ATLANTIC SALMON TRUST

REPORT OF A WORKSHOP ON SALMON STOCK ENHANCEMENT

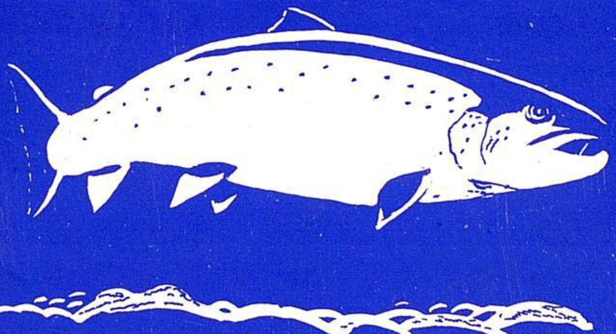
By E. DAVID LE CREN

Held at the

UNIVERSITY OF SURREY, GUILDFORD

on

9th to 11th April, 1984



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THE ENHANCEMENT OF SALMON STOCKS

Workshop at University of Surrey, Guildford

9-11 April 1984

Report compiled by E.D. Le Cren

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PITLOCHRY PERTHSHIRE

FOREWORD

In 1977 a group of fishery officers from the Water Authorities studied the efforts that had been made over many years to improve the propagation of the Atlantic Salmon. In their view, the widespread belief that natural propagation was everywhere an inherently wasteful process and could be improved by stocking was unfounded. Considerable circumstantial evidence persuaded them that artificial propagation as previously practised in England and Wales had achieved little, if anything, in increasing adult salmon stocks, because the efforts had been on too small a scale and too widely disseminated. In their Report, they went on to specify the conditions for which the use of hatchery reared stock would be effective and pointed out that the rearing of smolts was the most successful way of producing additional returning adults from a limited egg supply, but that this was expensive and not necessarily always the most cost effective. Furthermore, success in stocking depended critically on knowing when and where to place the stock in the river. They foresaw that the increasing demands for water would make the part that artificial propagation had to play in the future ever more important, but stressed the need for monitoring the results. Such monitoring had been almost completely lacking in the past.

It seemed to the Atlantic Salmon Trust that the time was ripe for a discussion of the progress made during the last seven years in furthering efforts to promote the preservation and enhancement of the stocks of this valuable natural resource. Consequently, the Trust invited a group of scientists from Universities, Water Authorities and Government establishments, together with some practical fishery managers to take part in a Workshop, one of a series devoted to the interests of the conservation of salmon.

As the reader of this report on the Workshop will note, useful knowledge has been gained in recent years about the factors which influence the propagation and survival of salmon and there is a better understanding of how to manage a fishery so as to maintain and enhance stocks, both by improving conditions for natural propagation and by stocking. The reader will equally note how much remains to be done. Nevertheless, there is ample scope for improvement by the application of existing knowledge given the will and the resources.

These Workshops give those participating the opportunity to give an account of their experiences, but also their differing views, views which are sometimes in conflict with those of the Trust. However, it is from such conflicts of opinion that progress is stimulated. We are most grateful to David Le Cren for giving us such a well balanced report of the papers delivered and views expressed at this Workshop.

Sir Ernest Woodroofe, PhD, FInstP, FIChemE.
Chairman, Honorary Scientific Panel.

INTRODUCTION

The Atlantic Salmon Trust's Workshop on salmon stock enhancement was held at the University of Surrey at Guildford on 9-11 April 1984, under the Chairman-ship of Sir Ernest Woodroofe.

Eleven papers were circulated in advance and then spoken to briefly by their authors. Each paper was followed by a discussion and there was also a general discussion at the end of the Workshop. In addition, there was an informal introductory talk and a brief summing up (both by Dr. Harris).

The following summary account of the Workshop has been prepared subsequently and is based on the written papers, notes of their spoken presentation and rather full records made at the time of the discussions. I have deliberately re-organised the topics into what I believe is a logical order and re-worked the emphasis of the various points made in the papers and discussion. Some of the themes and ideas came up several times in different contexts at various times and are more conveniently discussed in one place. Where a statement is derived mainly from one or two of the contributed papers I have quoted the author's name followed by the letter 'P' (for 'paper'). All the papers are listed on p.XX. Where a major point was made in discussion, particularly where it introduced factual information not otherwise available, the contributor's name is quoted followed by the letter 'D' (for 'discussion'). I have also included references to a small number of published works where these were quoted as giving information particularly relevant to the Workshop. A list of the names and addresses of the participants is given on page YY. In this way, I hope that readers will be able to follow up any points about which they require further information.

In this account the following conventions are followed: 'Salmon' refers to the Atlantic salmon (Salmo salar L.) unless another species is referred to by name. There are also references to the brown trout and sea trout, the former confined to freshwater, the latter migrating to the sea; both belong to the species Salmo trutta L. The successive stages in the salmon's life cycle are called egg; alevin (hatched fish with a yolk-sac still in the gravel); fry (the short transition stage when the fish have emerged from the gravel and are beginning to feed); parr (after the yolk-sac has been fully absorbed until smoltification begins - the freshwater feeding period); smolt (the stage when seaward migration occurs); grilse (salmon which return to spawn after one winter in the sea); kelt (a salmon that has spawned but not yet returned to the sea). Other terms are defined where they first occur or have obvious meanings.

The various main themes of the Workshop are discussed here in an order starting with science and natural propagation and then moving towards management, more artificial stock enhancement measures and finally legal, social and political aspects. Though this order has some logic, I must emphasise that the fundamental aspects of the legal and social basis for the practice of salmon stock enhancement were discussed at several points in the proceedings, particularly in the Introduction and Summary (Harris P1, P2).

