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Restoration of Riverine Fisheries Habitats

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EXECUTIVE SUMMARY

TO BE ADDED

A. LITERATURE REVIEW

1. INTRODUCTION

1.1 SCOPE OF THE REVIEW

1.1.1 General

This literature review concerns the physical restoration of riverine fisheries habitats and includes information on the habitat requirements of salmon, trout and coarse fish, and methods of evaluating the success of restoration schemes. Many papers are non-specific and deal with general principles of habitat restoration and evaluation, but where possible the information on salmon, trout and coarse fish is given separately.

1.1.2 Source of references

The majority of references listed in the Bibliography were obtained from a computerised literature search on restoration schemes and procedures in the U.K., Europe and North America. References were obtained from the Aquatic Sciences and Fisheries Abstracts 1979-1990, and from the Freshwater Biological Association's current awareness files 1970-1991. A database containing 250 records was compiled to include all relevant items from these searches, together with previously known references. Inter-library loans were obtained for references not held at the Freshwater Biological Association's library at The Ferry House. Further examination of the material in the database showed that some items were not relevant to this project, but revealed other references that are of relevance. The latter group are included in the Bibliography, which contains a total of 249 items.

1.1.3 Details of the Reference Material

The Project Schedule (Strategy: Method 4) envisaged that much of the North American literature would be of limited value for this review. Nevertheless, restoration work in North America has a long history, especially with respect to salmonid fishes, and papers on this subject dominate the Bibliography. Some papers (not only from North America), though they deal with aspects of physical restoration, are primarily concerned with improvements in water quality or the opening up of new areas to salmonids by the provision of fish passes. In such papers, restoration includes provision of artificial spawning channels and/or stocking from hatcheries. Information on these aspects is not included in this review.

There were very few papers from any source on the restoration of coarse fish habitats. This may be because coarse fish habitats are less in need of restoration, but a conclusion from Section I of the Questionnaire is that, overall, coarse fish rivers in the NRA Regions are in greater need of restoration work than are salmonid rivers.

As an indication of the level of restoration activity in the U.S.A., in 1984 approximately 1.5 million U.S. dollars were spent by state agencies to construct and install freshwater structures. These comprised 44,643 structures on 1582 water bodies, including 427 coldwater (salmonid) streams and 45 warmwater (coarse fish) streams (Seaman and Sprague, 1991).

A breakdown of the Bibliography into various categories (Table 1) indicates the principal source of most of the information.
The 'General' category contains papers on habitat restoration and techniques of evaluation. 'Salmon' refers to Atlantic and Pacific salmon species, and 'trout' refers to anadromous and non-anadromous trout. 'Salmonid' refers to papers in which these two groups of salmonids are not distinguished. 'Coarse' refers to any non-salmonid species.

Table 1. Separation of the 249 items listed in the Bibliography according to fish category and country/continent of study.

	U.K.	Europe	North America	Totals
Salmon	11	4	15	30
Trout	7	6	48	61
Salmonid	12	3	12	27
Coarse	24	11	9	44
General	17	5	65	87
Totals	71	29	149	249

2. HABITAT REQUIREMENTS

2.1 GENERAL

The potential for physical restoration of riverine fisheries habitats in England and Wales is very high. Brookes et al. (1983) reported percentages of channelized river in the 10 NRA Regions ranging from 41% in the London area and 33.7% in Severn-Trent and Yorkshire, to 12.3% in the Northwest and Thames Authority areas. Overall, they estimated that 24 % of main river had been channelized.

An underlying assumption of much restoration work is that cost/effectiveness can be achieved by improvement to the habitat and then 'letting the fish do the rest' (Solomon, 1983; Le Cren, 1984). Although much can be achieved on this basis, restoration will be more effective if the habitat requirements of the target species are incorporated at the project design stage. Restoration work can then be carried out so as to change those features of the physical environment that limit the production of the target species. There is considerably more information on this topic for salmon and trout than there is for the many species of coarse fish.

As early as 1932, Hubbs et al. stated that the effective improvement of trout waters rests on two fundamentals: to know the habitat requirements of the fish, and to determine the factors that limit their abundance. This basic idea of relieving the bottleneck(s) in the life cycle of the target species is pertinent to the restoration of all types of fishery.

Many authors emphasize the importance of planning restoration on a catchment basis, rather than through separate small scale projects, and details of these papers are given later. Such large-scale planning requires an interdisciplinary approach, and this is increasingly the practice in the U.K., as is exemplified for the River Thames catchment by Gardiner (1988). However, here the distinction needs to be made between *restoration* of damaged riverine habitat, and the *mitigation* of proposed engineering works at the planning stage by consideration of environmental factors, including fishery requirements.

An important difference between salmonid fish and coarse fish restoration projects was emphasised by Lyons and Courtney (1990), and is particularly appropriate to the U.K. Coarse fish species usually occupy larger rivers than salmonid species, a fact that has two important practical implications for restoration projects. Firstly, habitat restoration measures on the larger coarse fish rivers are usually on a much greater scale than those on salmonid streams, with attendant increases in practical difficulties and costs. Secondly, coarse fish habitats are more often exploited for a variety of water uses, including water sports and navigation, whose demands must also be incorporated into any restoration scheme.

The following sections summarise the habitat requirements of salmonids in general, and specific requirements of trout and salmon.

