries is likely to be greater on those which are dominated by MSW fish.

4.5.2 Effects of the drift net fisheries off the coasts of Ireland and north-east England

Although there were traditional fisheries in both these areas, the catching power of these fisheries increased greatly in the 1960s with the introduction of more efficient nets manufactured from synthetic twine. The recapture sites of fish which have been tagged in the Northumbrian fishery indicate that its influence is mainly concentrated on stocks from rivers on the east coast of Scotland between the River Bervie and the River Tweed. There is little information on the river stocks being exploited by the Irish drift net fishery. In 1978–83, the reported Irish and Northumbrian drift net mean catches were 753 t and 187 t respectively. As both these fisheries tend to catch grilse, any effect on rivers possessing mostly salmon is likely to be marginal. Potter and Swain (1982) pointed out that more than 90% of the fish caught in the drift net fishery off the north-east of England were destined for Scottish rivers. No comparable data describing the source of the fish caught in the Irish drift net fishery are available.

4.6 Sea temperature

Martin and Mitchell (1985) suggested that the sub-arctic sea temperature has a major influence on whether fish return as grilse or as salmon. In periods, especially since 1960, when sub-arctic temperatures were below average, the percentage of fish returning as grilse increased.

4.7 Non-catch fishing mortality

Non-catch fishing mortality includes fish which are removed from the population by whatever means but are not reported as having been caught, eg non-reported catches by legal means, fish caught both in the sea and in fresh water by illegal means, and fish dropping out of nets either dead or dying subsequently. Although these catches cannot be quantified, it is unlikely that they remain constant from year to year or from area to area. In 1962, a legal drift net fishery operated off the Scottish coast. This method of fishing was banned in 1963 and significant enforcement effort continues. Nonetheless, illegal fishing using similar techniques continues off the Scottish coast and the catch cannot be quantified. Non-catch fishing mortality could have been greater in 1970–80 than in 1950–60.

4.8 Mortality

For most years in 1961–76, the estimated natural sea mortality of North Esk salmon varied between 54% and 79% (Shearer 1984b). In 1980–82, it increased to 86% and did not fall below 83% in any of the years.

4.9 Conclusions

Most of the information examined in this paper came from fisheries which are only allowed to operate for rather less than half the year, although salmon are known to return to fresh water throughout the 12 months. This can cause difficulties in interpreting the data. For example, if the timing of the runs has changed (there is some evidence that this may have occurred), the proportion of the total stock available for exploitation during the fishing season may have declined. As a result, a below-average catch would not signify a small total stock as the spawning escapement would have been augmented by those fish which normally would have been caught during the fishing season.

The lack of reliable data describing the effort put into catching salmon is another major difficulty in interpreting catch trends. Thus, the results of any comparisons between catches by years and by gears and their relationship to the spawning stock must be suspect. An added difficulty is that, since the early 1960s, Scottish salmon stocks have been exploited outside Scottish home waters. The data available from these fisheries were insufficient to estimate the loss to Scottish home water catches. Non-catch fishing mortality has also fluctuated widely over the period.

Nevertheless, the long-term catch data examined, in addition to indicating wide fluctuations, showed that in all 3 rivers (Spey, Dee and Tweed) changes (a decrease followed by an increase in the proportion of grilse) have occurred in the sea age composition of the catch. They show that, while the mean catch of salmon in the Spey was greater in the 1800s than in the 1900s, the mean catch in 1900–39 was little different from the corresponding value in 1940–83. Catch trends in the River Dee were different, the mean catch in 1900–83 being more than twice the corresponding value in the 1800s. The long-term catch data also showed that mean grilse catches in the Spey in the 1800s were approximately 4 times greater than the corresponding catches in the 1900s. However, the mean grilse catch in 1940–83 was about twice the mean catch in 1900–39. On the other hand, the Dee grilse catch trend was different because there was little difference between the mean values for the 1800s and 1900s (Table 1).

The national statistics (1952–83) showed that the increase in the total Scottish catch in the late 1960s and early 1970s was not sustained, and the numbers have now returned to the level of the 1950s. Catches by sea and river nets have declined, although angling catches have remained remarkably stable. However,

Table 1. Grouped Spey, Tweed and Dee mean salmon and grilse catches in 1850–1983

Interval	Salmon Spey	Salmon Tweed	Salmon Dee	Grilse Spey	Grilse Tweed	Grilse Dee
1850–99	10010	11205	1068	19928	15281	897
1900–83	4740	9340	2533	4343	7067	842
1900–39	4715	9248	2435	3524	4877	634
1940–83	4760	9423	2623	5088	9057	1031

the distribution of the angling catch has shifted. Whereas 32% of the mean annual catch was taken before 1 May in 1952–56, the corresponding value in 1977–83 had declined to 18%. When examining total rod catches, the increase in the proportions of the angling catch taken after 30 April tended to mask the decline in spring catches. The sharp decline (70%) in the total Scottish spring catch in 1952–83 could indicate that this component of the stock is presently under some pressure, even though a general decline in total stocks has not been confirmed.

The counts of potential spawners at Aigas and Pitlochry Dams over the time series examined gave no clear indication of any definite trend, but, if the last 6 years' data from Pitlochry are examined in isolation, there was a downward trend. This observation would fit the belief that spring fish stocks could be declining in some rivers. However, because the performance of these counters can be affected by changes in the environment, the accuracy of these figures is open to some doubt.

The number of smolts produced annually in the North Esk and Girnock gives no indication that the smolt production from these 2 watersheds has declined over the last 20 years. The data suggest that the numbers of female spawners presently entering these systems are not limiting the overall smolt production.

It is unfortunate that the present data are insufficient to draw firm conclusions about the strength of past and present stocks. A measure of stock abundance requires more precise data on catch, and effort expended taking that catch, and the proportion of the total stock available for exploitation.

