ATLANTIC SALMON TRUST

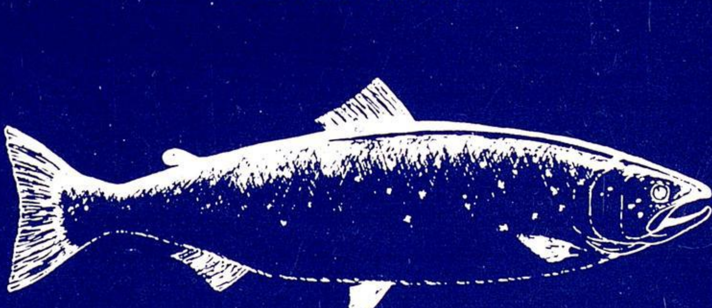
ATLANTIC SALMON FEDERATION

THE BENSINGER-LIDDELL MEMORIAL ATLANTIC SALMON FELLOWSHIP 1983

SALMONID ENHANCEMENT IN NORTH AMERICA

Description of some current Developments and their application to the U.K.

D. J. SOLOMON



The Atlantic Salmon Trust
Moulin, Pitlochry
Perthshire PH16 5JQ
Telephone: Pitlochry (0796) 3439

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This Atlantic Salmon Fellowship, which honours the memory of two outstanding salmon conservationists from both sides of the Atlantic, was established by the International Atlantic Salmon Foundation (now the Atlantic Salmon Federation) and the Atlantic Salmon Trust to encourage the exchange of expertise in Atlantic Salmon research, management and conservation in the United Kingdom, North America and elsewhere throughout the North Atlantic.

This Report is made by Dr. D.J. Solomon, who was awarded the Fellowship for 1983. After completing a Ph.D. at the University of London, David Solomon joined the Salmon and Freshwater Fisheries Laboratory of the Ministry of Agriculture, Fisheries and Food in London in 1971. He moved to the Fisheries Laboratory at Lowestoft in 1977, and is currently in charge of a small group responsible for R & D on salmon, freshwater and inshore coastal fisheries. His own research has been mainly on the ecology and migration of salmonids, and on the effects of water resource management on fisheries.

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SALMONID ENHANCEMENT IN NORTH AMERICA - DESCRIPTION OF SOME CURRENT DEVELOPMENTS AND THEIR APPLICABILITY TO THE UK

D. J. Solomon

1. INTRODUCTION

The developments described in this report were investigated during the tenure of the Bensinger-Liddell Memorial Salmon Fellowship in 1983, awarded by the Atlantic Salmon Trust and the International Atlantic Salmon Foundation. The 'memorandum of application' on which the Fellowship was awarded detailed the subject of the study:

> "The aim of this proposed study is the assessment of a range of salmonid stock enhancement techniques at present used with great success in North America with a range of species, and their applicability to Atlantic salmon and European trout fisheries management. Stock enhancement has gained a bad reputation in the UK in recent years, following the recognition of the doubtful benefits of many stocking programmes. Over the years, many millions of eggs, fry, parr and smolts have been released into rivers with virtually no check of efficacy, and no detectable long-term benefit. Little thought was given to the suitability of the donor stock for the new environment, the carrying capacity of the river, the best life-history stage to release, and many other factors. The ensuing widespread disillusionment with stock enhancement practices is quite understandable. However, there is no *a priori* reason why many of the practices used successfully on, for example, Pacific salmon, should not be equally effective on our own species*."

Emphasis was placed throughout upon practices which involved the use of the natural environment rather than on hatcheries, for the following reasons:

(a) The natural environment approach, "improving or restoring the habitat and letting the fish do the rest" is arguably more ecologically and genetically acceptable than using hatcheries and fish farms and perhaps material from distant stocks. Where the scope exists it is also likely to be more cost-effective.

(b) Hatcheries of the typical North American design are very expensive to construct and run, and major developments along such lines are unlikely in the near future in the UK.

(c) Some stocks in the UK, in particular in England and Wales, are lower than historic levels and it is therefore argued that there is rearing potential which is currently unavailable or at least underused.

(d) Even in those rivers where there are insufficient spawning fish to provide fry to utilize all the available habitat, and restocking may appear necessary, there is scope for habitat amelioration or other alternative fishery management practices. Giving what naturally-produced fish there are a better start in life, a higher juvenile

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*Developments involving introduction of non-native species were specifically excluded from consideration.

survival and, until stocks build up, a lower adult exploitation may be a most effective enhancement strategy.

The role of hatcheries in an integrated enhancement programme is not denied, and indeed the fellowship tour included many hatcheries. Several basic hatchery developments are covered in this report, but detailed consideration of design and operation were not investigated.

A major theme of the investigation was consideration of the 'philosophy and politics' of enhancement programmes. Factors include reasons for enhancement, who pays, who benefits, definition and evaluation of success, and organization. This is an area which has been poorly developed in the UK; in some instances, North American programmes have a similarly doubtful foundation but in other cases there is an extensive basis of justification, evaluation, benefit/cost analysis, etc.

Two visits to North America were made during the fellowship. The first, from 24 May to 14 June, was to British Columbia to investigate fry rearing, habitat engineering, the Canadian 'Salmonid Enhancement Program' (SEP) and to visit a range of fishery establishments. The second visit, from 11 August to 16 September, was timed to coincide with adult returns and included a brief visit to the Atlantic coast (New Hampshire, Maine and New Brunswick) plus Montana/Wyoming, Alaska and Washington. Inevitably with attempting to organize an itinerary for a tour of a distant country, the visits were of varied relevance to the essential direction of the study; some were disappointing, while others were unexpectedly very valuable. Without intending criticism of the many generous people who showed me around and offered hospitality, some of the visits duplicated certain aspects and missed out others. For these reasons a day-by-day account of the tour would not be very constructive, so I have selected a number of the more important developments I was shown.

Apart from developments on the Atlantic coast, most of the work described involves species which do not occur in the UK. The possibility of using Pacific salmonids for developments in this country was specifically excluded from this investigation, so how relevant are the practices to our own situation? Many of the habitat requirements and population constraints, study methodologies and fishery considerations are immediately comparable; in other cases there are important differences, but nonetheless a consideration of successful practices can suggest similar possibilities for our species.

The main species involved in the developments described are:

Coho salmon, <u>Oncorhynchus</u> <u>kisutch</u> Ecologically rather similar to Atlantic salmon, with a freshwater parr stage of 1-4 years followed by smoltification in the spring. A major sport species in both salt and fresh water.

Chinook salmon, <u>O</u>. <u>tshawytscha</u> Occurs mainly in large river systems, and is the largest of the Pacific salmonids running to over 45 lb - needless to say a prime sport species. Most remain in fresh water for a year before smolting, but some strains emigrate after just a few months.

Sockeye salmon, <u>O</u>. <u>nerka</u> (the red salmon in tins) Has a complex life cycle, with the fry migrating from streams into lakes where they live for a year or more before smolting. Not a major sport species but a most important commercial resource.

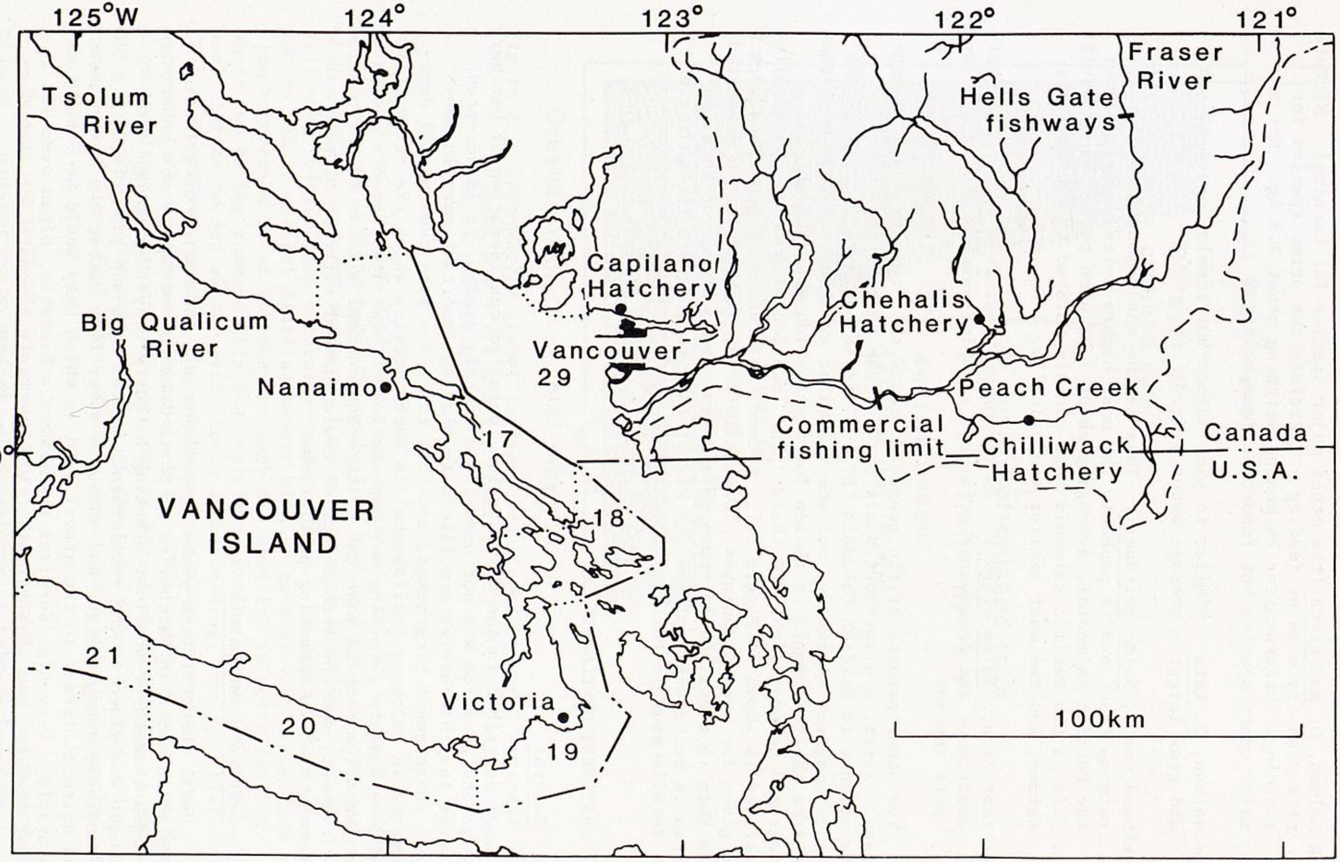

Figure 1.1 Southern Vancouver Island and the lower Fraser River valley, British Columbia.

Pink salmon, _O. gorbuscha_ (the other major species for canning) Migrate to sea as fry without feeding - therefore the prime species for ranching. Return after 16 months weighing about 2.5 kg. Not a major sport species but important commercially.

Chum salmon, _O. keta_ Similar to pink salmon but remain longer at sea and grow larger - average about 4 kg.

Steelhead trout, _Salmo gairdneri_ This is the anadromous form of the rainbow trout and is probably the most highly prized sport fish of the Pacific salmonids, averaging about 3 kg upon return as an adult. This is the Pacific salmonid most closely related to the Atlantic salmon, and the most similar ecologically.

Cutthroat trout, _Salmo clarkii_ As the brown trout this species has both anadromous and freshwater strains. A spring spawner, it is a major sport species.

Two other aspects of the presentation of this report should be mentioned. First, a disproportionate part of the description covers developments in British Columbia (BC). This is not a reflection of the lack of progress elsewhere, but where similar examples exist in more than one area the BC example is chosen for description to highlight the integrated nature of the SEP there. The location of most of the BC sites described is shown in Figure 1.1. Second, references to published work are given for most techniques. Generally later information is presented here than is contained in those references - they are given to allow access to background information rather than to indicate the source of the details used in this report.

2. HATCHERY DEVELOPMENTS

2.1 General

As described in the introduction, detailed consideration of hatchery design and practice was not undertaken in this study. It is accepted however that hatcheries are likely to play an important part in many stock enhancement programmes, and that there are some fundamental developments in hatchery 'philosophy' in North America which are relevant to any developments involving our own species. These developments basically involve attempting to make the culture environment similar to the natural environment, and the methodology of evaluation of efficacy of releases of hatchery fish in enhancing populations.