2.2 SALMONID HABITAT REQUIREMENTS

There are different degrees of spatial segregation (Le Cren, 1984) and temporal segregation (Heggberget, 1988) in the spawning of salmon and trout, but overlaps do occur and, on occasion, hybrid parr have been found (e.g. Solomon and Child, 1978). The information that follows is derived largely from studies of habitat requirements for salmon and trout separately. However, it should be noted that these preferences may change when salmon and trout live sympatrically, as has been noted in the phenomenon of 'interactive segregation' (Nilsson, 1967). Kennedy (1981) describes inter-relationships between juvenile trout and salmon observed in the River Bush, Northern Ireland.

Solomon (1983) claimed that habitat needs for trout are less defined than those for salmon because the trout species is more plastic in its behaviour. He suggests that it is not so dependent upon fast-flowing water as is the salmon, though access to suitable cover is important.

In the sections that follow, brief details are given of the habitat requirements (excluding water temperature) of salmonids in general, and trout and salmon in particular. Further information can be obtained from the references listed at the end of each category.

2.2.1 Salmonid spawning requirements

a) Gravel size: median diameter of 20-30 mm. Spawning (riffle) areas of non-compacted, stable, permeable gravel with little sediment deposition.
b) Water velocity (at 0.6 depth): >15 cm s^{-1}, or <2 female body lengths s^{-1}.
c) Gravel depth: ideally 0.4-0.5 female body lengths, but shallower gravel may be

suitable, depending on the pattern of intragravel flow.

d) Water depth: ideally > female body depth (or 0.2 female body lengths).

e) Absence of barriers to upstream migration of adults to spawning grounds. This is important even for non-anadromous brown trout, because some of these fish also move upstream to headwaters in order to spawn.

References: Peterson (1978), Gonczi, A.P. quoted by Crisp <u>et al.</u> (1984), Crisp and Carling (1989).

2.2.2 Fry/juvenile (parr) requirements

a) Diversity of pool:riffle habitat that provides cover close to the spawning area.

b) Diversity of substrata, from gravel to boulders, to provide cover for the fish and habitats for fish food organisms.

c) Bank side cover (overhanging trees and/or undercut banks) to provide fish cover and habitats for fish food organisms).

d) Low to moderate stream gradient and flow velocities (see sections 2.3 and 2.4 for specific requirements for trout and salmon). Experimental evidence indicates that there is no critical stage in young salmonids when they are more susceptible to downstream dispersal. Thus, they do not respond passively to different flow velocities, but rather they respond positively to particular flows.

References: Lindroth (1955), Kalleberg (1958), Jones (1975), Kennedy (1981), Crisp (1991), Crisp and Hurley (1991 a,b).

2.3 TROUT HABITAT REQUIREMENTS

a) Spawing gravel: Higher (83-96 %) survival to emergence when % sand <10 (when gravel contains 40 % sand, survival is down to 4 %)
Gravel size: 33 % survival to emergence at mean size of 1.5 mm, but 80-90 % survival at 9.6 and 32 mm diameter. Premature emergence of fry at small gravel sizes (1.5 and 4.8 mm), but not > 9.6 mm.

b) 0+ trout: Preference for flow velocities < 25-30 cm s^{-1};
Preference for shallow riffle habitats.
Low rate of dispersal of post-alevins at 25 cm s^{-1} but increasingly higher rate in flows > 25 cm s^{-1}
Need to have suitable cover within 90 cm.

c) 1+ trout: Generally prefer flow velocities > 30 cm s^{-1} and depths > 30 cm.
Need to have cover within 300 cm.

References: Bohlin (1977), Egglishaw and Shackley (1982), Olsson and Persson (1986, 1988), Heggenes and Traaen (1988 a,b), Belaud <u>et al.</u> (1989), Lambert and Hanson (1989), Crisp (1989, 1991), Crisp and Hurley (1991 a,b), Kondolf (in press).

2.4 SALMON HABITAT REQUIREMENTS

a) Emerging salmon fry: high rate of downstream dispersal at 7.5 cm s^1, lower dispersal rate at 25 - 70 cm s^{-1}. Probably tend to avoid these high and low velocities.

b) 0+ salmon: Generally prefer velocities of 50 - 65 cm s^{-1} (i.e. salmon are adapted to tolerate faster flow velocities than 0+ trout because of their larger pectoral fins). Parr < 7 cm prefer 10 - 15 cm deep riffles, substratum of 1.6 - 6.4 cm pebbles. Larger parr prefer depths > 30 cm and boulders > 25.6 cm diameter.

References: Lindroth (1955), Symons and Heland (1978), Solomon (1983), Kennedy (1984), Bley (1987), Crisp (1991), Crisp and Hurley (1991 a,b), Heggenes and Borgstrom (1991).

2.5 COARSE FISH HABITAT REQUIREMENTS

2.5.1 General

In comparison with our knowledge of salmonid habitat requirements reviewed in the preceding sections, very little is known of the requirements of coarse fish (see Copp, in press). Consequently, this section will be confined to a very general overview.

In the sections that follow, details are given of spawning and fry/juvenile habitat requirements. Information is not presented for adults because of the lack of detailed studies and the fact that such stages have the least demanding habitat requirements. Given suitable water quality conditions, coarse fish adults can survive in a range of physical habitats. Exceptions to this general rule do occur, for example the requirement for physical cover of chub (Leuciscus cephalus) (Swales & O'Hara, 1983), but it is probable that habitat-related bottlenecks to successful population recruitment and abundance largely involve spawning and nursery grounds.