5 Summary

5.1 This paper describes the sources of data which are available to assess the state of Atlantic salmon stocks in Scotland.

5.2 Catches of salmon and grilse taken by nets have fluctuated widely between years, but angling catches have remained markedly stable in 1952–83.

5.3 An increase in the annual catch of salmon plus grilse in the late 1960s and early 1970s was not sustained and the catch has since declined to a level similar to that in the 1950s.

5.4 This decline was mostly borne by the net fisheries.

5.5 Catches of spring fish showed the most marked and longest decline, and grilse the smallest.

5.6 The angling share of the total catch by all methods has increased.

5.7 An examination of the long-term catch trends show that trends for the Spey differed from catch trends for the Dee in a number of important aspects. For example, in the Spey there was an initial decline in catches of grilse and MSW fish and a subsequent increase in the catches of both sea age groups, whereas in the Dee catches of MSW fish showed no downward trend over the whole period from 1872 and grilse catches remained stable until 1960–64, since when they too have shown a steady increase. Although grilse catches on the Spey recovered, they did not rise to their previous high levels.

5.8 Grilse were less important to the Dee fishery than to the fisheries on the Spey and Tweed.

5.9 The ratio of grilse to salmon in the catches varied widely and its present value does not differ from that operating in the 1850s.

5.10 A comparison between the rail and steamship returns and present catch figures suggests that total Scottish catches have not changed substantially over the last 100 years.

5.11 The counts of potential spawners passing the Aigas and Pitlochry Dams did not show any overall downward trend.

5.12 There was no evidence of a downward trend in smolt production from either the North Esk or the Girnock.

5.13 Due to lack of reliable data describing the effort expended in catching fish and of the proportion of the stock available for exploitation, it was not possible to calculate the number of potential spawners.

5.14 The main requirement is for precise information on the effort put into catching salmon by each method, and on the magnitude of non-catch fishing mortality, for consistent catch reporting, and for some measure of the fish migrating into rivers outwith the fishing season, including their biological characteristics.

6 Acknowledgements

I am most grateful to Aberdeen Harbour Board, Mr K Anderson, Berwick Salmon Fisheries Co Ltd, and Mr Robert Clerk, Messrs Smiths Gore, for permission to use the catch data from net and coble fisheries operated on the Dee, Tweed and Spey. I am also grateful to Mr Francis G Johnston, NSHEB, for permission to use the salmon counts at Pitlochry and Aigas Dams, and to colleagues for help in abstracting the data.

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Appendix A. Information on salmon caught required by the Department of Agriculture and Fisheries for Scotland

DEPARTMENT OF AGRICULTURE AND FISHERIES FOR SCOTLAND

Salmon and Freshwater Fisheries (Protection) (Scotland) Act 1951

RETURN OF CATCHES OF SALMON FOR THE YEAR 1982

1. The Secretary of State is authorised by section 15(1)(*b*) of the Salmon and Freshwater Fisheries (Protection) (Scotland) Act 1951. to collect statistics of the salmon fisheries. The object of doing so is to provide information which will assist in protecting and developing the fisheries.

You are required to complete this form and forward it to the Secretary, Department of Agriculture and Fisheries for Scotland. Fisheries Division, Room 433, Chesser House, Gorgie Road, Edinburgh EH11 3AW, as soon as possible after the close of the 1982 fishing season or not later than one week after the closing date for salmon fishing by rod and line in your District in 1982.

2. If you are operating more than one fishery in the same fishery district you may combine the returns on one form.

3. If the information provided in this return relates to more than one fishery for which separate forms have been issued please give here the names and code numbers of the other fisheries included:

____

____

IMPORTANT

4. Please state as accurately as possible exact location of all fisheries to which this return relates, including limits of the fishery, and, in the case of river and estuary fisheries, whether on right or left bank. Please also give grid reference(s).

____

____

____

5. Please complete ONLY IF YOU ARE NO LONGER PROPRIETOR OR OCCUPIER-
I am no longer the proprietor of the fishing by rod and line or the occupier of the fishery for operation by methods other than angling.

The new proprietor/occupier is:

Name ....

Address ....

....

Date of termination
of ownership/tenancy ....

6. Please enter the date when you complete the return and sign below.

Date ....

Signature of Proprietor/Occupier ....

Address ....

....

In terms of Section 15(2) of the 1951 Act failure to comply with the requirement contained in paragraph 1 above or the making of a false statement is an offence.

PART I—RETURN OF FISH CAUGHT BY ROD AND LINE

(To be completed by the proprietor of the fishery)

Please enter below fish caught on your fishery (whether by yourself or by your tenants) during 198....

FOR OFFICIAL USE		SALMON		GRILSE		SEA TROUT	
		Number	Wt (lbs)	Number	Wt (lbs)	Number	Wt (lbs)
101	January						
102	February						
103	March						
104	April						
105	May						
106	June						
107	July						
108	August						
109	September						
110	October						
111	November						
9-11		22-26	27-32	33-37	38-43	44-48	49-54

PART II—RETURN OF FISH CAUGHT BY NET AND COBLE (SWEEP NET)
FOR FIXED NETS SEE OPPOSITE PAGE

(To be completed by the occupier of the fishery)

Please enter below all fish caught by net and coble, and the number of crews and men employed in each month of 198....
If the number of crews or men varies during the month please give the maximum and minimum numbers.

FOR OFFICIAL USE		Number of crews employed		Number of men employed		SALMON		GRILSE		SEA TROUT	
		Max	Min	Max	Min	Number	Wt (lbs)	Number	Wt (lbs)	Number	Wt (lbs)
202	February										
203	March										
204	April										
205	May										
206	June										
207	July										
208	August										
209	September										
9-11		12-13	14-15	16-18	19-21	22-26	27-32	33-37	38-43	44-48	49-54

PART III—RETURN OF FISH CAUGHT BY FIXED ENGINES

(To be completed by the occupier of the fishery)

a. Please enter below all fish caught by fixed engines and the number of traps in operation and men employed in each month of 198.... If the number of traps or men varies during the month please give the maximum and minimum number.