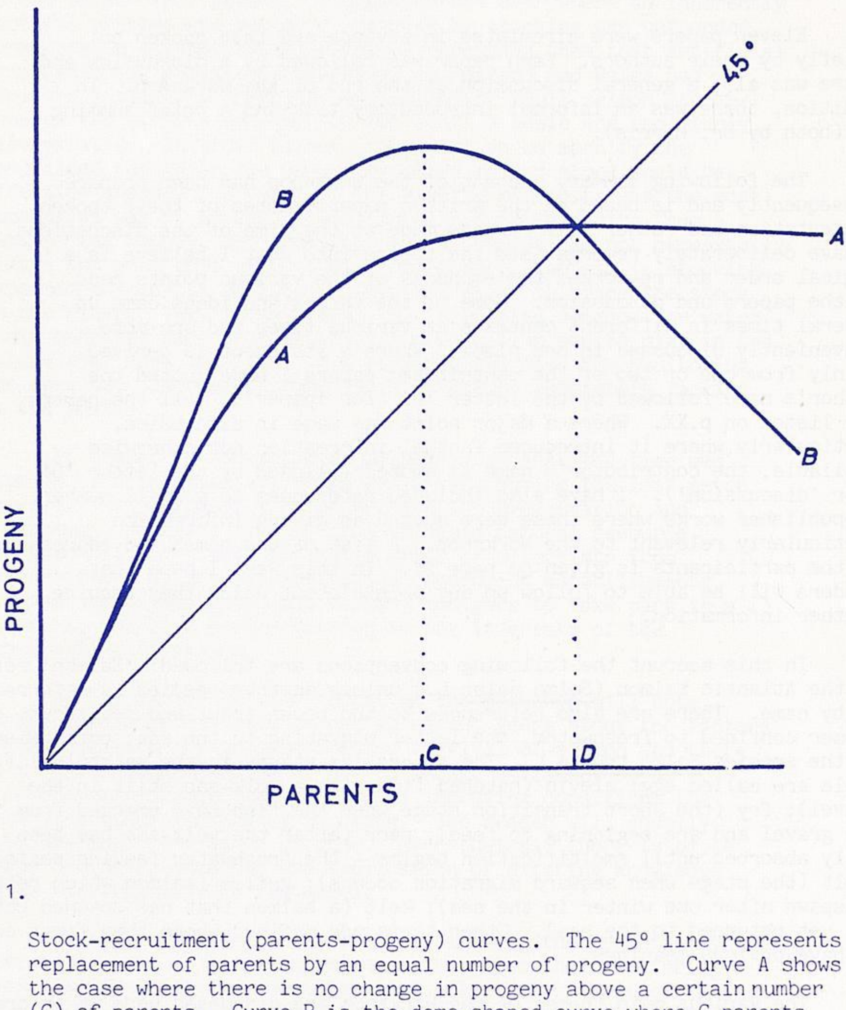

Fig. 1.

Stock-recruitment (parents-progeny) curves. The 45° line represents replacement of parents by an equal number of progeny. Curve A shows the case where there is no change in progeny above a certain number (C) of parents. Curve B is the dome-shaped curve where C parents produce the maximum number of progeny. With curves of type B, an equilibrium point is where the curve cuts the 45° line (i.e. with D parents). Without any removal of parents by fishing, the population will fluctuate round this point D. Curves of type B have been found for several salmonid fish.

POPULATION DYNAMICS

The historical basis for the practice of stocking eggs or fry of salmon into rivers so as to enhance the number of returning adults was based on the assumption that mortality in these young stages was high and increasing their abundance artificially must in turn increase the subsequent number of adults. From about 1928 onwards (particularly in Canada and New Zealand in relation to species of Oncorhynchus (the Pacific salmon)) this assumption began to be questioned. Evidence was accumulated that showed a) that mortality in the egg and alevin stages were not necessarily high, and b) the numbers in many natural situations were so large that the numbers that could in practice be added by stocking would be relatively small. Though long-term observations on Pacific salmon were continued, only relatively recently has the relationship between numbers of spawners and numbers of resultant progeny (recruits) been researched in the Atlantic salmon.

Stock/recruitment relationships. The 'stock/recruitment' relationship can be shown on a graph where the numbers of progeny or recruits are plotted against the numbers of parents or the stock that gave rise to them (Fig 1). The shape of the curve that relates progeny to parent stock can take various forms but usually is a variant of curve 'B' in Fig 1. (Ricker 1954, 1975). It will be seen that the maximum number of progeny is produced by a moderate number of parents (C) and this number of recruits can be much greater than the number of parents producing them - thus allowing a crop to be removed by a fishery. The parent stock at level D is the stable level at which an unfished stock will fluctuate. In some situations it appears that the stock/recruitment (or 'parent/progeny') curve is more like that of curve A in Fig 1. Here, any increase in the number of parents above C produces the same number of progeny - neither more nor less. Curves of type B with descending right-hand limbs are often known as belonging to the 'Ricker' type, while curve A is called a 'Beverton & Holt' type. (Elliott (1985) reviews models for stock-recruitment curves).