2.2 Substrate incubators

Until about fifteen years ago, almost all incubation of salmonid eggs and alevins in hatcheries in North America and Europe was undertaken in open baskets or shallow, stacking hatchery trays. Although some thought was given to the requirements of the eggs and young fish, e.g. by maintaining subdued light and adequate water flow rates, the environment was quite different to the gravel redd in which they would be incubated naturally. Very high survival rates were achievable, often over 90% to first feeding, and this situation was certainly adequate for fish destined to spend much of their lives being reared in the hatchery. However, many of the young fish were being reared for release as unfed fry or after just a few weeks of feeding. Problems of marking such fish made

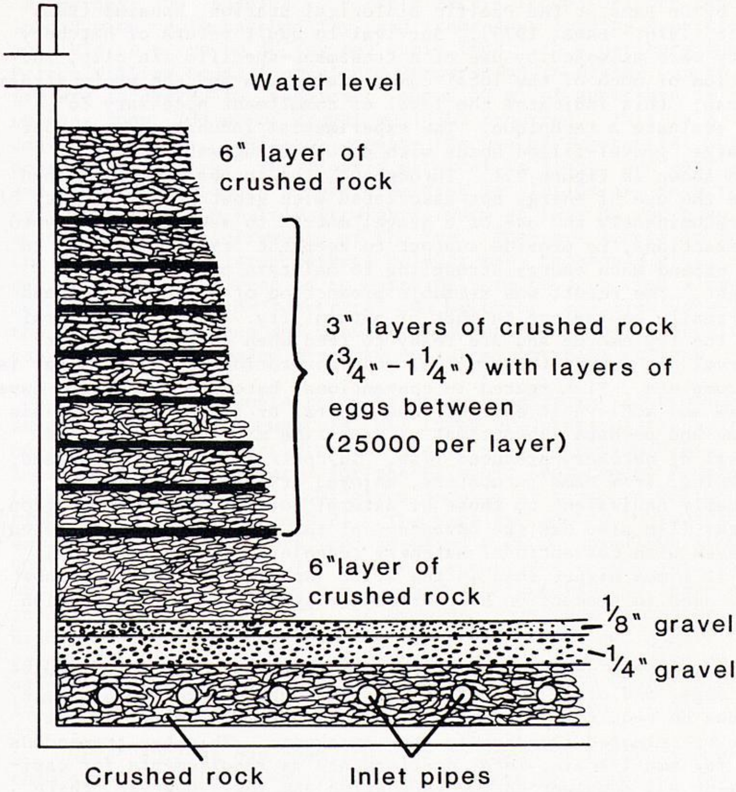

Figure 2.1 Deep-matrix gravel incubator developed by Bams. Overall dimensions 4 x 4 x 8 ft, capacity 200 000 eggs with a flow of 200 litres per minute.

evaluation of survival difficult, but a general lack of apparent increase in adult numbers in 'enhanced' populations led to a growing awareness that hatchery-produced stock may have a very much lower survival rate following release than naturally-produced fish. In Britain, this realization led to general disillusionment with release of very young fish from hatcheries as an enhancement method. However, in North America, where two of the commercially most valuable species (pink and chum salmon) migrate to sea as fry with little or no feeding, the potential for this approach was so great that attempts were made to overcome this apparent lack of fitness of hatchery fish. This led to a series of developments of great importance, not just in effective incubation techniques, but also in the understanding of the physiology, ecology and behaviour of young fish which allows a degree of *a priori* evaluation of new methods.

During the 1960s, there were several developments involving evaluation of gravel incubator systems, in an attempt to make the culture environment more natural. One of the more thorough assessments, in that it followed the fate of the young fish through to adult return, was that undertaken by Dr Bams at the Pacific Biological Station, Nanaimo (Bams and Crabtree, 1976; Bams, 1979). Survival to adult return of hatchery and wild fry were assessed by use of a treatment-specific fin clip, and by examination of much of the local commercial catch and the whole stream run at a trap; this indicates the level of commitment necessary to thoroughly evaluate a technique. The experimental incubation was undertaken in large, gravel-filled boxes with an upwelling water supply; details are shown in Figure 2.1. Throughout, the incubator was planned to minimize the use of energy not associated with growth, by a variety of tactics, predominantly the use of a gravel matrix to separate the fry to reduce interactions, to provide support to keep the fry upright (fry in flat trays expend much energy struggling to maintain posture) and to exclude light. The result was reliable production of fry of a size and quality virtually equivalent to that of natural fry. As in the natural situation, the fry emerge and are ready to feed when they reach their maximum larval wet weight (MLWW), i.e. when absorption of the yolk sac is virtually complete. Fish reared in conventional hatchery conditions have a lower MLWW and achieve it earlier than natural or incubator fry. This smaller size and perhaps sub-optimal release time may account for the poor survival of hatchery-produced fish. In contrast, the fry released, without feeding, from Bams'incubators, enjoyed fry-to-adult survival rates virtually equivalent to those of natural (wild) fish. In addition, the incubator fish also had the advantage of the high egg-to-fry survival rates achieved with conventional hatchery techniques, which at 75-90% were 10 to 12 times higher than in the wild. Gravel incubators are now extensively used in production hatcheries throughout the Pacific region of North America.

Such deep-matrix gravel incubators are generally loaded with newly-fertilized eggs, and offer an ideal environment up to the swim-up stage. There is thus no requirement for any other hatchery equipment, if the fish are to be released immediately upon emergence. This has tremendous advantages for small-scale, local developments as requirements for capital investment and manpower during incubation are low. However, there are several minor disadvantages in certain situations. Firstly, the opportunity to transport eggs during the resistant 'eyed' stage is lost. Although incubators can be loaded with eyed eggs or newly-hatched fry, the advantage of a single hatchery system is negated. Secondly, the system is bulky, particularly important if the environment requires that incubation must be undertaken under cover. Thirdly, cleaning and handling the large volumes of gravel involved is a significant problem in large-scale applications. These constraints have led to a number of developments.

Separate incubation of eggs to the eyed stage allows their movement at this stage, it allows thermal shocking to make any dead eggs opaque so that they can be removed, and allows a number of other incubator systems to be used for the fry. An early development was the 'Netarts' box, described by McNeil and Bailey (1975), which involved a shallow gravel matrix into which newly-hatched fry were allowed to swim from egg-holding screens supported above the matrix. Other systems use plastic substrates in place of gravel, with the aim of maximizing void space of optimal dimensions. Plastic turf (developed for indoor sports centres) has been used with some success, but is not ideal and is little used now. Bams and Simpson (1977) describe developments up to 1976 and provide a useful analysis of critical factors in egg and fry incubation. More recently, great success has been achieved using plastic mouldings designed for use in biological filters, where the constraints of maximum surface area and maximum void space are similar. Two types are widely used, termed

'Bio-rings' and 'saddles'. Plastic matrix incubators are generally loaded with newly-hatched fry, and tremendous loading densities are possible, e.g. up to 30 fry per cubic inch. In a hatchery run by the Prince William Sound Aquaculture Corporation in Alaska, up to 90 million fry are incubated in 'saddles'; about 50 m^3 of substrate is involved, whereas about 200 m^3 of gravel would be required. This is a critical consideration as conditions require the use of substantial buildings to house the hatchery. The plastic material is light, and easily handled and cleaned. Although separate holding facilities are required for the eggs, these can be fairly straightforward as they do not have to take account of the requirements of the fry. They are generally incubated to the eyed stage in large baskets holding many thousands of eggs. After eyeing, they are spread on to hatching screens supported a few centimetres above the substrate. On hatching, the alevins swim through the perforated screen and penetrate the matrix. Newly-fertilized eggs can of course be loaded directly on to the hatching screens.

In British Columbia there has been significant development of stream-side gravel incubators, and these are particularly suitable and popular for public-participation projects (see section 7.6). The Stream Enhancement Guide prepared for the Salmonid Enhancement Program (Government of Canada, 1980) gives details of a proven design for incubating 50 000 eggs (Figure 2.2). The eggs are packed in layers of gravel as in hatchery incubators, and supplied with an upwelling flow of 50 l/min. The emerging fry can be discharged directly into the stream, or retained in a screened box for manual dispersion if large numbers are involved (see section 3.2). In Wyoming, in-stream incubators are being used to hatch cutthroat trout in new areas (Kiefling, 1983). In this case the eggs are contained in trays, and the fry emigrate on hatching and seek refuge in the natural stream gravel. The water inlets are carefully screened to exclude predatory insects and small fish.

Great success has been achieved in Japan in hatcheries producing chum salmon in shallow-matrix gravel incubation channels, and several hatcheries in BC and Washington have recently adopted this approach, including the Chehalis hatchery on the River Fraser system. There are twenty channels, each 24 m long, 2 m wide and 0.2 m deep. The beds are covered with a single layer of gravel, and the total capacity is about 14 million fry (15 000 per m^2). The maximum water requirement is about 6 m^3/min. The eggs are incubated in a conventional hatchery, then spread onto hatching screens after reaching the 'eyed' stage. Bams (1982, 1983) undertook an analysis of the 'quality' of fry produced in a Japanese-style hatchery (JSH) compared to those produced in deep-matrix gravel (DMG). He found that the JSH fish emerged earlier, and at an earlier stage of development, i.e. before they had achieved MLWW. If released at that stage it is likely that the JSH fish would have been significantly less fit than the DMG ones. However, at the end of 8 weeks feeding (standard JSH practice), the JSH fish were significantly larger than their DMG equivalents, due to the extra feeding period available to them. Their emergence from the matrix about 44°C days before MLWW corresponded closely with an experimentally-determined maximum growth potential from first feeding about 40°C days before MLWW. Generally in JSH practice, development is accelerated by the use of groundwater supplies, which are warmer than stream temperatures during winter and spring. The 8-week fed fish are then released at the same time as the natural stream emergence, a factor which has been shown to be critical for maximum survival. These observations highlight the need for understanding factors which influence fry fitness, and for matching hatchery practice with the stage and time at which fish are to be released. The poor track record of UK hatchery

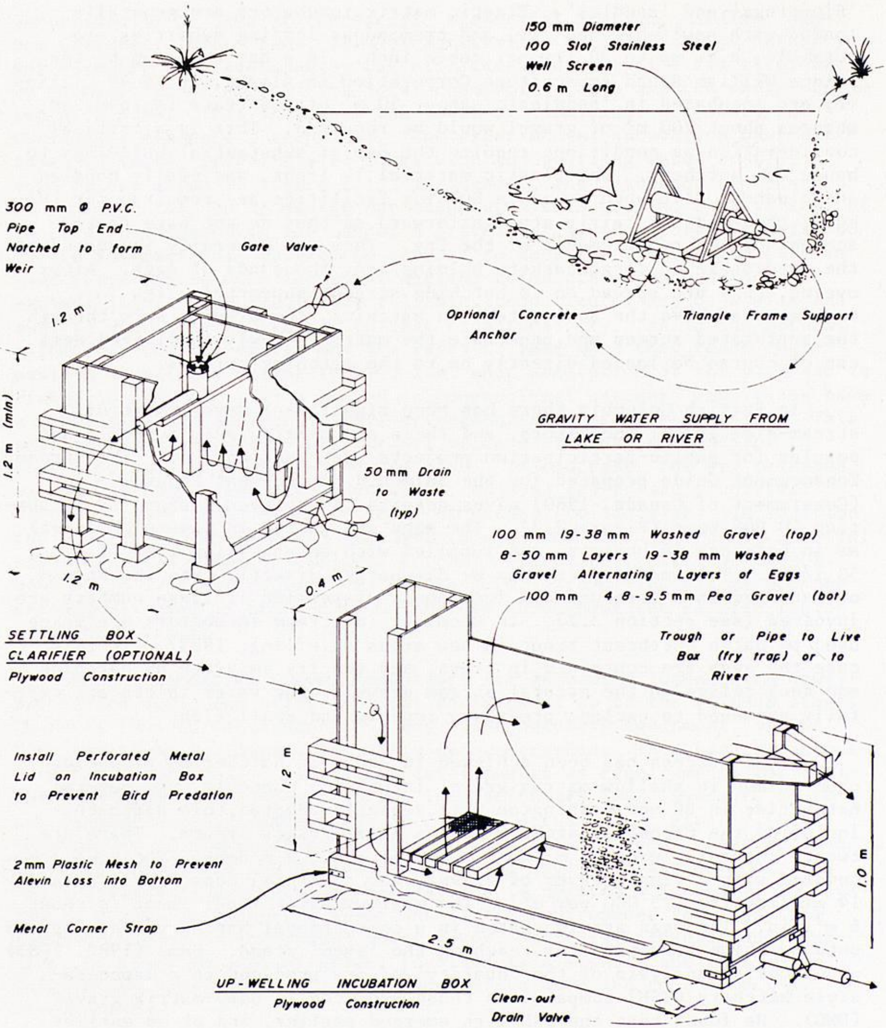

Figure 2.2 Stream-side incubator for 50 000 salmon eggs. Reproduced from 'Stream Enhancement Guide', Government of Canada (1980).

releases of unfed fry suggests that our species may have similarly critical constraints. It is suggested further that there could be considerable scope for investigation along the lines of the North American developments discussed above.