Given the number of coarse fish species and the paucity of species-specific information, the following sections are structured not by species but by the classification of reproductive groups proposed by Balon (1975) and amended by Balon (1981). While some of these groups do not have representatives in U.K. rivers, this classification has been widely adopted and was used, for example, in a recent review of European cyprinids by Mills (1991).

2.5.2 Spawning requirements

Most U.K. riverine coarse fish fall into Balon's ethological section of Nonguarders (Section A of Balon's classification) and ethological group of open substratum spawners (A.1). Within this group, there are several guilds defined by the type of spawning substratum utilised.

Lithophils (A.1.3) are rock and gravel spawners with benthic larvae. The early-hatching embryo is photophobic, has moderately developed respiratory structures and hides under stones. U.K. riverine coarse fish species include dace (Leuciscus leuciscus), barbel (Barbus barbus) and chub.

Phytolithophils (A.1.4) are non-obligatory plant spawners. Adhesive eggs are laid on submerged items, preferably aquatic macrophytes, although other substrata may be used in their absence. The late-hatching embryo is photophobic and has moderately developed respiratory structures. U.K. riverine coarse fish species include bleak (Alburnus alburnus), common bream (Abramis brama), perch (Perca fluviatilis), roach (Rutilus rutilus) and ruffe (Gymnocephalus cernuus).

Phytophils (A.1.5) are obligatory plant spawners. Adhesive eggs are laid on submerged live or dead macrophytes. The late-hatching embryo is not photophobic and has extremely well developed respiratory structures. U.K. riverine coarse fish species include common carp (Cyprinus carpio), rudd (Scardinius erythrophthalmus), silver bream (Blicca bjoerkna), tench (Tinca tinca), pike (Esox lucius) and spined loach (Cobitis taenia).

Psammophils (A.1.6) are sand spawners. Adhesive eggs are laid in running water on sand or fine roots over sand. The embryo is photophobic and has poorly developed respiratory structures. U.K. riverine coarse fish species include gudgeon (Gobio gobio) and stone loach (Noemacheilus barbatulus).

One other U.K. riverine coarse fish species, the grayling (Thymallus thymallus), falls along with our native salmonids into Balon's ethological section of Nonguarders, ethological group of brood hiders (A.2). Within this group, these species are classified as lithophils (A.2.3), or rock and gravel spawners. Eggs are buried in gravel depressions (redds) or in rock interstices. The early-hatching embryo is photophobic.

Several other U.K. riverine coarse fish species are classified as Guarders, ethological group of nest spawners (B.2), although only one, the zander (Stizostedion lucioperca), is of fisheries importance.

Ariadnophils (B.2.4) are glue-making nesters. The male guards eggs deposited in a nest bound together by a viscid thread spun from a kidney secretion. Eggs and embryos are ventilated by the male despite the embryos having well developed respiratory structures. U.K. riverine coarse fish species include three spined and ten spined sticklebacks (Gasterosteus aculeatus and Pungitius pungitius).

Phytophils (B.2.5) are plant material nesters. Adhesive eggs are attached to plants and the subsequent embryos hang on to plants by cement glands. Embryos are ventilated by parents despite having well developed respiratory structures. The only U.K. riverine coarse fish species is the zander.

Speleophils (B.2.7) are hole nesters. Eggs are laid in burrows. The embryos have well developed respiratory structures. The only U.K. riverine coarse fish species is the bullhead (Cottus gobio).

2.5.3 Fry/juvenile requirements

The habitat requirements of fry/juvenile U.K. riverine coarse fish species have been little studied, partly because of the lack of universal identification keys and quantitative sampling methodology (for cyprinids see review by Mills, 1991). While advances have been made in recent years with respect to both identification keys (Mooij, 1989) and electrofishing techniques (Copp, 1989) for the larvae of some species and habitats respectively, the field is in need of considerably more attention.

Water flow rates as such are outside the remit of this review, but it is clear that currents are a major factor in the ecology of young coarse fish. In his review of cyprinids, Mills (1991) noted that, in the River Frome, newly-hatched dace larvae can swim at only c. 17 mm s^{-1} and therefore they congregate in nursery areas where the current speed is below 20 mm s^{-1}. In the River Hull, 50% of 7.5 mm roach larvae could hold station against a current speed of 69 mm s^{-1}, but again in their natural habitat they chose to hold station among macrophytes where the current was below 20 mm s^{-1} (Lightfoot,1979).

A more recent and extensive study of the habitats of larval and 0+ roach has shown the importance of other environmental factors in addition to river currents in determining microhabitat use. In a study of the flood plain of the Upper River Rhone in France, Copp (1990) found that the microhabitat use of young roach was characterised by two transitions. Initially, little selection was shown by the relatively immobile larvae, which attached themselves to vegetation by adhesive glands and thus stayed largely in the spawning habitat. However, with the development of their sensory and motor capabilities, the larvae actively selected microhabitats in association with ligneous debris, vegetation, lentic waters and shallow depths. The second transition occurred at the juvenile stage, when the roach ceased their association with vegetation and ligneous debris and became significantly associated with water depths of 0.2 to 0.5 m.