Hay (P) and Gee (P) presented papers summarising the results of rather different research projects on the Girnock Burn in Scotland and the River Wye system in Wales, respectively. Hay (P) Buck & Hay (1984) studied the immigration of adults and the emigration of the resultant parr in the Girnock Burn over fourteen year-classes. Their data provided clear evidence of density-dependent mechanisms regulating the numbers of emigrants to a range much smaller than that of the numbers of eggs from which they were derived. Above a certain ('optimum') number of spawners no increase in the number of eggs led to any increase in the number of progeny. The data did not reveal what happened at very large numbers of eggs and could be interpreted in different ways; there was no clear evidence of a descending right-hand limb to the stock/recruitment curve (Fig 1,B) (Ricker 1954) and the curve seems to be what is known as the 'Beverton & Holt' type rather than the 'Ricker' type (Fig 1, A)

Gee (P) and Gee, Milner & Hemsworth (1978) determined the survival of salmon from the early parr stage to the pre-smolt stage and showed that this was inversely related to the initial density, and gave a strongly dome-shaped 'Ricker' curve (Fig 1,B). These data were obtained from sampling a large number of different salmon-rearing streams in the Wye system. (Elliott (1984) had obtained a similar curve for the survival of sea-trout parr over seventeen years in a Cumbrian beck). Shearer (P) has found a Ricker type curve (Fig 1,B) for the salmon in the North Esk; and, in theory, this would allow the sustained high exploitation rate found in this river.

Density/dependent mechanisms There was considerable discussion about the possible mechanisms producing stock/recruitment curves. Hay (P) stated that there was no evidence for overcutting of redds when spawners were abundant in the Girnock Burn. Losses in the fry and early parr stages could be due to both dispersal and mortality, though there was a general belief that fry that move downstream have a poor chance of survival. Crisp (P & D) and Solomon (D) emphasised the likely influence of environmental factors such as flow, and Crisp pointed out that the behaviour of fish changed markedly with the stage of development; he had also found differences between trout and salmon in how they reacted to differences in flow at different stages, but the exact details of these differences were not yet clear. Experience with liberated fry (Kennedy (P), Egglishaw (D)) suggested that 200 to 300m was the maximum distance downstream that salmon fry would disperse.

Hay (P) showed that in the Girnock Burn one of the mechanisms appeared to be an effect of density on the growth of parr coupled with a negative correlation between the density of 1+ parr and the survival of 0 group parr. There was also enhanced growth among 1+ fish leading to earlier migration when older parr were scarce. This led to slightly less variation in total emigration each year than in the migrants derived from each spawning.

Discussion on density-dependant mechanisms extended to some consideration of the marine phase, but experiences differed over the degree of correlation between numbers of smolts and numbers of returning adults. It was agreed that mortality among smolts in estuaries and during their first period at sea could be high.

Gee (D) pointed out that even if the mechanisms causing stock/ recruitment relationship were not known, an empirically established model could still be used as a basis for management.

THE STREAM HABITAT

Papers by Kennedy, Crisp, Solomon and Gardiner dealt with the stream habitat and requirements for successful spawning, hatching and rearing. These papers and that by Egglishaw, also contributed to techniques for the survey of streams, the assessment of their potential for increased salmon rearing and the techniques of stream improvement and stocking.

The requirements for spawning Access of spawners to spawning grounds was mentioned only in passing at this Workshop, though it appeared to be understood that this was an obvious necessity. Egglishaw (P) and Gardiner (P) pointed out that many otherwise suitable spawning and rearing grounds devoid of salmon were so because they were above impassable obstructions and an efficient way to increase salmon production might be to remove such obstacles. Participants knew of obstructions or ineffective fish passes in England and Wales whose removal or improvement would almost certainly enhance production. Kennedy (P), Solomon (P) and Crisp (P) outlined the requirements for spawning sites. They had to be accessible and be adjacent to holding pools where spawners could rest. The water had to be flowing at moderately fast speed, preferably accelerating over gravel of mixed sizes that did not contain too much silt or fine sand and was not compacted. The exact requirements in terms of gravel size distribution and structure, and flow conditions over and through the gravel were not yet fully understood and there was evidence that fish did not always choose to spawn in areas that appeared to be satisfactory. It was also important that spawning sites should be in or immediately above suitable rearing grounds. Crisp (P) pointed out that, at least in some streams subject to spates, quite a high proportion of the redds could be destroyed by floods and the number of hatching alevins was probably well below the rearing potential of these streams. Research was in progress to determine the exact nature of spawning gravels, the depth at which eggs were laid and the flow rates of water, oxygen levels and actual survival of eggs in the gravel; few quantitative data had previously been available on these matters.

The requirements for rearing

Research in various streams (Kennedy P, Solomon P, Gardiner P, Crisp P) had determined the natural populations of parr, and their survival and growth, in relation to features in their stream environment. Physical requirements include streams of moderate size; salmon parr are not usually found in the smallest streams, nor are they abundant in large, deep rivers. Ideally most of the stream should be taken up by riffles over which the water flows fairly fast. The substratum should be varied with gravel and stones of varied sizes; this ensures a range of current conditions near the bottom and obstructions to vision between each salmon parr and its neighbour, (thus reducing territorial agression). The banks should provide cover to which the parr can escape to avoid predators. The substratum should be stable. Gardiner (P) and Crisp (P) mentioned the need for a suitable temperature regime. Crisp discussed the effects of river regulation on temperature, while Gardiner stated that maximum summer water temperature of between 15°C and 23°C was preferable.

Kennedy (P) stressed the importance of water quality, particularly the absence of pollution from agricultural or other sources. Egglishaw stressed the dangers of acidity; the pH should not fall below 5.5.

Several participants mentioned the need for a good supply of invertebrate food, but it seemed to be accepted that streams that met the physical and chemical requirements would normally provide an adequate food supply. Competition between trout and salmon parr was also emphasised. Kennedy showed data on the distribution of 0 group and I group salmon with or without each other and with or without trout. In the presence of trout, which tended to occupy the slower flowing and deeper water, salmon parr would be confined to shallower and faster water. This 'interactive segregation' thus caused a reduction in the area of suitable rearing water available to salmon parr. The effects of predators, such as gossanders, on reducing salmon parr survival was also mentioned, though it was doubted if control would often be feasible for reasons of bird conservation.