FOR OFFICIAL USE		Number of traps in operation		Number of men employed		SALMON		GRILSE		SEA TROUT	
		Max	Min	Max	Min	Number	Wt (lbs)	Number	Wt (lbs)	Number	Wt (lbs)
302	February										
303	March										
304	April										
305	May										
306	June										
307	July										
308	August										
309	September										
9-11		12-13	14-15	16-18	19-21	22-26	27-32	33-37	38-43	44-48	49-54

b. Please indicate below in the appropriate places the numbers of each type of fixed engine used:

1	2	3	4	5	6	7	8	9
Bag nets (Total number of bags fished)	Fly nets	Jumper nets	Stake nets (Maximum number of pockets fished)	Poke nets (Maximum number of pokes)	Yairs	Haaf nets (Total number of Permits)	Cruives (Number of traps fished)	Others
55-56	57-58	59-60	61-62	63-64	65-66	67-68	69-70	71-72

FOR OFFICIAL USE—DESCRIPTION OF FISHERY

	3-5	6-8
SALMON FISHERY DISTRICT	DISTRICT CODE NUMBER	FISHERY CODE NUMBER

Is there a basis here for prediction?

J D PIRIE
Department of Natural Philosophy, University of Aberdeen

1 Introduction

There is clear evidence that the pattern of migration of adult Atlantic salmon to Scottish fresh waters has not been static during the past 2 centuries. The timescale of discernible changes in the migration pattern is about a decade, although superimposed on these secular changes are year-to-year variations of at least a factor of 2 in a particular component of Scottish catches. The factors which determine the yearly strengths and timings of the runs into Scottish fisheries have not all been identified, let alone their interactions and individual importance. However, events for which reliable records, specifically of catches during the 19th and 20th centuries, have been kept suggest that changes will continue to unfold.

Most of the data available on salmon runs in Scottish waters are catches. These provide a varying measure of the numbers present and do not give information outwith the relevant fishing seasons. However, bearing in mind these limitations, one should make best use of those of the existing data to which one has access. Catches are also the main interest of most fishermen.

2 The past

A comprehensive study of Scottish catches from 1790 up to 1976 has been presented by George (1982). He demonstrates that there have been changes in:

i. the numbers of fish available during the fishing season;
ii. the relative numbers of fish of different sea ages;
iii. the time of arrival of a particular sea age group;
iv. the average weight of a given sea age group.

These changes may not be in phase for different parts of the British Isles or further afield, and a particular pattern in the return migration in one region may never be part of the sequence in another region. Neither will all 4 be independent of each other, eg (i) and (iii) or (iii) and (iv).

Essentially, and particularly for the east coast, Scottish catches have featured:

i. periods with a high proportion of salmon (multi sea-winter fish (MSW)) and modest catches;
ii. periods with a high proportion of grilse and higher catches;
iii. times when (i) and (ii) effectively overlap giving high catches; and
iv. times with both salmon and grilse numbers at modest levels giving low catches.

Perhaps, at present, we are in a type (iv) period. Additionally, periods dominated by salmon, viz type (i), may not all be alike, the most recent one probably involving more early season fish than have been recorded before. Figure 1 displays these episodes of Scottish catches.

Detailed catch data have been released by the Department of Agriculture and Fisheries for Scotland (DAFS) for 1952 onwards, but these data do not contain the full range of fishing patterns experienced in Scotland, eg years with low grilse numbers as in the 1920s and 1930s.

Data on weights can be misleading if grilse and salmon have not been correctly identified. It does seem, however, that the average grilse weight is larger when they are numerous (and more run later?). Menzies and Smart (1966) showed how the average weight of salmon had been decreasing during the previous decades, but at least in part this decrease was probably a consequence of a changing mix of different types of MSW fish. It does, however, seem that in recent years very large salmon have become rarer. Writing in 1912, P D Malloch comments that fish of 22·7–27·2 kg were often caught in nets in the River Tay and that he had seen 40 fish all over 18·2 kg from the nets in one day. Angling results parallel his comments, judging by lists of exceptionally large rod-caught fish. Most of these very big fish were landed late in the season, but on the Thurso between 1918 and 1934 anglers landed 2 fish over 18·2 kg and 29 over 13·6 kg in the spring (Scott 1936), experiences not repeated, I suspect, in recent years. Similarly, on the Wye between 1910 and 1934, anglers captured 8 fish over 22·7 kg, 238 over 18·2 kg and 1833 over 13·6 kg.

The extensive literature on ocean fisheries (eg Cushing 1982) documents extensive and continuous changes in the abundance and distribution not only of most commercially important species, but also of creatures lower down the food chains. Many of these changes were unrelated to man's activities. Given the nature of the salmon's ocean journeying, changes in its yearly pattern of return migration should occasion no surprise. In fact, from the evidence available, it is doubtful if a normal pattern of salmon runs can be identified. The population structure may be continuously changing in response to many factors, a prevailing set of which may never recur. It may also be worth noting that around 1920 and as recently as the mid-1940s catches may have been lower than at present and, superficially at least, the long-term catch stability seems reassuring.