2.3 Rearing channels

As with fry for immediate release to the wild, it appears that the hatchery environment for older fish is quite different to that found in nature, and that the fish so reared are likely to be at a considerable disadvantage upon eventual release. Apart from the direct observation that hatchery releases often experience much lower survival to adult than natural stocks, there are also observations with coho salmon indicating significantly different behaviour patterns between wild and hatchery-released juveniles (Glova, 1978). Although the large numbers of fish usually involved in hatchery rearing precludes provision of entirely natural conditions, attempts have been made to make the hatchery environment more natural. Several hatcheries in British Columbia incorporate rearing channels, semi-natural 'streams' in which high densities of young fish are fed and reared. The bed is rock and gravel, with earth sides and luxuriant bankside vegetation is encouraged. The channels are covered with large-mesh netting to discourage predation by birds. The fish are placed in the channels a few weeks after commencing to feed. They are still dependent for the overwhelming majority of their intake upon artificial food, but the small supplement of natural food produced in the channel, brought in by the flow and falling from the surrounding vegetation, is considered important. It is suggested that the fish learn to hunt natural food and do not become preoccupied with a pellet diet, and they learn to feed competitively, important attributes upon final release. Although requiring a little more space than conventional hatchery ponds, at the Chilliwack Hatchery in BC (Figure 2.3) about 300 000 coho and 150 000 steelhead smolts are produced each year in channels just a few hundred yards long. Another advantage of channels is that they are of more aesthetically pleasing appearance than conventional hatchery plant, an important consideration as many salmon hatcheries are situated in areas of natural beauty.

Another step towards natural rearing is represented by the experimental rearing channel for coho developed by Dr Mundie (Nanaimo Laboratory) on a side-channel of the Big Qualicum River. The channel is 400 m long, 4 m wide and comprises 25 pools (10 m x 1 m deep, flow 0.1 m/sec) and 25 riffles (6 m x 0.2 m deep, flow 0.6 m/sec). The overall slope is 0.004, and the pools provide cover for the fish, and the riffles produce invertebrate food. The carrying capacity is about 500 000 fish, which can be reared on about 20% of the food that would be required in a conventional hatchery. The channel cost about $200 000 in 1975, and predator fencing and a walkway a further $50 000. Bird netting was added subsequently at a cost of about $11 000. Although coho appear more amenable to high-density rearing than Atlantic salmon, there could be considerable scope for similar investigations for our own species. Mundie (1974) discusses the whole concept of maximum utilization of rearing habitat.

2.4 Size and time of release of smolts

An important series of experiments was carried out at the Nanaimo Laboratory by Bilton *et al.* (1982). Variable return performance of releases of hatchery-reared coho smolts indicated that the time of release, and perhaps size of fish at release, were important in survival terms. In 1975, Bilton released 57 marked groups of coho, classified by time of release and size. The groups varied from about 1 000-4 000 fish and were marked with coded wire microtags (see section 7). The rates of return of each group were analysed according to several criteria,

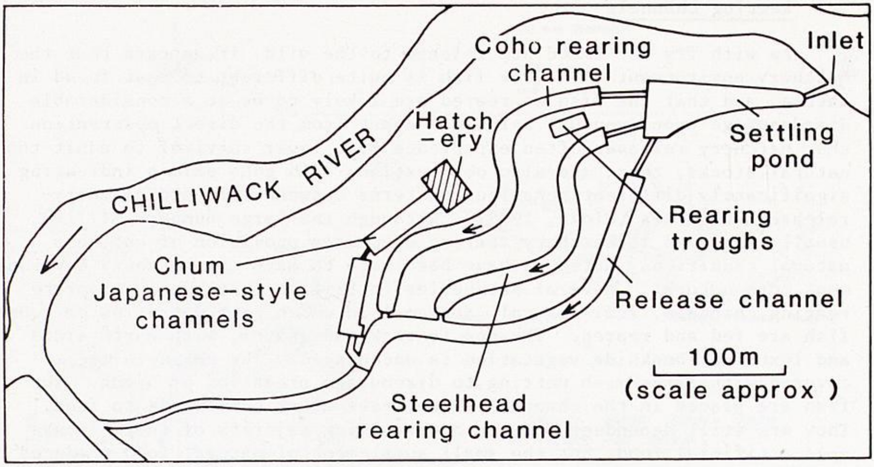

Figure 2.3 The Chilliwack hatchery, on the Chilliwack River in the Lower Fraser Valley. Coho and steelhead eggs are incubated in the enclosed hatchery, then reared for about two months in small rearing troughs. They are then transferred to the semi-natural rearing channels. The coho channel is approximately 300 m long and 5 m wide, and has a capacity of 300 000 smolts. The steelhead channel is about 250 m long and can produce 150 000 smolts.

e.g. % survival to adult, biomass return, benefit/cost. The survival rate to adult is shown in Figure 2.4(a); it is immediately apparent that there was a great range in performance according to size and release time, with a relatively narrow 'window' for optimal performance. Previously, many hatchery operators aimed for large smolts as early as possible in the spring, i.e. top left of graph, clearly a mistaken aim. Figure 2.4(b) shows an analysis based upon benefit/cost ratios. The pattern is rather different because account is taken of the weight of adult returns plus the increased costs of production of larger and later-in-the-season smolts.

These results are clearly of great importance to hatchery operations, particularly if, as seems likely, the observations can be used predictively. There is also scope for using such observations to identify critical factors in marine survival, again to aid planning of releases. It would appear likely that a similar situation exists for Atlantic salmon, and an equivalent investigation could transform the economics of smolt releases.

3. RANGE EXTENSION

3.1 General

The practices described here are those which involve transfer of fish to a new river system, and transfer of fish to isolated or unused parts of the same river system. Any developments which involved allowing access to headwaters etc. would also be covered, but there appear to be

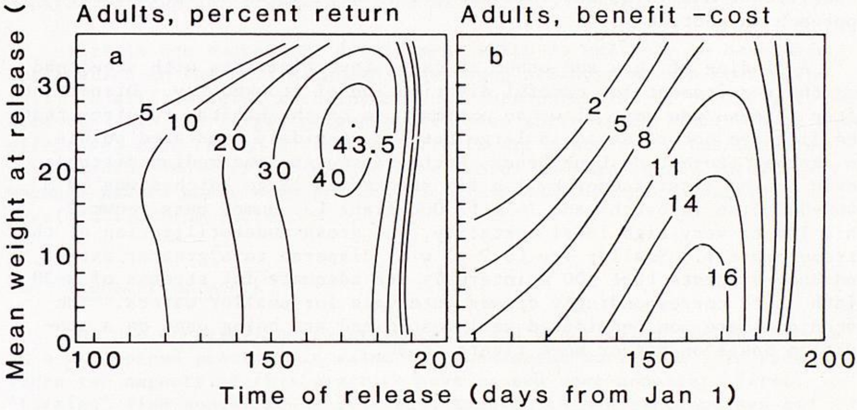

Figure 2.4 Influence of time of release and mean weight at release of coho smolts on (a) percentage adult returns (fishery plus escapement) and (b) benefit-cost ratio of adult returns. Redrawn from Bilton et al. (1982).

relatively few examples of this approach in North America which offer any new information for UK application. Fish pass designs are generally similar to those in this country, with perhaps a greater use of passes to circumvent massive obstacles such as hydroelectric dams, and the use of lightweight, prefabricated Denil passes which can be airlifted into remote sites.

Many of the restocking and transfer practices in use in North America have also been used in the UK and discussion is therefore limited to situations where something new can be learned, for example where a development was particularly successful, better evaluated than UK equivalents or illuminates an important principle.

3.2 Stocking unused streams

Much of such work done on North American species is of little relevance to the UK situation. One series of studies which is of interest is that involving steelhead trout, part of the Canadian SEP (see section 7). The points of interest derive partly because of the similar biology of steelhead and our native salmonids, and partly from the thorough evaluation of the practices.

The first investigation is taking place on the Keogh River, in northern Vancouver Island (Slaney, Billings and Smith, 1980). Fed fry of 0.3 g were stocked into a tributary isolated by falls, but which already contained resident salmonids. Low density stocking (less than one fry/ 2 m^2) gave good survival and growth, while above that density growth (but not survival) was depressed. Survival to 1+ was about 32%, and about 5% to smolts at 3+ and 4+. Costs, including time for stocking, were about $(Can) 0.06 per fry, $1.20 per smolt, $12 per adult fish generated. As this investigation is part of the SEP it is subjected to rigorous benefit/cost analysis, and this project is used as an example of the approach in section 7.

A finding of this and other stocking investigations with steelhead was the requirement for careful distribution of stocked fry. Dispersion after release was very slow, so optimal use of the habitat requires that the fish are not released in large batches at widely separated points. In another project on Lynn Creek, North Vancouver, the median distance moved in the first summer by 1 g fry stocked in large batches was 40 m (400-500 fish in batch) and 24 m (2 000 fish) (J. Hume, pers. comm.). This led to very high local mortality, and gross underutilization of the stream habitat. Smaller fry (0.2 g) will disperse to a greater extent, and Hume suggests that 500 m intervals are adequate for streams of 8-20 m width, with correspondingly closer intervals for smaller waters. The techniques are now considered well tested and are being used on a production basis on ten or more rivers in BC.

3.3 Stocking lakes

A technique of enhancement used with considerable success in Alaska is the stocking of fishless lakes with fry of coho salmon. Generally the lakes are unpopulated because their outflow streams have falls which are impassable to upstream migrants, but through which smolts can nevertheless pass downstream without damage. Stocking at a rate of about 1 000 fry per acre gives very high survival rates to smolts, up to 60% in some cases. Growth is fairly slow, with some fish smolting at 1 year at 8-11 cm (4-11 g) at 2 years at 10-15 cm (7-30 g) and older. Good adult returns of up to 20% of smolt numbers have been achieved. This technique is now being used by some of the regional aquaculture corporations (section 7.5).

This technique has been tried with Atlantic salmon, with mixed success. There are few fishless lakes in the UK, and competition with other species would reduce smolt production, but most still waters would be significantly more fertile than those in Alaska. If smolt outputs of up to 500 per acre could be achieved there could be significant scope for use of a range of waters, including gravel pits. Supplementary feeding, along the lines of the rearing channels described in section 2.3, has been tried successfully in rearing young chinook in a lake system in Olympia, Washington. This would appear to combine the benefits of rearing under natural conditions with the higher densities associted with hatcheries. Again there appears to be significant scope for investigation with Atlantic species.

One of the most successful aspects of the Canadian Salmonid Enhancement Program has been the addition of inorganic nutrients to lakes where sockeye are rearing (Salmonid Enhancement Program, 1981). In 1981, 218 tonnes of inorganic nitrogen and 63 tonnes of inorganic phosphorus were added to eleven lakes. The nutrients are distributed in dissolved form from aircraft, at approximately weekly intervals throughout the growing season. Such regular, low-dose treatments are found to be virtually entirely absorbed by planktonic algae within hours; the production of zooplankton, on which the young sockeye feed, is greatly enhanced. This leads to increased production of sockeye, both in terms of numbers and growth, which imparts a higher marine survival rate. The estimated adult returns generated by the 1981 treatment are about 630 000 fish, indicating a benefit:cost ratio of 2.4:1. There is considered to be scope for the carrying capacity of the eleven lakes to be further boosted to eventually generate runs of over 4.5 million adults.

This is one successful development which is unlikely to have wide application in the UK. Although many young Atlantic salmon rear naturally in still waters, such intentional eutrophication is unlikely to be acceptable in the large, oligotrophic lakes where it is likely to be most effective, even though no adverse effects are apparent in the Canadian experiments. However, it may well be useful in some small, intensively managed waters where high production levels make inorganic nutrient levels a limiting factor.