Surveying spawning and rearing areas

Kennedy (P) reviewed techniques for surveying spawning and especially rearing streams with the aim of assessing their potential, and matching this against the extent to which they were already used. He made considerable reference to Milner (1983) and other authors. Gardiner (P) described the techniques that had been developed in Scotland and Egglishaw (P) also referred to these in reference to stocking.

It was agreed that much could be done at the desk using maps, reports on the waters (e.g. from bailiffs) and sometimes aerial photographs, coupled with catch records where these were available. The basic data obtainable from such sources included stream width, altitude and slope (giving estimates of current speed), as well as information on water quality and sometimes the distribution of at least adult and spawning salmon.

Field surveys were used to supplement the 'desk' data. They could be carried out at varying degrees of objectivity and detail, but usually involved a sampling framework, the measurement of width, depths, type of bed, current speed and proportions of riffles, pools and runs. Subjective assessments of cover, bank vegetation and other features might be included and sampling for salmon parr and other species carried out by electrofishing. Occasionally bottom fauna would be sampled to assess food-status.

Kennedy (P) commented on the degree of correlation between the results of stream surveys and the abundance of salmon parr found; Milner (1983) had compared trout and salmon populations with survey results. The actual correlations found were not very encouraging; between about 20% and 70% of the distribution of fish could be accounted for by models based on the survey techniques, depending upon the detail into which the surveys went.

Detailed field surveys were inevitably labour-intensive and the general conclusion seemed to be that desk survey coupled with subjective observation by experienced workers would yield estimates of salmon parr populations or estimates of rearing potential that were nearly as accurate as elaborate quantitative physical surveys. Nevertheless, there were cases where the best judgement had proved inaccurate, and this showed that there was still something to be learnt about the distribution of salmon parr in relation to their environment.

The improvement of streams for spawning and rearing

Solomon (P) and others discussed the potential for stream improvement on the assumption that one of the most cost-effective ways to enhance salmon production was to improve the habitat (or restore it to its former state) and then 'let the fish do the rest'. Solomon (1984) provided examples from North America, especially from recent Canadian practice in improving and extending spawning facilities for Pacific salmon species. He pointed out that the first way to enhance salmon recruitment was to provide access past barriers to upstream migrants. It was also possible to manage the escapement through controlling the fishery on different 'runs' of fish, and quite elaborate changes week by week in the fishery regulations were now practiced on the Pacific coast of North America to control the exploitation of seperate runs of species of salmon.

Concretion or compaction and silting of spawning gravels could also be treated by two or three different physical processes. The gravel could be ploughed or cleaned of silt in a 'vibrating bucket' or by other more elaborate means. North Americans had also practiced the removal of spawning gravels and their replacement in other parts of a stream. Finally, there was the creation of completely new spawning channels; in the best-known case, in combination with a dam to regulate the flow and remove damaging spates and silt.

The improvement of rearing grounds for parr will follow the criteria of the ideal parr habitat discussed above. It is important to note that different species of salmonid differ slightly but significantly in their requirements and this applies to salmon and trout in Britain. One of the most successful North American practices is the provision of rearing space with controlled discharge; these can be side channels fed by a sluice from the main river or fed by ground water or completely regulated streams fed by a reservoir.

In Britain the rivers below reservoirs provide potential for flow regulation and rearing channels could often be constructed beside main rivers. In North America 'stream improvement' in the form of artificial weirs or deflectors, artificial bank-cover or the introduction of boulders into stream has been practiced for many years.

Many of these North American habitat improvements and developments have been carefully assessed on a cost-benefit basis and their success monitored by population and catch measurement. In several cases the benefit is known to have greatly exceeded the cost.

It was agreed that in Britain, the financial, legal and technical restraints on most fishery-managing organisations would, at present, preclude most of the more elaborate North American practices. On many British rivers the habitat for salmon rearing had deteriorated due to changes in land-use practices, and aforestation and felling had been damaging to fisheries. Intensification of upland agriculture had also led to increases in soil erosion and the silting of spawning gravels. It was also stated that it was difficult to persuade engineers to regulate reservoir discharges flexibly for the benefit of fisheries. Crisp (P) and others pointed out that the 'minimum prescribed flow' was a very inadequate way of managing water, partly because of the subtleties of the relationships between freshets and upstream migrations; the fish sometimes responding differently to artificial and natural freshets. On some rivers there was also a need for a flood just before the spawning season to remove silt. Further, the temperature of water released from impoundments could influence growth and the timing of events in the life history such as hatching and smolt migration.

Enhancement by stocking young stages

Egglishaw (P) described the recommended practices that he and his colleagues had developed in Scotland (since published as Egglishaw et al, 1984). Stocking would normally be practiced to establish salmon in a stream, or re-establish a run that had gone. Often salmon are absent from an otherwise suitable head-stream by a barrier to migration, and this can sometimes be removed or by-passed by a ladder. Eventually a run will establish itself by the straying of adults. Adults can be transported from another river, but this can have practical and genetic disadvantages. Therefore the best practice may be to stock eggs or young fish. A preliminary need, is of course, to survey the recipient stream to ensure that there are not already salmon present and that it provides suitable habitat (as described in a previous section).