In a later paper, Copp (1992) expanded his analysis to cover the microhabitat use of a range of young cyprinids in the Upper Rhone floodplain. In terms of microhabitat use, three groups of species could be identified: (a) chub and bleak, which used similar microhabitat during both larval and juvenile development; (b) roach, dace, and nase (Chondrostoma nasus), which used different microhabitats as larvae but whose microhabitat overlapped markedly as juveniles; (c) gudgeon, whose juvenile microhabitat overlapped slightly with those of other juveniles (no data were available on larvae).

Young and older chub and bleak larvae preferred lentic waters of between 0.2 and 0.5 m depth over silted gravel, with macrophytes and some ligneous debris. Young dace larvae inhabited a range of water depths and demonstrated a preference for macrophytes and attached periphyton, but avoided ligneous debris. In contrast, young roach larvae preferred depths of 0.5 to 1.0 m, with dense debris and/or macrophytes. As older larvae, roach moved into the moderately deep water (0.2 to 0.5 m depth) preferred by dace larvae. Juvenile gudgeon preferred areas of weak banks with currents and no macrophytes.

Copp (op. cit.) noted that, with the exception of gudgeon, after completion of juvenile metamorphosis all species showed a highly spatial overlap for lentic shallow waters. In addition, and again with the exception of gudgeon, all species showed associations with macrophytes in at least one stage of their development.

Copp followed his Rhone studies with a survey of the microhabitat use of 0+ juvenile fishes in the River Great Ouse catchment (Copp, in press). Although the young of 24 coarse fish species were encountered, only 10 were taken in at least 3% of the point samples that contained fish (many of the point samples had a zero catch). Copp considered that the paucity of plant-spawning species, including tench, rudd, silver and common bream (although Balon, 1981 classified common bream as a non-obligatory plant spawner) indicated a lack of backwater biotopes within the catchment. A similar shortage of lotic channel habitat was suggested by the restricted distribution of bleak and the absence of young barbel.

For the species that were present in significant numbers, canonical correspondence analysis revealed two gradients along which the 0+ fishes were distributed. Along the major gradient, the predominant variables for predicting microhabitat use were water depth, channel width and shape, substrate particle size, and water temperature. Along the secondary gradient, the predominant variables were water current, water conductivity, and the abundance of filamentous algae.

Stream/river habitats characterised by shallow depth, narrow width, low water temperature, the presence of riffles and runs, elevated water currents and large substrate particle size were preferred by young dace, minnow (Phoxinus phoxinus), stone loach, bullhead, three spined and ten spined sticklebacks. Relatively deeper, wider and sinuous channels, with slow to moderate currents and medium particle-sized substrata, were preferred by young chub and gudgeon. Even deeper, wider, slower-flowing (or lentic), silted, trapezoidal (regulated) channels contained the progeny of roach and perch.

Finally, for the later juvenile and young adult stages of coarse fish, physical structure has been demonstrated to have species-specific effects on feeding behaviour (Winfield, 1986; Diehl, 1988). Young common bream and roach are more efficient at feeding on prey in open water, while the converse is true for perch and rudd. It is likely that such effects will influence competitive interactions between species, with consequences for their habitat use and, ultimately, community composition.

NOTE: The values given in the above sections (salmonids and coarse fish) should be used for guidance, rather than absolute requirements. Many studies have shown between-site and between-season differences in habitat usage. Habitat *diversity* is essential to provide a range of niches in conditions of fluctuating discharge, temperature and food supply, and to accommodate changes in habitat preferences as the fish grow in size. This requirement is particularly important for coarse fish populations.

3. HABITAT RESTORATION

3.1 GENERAL

The underlying tenet of river restoration protocols is that by careful planning before modifications take place, a design simulating the natural situation as closely as possible can be developed that not only alleviates the problem, but also preserves those valuable habitat characteristics that already exist.

For the design of any restoration project, many authors (e.g. Hubbs et al., 1932; Cairns, 1990) state that the target fish species (there could be more than one species) must be specified, and the factors limiting their population clearly defined. The limitation could be in terms of growth, numbers (mortality) , spawning - or more than one of these variables. In this way, the aims of the particular restoration work can be clearly defined before work commences.

3.2 RESTORATION OF SALMONID HABITATS

3.2.1 Background

There is a considerable body of information on the physical restoration and/or improvement of salmonid habitats in streams and rivers, mostly based on North American experiences. Gould (1982) notes that freshwater enhancement of anadromous salmonids in North America has been practised since the late 1800's. Much of this information is summarised in the form of reviews or handbooks, e.g. Parkinson and Slaney (1975), Maughan et al. (1978), Finnigan et al. (1980), Gore (1985), Miller et al. (1986), Hunt (1988), Hunter (1991).

It is apparent, from the North American examples especially, that the utility of the various improvement devices is dependent upon their proper placement and an assessment of their limiting factors. As each stream has a unique combination of physical, chemical and biological characteristics, stream improvements need to be performed on a site-specific basis.

In considering the lessons that can be learnt from North America, Le Cren (1984) noted the agreement between participants at a U.K. workshop on the enhancement of salmonid stocks that ".... in Britain, the financial, legal and technical restraints on most fishery organisations would, at present, preclude most of the more elaborate practices".

There are four basic components of salmonid habitat:

a) acceptable water quality
b) food-producing areas
c) spawning areas
d) rearing areas (cover).