3.4 Transfer of stock

The use of eggs from geographically and genetically distant stocks is a widespread practice in salmonid enhancement worldwide. In recent years two aspects of this practice have caused some concern; first, 'foreign' fish appear to be less well adapted to new surroundings and thus suffer very high mortality rates, and, second, there is a possibility that the introduction will adversely affect local stocks in some way.

Several studies have indicated that, when 'local' and 'foreign' stocks of the same species are reared under identical hatchery conditions, the return rates following release are much lower in the 'foreign' stock, indicating a poorer adaptation to prevailing local conditions. By breeding from those 'transplant' fish which do return, improving results can be obtained as the new stock becomes adapted by natural selection. An interesting technique by which the process can be accelerated has been investigated by Bams (1976) on the Tsolum River, Vancouver Island. The method depends upon there being a small local stock still existing, albeit at too low a level to provide significant numbers of eggs for enhancement. The males represent a very much greater number of reproductive cells than the females, and one 'local' male can be used to fertilize the eggs of many 'foreign' females, to produce a 'hybrid' stock for release. The experiment was conducted with pink salmon, with similar numbers of pure foreign strain (from the Kakweiken River (KK) about 140 km north-east of the experiment site) and hybrid (Tsolum x Kakweiken (TK)) being released with different marks. Survival of the two groups to return to coastal waters was similar, as indicated by marked fish appearing in commercial catches. However, about three times as many TK fish were observed in the lower river than KK fish, and about ten times as many at the hatchery weir on a tributary. Thus the locally-adapted paternal genes inferred a greatly enhanced homing ability. The survival of KT fish was similar to that observed in other years for pure local fish (TT), but their relative numbers in the river and at the hatchery weir appeared lower, i.e. the hybrid stock appeared intermediate in homing ability between the local stock and the donor stock. However, the enhanced return rate of the hybrid stock to the river compared to the donor stock indicates the potential for this approach. The apparently equivalent survival to return to coastal water indicates how careful one must be in defining success of a technique; in this case, returns of marked fish from local commercial fisheries does not mean success if returns to the river are desired.

The second aspect of concern, the possibility of a transplanted stock damaging local stocks, is difficult to evaluate because it is based on biological principles rather than on specific examples of damaging experience. Apart from the remote possibility of transfer of a virulent disease, most of the suggested effects are subtle, e.g. reduced fitness as a result of introduced fish breeding with local fish, or even virtually ousting the local stock by pressure of numbers. Any resultant decline in stock size is unlikely to be precipitous and may be indistinguishable from decline due to other factors. The implication of Bams' work discussed above, that introduced fish are likely to stray more than locally-adapted fish, is borne out by observations on other transfers. This means that any deleterious effect may not be limited to the river where the fish were stocked. Informed opinion on the seriousness of the problem varies widely; some consider that 'unsuitable' genetic material will be quickly eradicated from the population by natural selection, while others consider that this process is largely responsible for the observation that increase in hatchery-produced coho in Oregon is coincident with declines in wild stocks (section 7). In the absence of firm evidence either way, the prudent path is probably one of cautious progress, not stopping all transfers but seeking where possible to utilize local genetic material, and to try to fully evaluate all restocking experiments.

4. HABITAT ENGINEERING FOR SPAWNING

4.1 The problem

In most healthy salmon rivers there is more than adequate spawning ground for production of fry to fully occupy all available territories. In some rivers, however, there may be inadequate spawning gravel. In others, previously suitable gravel may have been rendered of less suitability due to siltation or channel 'improvements'. Further, if increased carrying capacity is planned (section 5), extra spawning area may be required. What can be done in these cases? There are three basic approaches, viz improvement of existing gravel, provision of new substrate, and removal of the source of the problem, e.g. extreme flow or a silt source.

4.2 The ideal situation

It is difficult to define the ideal situation for spawning and incubation, although several attempts have been made in the past. What is possible is to describe the conditions prevailing where natural spawning takes place, and to link them with success or otherwise of spawning and survival of the eggs and alevins. Observations on Pacific salmonids are relevant to the UK situation as their requirements appear to be similar to those of native species.

Typically, spawning takes place in shallow water (a riffle) where flow is accelerating over gravel. Such a situation is usually conducive to intra-gravel flow of water, essential for survival of the eggs. Fraser (1975) describes various attempts to quantify optimal conditions. Among the more comprehensive was that for chinook salmon spawning in the Feather River, California, involving definition of potential spawning gravel as good, fair or poor. Based on this it was possible to predict the 'ideal' discharge, which promoted the greatest area of potential spawning gravel to the 'good' category. Peterson (1978) measured the physical characteristics of gravel used by spawning Atlantic salmon in New Brunswick streams. Size distribution of gravel varied widely but percentage sand (0.06-2.2 mm) appeared to be critical; more than 20% caused a very low permeability. A permeability of more than 1 m/h appeared to be necessary for successful emergence of fry, which corresponded to a sand content of 12-15%. Gravel compaction was also considered to be a critical factor.

Investigation by Carling (1979) of riffles used by Atlantic salmon on the River Tyne indicated that they were all in Fraser's (loc. cit.) 'good' category, with the most favoured having the lowest sand fraction. Once again, any concretion or compaction of the gravel appeared to reduce its attraction. From a consideration of discharge/depth/water velocity relationships Carling was able to propose discharge levels which were limiting, and optimal.

Brief mention must be made of two factors which make it difficult to proceed further with defining 'ideal' conditions. First, it is likely that in many situations the action by the fish itself in creating the redd will alter the composition of the gravel, reducing the fine sediment component by winnowing (McNeil and Ahnell, 1964); even the small pink salmon, with an average weight of about 2 kg, shifts about 100 kg of gravel in creating a redd (Semko, 1954). Carling (1979) however found no evidence of modification of gravel composition by salmon on the Tyne. The second factor is that a level of fine material in the spawning gravel may prevent penetration of detritus; Carling (in press) reports that a graded gravel of constant size quickly became blocked with silt, whereas mixed natural gravels are much less permeable to fine material. Thus the obvious 'ideal' of riffle composition of a single optimal sized gravel would appear to be a poor environment for eggs.

4.3 Gravel cleaning and planting

From the above considerations, there appear to be two gravel parameters which could be reduced beneficially, viz a high level of fine material, and any tendency towards compaction. Both are amenable to some extent to mechanical cleaning methods. Straightforward bulldozing works well in large rivers where the current is adequate to carry away the fines (Allen *et al*., 1981). Ploughing the stream bed can prevent compaction where access with the machinery is possible. The most consistently used area for spawning, and the area producing the greatest density of young fish, in the Candover Brook studied by Solomon and Templeton (1976) was a reach ploughed each year to prevent weed growth. It is in such chalkstreams, with high calcium level and very stable flow regime, that gravel compaction and concretion is likely to be a particular problem. It is possible that the spawning activity of the fish is itself a factor in preventing compaction in favoured areas.

The Wyoming Game and Fish Commission has made a study of gravel improvement for cutthroat trout spawning in groundwater-fed streams (Erikson, 1980; J. Kiefling, pers. comm.). A compacted surface layer, dominated by cobbles, overlay apparently suitable gravels in one stream. Pools (3 m wide, 1.5 m deep) were therefore excavated using a mechanical digger, and the material was dumped downstream to create new riffles (18 ft wide, 6 in deep gravel). Cobbles were removed by hand and used to stabilize the downstream face of the riffle. Over 10 years the number of spawning trout using the stretch increased from 6 to over 250. Two other tributaries were stocked with new gravel, placed into shallow excavated

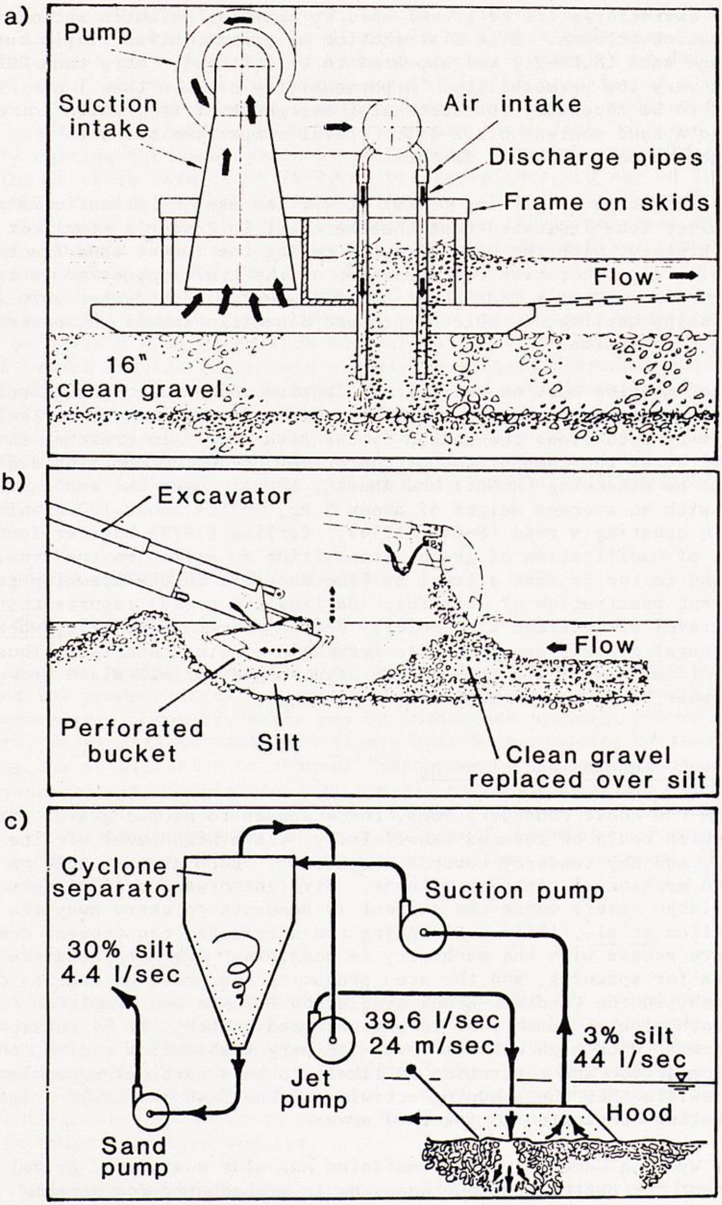

Figure 4.1 Spawning-gravel cleaning machines (section 4.3). (a) Air-water jet system for spawning channels, used with little success in natural streams (Andrew, 1981); (b) Andrew's (1981) 'vibrated bucket' method for natural streams; (c) silt separating system which discharges the slurry onto the bank (Allen, 1981).

holes; numbers of spawners have increased by 2.3 and 6.3 in the two streams. Occasional maintenance is required on the newly-created riffles mainly because the fish themselves displace gravel downstream while spawning.

The greatest interest in spawning substrate improvement has been on the west coast of North America, with a series of developments culminating in very successful (and expensive) spawning channels for Pacific salmon. These are unlikely to be a realistic development in the UK because rivers could not support such gross production of young fish of species with a significant riverine life history stage; channels are predominantly used for pink and chum salmon (which migrate to sea as fry) and sockeye (which migrate to lakes as fry). However, many of the other developments involving substrate improvement are of interest.

One of the main problems with gravel cleaning is that the silt is removed downstream, where it tends to resettle and perhaps cause degradation to other gravel. The 'vibrating bucket' method used on the Fraser River catchment (Andrew, 1981) overcomes this problem by burying the fines under the cleaned gravel. An excavator with a finely perforated bucket is used to remove a volume of gravel. This is then vibrated in the water to wash out the fines, which settle into the hole from which the gravel was removed. The gravel is then replaced to give a clean layer of about 30 cm over the fines. The estimated full economic cost of this technique is calculated at Can. \$1.25 per yd^2 (1981).

Andrew also describes a gravel cleaning machine, developed for cleaning spawning channels but used with limited success in rivers. It operates by jetting an air and water mixture into the gravel through pipes projecting 22 cm into the gravel, at 30 cm centres. Major problems arose with boulders, and dispersion of the fine material. The conclusion was that it had little potential for cleaning natural gravels, and that the vibrating bucket technique was more effective.