This paper is not concerned with any effect on Scottish salmon fisheries of disease, overcut redds, seals,

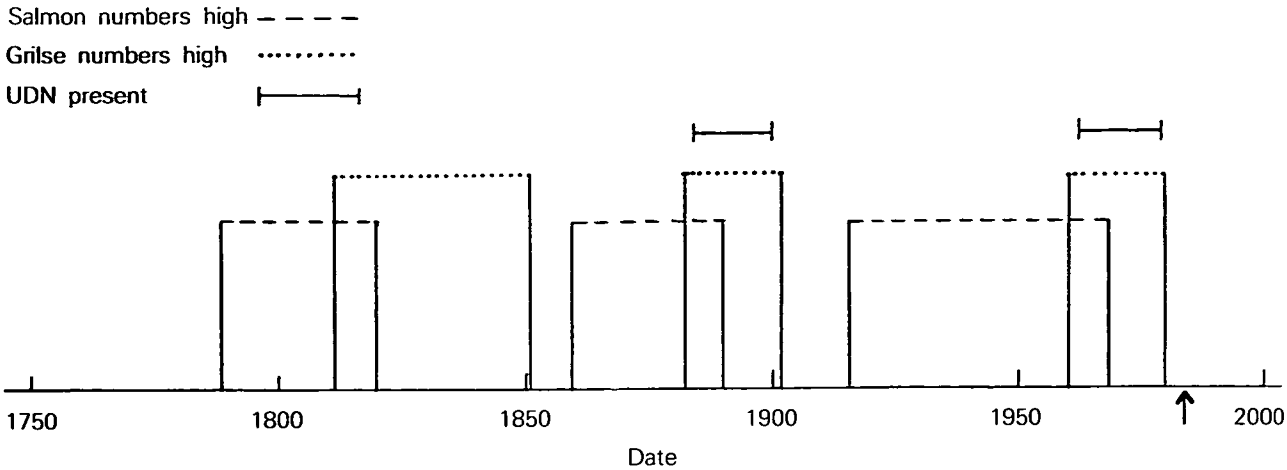

Figure 1. Episodes of Scottish catches

piscivorous birds and other contentious influences. Open seas fisheries about which much concern has been voiced have been discussed in a preceding paper. A cloud of uncertain dimensions on the horizon is that of water abstraction, draining and its consequences, and not least the controversial issue of the acidification of rivers and lakes.

3 The future

Looking to the future, there are 3 timescales of interest:

i. short, 1 to 3+ years;
ii. medium, 10 to 30 years;
iii. long, >30 years.

Three of the approaches to predicting ahead are as follows.

i. The formalism of time series: a branch of statistics.

ii. A stock recruitment model: the numerical simulation of the salmon's life history from the number of eggs deposited to the resulting number of spawning adults. All relevant genetic, environmental and random influences are incorporated.

iii. The identification of correlations with other phenomena which are thought to influence the salmon's life cycle.

Time series models based solely on catch data have not provided any surprising predictions for the immediate future. Essentially, the obvious trend in smoothed data is extended or the year-to-year fluctuations in catches result in a wide range on the prediction for reasonable confidence limits. This range increases as the time ahead increases. However, making the best use of time series techniques depends on the judgement of the user. Although an extensive suite of flexible number-crunching routines is nowadays at one's fingertips, someone with experience in time series might well extract more specific or noteworthy features. The many series examined by the author all exhibited year-to-year changes which reasonably passed a simple test for random behaviour. However, this test does not exclude showing that catches during different periods were significantly different, eg grilse catches for 1880–1900 compared with those for 1920–40.

Particularly in popular literature, the term 'salmon cycles' may be encountered, implying a regular periodicity in the adult stock abundance and return migration pattern changes. Regular oscillations in several natural phenomena have been identified with periods of 11 years, or integral multiples thereof. These regular changes are driven by variations in the solar input of energy, which has a well-established 11·2 year periodicity and probably flickers on a longer timescale. However, it would be surprising if this periodicity were detectable in salmon catches, given their separation on the biological chain, the feedback mechanisms present and the weakness of the solar signal. From catch data sets of sufficient length, the author has not isolated a significant periodic component. The distinct swings between, for example, high and low grilse numbers are best described as quasi-cycles with fluctuating period and amplitude. On a shorter timescale, however, the work of Martin and Mitchell (1985) includes an interesting development in the context of a periodicity in catches.

The establishment of a stock recruitment model and the acquisition of the relevant inputs pose a considerable challenge best left to those professionally occupied in the field. There remains method (iii) when enthusiasts like the author can speculate on trends in the strength and pattern of the return migration of adult fish. A combination of environmental and genetic influences is fairly certainly involved, but at the present time Occam's razor should probably be poised above one's theories.

A considerable body of information exists on the egg-to-smolt stage of the salmon's life history. The following features and questions are relevant here.

i. We do not know the extent to which smolts entering the ocean are already programmed for a given sojourn in the ocean. Research associated with salmon farming will greatly expand our knowledge in this area.

ii. Are our rivers reaching their potential in smolt production, and does the strength of the smolt run in a given river, which can vary by a factor of >2 from year to year, carry directly over to adult numbers in the following 3 years?

iii. Are there consequences of the observed changes in the mix of river ages in a year's smolt run?

Several authors (eg Scarnecchia 1984) put forward evidence for the early months in the ocean being a period when the survival rate may often vary considerably.

It seems that a major factor determining the survival rate from smolt to adult and the type of adult is the conditions fish encounter in the ocean. These include currents, upwelling and mixing zones, variable temperatures and salinity, and the associated distribution and abundance of prey species and predators. There is tempting evidence to associate 'colder periods' in the North Atlantic with higher proportions of grilse, and 'warmer periods' with higher proportions of salmon (Martin & Mitchell 1985), although this association may not hold for all stocks of Atlantic salmon. Little information seems to be readily available on the extent to which periods of high and low numbers or changing mixes of sea ages match for adults returning to different home waters. Information on this aspect might assist in anticipating future runs. Until we know more of the mechanisms and interactions which determine the details of the oceanic part of the salmon's growth and behaviour, climatic and oceanographic variations seem to provide a useful broad indicator of the runs of fish we will experience in the future.