The ratios of these components in a particular stream depends upon the stream's physical, chemical and hydraulic characteristics. Discussion of water quality is outside the terms of reference of this review, but it is obvious that physical restoration is useless if water quality is inadequate. In response to the Questionnaire sent to the NRA Regions, Yorkshire NRA distinguish between those sections of their rivers that could be improved immediately by physical restoration work, and those sections that first require improvement to water quality before such restoration work would be beneficial.

3.2.2 Planning

3.2.2.1 General

To be effective, the whole planning phase of a restoration programme should be based on detailed physical, chemical and biological surveys of the catchment (paper by K.F.Whelan in Mills, 1991). As Whelan emphasizes, this is because accurate evaluation of each phase of the project will be beneficial to future projects as well as to the current one. The migration of anadromous trout and salmon, and even the less extensive within-river movements of non-anadromous trout, means that restoration work to improve their riverine habitats must be planned on a catchment basis.

Solomon (1983) notes that, in many situations, enhancement of anadromous populations is not a sensible option for individual fishery owners, but that such work needs to cover whole river systems, in association with attendant problems of funding, regulation of harvest and conflicts with other interests.

General principles covering planning and management options are detailed by Rundquist et al. (1986) and Cairns (1990) and are equally applicable to salmonid and coarse fish populations. Rundquist et al. (op. cit.) note that selection criteria for habitat features include consideration of the aims of the project, the habitat requirements of the evaluation species and the physical constraints imposed on the features. Cairns (op. cit.) gives a check list of 22 questions to be addressed prior to the commencement of any restoration work. These are divided into four categories:

a. What is the aim of the restoration (e.g. should this be to return to the original condition; is adequate information available about the original condition available etc) ?

b. Which environmental attributes need to be rehabilitated ?

c. What are the environmental specifications for an alternative ecosystem ?

d. Would natural processes lead to rehabilitation more effectively ?

Cresswell (1989) discusses management strategy with respect to trout populations in Wales, without giving specific project procedures. From North America, Lee and Lawrence (1986) emphasize the need to learn from each restoration project, which means that the project must be designed carefully with specific aims, and the design should include monitoring of the effects (e.g. a before-and-after study). Full documentation of procedures and of results is, clearly, essential.

3.2.2.2 Initial recognition of the problem

The need for restoration work in salmonid rivers can be first indicated from declines in angler harvest that can be demonstrated to be more severe than would be expected from normal year-by-year variations, or from the results of routine surveys by the N.R.A. Many salmonid fishery managers keep careful records of anglers' catches, both for their own use and because of the requirement to give details each year to the N.R.A. Such information, for example, allowed changes in angler harvest and catch composition over 70 years to be investigated for the River Wye salmon (Gee and Milner, 1980). Also, details of local catch statistics obtained via a questionnaire on the performance of brown trout fisheries led Giles (1989) to conclude that many populations of wild brown trout in Britain had declined.

In recent years, the use of automatic resistivity counters to count the upstream movement of adult salmon and sea trout has increased the quantitative accuracy of salmonid population assessment. It has also been used to check the accuracy of rod catch data (Beaumont et al.,1991).

Routine monitoring programmes to provide baseline information on the status of juvenile fish stocks in Wales started in 1985 (Cresswell, 1989). This initially comprised over 350 quantitative or semi-quantitative surveys each year. In this region most recruitment is natural, but this may not be the case in some other areas.

In some instances it is only the proposal to carry out river channel works that has aroused interest about the likely effects on salmonid fish populations, as in the River Camowen, Northern Ireland (Kennedy et al. (1983).

In North America, many publications result from design studies that have examined in detail the effects of an anthropogenic disturbance and have made recommendations for mitigation and future protection of the fishery, e.g. Fraley et al. (1989), who examined the effect of a hydropower development on fish populations in the Columbia River, Montana. Unfortunately, most studies suffered from a lack of baseline information about the fish stocks.

3.2.2.3 Specificity of the restoration

Increase in habitat diversity has been the underlying theme of most salmonid stream restoration work. The work by Hunt (1971, 1976) on Lawrence Creek, Wisconsin, in which increase in cover and in the frequency of pool:riffle sequences produced an increase in the standing crop of brook trout, Salvelinus fontinalis, provided the stimulus for more recent restorations of trout and salmon habitats.

3.2.2.4 Scale of the restoration

Although planning on a catchment basis is recommended for most restoration work (e.g. Lyons and Courtney, 1990), most salmonid references in the Bibliography describe localized schemes. Many of these have clearly led to improvements in the local populations in numbers of fish or improved spawning or rearing habitat. However, the problem in assessing the results is to separate the short-term redistribution of fish within the stream from long-term changes in overall stock size. No studies reported in the literature have been sufficiently wide-reaching or long-term to address these aspects adequately.

3.2.3 Methodology

3.2.3.1 General

Most of the techniques used to restore salmonid habitats seek to increase habitat diversity (especially the frequency of pool:riffle sequences) in order to create habitats for the different salmonid life stages. Thus, it is important to know the habitat requirements of these stages at the design stage of a restoration project. It is also essential to know the limiting factors for the salmonid populations in the target stream, so that the restoration project can be tailored accordingly.

3.2.3.2 Instream Structures

Instream structures have been widely used to increase habitat diversity through alterations to flow, channel morphology, substratum composition and cover. Gore (1985) and Brookes (1988) both give useful reviews of the techniques available, and several North American publications give extensive details (e.g. Parkinson and Slaney, 1975; Finnigan et al., 1980; Hunt, 1988). These techniques include low level dams or weirs, gabions, current deflectors, boulder placements and bankside cover. Most depend on the availability of local materials, so they may be constructed from logs, brushwood, stones, boulders or artificial materials - or a combination of materials.