Stocking can be made at the green-egg stage, or as eyed-eggs or unfed (swim-up) fry, parr or smolts. Each stage has some advantages and disadvantages. Each successive stage costs more than the previous one, but will normally show a successively greater survival as returning adults. Most of the data on survival Egglishaw (P) provided were for fish planted as unfed fry. Survivals to the end of the first growing season in headwaters of the River Tummel averaged 19.5% and an average of 41 to 48% of these survived their second year. From these and other data it is possible to plan rates of stocking to produce probable numbers of smolts and also to match stocking rates to the rearing potentials of the recipient streams; such planning should always be practiced. The results of stocking programmes should also be monitored to assess their success. Experiments in the Tummel showed that a planting density of 5 fry per square metre produced the optimum results.

Genetic and other problems with the source of material to stock.

Cross (P) described modern biochemical research on genetic differences within the Atlantic salmon species. It had been demonstrated that salmon from different parts of the species' range differed genetically, and even within parts of one large river system differences could be detected. In general, the further the geographical distance between two salmon stocks the greater their genetical differences.

While the enzymes used for electrophoretic taxonomy appeared to be functionally neutral and thus not adapting a race to success in its particular river, other undetected genetic differences might be adaptive. Moreover, it appeared that the migratory behaviour and homing of salmon was partially genetically determined even though home-stream imprinting was also important. (The existence of genetic differences is, itself, evidence that homing is generally accurate).

All this meant that, in practice, it was wiser to choose parents from the same, or a nearby river system, when producing eggs or young for stocking.

There can be deleterious genetic changes if too few (less than about 40) parents are used as broodstock in hatchery reared salmon.

The common disease organisms of salmon differ genetically between geographical areas, so there may also be dangers from disease in the unwise selection of broodstock.

The possible dangers from stocking salmon from distant rivers, which would have genetic differences, was stressed at several points in the discussions. There was also emphasis (Shearer (D)) on the disadvantaged of stocked fish having different age-at-maturation habits, so that stocking in a river with 2 or 3 sea-winter salmon might introduce undesireable grilse. While environmental conditions did have a major influence, there was also a genetic component in the factors determining the ages of smoltification and return to spawn. In general, hatchery reared fish tended to return as grilse.

The development of the cage farming of salmon has led to frequent availability of excess eggs and parr originating from farm broodstock. It is a basic tenet of good conservation practice that the purity of possibly unique wild genetic strains should not be put at risk by introductions. (such wild strains may also contain genes of value in the future breeding of new domestic varieties). Further, strains selected for cage rearing might not be successful in a natural environment. Consequently it was thought that there could be risks from use of ex-farm eggs or juveniles for stocking in the wild and in the ideal situation this should not be done. However, the situation was obviously far from ideal with some of the wild stocks severely depleted. Clearly there was a need for more information about the performance of ex-farm stock in the wild and in the meantime, use of such stock should be limited and with proper safeguards to minimise genetic and disease risks.

STOCK MANIPULATION TO PRODUCE SALMON FOR FISHERIES

There was general concern that the purpose of the enhancement of salmon stock was primarily to benefit fisheries. This meant that stocks must be enhanced with fish that were of the right size and that arrived at the coast and entered estuaries and rivers at a time of the year when they were available to the various fisheries.

Shearer (P) provided detailed factual data derived from analysis of the river and sea ages of catches of salmon belonging to the River North Esk over a period of twenty years. During part of this period fish were caught in a trap outwith the legal fishing season, for some years smolt runs were estimated and samples tagged and during the last three years a successful counter operated. All these data provided full demographic information on the North Esk salmon including details of the migratory behaviour and catches of each river and sea age-group.

Salmon run into the North Esk at all seasons of the year. The date of entry of an individual fish will depend upon its age, and independently its size when a smolt, the number of winters it has spent in the sea, its size and its sex. The proportions of fish returning after one or two winters in the sea respectively is also influenced by hydrographic conditions in the sub-arctic Atlantic the previous year. Further, there is evidence that multi-sea-winter fish penetrate to spawn further upstream than grilse; it is the headwaters of many rivers that have recently been affected by changes in land-use practices.

Fish caught in the traditional legal fisheries were, largely, not selected for size but modern interception and illegal fisheries mostly operate with gill-nets which are selective. Over the past twenty years there have been marked changes in the proportions of fish returning as grilse or two-or-more sea-winter fish; grilse increased in proportion during the 1960s and then declined in the late 1970s.

As grilse enter the river mostly between June and October, many do so outside the fishing season. Fish that have spent longer in the sea run earlier in the season and so are available to the fisheries for a longer period.

Thus any manipulation of the escapement so as to enhance the stock of fish must take into account the needs of the fisheries in terms of the sea-ages of the fish available to them, and the fact that, at present, much of the run takes place outside the season.

The stock-recruitment curve for the North Esk is of the dome-shaped Ricker type (Fig 1, B) and the optimum number of spawners (i.e. that producing most smolts) is well below the probable numbers if there were no intensive fisheries; a larger escapement would be likely to produce fewer smolts. Indeed, as calculated from the results of smolt and adult tagging experiments, and judged on the basis of catches, it appears that the proportion of the adult run removed prior to spawning has been very high without obvious detrimental effect on the stocks.

There was general agreement that control over fisheries should be much more flexible. Particular reference was made to droughts and low-flow conditions. In some estuaries both commercial and rod fisheries were affected by low flows but drift net fisheries might not be. This suggested the need to have flexible regulations that could distinguish between different fisheries.

One problem with 'week-by-week' control of catches was the difficulty in obtaining information about the abundance of an age-group that might be available to migrate up the river in a few weeks' time. Although a successful automatic counter could now be built and operated, it would not distinguish between age-groups of fish, and, ideally, management should be able to control the exploitation rates on different age groups.