In the short term, the runs are already in the pipeline and the best prediction for this year is 'the same pattern as last year', bearing in mind the 'noise' superimposed on the trend.

In the medium term, one cannot foresee a major reversal of the much lamented decrease in the numbers of 2SW and 3SW fish, unless there is a return to the major northern hemisphere warming of the 1910–40 period. Salmon may have responded rapidly to consequences of this warming and the ensuing pattern of runs extended into its aftermath. This 20th century optimum induced major changes in the distribution and abundance of many species of fish, interestingly and spectacularly so for the cod fishery on the west Greenland banks. Cod (and salmon?) appeared in the area between 1912 and 1923, and the fishery peaked in the 1960s but has now fallen by a factor of 10.

It also seems that in successive fishing seasons when grilse numbers are building up, numbers of MSW fish decline less rapidly, resulting in a sequence of productive seasons, as occurred in the 1960s and early 1970s on the east coast of Scotland when the natural mortality in the ocean may have been less than at present (Shearer 1984).

Grilse numbers have now fallen from their peak and salmon numbers are not high. From the past 2 centuries, there seems to be no precedent for grilse numbers building up again so soon after a peak. We should probably anticipate an increase in salmon numbers, but we cannot exclude the possibility that the proportion of grilse might increase. As to which time of year the bulk of these will enter fresh water, one cannot be categorical. I would anticipate +SW fish rather than 2SW and 3SW fish for most rivers, if the pattern for most of this century of a uniquely high proportion of 2SW and 3SW fish was associated with the climatic conditions, which were unusual for recent centuries at least. Whether the post-1940s cooling trend in the North Atlantic area will continue, stabilize, or reverse is not known. Equally uncertain is whether +SW fish running after the close of the fishing seasons as at present are at times a vital source of spawners, or depress numbers of earlier running fish, or neither.

With modern-day monitoring of fish stocks and their year classes, and global surveillance of climatic and oceanographic parameters, it may well soon be possible to predict both short/medium-term trends and the substantial year-to-year changes in fortune which salmon fisheries experience. However, the relatively small scale of the Scottish salmon fishery seems unlikely to provide or justify the necessary finance to achieve this prediction, unless as a spin-off from or combined with other monitoring activities. Nonetheless, the cost, availability and quality of remotely sensed charts of oceanographic parameters could change rapidly as technology advances.

In the long term, with the present gaps in our understanding of its biology and the threats real or imagined to its well-being, forecasts for the fortunes of the Atlantic salmon in the 21st century can carry little weight. Stock recruitment models and the quality of their input data may then be refined to the point where a fishing season will hold no surprises. Additionally, legislative and economic circumstances might be favourable for salmon ranching activities. Combined with the likely developments in imprinting and salmon farming techniques, this might allow those with management control to set up a predetermined pattern of migration into their river. Opinions will no doubt differ on the desirability and attractiveness of this prospect.

4 *Conclusion*

Finally, on the question posed in the title of this paper

'Is there a basis here for prediction?', the short answer must be 'No' regarding specific projections for the years ahead. Therein, for many of us, lies our fascination with *Salmo salar.*

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Salmon population studies based upon Scottish catch statistics: statistical considerations

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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.

5 Acknowledgements

I am most grateful to Mr W M Shearer (DAFS) and Dr P S Maitland (ITE) for introducing me to the subject of salmon population dynamics and for many instructive discussions. I am also indebted to Mr W M Shearer for supplying me with copies of many papers on this subject, and for permitting me to quote from any of his papers.

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Summary

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The Atlantic salmon generates interest from a wide variety of sources. As a resource, in the most general definition of the word, it is a major recreational attraction; it is exploited commercially in fresh water, along the coast and in the open sea; and in the field of aquaculture its importance is increasing. To the scientist, there is an intellectual challenge to understand and explain all the transformations in physiology and behaviour built into its complex life history, which in most cases involves hatching and developing in fresh water, emigrating and growing in the sea, and returning to fresh water to spawn. Further, the salmon clearly presents unusual problems to the manager and administrator.

Against this background, any symposium on salmon is likely to be relevant and stimulating, but the timing of the ITE symposium in February 1985 was particularly appropriate for a number of reasons, not least because of increasing concern about possible long-term effects of the open sea fisheries, and because of the expanding production from fish farming. In addition, as pointed out by Dr Jenkins in the preface of this volume, there was no clear consensus on the current status of the resource, so an open discussion involving ecologists experienced in other fields offered great attractions. The symposium could not have covered in detail the full range of salmon interests and did not attempt to do so, but the 15 talks over 2 days produced a solid basis for discussion. It was against this background that Professor Dunnet opened the symposium and in his introduction drew attention to the complex web of relationships and interests that centred on the salmon.

The first talk, by Mr Ross, dealt with the legislative background. In his extensive review, the story seemed to be of much activity in the early days but later of a running out of steam reaching almost a full stop following the publication of the Hunter Report in 1965. An important point for the future, and this was agreed in discussion, was for a better method of financing the Boards; other issues included action on illegal catching and attention to the dangers of water abstraction. It had always been obvious that the salmon was unusual among fish in its tremendous diversity of physiology, behaviour and habitat, but this talk perhaps added another item to the list of its features: is there any other single species of fish that has generated such a substantial legal background?

Mr Smart's contribution, providing a useful survey of fishing methods, also included legal considerations and delved into history. He reminded us particularly that, although the basic design of salmon nets had not changed much in the past 100 years, there had been technical developments including a progressive introduction of new types of synthetic material giving substantially improved nets and rods. He also reminded us that these contributed as well to more efficient poaching, so that improvements are not necessarily all to the good. It is perhaps significant that his comment 'angling today is as commercial as netting' went unchallenged, but equally unchallenged, and I am sure totally acceptable, was his final remark that 'what we must all ensure is that there are salmon for generations to come'.