Ehlers (1956) evaluated the survival of a variety of devices 18 years after they had been installed in the Kaweah River,

California, which is subject to summer and winter spates. Only 10 of 41 improvement structures remained in operation after this period. Loose rock dams were not effective for any length of time and needed constant maintenance, whereas log dams and current deflectors well secured to the bank survived extremely well, especially if willows or other rooted vegetation grew at their ends. Hunt (1985) evaluated 45 stream habitat developments in Wisconsin trout streams, and concluded that bank covers and current deflectors were the most successful devices for increasing trout standing stocks.

In North America, electrofishing surveys showed that populations of brown trout were increased over seven years in three South Dakota streams by, respectively, 94 %, 404 % and 214 % following installation of wing (current) defectors, random boulders and bank 'riprap' (Glover, 1986).

In Sweden, the insertion of boulder dams and log deflectors increased trout densities by 200 % and biomass by 400 %, whereas boulder groups and deflectors made of boulders had no effect. The rise in biomass was attributed to an increase in the densities and survival of older fish (Naslund, 1987).

In Denmark, Hermansen and Krog (1985), in attempts to rehabilitate spawning beds, found that stream deflectors did not function in streams with a slope less than 1:4000, or in streams with a high sediment load.

The installation of rubble mats proved effective in increasing the local population densities of trout and salmon parr in the River Boyne, Ireland (O;Grady et al. in Mills 1991), presumably by immigration from adjacent areas of the river.

3.2.3.3. Substratum restoration

The restoration of the gravel substratum to improve spawning habitat is much more common in North America than in the U.K. (e.g. White and Brynildson, 1967; Hall and Baker, 1982). Expensive mechanical riffle sifting machines, which use a water jet to flush out fine materials are not uncommon (Mih, 1978; Mih and Bailey, 1981). Hall and Baker (1982) reduced the concentration of fine particles (less than 0.84 mm) in gravel from 18 % to 10 % using a bulldozer, which resulted in a substantial increase in fry survival (*Oncorhynchus* sp.).

Solomon (1983) noted that the scope for gravel restoration in the UK is limited but significant. He suggested that it was best done where an advantageous cost/benefit ratio can be achieved and the improvements persist (e.g. not where compaction or siltation can re-occur soon after the restoration).

In the U.K., Solomon and Templeton (1976) observed that the most consistently used area for spawning in the Candover Brook, a southern chalk stream, and the area showing the highest densities of trout fry, was a section ploughed each year to prevent weed growth. This process considerably alleviated the problem of gravel compaction and concretion that resulted from the high calcium level and relatively stable flow regime of the stream. Similarly, removal of *Ranunculus* and loosening of gravel by hand raking led to an increase in numbers of spawning trout in the River Avon, Hampshire (Kemp, 1986).

3.2.3.4 Channel restoration

Substratum restoration and installation of instream structures, described above, can lead to noticeable changes to stream channels. Thus, in North America, Hunt (1976) made substantial changes to the meandering and pool:riffle sequence of Lawrence Creek, with pronounced increases in brook trout production.

Spotts (1986) describes the relocation of 990 m of brown trout stream as a result of road construction. Opportunity was taken to narrow the channel and thus increase flow velocity, and to install various instream devices. In the first five years the brown trout biomass increased from 6.1 kg ha^{-1} to 64.1 kg ha^{-1}. In 1986, some the instream devices were still functioning and the trout biomass was still significantly higher than before the relocation of the channel. Changes to the population densities of several non-salmonid species were also recorded.

In contrast to these schemes, no major channel restoration projects for salmonid streams are recorded in the U.K. and European literature.

3.2.4 Evaluation

3.2.4.1 General

In a review of publication of restoration projects in North America, Hall and Baker (1982) observed that their task had been made difficult by the scarcity of written information about past work, and the lack of an accurate assessment of their outcome. They suggested that this was due, in part, to editorial decisions against publication of inconclusive or unfavourable results. Examination of the North American literature 10 years later leads one to the same conclusion, though there are some exceptions.

The assessment of riverine habitat improvement schemes can be carried out either by lengthy before-and-after studies on the impacted stream, or through lengthy comparison of the target stream with a similar one that already supports a large natural population of the desired species (Cooper, 1972). The vast majority of examples in the literature are of the first of these two options. Tarzwell (1938) gives one of the few examples of evaluating stream improvement by comparison with an unaltered stream.

3.2.4.2 Fish populations

Assessment of the stocks of stream salmonids has entailed electrofishing surveys, traps, the use of resistivity counters or examination of angler catch returns. Kennedy et al., (1983) carried out electrofishing surveys over 11 years to determine the effects of a land drainage scheme in Northern Ireland. Though no direct restoration work was carried out, the authors suggested that the long-term recovery in standing crops of salmon and trout that they observed probably resulted from an increase in cover and current deflectors through dislodging into the river of anti-scour ‘rip-rap’ from the outside of bends.

Electrofishing surveys can be time consuming and labour intensive. To alleviate this problem, Kennedy and Crozier (in Mills, 1991), working on the River Bush, Northern Ireland, found that the catch of salmon fry in a five minute period provided an accurate index of abundance. They were able to use this to pin point areas that in the river that needed attention, either in terms of pollution or for physical restoration.