STOCK ENHANCEMENT BY SMOLT RELEASE

A paper by Browne described three years' results from the adipose fin-clipping and coded wire tagging of smolts (and a few parr) reared in four rearing stations in the Republic of Ireland and released in a variety of ways. The successful wire tagging allowed comparisons between the rates of return of wild and reared smolts and assessment of the contributions made by the rearing stations to the national catch. Over three years the returns from reared smolts ranged from 0.19% to 4.69%. The commercial catch is mainly grilse and 77% of the total catch is now made by drift net fisheries, the remainder being taken roughly equally by traps and angling.

The four rearing stations differ in their primary purposes and methods of operation. Two, on the Shannon and Lee were constructed to rear smolts for rivers where natural propagation had been largely destroyed by hydro-electric power development. One, at Newport, is primarily a research station. Much of the variation in returns could be correlated with the timing and mode of release of the smolts; early-released smolts did not contribute as much to the catches as late-released fish. The returns from tagged wild smolts were generally much higher than those from reared smolts. Nevertheless the best rearing stations could produce smolts at a cost that approximately matched the value of the catch resulting from them. The results of these experiments showed that there is still considerable scope for improving the efficiency of rearing smolts and the effectiveness of their release.

The results from the Burishoole fishery and experimental station at Newport were examined in more detail by Twomey (P). She showed that to the return from the commercial fishery should be added the value of the salmon caught by anglers (and some value also from the eggs used for propagation by the hatchery). The full economic value to the community of each salmon caught by anglers was about £400 (Irish anglers £300, foreign anglers £600), because angling brought in considerable tourist earnings to the nation. It was estimated that each smolt reared cost about 50p (to which should be added a similar amount for capital costs and overheads, Piggins (D)). On this basis, smolt rearing in an efficient station was economically well worth while. The Kielder hatchery produces about 100,000 1+ smolts for about £80,000; a similar cost (Champion (D)); but some other rearing stations may not have good control over costs. There was some disagreement over the most cost-effective stage at which to stock salmon, but it was pointed out that in some of the Irish rivers natural rearing grounds no longer existed. It was generally agreed that more needed to be known about the economics of stocking; a worth-while research project could gather comparable information from a number of sources about the full costs of stocking with eggs, fry, parr and smolts and relate these to the return of adults and their contribution to various fisheries. The economic returns can also be measured in various ways, and may include some social benefits that are difficult to assess in monetary terms.

LEGAL, SOCIAL AND POLITICAL ASPECTS OF SALMON ENHANCEMENT AND MANAGEMENT

The workshop had originated partly as an assessment of progress (at least in England and Wales) since the publication of Harris (1978). Since then, salmon propagation, as a means to enhance stocks, had declined even further in England and Wales. Harris (P) drew attention to the need to consider the question of why it was wished to enhance stocks and who would benefit; this theme re-occured frequently in discussion.

The Salmon and Freshwater Fisheries Act of 1975 requires the Regional Water Authorities in England and Wales to 'maintain, improve and develop fisheries' but does not state for whose benefit this should be done. There may be some social benefit in the conservation of the salmon (in its various genetic races) as a species, but the main social benefit must be to commercial and sport fisheries. In Wales (Harris (P)) the sport fishery for salmon is worth about £15 million p.a., compared with about £200,000 for commercial fishing for salmonids. In Ireland, sport fishing is worth between 50% and 60% of the total income from fishing. In both countries a good share of the angling income is derived from tourists coming from outside. In some other cases expensive salmon propagation and enhancement schemes are carried outin mitigation for hydro-electric or water-resourse development.

In Scotland the situation with a relatively large commercial fishery has been complicated by the development of interception fisheries, e.g. off Greenland and the Faroes, illegal off-shore drift net fisheries, the legal fishery off the Northumberland coast and by salmon farming. As well as the direct value of the salmon in the form of its flesh, commercial fisheries have a social worth in providing employment especially to less favoured communities.

In Britain at least there seemed to be an urgent need for a new look at fisheries legislation both to clarify the aims of the fisheries management and to allow the manager greater flexibility both to manipulate the stocks of fish and to control the various different fisheries. It was clear that the stock of salmon must be considered not only in quantitative terms, but also in terms of its age groups running at different periods of the year. The management of fishing that is now being practised, especially restrictions on fishing, in North America would not at present be legally or socially feasible in Britain, but North American experience shows what might be done and also that it is possible to educate fishermen into understanding what their needs really are and the scientific reasons for management practices. There is also a need for the application of better cost-benefit analysis for fishery enhancement projects, and for better practice in the monitoring of their success.

The growing economic importance of sport fishing for salmon requires not only extensions to the periods of the year when fish are available in the river, but also to the catchability of those fish and their quality. Management for catchable stock also implies better and accurate records of both catches and the effort employed in catching them.

Several participants regarded most of their management activities (including some stocking) as more an attempt to mitigate the worst effects of human degredation of the salmon's environment than an attempt to enhance stocks. A survey among fishery managers present showed that, in Britain at least, deliberate enhancement activities were now rare. Stansfeld (D) suggested the exploration of ways in which the salmon farming industry might assist in the enhancement of natural stocks, e.g. by making available for stocking excess eggs or juvenile fish, but there was some apprehension about the use of material originating from salmon farms, even if special strains might be bred for planting.

It was agreed that there was a need for further research, e.g. on the stock-recruitment relationship, the possibilities in the manipulation of exploitation and in the marine phase of the life history, and the need to learn more about catches and the international fisheries. There was also a need to follow up the results of some recent research and apply them in practical management experiments.