The basic biology of the salmon was well covered. Dr Mills outlined the life history and pointed out that our present-day understanding was preceded by earlier confusion. He reviewed the problems of salmon ecology, stressed the importance of water temperature, and touched briefly on such issues as predation and disease. One important point was that our data collecting tends to be confined to the times of the fishery, so that there are substantial seasonal gaps. His plea was for studies of river systems throughout the year, and indeed for experimental netting twice a week during the annual close season. When one considers the extensive data collected for marine fisheries management, this seems a modest proposal.

After these 3 lectures on basic aspects, attention turned to the field, and a sequence of 3 papers dealt with wild stocks. First, Mr Dunkley discussed changes in salmon and grilse runs over the past 30 years, but noted the importance of taking stock components and fishing methods into account when assessing the overall pattern. The greatest decline over the period was clearly in the spring salmon component. He emphasized that our data were based on *catches* and that we had little information on *stocks*, a valid distinction which implicitly echoed Dr Mills' call for more surveys. The subsequent discussion raised questions on salmon populations in the near-shore regions and on the potential effects of industrial fisheries on smolts and the food of post-smolts, highlighting our lack of knowledge of smolts in their early days at sea.

In the second paper in this sequence, Mr Shearer dealt with home water exploitation of salmon and described a long series of tag-recapture studies for each of the major fishery regions. He estimated the percentage rates of exploitation but was careful to emphasize that his data were not in any sense absolute measurements. Although they were not precise, he was confident that the order of magnitude was right. The result showed that there was considerable regional variation in the levels of exploitation, with the highest values in the east coast of Scotland, and suggested, perhaps surprisingly, that exploitation rates were fairly low.

The third field paper carried us out to the open ocean with an account by Dr Shelton of the history of interception fisheries which developed in the 1960s at Greenland (by gill net) and at Faroe and in the Norwegian Sea (by floating long-line), and with brief reference to the drift net fisheries off the west of Ireland and Northumberland. He discussed the difficulty of calculating accurately the loss caused by these fisheries to home water stocks, and, while he would like to see the major interception fisheries stopped, his comment that 'the Faroese see us as smolt producers and themselves as salmon producers' nicely encapsulates the problem. In discussion, we noted the value of tagging adults at the sites of the fisheries and also young fish in our rivers to learn something about the structure of the intercepted stocks.

The group of papers on fisheries was neatly rounded off by an account from Lord Thurso of the management of a single river system supporting a fishery which involved both angling and netting. This appeared to be a model situation in which competing interests were co-ordinated, providing the ideal situation for the happy angler who was given every consideration of his comfort. The need to protect spawning stocks in the upper reaches of the river was emphasized, the importance of taking account of the rearing capacity of the river was noted, and threats from brown trout and birds were recognized. An attractively relaxed attitude to management was presented, summarized by the advice 'Don't get too excited by short-term fluctuations', but the recipe for successful management was that the river should be fully fished, although it was suggested that netting should perhaps be 'mildly inefficient'. The advantages of unified management from river source to sea were obvious.

Three papers specifically addressed salmon farmiing. The first, by Mr Stansfeld, drew attention to the big increase in the salmon supply over the recent part of the past 25 years due to the introduction of farmed fish. He referred to the price level in real terms and showed that we are now in a relatively stable situation in spite of the increasing farm production. Among the effects of marketing farmed fish, he listed stability of price, reduction in amounts of frozen wild salmon, and a general improvement in quality control. He was optimistic about the future, predicting that wild salmon will always be sought after and sold at a premium but, like other speakers, he emphasized the need for adequate control of illegal fishing. In the discussion, one of the subjects raised was salmon ranching, and the lessons to be learned, particularly from Japan, were considered.

The paper by Drs Laird and Needham asked the question 'What can fishermen and fishery biologists learn from salmon farms?' The answer seemed to be, quite a lot! Four general areas were explored: identification and evaluation of stock characteristics; basic life cycle information; better understanding of water quality requirements; and improved procedures for production of eggs and fish for augmentation and for the sustaining of wild stocks. In the discussion, the question of growth and grilsing came up. The debatable point was made that fish grew faster because they were grilse, not the other way round. There was also a cautionary note; the environment in a hatchery is so different from that in the wild that extrapolation of observations from one to the other must be done with care.

In the third talk in this sequence, Dr Maitland considered the impacts of fish farming on wild stocks. He stated firmly that many of the activities related to culture and enhancement are not in the best interests of wild fish stocks. He raised the question 'Can man affect the genetics of wild populations of fish?' and his answer was 'yes'. It was significant that, in the wild, cultured fish always performed less well than local stocks. He proposed for fish farmers an 8-item code of practice designed to protect wild stocks. This paper generated much discussion, and even some heat. The comment that more than half the rivers in Britain had been stocked with non-indigenous strains brought the reply that regular stocking with large numbers would be needed for an impact. From the Norwegian side, concern was expressed about the effects of the release of farmed fish on wild stock. The need to assess the problem was stressed. The crucial question was whether there was any clear evidence that stocking with a different strain of Atlantic salmon would have an adverse effect, and it seemed there was none.

On the second day, 4 papers addressed the status of present catches. Information was provided first on salmon catch statistics from Norway and Ireland.

From Norway, as well as supplying highly relevant data for comparative purposes, Dr Hansen gave a valuable account of an ocean ranching facility, filling what had been a significant gap in our coverage. The Irish contribution by Dr Browne helped again to emphasize that one cannot rely on statistics to say much about the stocks. The speaker's apology for one of the slides that 'It is not a very good slide but they aren't very good data' was a comment that drew sympathy from the audience.