A gravel cleaning machine described by Allen et al. (1981) overcomes some of the drawbacks of Andrew's gear by recycling the silt/water mixture and removing most of the silt in a cyclone separator. About 70 gallons per minute of a slurry containing 30% silt is sprayed on to the bank well away from the stream. Again boulders were a major problem, and there were a number of other 'teething troubles' with the prototype under test, but the conclusion was that there was some significant potential for the equipment.

In deciding the viability of any approach to gravel cleaning, one must take account of the cost of the exercise, the immediate benefit, and the longevity of any beneficial effects. The obvious immediate benefit is the use of cleaned areas by an increased number of spawners. However, if these fish would otherwise have spawned successfully elsewhere, one must consider the stream as a whole, and also evaluate survival of eggs to emergence of the fry. The duration of beneficial effects is very limited in some situations; Carling (1979; in press) reports very rapid re-incursion of fine material into graded gravels and gravel winnowed by redd digging, in a river with high suspended solids loads. However, a number of North American studies have indicated reasonable life-span of ameliorating effects. Andrew (1981) found that siltation was much more rapid at the upstream end of a cleaned 2 300 ft length of stream than at the downstream end, indicating that the gravel was acting as a bedload collector. After a year the upper 200 ft contained a similar level of fines as uncleaned gravel. About 400-500 ft from the upstream end about half the effective cleaning had been lost after a year. An additional problem was that there was increased erosion of cleaned gravel.

Seeb et al. (1981) describe the changes after 1971 when a 600 ft length of channel on Perkins Creek, Washington State was 'planted' with graded gravel. Board weirs were also installed to control shifting gravel and adjust the gradient to 0.2%. Streambed fines were reduced from 23% to 11% and egg survival increased from 28.6% (1969-71) to 59% (1972-74) average. Heavy logging activity in 1977 increased fines to 21%, and egg survival fell to less than 1% in 1978. The gravel was again replaced with clean material, and in 1980 the level of fines was 8.2%. It appears in this case that the beneficial effect lasted for several years until logging activity reintroduced an exceptional silt load.

4.4 Application to the UK situation

The scope for use of gravel improvement in the UK is probably rather limited but significant. In areas where poor spawning conditions really are a limiting factor it is likely that an advantageous benefit/cost ratio can be achieved. This is particularly so when developments can be undertaken where conditions are such that rapid deterioration of beneficial effects is not likely. Such situations include chalkstreams and other groundwater-fed rivers, regulated rivers below reservoirs, rivers flowing from natural lakes, and side channels, mill streams, etc. where extremes of flow can be controlled. There may too be scope for initial treatment of gravel where it is hoped that the fish themselves will subsequently prevent compaction, and in situations where the source of a silt problem can be controlled. In many streams much of the suspended solids load emanates from particular activity, e.g. forestry cutting, or from point sources such as eroding banks on bends or banks damaged by cattle. Appropriate stream improvement developments have been studied in several locations in North America (e.g. White and Brynildson, 1967, see section 6). The observation by Andrew (loc. cit.) that the upstream few hundred feet of area of cleaned gravel are rapidly resilted leads to the consideration of arranging annual cleaning of such an area at the upstream end of a larger cleaned reach, where access with the required equipment is straightforward; i.e. a short length would be 'sacrificial' and would act as a settling tank.

The scope for lasting effective gravel cleaning in regulated streams is fortunate as it is in such situations that much concern lies about declining salmonid stocks. In addition, there is great potential for regulation to optimal spawning discharge as proposed by Carling (1979) and discussed above. There is also scope for freshet releases to specifically remove sediment from riffles; such an approach has been used successfully on the Colorado River below Granby Dam (Eustis and Hillen, 1954.)

5. HABITAT ENGINEERING FOR REARING

5.1 The problem

In most Atlantic salmon and migratory trout populations the ultimate factor limiting population size is the carrying capacity of the stream or river for juvenile fish. In both species the parr are strongly territorial and the number of effective 'territories' is finite. For a variety of reasons many streams are amenable to manipulation to increase carrying capacity; in particular, many of man's activities have degraded the stream environment to reduce the areas usable by young salmonids. As with spawning conditions, a sound approach is to establish the perceived ideal situation, and then to consider measures to achieve this.

Although the ecology and behaviour of juvenile Pacific salmon is rather different, much work on North American Salmo spp. is relevant to our native species.

5.2 The natural situation

A consideration of the ideal situation for rearing is more difficult than for spawning, as the requirements for different species are significantly different, and care must be used in interpreting studies on other species. Also, where two or more species of salmonids occur together in streams, the differences in their behaviour tend to become exaggerated, which serves to avoid direct competition. This phenomenon is termed interactive segregation, and is discussed in detail by Solomon (1979). Thus care is needed in interpreting the niche occupied by a species where it occurs together with another. Further, any conception of an ideal habitat must take account of whether mixed or single species population enhancement is the goal. A thorough evaluation of the 'ideal' situation is therefore needed before the validity of various potential enhancement practices can be judged.

Symons and Heland (1978) found highest densities of 0+ and older salmon at stream velocities of 50-65 cm/s. Stream tank experiments showed that salmon less than 7 cm in length preferred shallow riffles (10-15 cm deep) with a pebbly substrate (1.6-6.4 cm stone diameter). As they grew larger their preference changed for deeper (more than 30 cm) riffles containing boulders (greater than 25.6 cm diameter). Lindroth (1955) found that both young trout and salmon preferred shallow water (20-30 cm), especially in the margins of the large rivers that he was studying. Salmon have been reported to occupy territories in deeper water; Saunders and Gee (1964) found significant numbers of 1+ and 2+ fish occupying pools on a long-term basis. Observations on marked fish showed pool fish and riffle fish retaining their respective habitat choice throughout the period from August to December. The 0+ fish occupied mainly shallow riffles, moving into deeper water during the autumn. The only other salmonids present were brook trout, at a very low density.

Salmon are able to maintain position in fast flows with little effort by using their large paddle-shaped pectoral fins to keep themselves applied firmly to the substrate, e.g. on top of a large stone (Kalleberg, 1958). In this respect they are better adapted to rapid flows than are any of the other salmonids.

Thus Atlantic salmon parr appear to prefer shallow, fast flowing water in summer, and slightly deeper water in winter. The virtual absence of juvenile salmon in slower water in summer is certainly largely due to this preference, but is also likely due to competition with trout, which occur in virtually all salmon streams in the UK. Trout are more aggressive than salmon, and appear to dominate in slower water. The trout appear to be unable to compete in faster water however, and a clear interactive segregation takes place.

The ideal situation for juvenile trout appears to be less well defined than for salmon, probably because the species is more plastic in its behaviour. Although they are often found in fast water they appear to be less dependent upon it than salmon. Particularly for the younger year classes (the stage of interest in sea trout) cover is an important factor: many 0+ fish are found in association with bankside cover in overgrown streams. Habitat diversity is also important in providing a range of niches in conditions of fluctuating discharge, temperature and food supply.

For both salmon and trout, a relatively stable discharge appears to be advantageous. Streams with naturally stable flow, e.g. chalkstreams, are often extremely productive as a salmonid habitat. This is probably largely a matter of lack of extremes, as both very low and very high discharges are damaging. It is likely however that some fluctuation of discharge is desirable, to maintain habitat diversity and to clear away deposits of detritus and silt.

Within these general habitat conditions, there is a range of factors which influence the stream 'carrying capacity':

(a) Area of bed suitable for territories. Especially in larger streams and rivers, the areas suitable for young fish may be rather limited. In a wide range of natural streams studied, the area utilized by any one age group of a salmonid species has typically been between 2 and 20% of the total area (Allen, 1969).

(b) Age/size of fish. The size of territory increases with the size of fish. Kalleberg (1958) found that about a month after the fish emerged from the gravel salmon territories were about 0.02-0.03 m^2, in a fairly tightly packed mosaic. Larger parr (up to 15 cm) occupied a square metre or more in open water, and a 23 cm trout commanded about 4 m^2.

(c) Visual obstructions. Where fish are unable to see one another, a higher density can be supported. In one of Kalleberg's (1958) stream-tank experiments, mean territory size was reduced from 0.095 to 0.045 m^2 by exchanging gravel for rocks. Turbid water produced the same effect.

(d) Current speed. Symons and Heland (1978) found highest densities of salmon parr (1.0 and 0.8 fish per m^2 for 0+ and older fish respectively) under natural conditions in water velocities of 50-65 cm/s. At sites with lower or higher velocities maximum densities decreased. Kalleberg (1958), using a stream-tank, found that increasing velocity (maximum perhaps less than 65 cm/s) decreased territory size, and suggested that this might be because the fish were forced to vacate their 'rock top' stations and shelter among the stones, decreasing visual contact. Chapman (1966) suggested that smaller territories at higher water velocities were appropriate as the fish could exploit invertebrate drift in a similar volume of water by commanding a smaller area or width of stream.

(e) Food availability. As territory defending is believed to be a feeding-motivated behaviour, it is likely that territories will be smaller where food supply is great. As stated above, Chapman (1966) suggests that smaller territories at higher current speeds could be due to the greater supply of drift organisms. Chapman and Bjornn (1969) discuss the evidence for food-linked territory size, but it is inconclusive. Symons (1971) reported results from an experimental stream tank which demonstrated increased aggressive behaviour during periods of food deprivation.

(f) Presence of other year classes. Symons and Heland (1978) report that 1+ salmon (over 10 cm in length) reduced the number of the younger year class (less than 6 cm in length) in deeper water by chasing and occasionally catching and eating them. Agonistic behaviour, associated with territory defence, was not manifested between the year classes until the 0+ fish were larger than 6.5 cm, the size at which they start to vacate their territories in shallower water and establish territories 'alongside' the older fish. Kalleberg (1958) found that small parr vacate their 'station' and hide in the gravel nearby when a larger parr approaches - thus it was possible for a small fish to occupy a territory within the much larger territory of a larger fish for 'several days'.

5.3 The scope for habitat improvement

From the above considerations there appear to be several aspects of the habitat which are amenable to modification for stock enhancement. These include:

Control of discharge. Although control of whole river discharges for fishery purposes alone is unlikely to be practicable, it is nevertheless one of the most potentially powerful techniques for stock enhancement. Many rivers and streams in the UK are regulated for water supply purposes, and may be valuable nursery grounds for salmonids either as they are or with relatively little modification of flow regime (e.g. reallocation of use of fishery 'water bank').

The Big Qualicum River in Vancouver Island, Canada is a fine example of what can be achieved by flow control. A dam was built expressly for fish enhancement purposes, and a 'spatey' tributary was diverted. The total catchment is 150 km^2, and 13 km of river are managed between the dam and the sea. Although the species involved are Pacific salmon with different limiting factors to our species, the production achieved is impressive, with up to half a million adult salmon per year returning or being caught at sea.

Use of side channels. Perhaps the most practical proposition for flow control, and some of the other habitat modifications described below, lies in the use of side channels which take only a part of the river flow. Many such channels exist in the form of mill leats, irrigation carriers or natural braided channels and some already have sluices to control intake. Further, engineering of new channels is likely to be very much cheaper than a structure to regulate whole river flow. Incorporation of the optimal gradient and various 'habitat structures' is likely also to be much simpler in a side channel than in the main stream. Although the area of such channels is likely to be small compared to a whole river system, high densities of fish can be supported by optimal conditions. With careful management it is possible that a channel 1 000 m long, 10 m wide could produce up to 5 000 smolts, equivalent to the production of many small rivers.