The importance of research and its application should not be judged solely on the market value of the commercial catch but by an evaluation of the full economic and social benefits that salmon fishing brings to the community.

COMMENTARY AND CONCLUSIONS

The final part part of this report on the Salmon Enhancement Workshop will attempt to draw together the more important and newer ideas that were presented and discussed and make some suggestions in terms of practical policies for action. Inevitably, this commentary may be biased towards the editor's personal viewpoint but may, thereby, be more readable and coherent. Advantage will also be taken to cite a few papers that have become available in a published form since the Workshop was held; these will provide more detailed guidance or explanation. The principal points will be dealt with one by one.

1. Spawning, and stocking with eggs or fry. There seems little doubt that the stock-recruitment relationship for salmon will often follow the type shown as curve 'B' in Fig 1 (p.). This means that only a proportion of the total adult run that returns to the coast needs to spawn to produce the maximum number of progeny. What this proportion is will vary from river to river but may be as low as 10% to 20%. Thus, adding more spawning fish, or eggs or fry, to a river system will benefit future stocks only if there is space available for rearing these extra fry to the smolt stage; it is in the early parr stage that natural population-control mechanisms mostly operate. Nevertheless, the distribution of spawning areas in a river system does not always coincide with good rearing areas so there may be potential benefit in re-allocating spawning effort or eggs. Furthermore, in many river systems suitable rearing tributaries are not used by salmon and these should be developed. Where natural or artificial barriers to spawning migration can be removed or by-passed by fishways, this should be done. In other rivers, eyed eggs or fry, derived from excess spawners from the same or adjacent rivers could be planted in the unexploited tributaries following the guidelines of Egglishaw et al, (1984). It would seem that only rarely are salmon stocks limited by the total area of suitable spawning gravels available, but there may be a few instances where spawning beds require treatment or where spawning channels might advantageously be created alongside rivers, as has been tried successfully in North America (Solomon 1984). There is evidence that where impoundments regulate river flow, salmon reproduction could be enhanced by manipulation of flows in ways sympathetic to fish needs; there is scope for the education of engineers in these needs and for more flexible legal regulations.

2. Rearing areas. The populations of many salmonid fish appear to be limited naturally by the area available to rear fry to the smolt stage, but the exact environmental criteria for the optimum natural production of smolts is not fully understood. An absence of pollution, adequate dissolved oxygen, summer temperatures between about 12° C and 15°C, relatively fast flow over gravelly substrata and few predators are obvious requirements. Where current speed is too slow, trout may tend to suppress young salmon. Simple desk surveys of streams can suggest their potential for rearing salmon with some, but not complete accuracy; more detailed field surveys are better but not enough to warrent their cost. There may well be scope for

stream improvement works in Britain and Ireland in some of the ways used in North America (Solomon 1984); but the opening up to salmon rearing of unused or under-used tributaries might be more cost effective. In some streams, that would otherwise be good for young salmon, unsympathetic land-use practices, pollution from agriculture, or the acidity of the water prevents good survival of eggs or young fish.

3. Artificial propagation of smolts. Where natural salmon-rearing streams have been destroyed, e.g. by hydro-electric schemes or major land-drainage operations, recourse has been made to artificial smolt-production. The evidence from Ireland shows that this can make a worth-while and economic contribution to overall catches. However, the survival of artificially-reared smolts to returning adults (or adults caught in fisheries) varies very greatly and rarely does it approach the survival rate for wild smolts. It is clear that much could still be done to bring the quality of smolts produced by many rearing stations up to that of the best. It is also clear that the site and timing of the release of the smolts is a critical part of the whole operation.

Young salmon can be stocked at various stages between egg and smolt; each successive stage costs more but yields a greater survival as returning adults. There is need for a more critical assessment of the optimum stage at which to stock in terms of cost-benefit.

4. Genetic problems. The use of artificial propagation, the stocking of eggs and fry and the movement of salmon stocks from one river system to another raise problems associated with the slight genetic differences now known to exist between salmon from different rivers. Genes, as well as environmental influences play a part in such critical aspects of the life history as ability to home, the age of smoltification and return and the season of up-stream migration. Until more is understood about this, great caution should be exercised in moving salmon (at any life-history stage) from one river to another, especially if the rivers are geographically far apart.

Commercial salmon farming often has eggs or juveniles available for disposal and it would be advantageous if these could be used to enhance natural stocks, especially where these have suffered depletion. But, in most cases material from farms might be genetically unsuitable for stocking into the wild and so caution in the use of farm stocks was advocated.

Wilkins (1985) reviews the genetic problems in salmon management.

5. Age groups and the timing of runs. Good commercial and sport fisheries for salmon depend upon fish of suitable sizes being available throughout as much as possible of the legal season. At present, in many rivers, too high a proportion of the fish are grilse and too many fish run after the end of the season. The good quantitative evidence available from the North Esk and elsewhere shows the influence that smolt age and size within each age group has on the time of year and sea-age when the fish return to the river. When rearing smolts for release into the wild and when enhancing natural smolt rearing, great care is needed to produce smolts that will return as two-sea-winter fish and run relatively early in the season. Interestingly, the enhancement of production in more inland and upland tributaries may tend to increase the proportion of adults that are older, larger and earlier-running.