Scottish statistics were then dealt with by Mr Shearer who made the significant remark, 'Data before 1850 were better than those of later years because people began to realize the value of the fishery'. An assessment of data from all sources suggests that, although Scottish catches fluctuated widely over the past 100 years, there have not been substantial overall changes. In recent years, however, numbers of salmon returning in spring have declined, and in the past decade catches by nets have been reduced while numbers caught by rod have not. The problems in assessing stocks are that much of the information comes from fisheries operating for less than half of each year; reliable data on catch per unit of effort are lacking; the true impact of interception fisheries is unknown; and non-catch mortality is fluctuating and unquantifiable. It is thus hardly a surprising conclusion that, while it is possible to tabulate catches, the present data are insufficient to support firm conclusions about the strength of past and present stocks. In the lively discussion that followed, the possibility was raised that rigidly defined fishing seasons could have become out of phase with the returning runs of the various age groups. This situation would complicate any attempt to interpret catch statistics, as stock components that had not declined (or might even have increased) might either not be available to the fishery or might be available for a shorter time than previously.

In the fourth talk in this sequence, the always refreshing Dr Pirie entertained the audience with what he modestly described as a non-specialized view of the problems. He categorized 3 ways of looking ahead: statistical time series; stock and recruitment models; and 'personal assessment' which involved simply looking at and speculating on the data. He was more enthusiastic about this third approach than about the first 2. His suggestion of monitoring a wide variety of ocean parameters in the hope of finding a correlation must be considered with care. It is likely to be most expensive and I would prefer to have had a distinct hypothesis to test. However, he did lead us back into the biology of salmon, and, while he started as a pessimist by saying he could not predict the future, he ended optimistically by at least expecting to catch salmon in the next decade.

In the final paper, Mr Lakhani set out to examine the statutory Scottish salmon catch statistics, asking to what extent they could be accepted as a valid sample and used to assess fluctuations and trends. He began by reminding us of the rigorous requirements for valid statistical inference and went on to provide a useful summary of the statutory background to the collection of Scottish salmon and sea trout catch statistics. He emphasized that these data do not provide an adequate basis for generalizations about total salmon stocks. They refer to only a portion of the stock in only part of any year; they are not supported by sufficient quantitative information on fishing effort; and, for various reasons, there is a significant amount of non-reporting. The paper illustrated the dangers of ignoring these deficiencies, and discussed ways of obtaining an index of the abundance of salmon in the open sea, but pointed out that these were prohibitively expensive or had statistical or biological limitations. In discussing the statutory catch statistics collection, Mr Lakhani called it 'a non-experimental observational programme', and referred to its underlying 'sampling scheme'. He thus appears sometimes to confer on it a higher status than is claimed for what is nothing more than a simple record of legal home water reported landings.

Many of the points he made about the statistical limitations of the statutory data collection had already been raised by previous speakers or were well covered in the discussions. It was widely recognized in these discussions that catch and stock are not synonymous, and also that a fully adequate assessment of stocks as a whole would require very much more information than is at present available, including data on the sea life of the salmon and on the interception fisheries. In the latter context, Mr Lakhani, referring to the difficulties of assessing the effects on home water stocks of the removal of salmon by high seas fisheries, remarked that this aspect appears not to have been discussed in the literature. However, these matters are the concern of appropriate working groups of such bodies as the International Council for the Exploration of the Sea (ICES), where they are fully examined. In addition, findings about the difficulties of assessments, if not published as scientific papers, are available to the managers who need them and are well known to those involved in that aspect of salmon research. Ultimately, decisions must be made on the facts available. For the river manager, his catches and the strength of his spawning stock are features of immediate interest, and the stocks of fish which survive the natural and man-made rigours of sea life do constitute a valid population for assessment. Attention to all these matters at this late stage in the symposium may seem superfluous in view of their previous exposure, but they are of vital importance and the paper did no harm in focusing the issues again for discussion.

Throughout the symposium there had been opportunities for questioning specific contributions, but at the end a general discussion session allowed participants to range over the whole field, and, in addition, written comments were provided. Much of this final session was focused on the desire to estimate the variability of salmon stocks from year to year. One approach would be to improve the catch data. This improvement could be achieved in part by obtaining more and better information on fishing effort, perhaps by focusing on selected fisheries and/or on specific areas, as was already under way on the Rivers North Esk and Spey. The need for better data was recognized by the ICES North Atlantic Salmon Working Group which has chosen Index rivers in each salmon-producing country. However, an adequate assessment of stocks requires more than just improved catch data. These must be augmented by counts of fish running in rivers, and such counts are being obtained by both automatic and manual procedures. The proposed counts would contribute to a more accurate estimate of the spawning escapement, which in turn could usefully be supplemented by measurement of parr density in nursery streams and by counts of smolts migrating downstream. Finally, it would be valuable to be able to apportion the total smolts in terms of their contribution to the various components of the stock, eg spring fish, summer fish, etc, and to quantify these components.

This discussion led to a consideration of just what was meant by 'stock'. It could perhaps be defined as the number of smolts leaving the freshwater system, but while this statistic would be relevant to the total picture, the home water fisherman would be more concerned with the population directly available to him for exploitation, for example the total number of fish running up river during the fishing season. This suggestion brought us back to the importance of fish counters.

In the discussion, a strong plea was made for more attention to the biology of the fish. It was pointed out that the symposium had concentrated strongly on numbers, but that an understanding of population dynamics required biological insight. For example, salmon returned to fresh water to reproduce, so it could be argued that what controls maturity was the key to their movements. Several aspects of stock management were raised; for example, it would be important to know more about the home water origin of the open sea interception catches. On the question of predation, it was said that a dead smolt could be a lost salmon, and goosanders on rivers, and herons, gulls, terns, mergansers, cormorants and eels in estuaries were recognized as significant predators. The damage done by seals was also noted.