In BC there has been a particular study of the use of groundwater-fed channels as spawning and rearing grounds, as part of the SEP. Marshy areas near large rivers are excavated to create streams fed by seepage

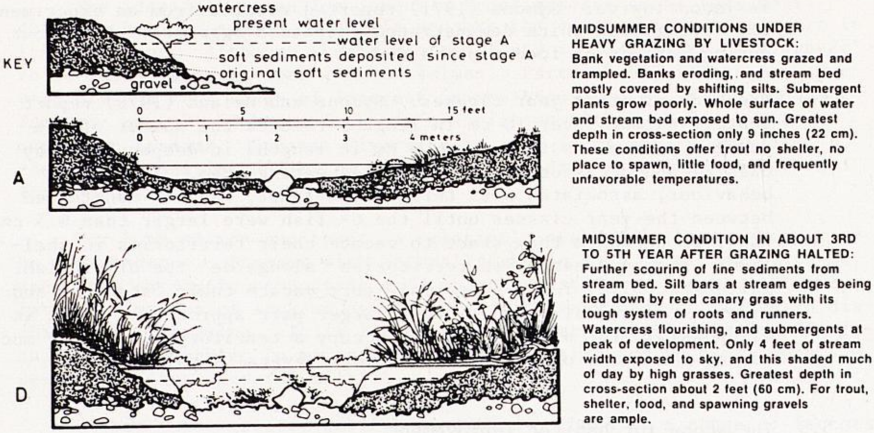

Figure 5.1 Two diagrams from a series showing the effects of bankside grazing and its prevention, reproduced from White and Brynildson (1967).

from groundwater or from the main river itself. Such water sources remain clear and stable whatever conditions obtain in the main river. The streams join the main river usually a kilometre or so downstream. One such side stream in the Fraser Valley, Peach Creek, is about 1.5 km in length and cost only about Can $10 000 to excavate in 1981. By 1983 bankside vegetation had developed to create a productive and attractive stream. The main river which 'feeds' it by seepage is a large, flashy stream with constantly shifting bed, and poor production of salmonids.

Increasing area suitable for territories. As quoted in section 5.2, Allen (1969) suggests that typically only between 2 and 20% of stream area is suitable for any one age class of salmonid. There is thus theoretically scope for increasing suitable area by five- to fifty-fold by engineering. What is the practical scope? Even if possible it would be undesirable to turn whole rivers into optimal rearing areas as there would then be poor holding and fishing areas for adults. Nevertheless, the scope is considered to be very significant. Realistic possibilities include manipulation of gradient (decreased by use of stop weirs, increased by pool and riffle configuration), depth, current speed (use of weirs, deflectors, or changes in channel width) and provision of cover. Extensive studies of this approach to enhancement have been made in North America (e.g. White and Brynildson, 1967; Ward and Slaney, 1981; Government of Canada, 1980) though careful interpretation of results is needed to extrapolate to European species.

White and Brynildson (1967) and Ward and Slaney (1981) provide details of the value of provision of cover in salmonid rearing streams. One of the most effective methods is by prevention of damage to bankside vegetation by grazing livestock; White and Brynildson (1967) present some graphic illustrations of the effect of bankside grazing, and the effects of its cessation (Figure 5.1). Solomon and Paterson (1980) suggest that a significantly reduced production of 0+ brown trout in low-flow years in a chalkstream was due to the unavailability of established margins for cover. Bankside vegetation, in addition to providing cover, can represent a significant food supply in the form of falling insects, and can stabilize banks and prevent erosion.

A study of the use of structures to improve production of steelhead parr has been made by a team from the University of British Columbia (Ward and Slaney, 1981; P. A. Slaney, pers. comm.). This is of particular interest as the steelhead appears to be the Pacific salmonid with habitat preferences closest to those of the Atlantic salmon. They have found that clusters of boulders placed in riffles greatly increase carrying capacity, and that a range of other structures is also effective (see Figure 5.2). They found provision of large boulders to be cost-effective in spite of costing $18 each to place in the stream by helicopter. Small boulders (less than 800 kg) were less effective as floods tended to erode the surrounding bed and bury them. Felled conifers, tree trunks and tree root balls, tethered to the bank, have been used successfully to provide cover for juvenile trout in a variety of North American locations (e.g. Government of Canada, 1980; Wyoming J. Kiefling, pers. comm.) (Figure 5.2).

Increasing food production. Although rearing space is the ultimate limiting factor in limiting stream production of our native salmonids, food supply can also limit production by:

(a) limiting production well below carrying capacity;

(b) increasing territory size (section 5.2);

(c) limiting growth so that smolt age is increased.

Supplementary feeding in rearing channels has been discussed in section 2.3, but there are possibilities for enhancing natural food production. Fertilization of streams with inorganic nutrients is generally considered to be impractical (Harris, 1978) due to the quantities of material needed to maintain elevated levels, and the logistic problems of continuous dosing. Two possible ways around this are feeder lake enrichment, and the use of flow-release granules. The former may occur incidentally in British Columbia downstream of lakes receiving enrichment for salmonid enhancement purposes (section 3.3). Lakes are treated weekly by aircraft dropping dissolved nitrates and phosphates throughout the growing season. Slaney (1982) describes an experiment on the Keogh River on Vancouver Island involving inorganic nutrient enrichment. In 1981 small amounts of nutrient were added continuously at four sites in a 1 km stretch. Phosphorus was increased from 0.001 to 0.01 ppm and nitrate from 0.01 to 0.1 ppm. Within weeks increased micro algae growth was apparent and insect larvae flourished. After 10 weeks both juvenile coho and steelhead had doubled in weight, not normally achieved for a year. Since 1982 a slow-release pellet has been employed (nutrient granules coated with soya bean resin). The pellets are dispensed along the length of the stream from a helicopter, and a single application should last for a growing season. In nutrient-poor streams, doubling of salmonid production is predicted.

Enrichment with organic material has been tried experimentally; a current experiment involves the use of soybean and wheat grain added to stream gravel in the Big Qualicum, Vancouver Island (Salmonid Enhancement Program, 1981). This led to a doubling in biomass of benthos.

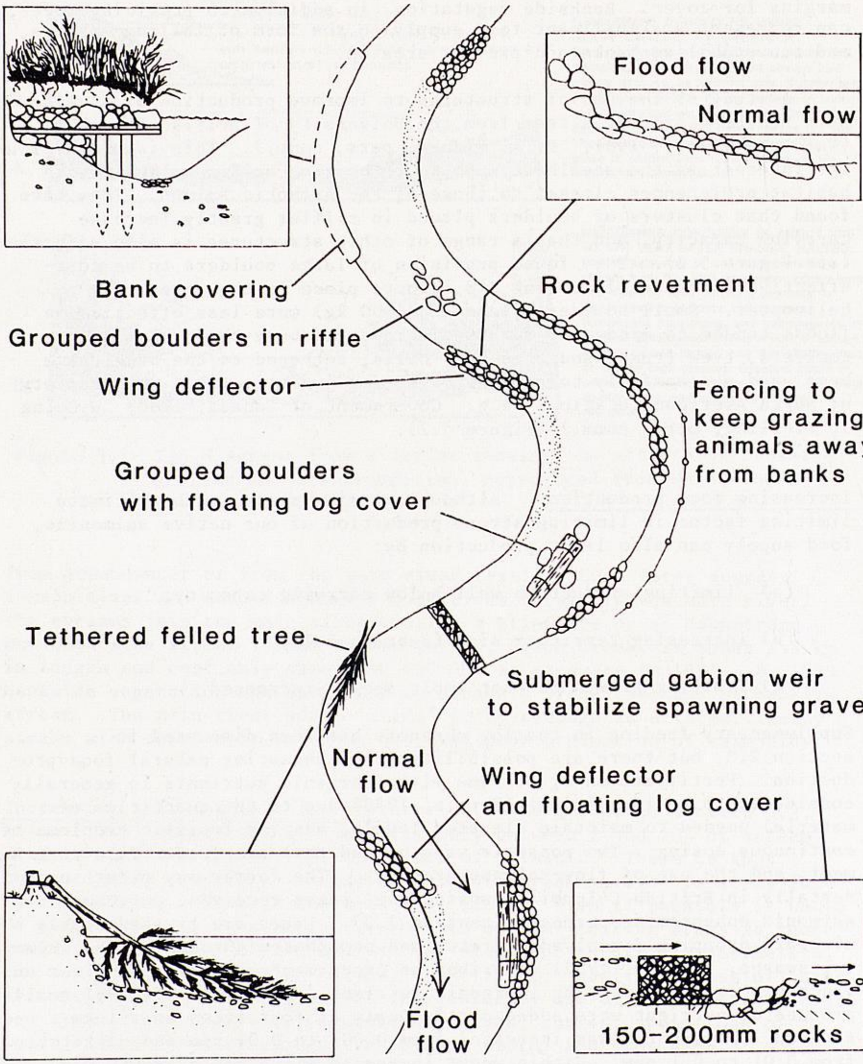

Figure 5.2 Stream structures to improve spawning and rearing habitat, recommended by several studies. Based on White and Brynildson (1967) with additions.

Stream enrichment is likely to be useful only where nutrients are naturally very low, and there may be some objection to its widespread adoption. It is effectively changing the very nature of oligotropic streams and may be resisted on conservation grounds.

6. STOCK MANAGEMENT

6.1 General

A widespread view on the west coast of North America, where stock enhancement practices are being widely developed and utilized, is that one of the most effective techniques is the proper management of spawning escapement. In practical terms this means regulation of exploitation by individual species and individual river and tributary stocks.

6.2 Regulation of commercial fisheries

Most commercial exploitation of Pacific salmonids takes place outside river mouths, and there are thus to an extent mixed-stock fisheries. However, an increasing knowledge of migration patterns and stock characteristics is allowing a degree of separate management. One of the best examples is that of the Fraser River in BC. This system supports vast stocks of pink and sockeye salmon, with smaller but nonetheless valuable stocks of coho, chinook, chum and steelhead. Some of the stocks are greatly enhanced (e.g. for pinks and sockeye by spawning channels, others by hatcheries) while others are naturally maintained. There are marked cycles of abundance, every four years for sockeye and every two years for pinks. The stocks are exploited by fishermen from both Canada and the US as they pass through coastal waters. Stocks fell during the earlier part of the century for various reasons, but have recovered in recent years due to careful management and stock enhancement. Commercial catches of pink and sockeye salmon average over 7 million fish per year. Clearly, the Fraser River salmon represent an extremely valuable, but difficult to manage, resource. Management of the pink and sockeye salmon is the responsibility of the International Pacific Salmon Fisheries Commission, established by Canada and the US in 1937. There is a wide range of complex regulations governing time, place and method of fishing, which are adjusted each year according to the expected abundance of various stocks. In addition, emergency orders are passed to 'trim' exploitation according to a detailed analysis on an almost daily basis. For example, the following emergency orders were among many that were issued in 1982 (International Pacific Salmon Fisheries Commission, 1983):

"<u>30 July</u> In order to secure additional escapement of summer-run sockeye the Commission approved the following regulatory changes: (1) That Area 29 of Canadian Convention Waters open to gill nets and trollers on 3 August for 1 day of fishing. (2) That the scheduled fishing in United States Convention Waters be delayed 1 day for 1 day of fishing in the week commencing August 1.

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

<u>1 September</u> In the interest of protecting delaying Adams River sockeye the Commission approved that Area 7A of US Convention Waters be closed to fishing effective 3.00 pm 1 September.

30 September Due to the declining numbers of sockeye in some areas and the need for harvesting of Adams River and Weaver Creek sockeye, the Commission approved the following regulatory changes.... (3) That Area 29-7 and 9-17 open to gill nets at 7.00 am 4 October for 12 hours fishing."

Fisheries management of this kind requires knowledge of two major factors. The first is the optimal spawning stock size of each stock and sub-stock, as a target for managed escapement. These are fairly well established for pink, chum and sockeye salmon, where the fry migrate away from the spawning stream immediately after emergence, i.e. spawning gravel area is the limiting factor. The second factor is the identity of the commercial catch at any time or place. Species breakdown is straightforward, and stock identification is achieved by use of morphological characteristics including size, stock-specific parasite fauna and from a knowledge of the timing and route of migration of different stocks.

This approach offers an alternative to within-river exploitation as an answer to the mixed-stock fishery problem. In the case of the Fraser River there are two main reasons why this alternative is necessary. First, pink, chum and sockeye salmon are rapidly nearing sexual maturity as they approach the river, and their quality is deteriorating; their capture in non-tidal waters is illegal. Second, there is a binding agreement between Canada and the US that the latter has a right to a proportion of the stock since it contributed to the construction of a series of fish passes at Hells Gate, which reopened much of the spawning grounds following a landslide.

Although such a situation does not exist in the UK, there is much to be learned from the Fraser River in terms of what is possible given knowledge of certain crucial biological factors. We are well short of such a level of knowledge of our own stocks.

6.3 Regulation of sport fisheries

Sport fishing for salmonids is extremely popular in North America, and although there is an abundance of good fishing, some rivers are heavily fished. Anglers' catch is a significant cause of mortality in many areas, and this is regulated in a similar manner to the commercial fisheries. In BC it is illegal to kill pink or chum salmon in non-tidal waters, and there are bag and possession limits for other species. Most rivers have individual regulations and many have separate regulations for different reaches including no-fishing areas and times, bait bans, catch limits and a ban on retention of wild (as opposed to hatchery origin) fish. This last regulation is of interest because it is usually applied to steelhead and thus might be relevant to our native species.