6. <u>Legislative, economic and social matters</u>. The Salmon and Freshwater Fisheries Act of 1975 inhibits the scope of water authority fishery managers in England and Wales because <u>fisheries</u> is legally interpreted as meaning the stock of fish rather than the catches of different groups of fishermen. There is thus an urgent need to bring the law up-to-date in respect of: a) knowledge of salmon biology, b) social needs and c) the flexibility in regulations that are essential if stocks are to be managed efficiently and positively. In general the value and potential value of wild salmon as a natural resource lie in its ability to provide recreation and tourist income more than in its value as food. It is not yet clear what the factors are that lead to better catches per unit sport-fishing effort, but maintaining good stocks of fish along rivers throughout the season is likely to be a primary one. More research is needed into the real social and economic benefits from the catches made by different types of salmon fishing.

A more modern and professional approach is also needed from salmon managers so that their projects - such as stocking programmes, stream improvements or new fish passes - are costed on a realistic basis against sound forecasts of benefits and then quantitatively monitored. This latter will require reliable and accurate data on both catch and fishing effort to be provided willingly by fishermen; this is a small return for them to give for the enhancement in catches that, hopefully, they will enjoy.

7. <u>Summary</u>. Among the most profitable actions towards salmon enhancement are, thus, likely to be:

a) Ensuring that all suitable areas for natural rearing are used, by opening up tributaries to spawners, or stocking eggs or fry in such tributaries.

b) Improving rearing streams by positive works, sympathetic river flow regulation and the control of damaging pollutions and land-use practices.

c) Where natural rearing is impossible, rearing smolts artificially using methods of husbandry and release that will yield the best returns to fisheries.

d) In all management, taking account of possible genetic problems until these have been more fully studied; stocking with wild material from only the same or nearby river system.

e) Paying attention to the age and size of natural and artificial smolts to ensure the optimum sea-age, size and running season on return.

f) Modernising the legal framework within which salmon management operates in Britain, so that the social and economic benefits of catches can be enhanced and flexibility introduced into regulations. Operating proper cost/benefit planning, control and monitoring for all management projects including the collection of accurate catch and effort returns from all fishermen.

APPENDIX I LIST OF CONTRIBUTED PAPERS

Browne, J.	Contribution of reared fish to the national catch in Ireland.
Crisp, D.T.	Effects of discharge regime on natural propagation of salmonid fishes.
Cross, T.F.	Genetic considerations in salmon restocking.
Egglishaw, H.J.	Guidelines for restocking.
Gardiner, W.R.	Surveying streams with a view to stock enhancement.
Gee, A.S.	Stock-recruitment relationship.
Harris, G	a) Workshop on stock enhancement: a broad view of developments during the last six years.
	b) Salmon enhancement workshop: summing up.
Hay, D.W.	Assessing the optimum level of natural smolt production of a river.
Kennedy, G.J.A.	Evaluation of techniques for classifying habitats for juvenile Atlantic salmon (Salmo salar L.)
Shearer, W.M.	Stock manipulation to produce optimum smolt production.
Solomon, D.J.	The improvement of natural propagation in rivers and streams.
Twomey, Eileen.	Evaluation of promoting natural propagation versus restocking.

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REFERENCES TO PUBLISHED LITERATURE

Buck, R.J.G. & Hay, D.W. 1984. The relation between stock size and progeny of Atlantic salmon, Salmo salar L., in a Scottish stream. J.Fish. Biol. 23, 1-11

Egglishaw, H.J., Gardiner, W.R., Shackley, P.E. & Struthers, G. 1984 Principles and practices of stocking streams with salmon eggs and fry. Scott. Fish. Inform. Pamph. 10. 22pp

Elliott, J.M. 1984. Numerical changes and population regulation in young migratory trout Salmo trutta in a Lake District stream, 1966-83. J. Anim. Ecol., 53, 327 - 350.

Elliott, J.M. 1985. The choice of a stock-recruitment model for migratory trout, Salmo trutta, in an English Lake District stream. Archiv. f. Hydrobiol. (in press).

Gee, A.S., Milner, N.J. & Hemsworth, R.J. 1978. The effect of density on mortality in juvenile Atlantic salmon (Salmo salar). J. Anim. Ecol. 47, 497-505.

Harris, G.S. (Ed) 1978. Salmon propagation in England and Wales. London: National Water Council. 62pp

Milner, N.J. 1983. Relationships between salmonid populations and habitat features in Welsh rivers. Welsh Wat. Auth. Area Tech. Fish. Unit. (North). Rep. 83/2. 28pp.

Ricker, W.E. 1954. Stock and recruitment. J. Fish. Res. Bd Canad. 11, 559-623.

Ricker, W.E. 1975. Computation and Interpretation of biological statistics of fish populations. Dept. Env. Fish. & Mar. Serv. Canada. Bull 191, 382pp

Solomon, D. J. 1984. Salmon enhancement in North America. Farnham: Atlantic Salmon Trust. 40pp.

Wilkins, N.P. 1985. Salmon Stocks. A Genetic Perspective. Atlantic Salmon Trust. (in press).

E. D. Le Cren -- Biographical note

E. David Le Cren took a degree in natural sciences at Cambridge and then, after a year at the University of Wisconsin, spent nearly all his career with the Freshwater Biological Association. For the first few years he studied the perch in Windermere and played the major part in the early stages of an experiment and study in fish populations that has now gone on for forty-five years. He then turned his attention to the trout populations of small streams in Cumbria and demonstrated the importance of territorial behaviour in young parr in the natural regulation of their population numbers. When he went to Dorset for ten years to set up and become the first Officer-in-Charge of the FBA's River Laboratory, he initiated the studies there on trout, salmon parr and other species in small chalk streams. In 1973 he returned to Windermere to become Director of the FBA until his retirement in 1983. The author of over thirty scientific papers on the biology of fish, Mr. Le Cren is a Fellow of the Institute of Biology and Institute of Fisheries Management, and was recently, for five years, President of the Fisheries Society of the British Isles.

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