Assessment of adult stocks, especially of salmon, using electronic (resistivity) counters (Mann et al. 1983; Beaumont et al., 1991) is becoming more frequent in U.K. rivers. As noted by Kennedy and Crozier (in Mills 1991), the counters are less expensive and cheaper to maintain than traps, though the structures (usually weirs) on which they are mounted are expensive. They also emphasize that choice of site is critical, though no details are given.

Assessment of numbers of adult salmon from redd counts is an option for spate free rivers, in which redds can be identified up to four months after spawning (Fox, 1981). However, many U.K. salmonid streams are subject to spates and, in these, redds soon become obscured (D.T.Crisp, pers. obs.).

Hunt (1988) in a review of 45 trout habitat restorations between 1953 and 1985, summarized the best variables to measure change as:

a) Total number of trout
b) Number of trout > 6 inches
c) Number of trout > 10 inches
d) Total biomass of trout
e) Number of angler hours
f) Number of trout caught by angling

Dividing (f) by (e) gives the angler catch-per-unit effort (see next section).

3.2.4.3 Fishery performance

The assessment of the success of stream restoration from angler catch statistics has been made difficult in many North American projects because restoration included restocking programmes. However, this process can be useful. Shetter et al. (1946) averaged creel census figures for the 3-year period before and the 5-year period after installation of deflectors in a Michigan brook trout stream. They recorded a 120 % increase in numbers of trout caught, but a 64 % increase in fishing effort (angler-hours). The number of unsuccessful anglers decreased by 20.3 %.

The difficulty of obtaining accurate returns of rod catch data, and the necessity to use various correction factors, limits the use of angling information to assess salmonid stocks (Small and Downham, 1985). In a review, Giles (1989) showed that trout and sea trout rod catches were significantly associated with stock density, but that the results were much less convincing for salmon. See also Mills et al. (1986). Nevertheless, useful information on salmon stocks was obtained over 70 years for the River Wye (Gee and Milner, 1980), and on U.K.brown trout fisheries (Giles, 1989).

3.2.4.4 Macroinvertebrates

Currently the N.R.A. Regions use macroinvertebrate surveys (RIVPACS) to help assess water quality in their rivers. Because most projects are aimed at increasing habitat diversity especially, in salmonid streams, the pool:riffle sequences, such biotic indices could be used as a measure of habitat change. However, few published studies have utilized aquatic invertebrates in this way but have looked directly at the fish populations. One example is that of O'Grady et al. (in Mills, 1991), who record an increase in invertebrate populations following installation of rubble mats on the bed of the River Boyne, Ireland.

3.2.4.5 Habitat morphology

Studies by Allen (1969), Hunt (1976), Binns and Eisermann (1979), Lambert and Hanson (1989) and many others have demonstrated that stream discharge and physical structure largely determine the status of salmonid stocks, given conditions of suitable water quality and recruitment (i.e. spawning success and early fry survival). Predictive models based on this relationship would enable the potential effects of stream restoration works to be quantified, without the necessity of direct surveys of the fish populations.

Binns and Eisermann (1979) found that though salmonids show species and size selectivity for various habitat features, their best model combined all age-groups for four salmonid species. This overcame the difficulties, when dealing with one species in a multi-species community, of separating variation attributable to biotic effects (including interactions between species) from that resulting from abiotic factors.

However, quantification of this relationship in the U.K. is not well advanced, partly because other limiting factors in the stream environment mean that the index of habitat quality is not necessarily an index of fish abundance. In addition, the 'probability-of-use' relationships for weighting habitat attributes are not well developed in the U.K. or, where they have been developed, they do not correspond well to U.S. data (Kennedy, 1984). This point is emphasized by the fact that, in North America, there have been a number of regional modifications of the Binns and Eisermann (1979) model to make it more appropriate for local conditions. An example is the Ontario Trout Classification System described by Bowlby and Imhof (1989). Kozel and Herbert (1989) tested four habitat assessment models for trout and concluded that the most useful habitat variables were: width/depth ratio, amount of overhead cover, average stream width, and the level of late summer flows.

To test the potential of this approach, Milner et al. (1985) developed habitat evaluation methods (HABSCORE) for salmonid streams in Wales, the basic habitat information being recorded on a standard form. They found that habitat attribute: fish population models explained up to 80 % of the variance in numbers of 10-20 cm trout in hard-water streams, but was less effective for soft-water streams. They also stressed the need to consider habitat features at both the site and catchment level. Despite the limitations of the technique, they concluded that the technique could provide a useful starting point for stock assessment, particularly in terms of precision and cost.

In France, Belaud et al. (1989) describe probability-of-use curves for riverine trout populations, which are similar to those originally outlined in a discussion of Instream Flow Incremental Methodology by Bovee (1982). Water velocity, depth and substratum type are the key environmental variables for which separate curves are given for trout fry, juveniles and adults. More general accounts on habitat structure preferenda are given by Stalnaker (1979) and Thielke (1985).

Cresswell (1989) notes that aspects of this approach have been used to identify areas of river that need particular protection from river engineering works, and also in the design of channel restorations to improve habitat value, though he gives no details.