Steelhead stocks throughout the Pacific north-west of North America are depressed due to a combination of heavy fishing pressure (both commercial and sport) and environmental degradation. As they are a highly-prized sport fish considerable efforts are being made to protect and increase stocks by a combination of hatchery production, environmental improvement, and regulation of catch. Rather than limit sport-fishing activity, the Fish and Wildlife Service of the Province of British Columbia introduced a catch and release regulation (Vander Sar, 1982; Obee, 1980). On most rivers, all 'wild' steelhead must be released immediately after capture. All hatchery-produced fish have their adipose fin clipped as a juvenile, and any fish retained by an angler must show a well-healed fin clip. The fish released after capture appear to survive to spawn without problems, and in many rivers it is believed that the immediate effect was to double spawning escapement. On some rivers there has at times been a total catch and release regulation, including hatchery fish. In other situations anglers will often voluntarily release hatchery-origin fish, now that they are convinced of the value of catch-and-release; on the Vedder-Chilliwack River (Fraser catchment) the declared sport catch in 1980/81 was 1 323 wild released, 24 hatchery released, 51 hatchery retained. The annual limit for fish killed per angler has been dropped from 40 to 20 in 1977, to 10 in 1980. Upon purchase of a $6 resident's steelhead licence, an angler is issued with ten catch cards. One must be completed immediately upon killing each fish, and to be in possession of a steelhead without a valid card is an offence. To cover those streams where some retention of wild steelhead is still allowed there are annual limits of 5 wild fish per annum, 2 per calendar month, 1 per day. After the wild release regulation was introduced in 1978, angler fishing effort dropped by 70%, but is now gradually increasing again. Catch rates (as opposed to kill rates) are now the highest recorded.

The catch and release regulation for steelhead is considered as a temporary measure, until stock levels are re-established. The evidence that released sport-caught fish would survive well came from studies in Washington and Oregon, and from BC where such fish were fitted with radio-tags and released. The immediately-apparent efficacy of the regulation vindicates its introduction. Release of 'unclean', coloured salmon in spawning condition is of course practised in the UK by law; is there scope for a wider application of catch and release? In the short term it would be unpopular with anglers, but perhaps it requires only a change of outlook; coarse fishermen are as keen on their sport nowadays as they were when many fish were retained 'for the pot'. If the measure were seen to be as effective as with steelhead most anglers would accept it, particularly as a temporary measure; it would be more acceptable than a total angling ban. An investigation of the likely effectiveness of such a measure would be required before any such regulation was considered.

An interesting variation of the catch and release approach is employed on Yellowstone Lake, Wyoming. Declining numbers of spawning cutthroat trout led to a minimum size limit regulation of 35.6 cm in 1970, but this had little effect in slowing the decline. In 1975, a maximum size limit of 33 cm was introduced, to exploit the compensatory survival pattern of younger age groups and to protect the older fish; the alternative was total catch and release, i.e. no fish to be killed.

A problem with any regulation in the UK governing catch and release, day or season limits or total angling closures lies in the private property nature of the fisheries; in North America, the great majority of fishing is public property. A riparian owner with exclusive rights of several miles of first-class fishing may resent being restricted to an annual catch retention limit at the same level as a member of a club controlling mediocre fishing. The fact remains, however, that on most small salmon rivers in the UK the majority of the catch is taken by relatively few, highly successful, anglers. If it is considered necessary or desirable to limit within-river exploitation, controlling the catch of the successful anglers is likely to be most effective.

6.4 Regulation of sexual development and sex ratio

In several countries there is currently active development of a range of techniques to produce sex-reversed, all-female or all-male, or sterile stocks of fish. The main application for these techniques lies in fish farming, but they also are of some potential value for fish released to the wild. Although much of the active work in this field is being undertaken in the UK, brief consideration is given to research in British Columbia because the results are being applied to the Salmonid Enhancement Program (section 7).

The two techniques of interest both involve the treatment of young fish with male sex hormones (androgens), which in high doses induces sterility, and lower doses, 'all-male' stocks. The first technique has been used by Dr Donaldson and his group from the West Vancouver Laboratory (Donaldson and Hunter, 1982; Hunter et al., 1982) on coho from the Capilano hatchery in Vancouver. Fish produced by this hatchery were returning in numbers greater than could be used for egg production, i.e. there was inadequate exploitation. The stock involved produced among the smallest adults in Canada, just a few pounds in weight, which returned after about 16 months at sea. However, a group which were sterilized by androgen treatment (by immersion of eggs and alevins followed by dietary administration for 3 months) did not mature and thus did not experience the urge to return to the river and hatchery. They remained at sea, growing rapidly because they were longer at sea and were not diverting energy into gonad production, contributing significantly to the sport and commercial fisheries. It is likely that record-sized fish can be regularly produced in this way. Application of this technique does of course depend upon significant fisheries for feeding fish and is thus likely to be of little application in the UK; the East Anglian sea trout fishery is perhaps the only sizeable fishery of this nature.

The second potential technique has not yet been used in enhancement programmes but has some promise. The 'all-male' stocks produced by low-dose androgen treatment contain about 50% sex-reversed, genetically female, functional males. Sex determination in salmonids appears to be on the same basis as humans, i.e. XX female, XY male. When the sex-reversed females, which produce viable sperm, are crossed with normal females, all-female offspring are produced. There is thus scope for manipulating the sex ratio in favour of females to a predetermined extent, where hatchery-reared fish are being used; the normal-female parent can of course be of wild stock origin. The value lies in hatchery-based enhancement programmes, such as that on the Thames, where number of 'local stock' eggs is severely limiting. As one male can be used to fertilize the eggs of at least ten females, the egg-take can be greatly increased by these manipulations. The all-female stocks produced are of course normal fish which have not themselves been hormone-treated. They therefore mature and return to the river normally, unlike the sterile fish discussed above. The potential for this technique is discussed by Donaldson and Hunter (1982).

7. PLANNING, FUNDING, AND EVALUATION

7.1 General

In most situations, enhancement of stocks of anadromous salmonids is not a realistic possibility for individual fishery owners. Normally whole river systems will be involved with all the attendant problems of coordination, funding, regulation of harvest and clashes of interest. These problems, coupled with the doubtful benefit of the rather meagre attempts at enhancement in the past, have effectively precluded most development in the UK. The earlier sections of this report have dealt with technical developments; if we assume for the moment that some of these techniques will work for our species, what can be learned from North America about how to fund, manage and evaluate enhancement programmes? Many of the problems have been faced (but not necessarily overcome) by the Canadian SEP, and a detailed consideration is justified.

7.2 The Salmonid Enhancement Program (SEP) in British Columbia

The SEP was established in 1977 with the aim of doubling stocks of anadromous salmon and trout in BC. This would restore stocks to their historical level of abundance, so the target was considered realistic. Current catches are about 70 000 tonnes, whereas around the turn of the century they were of the order of 150 000 to 175 000 tonnes. Funding is by direct government investment, with full cost recovery the ultimate aim; preliminary benefit:cost analysis suggested that this was realistic, by increased licence fee income and a commercial landing levy. If successful, gross fishing industry revenue could be increased by an estimated $274 million (Canadian at 1976 prices) annually by the year 2007. The increased employment potential would be of the order of 4 million man-days per annum. There would also be benefits to native peoples and remote areas, and to recreation. The Program is in two phases; phase I, with the aim of increasing production by about 24 000 tonnes, was originally intended to be five years but was extended to seven. Detail of phase II would be decided upon evaluation of phase I. Investment in phase I was approximately $157.5 million, of which $150 million was provided by the Federal Government with responsibility for salmon, and $7.5 million by the Provincial Government with responsibility for anadromous trout.

The techniques employed for enhancement are those described in earlier sections, with particularly heavy investment in hatcheries, spawning channels and lake enrichment. These techniques are particularly applicable to pink, chum and sockeye salmon which are predominantly commercial species; the targets in millions of pounds weight for phase I were: sockeye 9, chum 28.9, pink 3.8, coho 2.4, chinook 5.7, steelhead and cutthroat 0.2. A shortfall with pink and chum indicates that the increase actually achieved by phase I will be only about 87% of target, but the production achieved with species of sport interest is above target.

The performance of individual techniques and the programme as a whole are assessed on a five account system:

(a) National income account; all benefits and costs directly measurable in economic terms are handled by this account. Detailed benefit: cost analyses are constructed; the methodology is discussed in section 7.3. The 'balance' in the other accounts, more difficult to quantify in economic terms, is considered when assessing performance.

(b) Regional development; takes account of the value of development in areas away from the metropolitan centres of Vancouver and Victoria.

(c) Employment; assesses the value of job creation.

(d) Native people; assesses importance of development to West Coast Indian communities.

(e) Natural environment; assesses both the possible benefits and adverse impacts of individual developments including changes in stock characteristics, intra- and inter-specific interactions, stock manageability, cultural and educational potential, aesthetic value and naturalness, and recreational opportunities.

The original aims of phase I included a benefit:cost ratio of 1.5:1, and recovery of about 85% of costs (about 15% was considered non-recoverable in the form of social benefits). However, the benefit:cost ratio actually achieved is of the order of 1.3:1, and little progress has been made with cost recovery. A tidal-water sport fishing licence was introduced in 1981, which yielded $1.68 million, of which half was taken up by administration. Up to 1982, no commercial levy had been introduced, but increases in commercial salmon licence fees yielded about $1 million. By March 1982, the SEP expenditure stood at $115 million. In 1982, the Report of the Commission on Pacific Fisheries Policy (the 'Pearse Commission', Pearse, 1982) recommended that the unrecovered costs of phase I be written-off, and that future annual Federal funding be limited to:

(a) half the revenue from tidal-water sport-fishing licences ($2 million);

(b) half the revenue from a levy on commercial landings ($6 million);

(c) revenue from sale of eggs and fish from enhancement facilities ($0.6 million);

(d) an amount equal to the expenditure under phase I that was not intended to be cost-recoverable ($3.2 million).

The expenditure would be of the order of $12 million per annum plus any Provincial contribution; the 1981 (phase I) figure was $26.9 million plus $1.25 million of Provincial funds.

7.3 SEP benefit:cost analysis

All SEP projects are evaluated on a benefit:cost ratio basis under the 'National income account'. The way in which this is done is of interest because it indicates the thoroughness of the evaluation of SEP, and offers some guidelines for a similar approach elsewhere.

The benefits considered are:

(a) Value of commercial fish production, i.e. the wholesale value of the processed products.

(b) Value of recreational fish production measured by consumer surplus generated by Canadians (discussed below) plus increases in tourist expenditure.

(c) Value of native Indian food production.

(d) Value of other purposes, e.g. flood control etc.

The costs are:

(a) Cost of commercial fish development and management including: capital and operating costs of facilities, marginal costs of capture, processing, etc. the extra catch, value of land used and loss of natural resources, e.g. value of forest products foregone, costs of labour.

(b-d) Separable costs associated with recreational fish development, native Indian food production and other purposes along similar lines.

The factor of greatest interest in the UK situation is the benefit value of recreational fish production, and the assumptions used in making the assessment. In 1976, half a million anglers in BC fished on average six days a year, spending of the order of $100 million on products and services directly associated with sport-fishing: this represents about 10% of BC tourism-based expenditure. A survey of 'willingness to pay' for access to fishing indicated a mid-range of $15 per day, indicating a consumer-surplus-based notional rental value of the fishery of $45 million per annum. The assumption is that a doubled potential catch from stock enhancement would double the 'value' of the fishery; is this a valid assumption? It probably is in this case, as tourism in BC is growing at 12.5% per year, and the extra catch could be translated into extra fishing days with a similar catch, i.e. one is catering for an increased number of anglers. Few anglers, however, would be willing to pay more for better fishing. A survey of steelhead anglers reported by Obee (1981) indicates that fishermen on one river, the Thompson, would be willing to pay an average of $12.30 per day for current fishing, but only 40 cents more if their chances of catching fish were doubled. However, most indicated that they would fish more frequently (about 30% extra). Such detailed considerations, it is suggested, are a relatively poor indicator of the true value of a fishery, and a similarly poor basis for a 'cost recovery' exercise. This subject is discussed further in section 7.5

Slaney _et al_. (1980) present an example of SEP benefit/cost analysis, for the stocking of steelhead fry above impassable falls; the technical aspects are described in section 3.2. The example used is for stocking 100 000 m^2 of stream at an optimal density of 0.35 fry/m^2, i.e. 35 000 fry. The following inputs and assumptions were made:

(a) Adults for stripping were captured by angling by paid personnel; this makes the fry relatively expensive at $0.060 but ensures that they are local stock. The above average cost estimate takes account of all hatchery costs to produce 0.3 g fry.