On the wider question of the ecology of smolts at sea, concern was expressed about the developing industrial fishery for sand eels, with the suggestion that this might affect stocks directly by catching smolts, or indirectly by reducing the food of the growing salmon. Competition was discussed, and it was noted that, as a result of glaciation, many fish species found in small streams elsewhere in Britain did not reach fresh waters in Scotland. There was a view that anything that could be done to prevent the introduction of such species would be desirable. Finally, the need for more knowledge of the biological characteristics of natural stocks was emphasized.

Turning to physical factors, the possible influence of temperature was raised, and an account was given by Mr J H A Martin of a study of the possible influence of sea temperature on the age of returning salmon. This study was based on data on the numbers and weight of grilse and multi sea-winter salmon caught by the Aberdeen Harbour Board in the River Dee and along the adjacent shoreline. The data set was particularly valuable because the uniformity of effort allowed the catch to be calculated in terms of effort expended, and most of the data referred to years before fishing for salmon in the high seas distorted the picture. Of various temperature series examined, the most useful was from the sub-arctic, where increase in temperature was shown to be associated with large numbers of multi sea-winter salmon returning and also with a reduction in the number of grilse. The average weight of grilse increased with grilse catch numbers. Regression equations for grilse and multi sea-winter fish for the period 1877–1972 showed a marked 4-year periodicity in the grilse catch data. The hypothesis was put foward that the migratory pattern changes between the periods when the minimum temperature in the sub-arctic regularly falls below 1–2°C and those when it is above 2°C.

In looking back at the symposium, it is clear that the full spectrum of interest in salmon could not have been covered in the time available and no 2 steering groups would have produced the same package of topics. Another approach might have called for specific papers on physiology and behaviour, on ecological aspects and predators, on the sea life of salmon and ranching, on disease and pollution, and on organizational matters such as the prospects for the North Atlantic Salmon Conservation Organization. However, in the event, the 15 presentations, together with the ensuing discussion, contribute an invaluable background against which to consider the Atlantic salmon in Scotland, and in particular the status and prospects of the home fishery. Indeed, this subject was never far from the thoughts of the participants, and the fact that it is difficult to produce unequivocal conclusions testifies to the complexity of the situation.

The symposium highlighted the fact that understanding and predicting stock fluctuations demand information on parr production and smolt survival, on mortality at sea including that due to interception fisheries, on fishing effort and mortality in estuarine and fresh waters, and on spawning escapement. However, as the discussions made clear, even the acquisition of good quantitative data on these aspects will not tell the whole story. For an adequate understanding, the quantitative data must be supplemented by a biological awareness based on knowledge of the physiology, behaviour and ecology of the fish and the relevant controlling factors. Clearly, a great deal of research is required, both academic and applied. The current DAFS research programme on salmon represents a government contribution and is designed, within the limits of its resources, to address several of the problems outlined. It includes the monitoring of Scottish home water fisheries by a comprehensive system of catch recording and sampling and by tagging experiments to measure home water exploitation rates by netsmen and anglers. In co-operation through ICES with salmon biologists from other countries, estimates are made of losses to home water stocks due to high seas salmon fisheries. The dynamics of exploited salmon populations in fresh water are studied in selected populations by sampling and counting to elucidate the relationship between egg and deposition of smolt production and the natural and fishery-induced mortality that may affect both. In a programme of ecological studies, the processes that control production of juvenile salmon are examined. The data are used to estimate total Scottish smolt production and to advise on methods by which it may be enhanced. Finally, an effort is directed towards understanding the extrinsic and intrinsic factors controlling smoltification and maturation, so that fluctuations in the timing and in the population structure of fisheries can be interpreted in terms of the underlying mechanisms in the freshwater and marine phases.

One would like to end the symposium with some tidy generalization on the state of the Scottish salmon stocks and a definitive prescription for further research. That is not possible, given the diversity of the issues, the gaps in the existing data base and the difficulties of filling them. What can be said in summary is that significant biological changes are detectable in recent years, with relatively fewer multi sea-winter fish and more single sea-winter fish which tend to return to fresh water later in the fishing season; that catches have declined from a peak in late 1960s and early 1970s to nearer the level of the 1950s; that the decline is most evident in the net catches, and particularly in those taken earlier in the year; and that rod catches are more stable, the decline being mainly in the spring component. It is relevant that, except for one major river that may have its own particular problems, the smolt production estimates available show no continuous downward trend. An analysis of all the facts suggests that at the present time the reduced catches are related more to biological changes than to overfishing. While the interception fisheries are clearly a cause for concern, it is worth noting that the decline in home water catches of multi sea-winter fish began before the distant high seas exploitation was catching significant numbers of fish. With the establishment of NASCO, there is now the mechanism for controlling these fisheries, and this, supplemented by full control of legal and non-legal catches in our coastal waters, will put these factors into perspective.

Turning to research and monitoring, the programmes already referred to are beginning to extend our understanding of salmon ecology and to build up precise data on exploitation rates for more fisheries over a wider area, leading to a time when we will be better able to address the problems discussed and, by relating the present reduced catches to the stock as a whole, to decide if the changes are part of a cyclical pattern or a downward trend.

But there is still much to be done. It is hardly necessary to raise again the need to supplement the data provided by the statutory catch statistics. In particular, the development of better fish counters, placed in the most suitable locations, is required to give the essential facts on numbers of fish, and provision must be made for sampling throughout the year to add information on age structure and on biological features. The aim must be to provide the knowledge as well as the administrative framework that will allow integrated stock management at all stages of the salmon's life history, and in all parts of its range from headwaters of streams to the open Atlantic.

The symposium was useful in bringing together a diversity of expertise and interests for discussion. If in addition it helps to focus attention on the urgency of dealing with the matters raised above, it will have served a very valuable purpose.

Appendix I

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ISBN 0904282 92 9
ISSN 0263-8614