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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.

7 References

Altukhov, Y.P. 1981. The stock concept from the viewpoint of population genetics. *Can. J. Fish. aquat. Sci.*, **38,** 1523-1538.

Carlin, B. 1966. Redogörelse für laxmärkning. *Ann. Rep. Swed. Salmon Res. Inst., 5th, 1965,* 1-4.

Egglishaw, H.J., Gardiner, W.R., Shackley, P.E. & Struthers, G. 1984. *Principles and practice of stocking streams with salmon eggs and fry.* (Information pamphlet no. 10). Aberdeen: Department of Agriculture and Fisheries for Scotland.

Food and Agriculture Organization. 1981. *Conservation of the genetic resources of fish: problems and recommendations.* (Fisheries technical paper no. 217). Rome: FAO.

Fetterolf, C.M. 1981. Foreword to the Stock Concept Symposium. *Can. J. Fish. aquat. Sci.*, **38,** iv-v.

Flick, W.A. & Webster, D.A. 1964. Comparative first year survival and production in wild and domestic strains of brook trout, *Salvelinus fontinalis. Trans. Am. Fish. Soc.*, **93,** 58-69.

Flick, W.A. & Webster, D.A. 1976. Production of wild, domestic and interstrain hybrids of brook trout *(Salvelinus fontinalis)* in natural ponds. *J. Fish. Res. Bd Can.*, **33,** 1525-1539.

Franklin, I.A. 1980. Evolutionary change in small populations. In: *Conservation biology: an evolutionary-ecological perspective,* 11-34. Sunderland: Sinaeur Associates.

Fraser, J.M. 1981. Comparative survival and growth of planted wild hybrid and domestic strains of brook trout *(Salvelinus fontinalis)* in Ontario lakes. *Can. J. Fish. aquat. Sci.*, **38,** 1672-1684.

Greig, J.C. 1979. Principles of genetic conservation in relation to wildlife management in southern Afrika. *S. Afr. J. Wildl. Res.*, **9,** 57-78.

Harlan, J.R. 1981. Who's in charge here? *Can. J. Fish. aquat. Sci.*, **38,** 1459-1463.

Harris, G.S. 1978. *Salmon propagation in England and Wales.* London: National Water Council.

Helle, J.H. 1981. Significance of the stock concept in artificial propagation of salmonids in Alaska. *Can. J. Fish. aquat. Sci.*, **38,** 1665-1671.

Ihssen, P.E. 1977. Physiological and behavioural genetics and the stock concept for fisheries management. *Proc. Annu. Meet. Int. Assoc. Gt Lakes Res.*, **1977,** 27-30.

Jessop, B.M. 1976. Distribution and timing of tag recoveries from native and non-native Atlantic salmon *(Salmo salar)* released into Big Salmon River, New Brunswick. *J. Fish. Res. Bd Can.*, **33,** 829-833.

Jones, J.W. 1961. *The salmon.* London: Collins.

Laird, L.M. & Needham, E.A. 1986. Salmon farming and the future of Atlantic salmon. In: *The status of the Atlantic salmon in Scotland,* edited by D. Jenkins & W. M. Shearer, 66–72. (ITE symposium no. 15). Abbots Ripton: Institute of Terrestrial Ecology.

Maitland, P.S. 1977. Freshwater fish in Scotland in the 18th, 19th and 20th centuries. *Biol. Conserv.*, **12,** 265-278.

Maitland, P.S. 1985. Criteria for the selection of important sites for freshwater fish in the British Isles. *Biol. Conserv.*, **31,** 335-353.

Maitland, P.S. & Evans, D. 1986. The role of captive breeding in the conservation of fish species. *Int. Zool. Yb.* In press.

Maitland, P.S., Regier, H.A., Power, G. & Nilsson, N.A. 1981. A wild salmon, trout and charr watch: an international strategy for salmonid conservation. *Can. J. Fish. aquat. Sci.*, **38,** 1882-1888.

Malloch, P.D. 1910. *Life history and habits of the salmon, sea-trout, trout, and other freshwater fish.* London: Black.

Menzies, W.J.M. 1939. Some preliminary observations on the migrations of the European salmon. *Proc. Am. Ass. Advmt Sci.*, **8,** 13-25.

Mills, D.H. 1980. *Scotland's king of fish.* Edinburgh: Blackwood.

National Council on Gene Resources. 1981. *California gene resource conservation program.* Berkeley, Ca: NCGR.

Needham, E.A. 1984. Are farmed salmon a genetic threat to wild stocks? *Fish Farmer,* **7,** 35.

Netboy, A. 1980. *Salmon: the world's most harassed fish.* London: Deutsch.

Nevo, E.H., Brown, H.D. & Zohary, D. 1979. Genetic diversity in the wild progenitor of wild barley in Israel. *Experientia,* **35,** 1027-1029.

Power, G. 1981. Stock characteristics and catches of Atlantic salmon *(Salmo salar)* in Quebec and Newfoundland and Labrador in relation to environmental variables. *Can. J. Fish. aquat. Sci.*, **38,** 1601-1611.

Ricker, W.E. 1981. Changes in the average size and average age of Pacific salmon. *Can. J. Fish. aquat. Sci.*, **38,** 1634-1656.

Ritter, J.A. 1975. Lower ocean survival rates for hatchery-reared Atlantic salmon *(Salmo salar)* stocks released in rivers other than their native streams. *J. Cons. perm. int. Explor. Mer.*, **26,** 1-10.

Ryman, N. 1970. A genetic analysis of recapture frequencies of released young of salmon *(Salmo salar* L.) *Hereditas,* **65,** 159-160.

Saunders, R.L. & Bailey, J.K. 1980. The role of genetics in Atlantic salmon management. *Proc. int. Atlantic Salmon Symp., Edinburgh,* vol. 2, 182-200.

Smith, I.R. & Lyle, A. A. 1979. *The distribution of fresh waters in Great Britain.* Cambridge: Institute of Terrestrial Ecology.

Thorpe, J.E. 1979. Ocean ranching: general considerations. *Proc. int. Atlantic Salmon Symp., Edinburgh,* vol. 2, 152-164.

Thorpe, J.E. 1980. *Salmon ranching.* London: Academic Press.

Thorpe, J.E. & Mitchell, K.A. 1981. Stocks of Atlantic salmon *(Salmo salar)* in Britain and Ireland: discreteness and current management. *Can. J. Fish. aquat. Sci.*, **38,** 1576-1590.

Utter, F.M. 1981. Biological criteria for definition of species and distinct intraspecific populations of anadromous salmonids under the U.S. Endangered Species Act of 1973. *Can. J. Fish. aquat. Sci.*, **38,** 1626-1635.

Wheeler, A. 1979. *The tidal Thames: the history of a river and its fishes.* London: Routledge & Paul.