(b) The costs of stocking depend on method used; manual is estimated at $500, by helicopter for inaccessible streams, $820. The total cost for rearing and stocking by hand is thus $2 600, or $0.074 per fry.

(c) The following 'life history' assumptions are made: 50% smolt at age 2, 50% at 3; survival from 1+ to age 2 and 3 smolts is 50% and 40% respectively; smolt to adult survival is 15%; 2 and 3 year adults occur in 3:1 ratio; 10% of fish survive to spawn twice; exploitation in 50%. This indicates an enhanced catch of 412 fish.

(d) A 'willingness to pay' figure of $25 per day was used, but is recognized as being too high. Catch success of 0.13 fish/day from local creel censuses indicates a value of $195 for each captured steelhead.

(e) All benefits and costs are discounted at 10% per annum.

The benefit:cost analysis for hand stocking 0.3 g fry is thus:

Year	0	1	2	3	4	5	6	7
Cost ($)	2 600							
Value of adults caught	0	0	0	0	18 780	24 460	7 040	500

Total cost $2 600   Total benefit $50 780   Benefit:cost = 19.5:1

Equivalent figures for larger fish stocked and for use of the helicopter are:

	0.3 g fry	2.0 g parr
Manual stocking	19.5:1	14.3:1
Helicopter stocking	17.3:1	13.1:1

All the 'assumptions' are based upon locally-made observations. Although the authors recognized that the 'willingness to pay' figure was too high, and subsequent observations suggested that the survival figures were optimistic, new inputs can be simply made and the figures adjusted as better estimates become available.

7.4 Assessing the efficacy of enhancement practices

There is clearly an overwhelming requirement to assess any technique which is used for stock enhancement in terms of success in achieving desired aims. This is necessary not only to allow the choice of optimal methods, but also to conduct continuing benefit/cost analyses and to satisfy all concerned that their money is being well spent and that any incidental effects are acceptable. Definition of success will depend upon one's viewpoint; one of the quickest and most lasting techniques for increasing stocks is likely to be a stop to all exploitation, but that is unlikely to reflect the interest of most people willing to pay for stock enhancement. The 'philosophy' of stock enhancement is discussed in section 7.5, and success here is assumed to be an overall increase in stock abundance which allows a sustained increase in yield to fisheries. It is necessary to not only assess the survival of the fish 'generated' by the enhancement practice, but also the abundance of the whole stock as 'enhanced' production may be at the expense of natural production. There are a number of reasons why natural production could be adversely affected, including 'overloading' stream-carrying capacity (section 5), adverse genetic effects (section 3.4) or diversion of funding enhancement from other fishery management activities. In Oregon, coho population levels have slumped to levels of the early 1960s, after an apparently successful hatchery programme had increased them to a record high in 1976; some fear that hatchery populations have replaced wild ones. There is further the possibility that the enhanced population, although surviving well, are less 'recoverable' by the interested parties than wild stock, e.g. because of less precise homing (section 3.4) or because of the timing of return with respect to the fishing season. It is therefore essential to assess the performance in space and time of the enhanced stocks, and any wild stocks upon which they impinge. The methodology for this is based upon standard fishery science survey techniques and is outside the scope of this report, but mention must be made of one technique which probably more than any other has allowed large-scale evaluation of enhancement practices, that is the coded wire microtag. The system was developed and described by Jefferts et al. (1963) and the current system involved the implantation of small, binary-coded lengths of stainless steel wire into the cartilage of the fish's snout. Standard length tags are 1 mm in length, but half-length tags are available which can be used on unfed salmonid fry. The three variable 'lines' of information (Figure 7.1) allow up to 64 'agency' codes and 4 096 batch codes. The presence of a tag is usually indicated by a fin clip, and the tag detected by a magnetic detector. X-ray-readable tags are available, and Northwest Marine Technology, who produces the tag system, is currently developing an X-ray viewer to remove the requirement for development of a photographic plate. The standard tag system is widely used throughout the Pacific Northwest, and between 1978 and 1982 over 116 million tags were released. Large-scale scanning of adult catches is organized, and the value to stock enhancement evaluation programmes has been tremendous. The work on time and size of release of coho, for example (section 2.4), would have been impossible without this technique. The potential in the Atlantic is also tremendous, and several countries are already using the coded wire tag system manufatured by NW Marine Technology including Scotland, England and Wales, and Eire.

7.5 Justification of stock enhancement (or 'who pays?')

As can be seen from this report, stock enhancement in North America is costly, long-term investment with uncertain returns. Even though the thoroughly administered SEP in BC has largely met its goals in terms of fish production, it is so far well short of its economic aim of full cost recovery. This raises a consideration of the three basic approaches to funding stock enhancement programmes (or indeed any fishery management activity); these are:

1. Government bears the cost of organizing and undertaking all developments, on the basis that it is enhancing a common-property natural resource from which a large proportion of the population will benefit directly or indirectly. For example, commercial salmon fisheries in Washington State contribute upwards of $100 000 000 (US in 1977) to the State economy, and the same stocks provide recreation for several hundred thousand anglers.

2. Government bears the initial cost, but attempts to recover the costs from those who benefit, i.e. 'the user pays'. This is of course the approach taken in the SEP in BC. As with option 1 the whole approach represents an investment on behalf of the population of the State but in this case a more immediate, measurable return is sought.

3. The 'user', or some group representing the user at a very much more local level than government, bears most of the responsibility for organization and cost from the start. Even here, however, some government involvement is usual to establish the framework for such developments, to regulate certain aspects (such as trapping brood-stock) which otherwise might not be authorized and to regulate fisheries such that the investor has a good chance of securing a worthwhile return, and to ensure that there is no adverse impact on other stocks or other interests. A good example is the arrangement developed in Alaska for salmon ranching. The Alaskan Private Salmon Hatchery Act was passed in 1974;

"It is the intent of this Act to authorize the private ownership of salmon hatcheries by qualified non-profit corporations for the purpose of contribution, by artificial means, to the rehabilitation of the state's depleted and depressed salmon fishery. The program shall be operated without adversely affecting natural stocks of fish in the state and under a policy of management which allows reasonable segregation of returning hatchery-reared salmon from naturally occurring stocks."

Among the regulations under this Act several concern fishery managment but also some concerning financial organization:

"Returning adult salmon become the property of the non-profit corporation only after their arrival at a designated location in proximity to the hatchery stream. The state is obligated to manage the common property fishery to provide escapement to the private hatcheries in the same manner it regulates to achieve escapements to streams with wild stocks."

"The non-profit corporations may use funds realized from the sales of fish and eggs to cover reasonable administrative and operational costs, debt retirement and expansion of facilities. Remaining funds shall be expended on fisheries research, salmon rehabilitation projects and other fisheries activities."

Although such operations in Alaska thus have to be 'non-profit', the originators and operators will generally have an interest in the common property fishery which is being enhanced.

The appropriate funding arrangement depends very much upon local conditions, legislation and policy. For example, the first option (government pays) may be considered inappropriate where access to the resource is exclusive or limited, e.g. a river with all angling privately owned. In practice, a combination of two or more of the three approaches is likely to be realistic; in the SEP in Canada, although most costs were considered appropriate for recovery from the users, some, yielding returns in social benefits, were not. Many of the practices used for stream improvements are most realistically funded and executed by local fishery owners as part of a whole catchment or regional programme funded by government. It is felt that further discussion of the policy of funding and organization is not appropriate here, but these matters are clearly of fundamental importance in enhancement programmes. Apart from the SEP relatively little has been written on this matter; some details of arrangements for commercial fishery enhancement will be found in Pearse (1982), Salmonid Enhancement Program (1978) (Canada); Lannan (1980) (Oregon); Donaldson (1980) (Washington); and McNeil (1980) (Alaska).

7.6 Public involvement

Most authorities with a salmonid enhancement programme involving government funding in North America recognize a responsibility towards the public in providing information and access to facilities. Many also recognize the positive value of public participation in terms of support when programmes are reviewed, manpower help, education and avoiding vandalism. Involving young people in enhancement projects is considered particularly important. It involves the industrialists and policy-makers of tomorrow in caring about fishery management during their formative years; some believe this to be one of the major potential achievements of SEP. It is well summed up by the extract from The Salmonid Enhancement Program (1978):

> "Salmonid enhancement presents a unique opportunity for a large untapped source of help from conservation-minded British Columbians to join with their governments in a creative restoration activity. The romantic appeal of salmon draws people into voluntary participation in program planning and active involvement in small stream improvement and protection. Besides this direct input, involvement provides an information and education function that leads to public acceptance of government's goals for fisheries, an understanding of fisheries regulations and an awareness of environmental requirements."

All SEP major projects (hatcheries and spawning channels) are open to the public, free of charge, during normal working hours. Extensive, attractive literature on the details of the individual facility, SEP and the biology of the species involved are also available free of charge. Many sites have permanent display boards and models, and staff are at all times available to provide further information. Extensive car parking facilities are provided, and there are often public toilets and a picnic area. The impression given is that the hatchery is public property and is there for the benefit of the public. Hatcheries in Washington are similarly open to the public, though with rather less information available; nevertheless visitors are made to feel welcome.

In addition, SEP publishes a regular glossy newsletter, "Salmonid", which is circulated free to schools, angling clubs and anyone else on request. This contains reports and articles on SEP facilities, public involvement projects and other relevant matters, well illustrated with colour photographs.

The public involvement projects are generally undertaken on small urban streams by schools, fishing clubs and landowners. Most involve removal of debris and obstructions to migration, and operation of streamside gravel incubators, but also include spawning gravel rehabilitation and provision of in-stream cover. Overall, public participation projects have indicated a 1.9:1 benefit cost ratio, better than the whole SEP average of 1.3:1. In addition, the public relations value has been tremendous.

8. SUMMARY AND CONCLUSIONS

The technique and approaches outlined have proved successful, at least to an extent, with a range of species. The aim of this report is not to be a 'how to do it' manual, but to provide just enough information to stimulate consideration of techniques which might be useful in the UK.

Attempts have been made throughout to suggest how applicable they are to our species and situation, but in most cases trials will be necessary to finally judge their usefulness. Some are obviously very valuable if they prove to be effective, while others may only be useful in limited circumstances. It is possible to rank some of the developments taking account of this, and of the stated 'preference' given in this study for improvements to 'natural' propagation rather than hatchery-based enhancement.

(a) <u>Likely to be of widespread applicability</u>

Matrix incubators (hatcheries and streamside) (2.2)
Rearing channels (2.3)
Stocking unused streams (3.2)
Use of side-channels (5.3)
Rearing habitat improvement (5.3)
Regulation of commercial fisheries (6.2)
Regulation of sport fisheries (6.3)

(b) <u>Likely to be valid but less widely applicable</u>

Stocking lakes (3.3)
Gravel improvement for spawning (4.3)

(c) <u>Of possible applicability in some situations</u>

Stream enrichment (5.3)
Lake enrichment (3.3)
Genetic manipulations (6.4)

Investigations which would appear desirable for evaluation of many of these techniques are:

(a) study of the 'ideal' stream environment and evaluation of techniques to create improvements to increase river-carrying capacity;

(b) investigation of the use of matrix incubators and consideration of the 'fitness' of the fry so produced;

(c) study of the influence of size and time of release of hatchery-reared smolts;

(d) investigation of the effectiveness of semi-natural rearing channels in hatcheries.

These considerations cover the technical aspects of stock enhancement; the organizational and financial strategies pose equal, if not greater, uncertainties. It is suggested that this whole area warrants thorough consideration. It is possible that any attempts at stock enhancement on a significant scale will be thwarted by insurmountable problems of organization, but hopefully an optimistic, but realistic, consideration of all factors involved would suggest a workable system. An independent inquiry, along the lines of the Pearse Commission (Pearse, 1982) in Canada, with all interested parties invited to make submissions, recommends itself.

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