3.2.5 Cost/benefit analyses

Published accounts of cost/benefit analyses of restoration projects in salmonid streams are sparse. Milner et al. (1985) compared the costs of four methods of assessing trout populations in relation to the precision of the results. They concluded that the smaller number of sites required to achieve the necessary precision using quantitative assessment (HABSCORE) more than offset the cheaper visual assessment method that needed many more site visits.

In France restoration of salmonid habitats and spawning grounds was estimated at 4.7 % of the annual budget for promoting and developing salmonid fisheries (in Mills, 1991). However, no details are given of the cost/benefit of this work.

The salmonid enhancement programme in British Columbia (Solomon, 1983) has been subject to detailed cost/benefit analyses. However, most of the costs arise from stocking exercises rather than physical restoration works. Nevertheless, the BC authorities are able to cost the benefits of their work by assessing the value of salmonid catches and related value to tourism and the fishing industry. Although the BC Government bears the initial costs of the enhancement programme they attempt to recover them on the basis of 'the user pays'.

Despite the many restoration projects that have been carried out in North American salmonid streams, very few published details of costs are given, as noted by Hunt ((1988). Everest and Sedell (1984) claim that costs can be determined relatively easily and biological benefits with some difficulty, but the most taxing exercise is to assess economic benefits associated with step-wise increases in fish populations.

One problem in assessing cost effectiveness relates to the stability of the restored habitat and the longevity of improvements to the performance of the fishery. Overton et al. (1981) compared the costs of restoration work in Californian streams with the monetary values of returning adult chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (O. mykiss) and the numbers of repeat spawners. After 10 years the benefit to cost ratio was 0.92, but this increased to 2.11 after 20 years. This effect of durability of restoration structures highlights the need to consider maintenance costs in any calculation of cost/benefit, a factor that has received scant attention in published accounts.

3.3 RESTORATION OF COARSE FISH HABITATS

3.3.1 Background

Physical structure is very important for coarse fish. Winfield (1986) and Diehl (1988) showed experimentally the effects of structure on the feeding behaviour of roach (Rutilus rutilus), common bream (Abramis brama) and perch (Perca fluviatilis). North American studies have been more extensive and often have involved field studies of community associations with in-stream structures, e.g. McClendon and Rabeni (1987) for smallmouth bass (Micropterus dolomieui) and rock bass (Ambloplites rupestris), and Hubert and Rahel (1989) for salmonids and cyprinids, including Semotilus and Rhinichthys.

Physical structure is important in all areas of coarse fish ecology, including feeding, cover, and spawning and nursery requirements. Loss of such structure has been held responsible for population declines, e.g. of cyprinids in major recreational fisheries in the Anglian NRA Region (Linfield, 1985), and even of the U.K. extinction of the burbot, Lota lota (Marlborough, 1970).

Habitat improvement is often a reinstatement of habitat diversity or heterogeneity following homogenising drainage work, often specifically addressing the loss of pool:riffle habitats. This statement is supported by Swales (1979, 1982b, 1989), Swales and O'Hara (1983), Edwards et al. (1984), Carline and Klosiewski (1985), Spillet et al. (1985), Lyons and Courtney (1990), and Kern (1992).

The literature search revealed that the documentation of coarse fish habitat restoration has been very limited in the U.K. and even more so in Europe. Nevertheless, these studies form the basis of this review. In North America, restoration of 'coarse' fish habitats in so called warmwater streams (defined as those incapable of supporting self-sustaining trout populations, Lyons and Courtney (1990)) has been more extensive, but largely concern species not found in the U.K., e.g. centrarchids, which have fundamentally different habitat requirements to the U.K. cyprinids. An exception is the common carp, which is not very important in riverine fisheries in either continent.

However, a recent review of 22 U.S.A. warmwater stream habitat restorations was made by Lyons and Courtney (1990). Although these authors recognised that such coarse fish restoration is a new field, they were able to draw some general conclusions and these will be reported below as appropriate. The few studies that were concerned with cyprinids are reported below in more detail, although again it must be remembered that these species (typically of the genera Notropis and Rhinichthys) are very different from the larger U.K. genera of Rutilus and Abramis.

A larger, but for present purposes less relevant, review of North American experiences of warmwater riverine habitat restoration schemes is given by Schnick et al. (1982) as part of a management plan for the Upper Mississippi River System. This immense work (714 pages covering over 1000 pieces of primary literature) provides a wealth of technical details, which may be of use in other warmwater or coarse fish river systems. The chapter on fishery management techniques contains particularly relevant sections on fish attractors, spawning structures, nursery ponds, wing dam modification, and side channel modification. Each section gives information on the situation to be restored or enhanced, a description of applicable techniques, an assessment of their impact on the environment, and some measure of costings. Although much of this information is specific to the morphology and hydrology of the Mississippi and the biology and ecology of its fishes, some of the general principles may be applicable in the U.K. Consequently, the present review on coarse fish habitat restoration indicates where relevant information is given by Schnick et al. (op.cit.), although the size of the latter precludes extensive review of its contents.

3.3.2 Planning

3.3.2.1 General

Most published accounts of coarse fish restoration works give few details of the planning involved. Nevertheless, this stage of restoration can be viewed as having three basic components:

a) initial recognition of the problem,
b) specificity of the restoration,
c) scale of the restoration.

3.3.2.2 Initial recognition of the problem

In most cases, initial recognition of the problem has been the simple observation of obvious loss of habitat by previous drainage work (Swales, 1982a; Swales and O'Hara, 1983; Edwards et al., 1984; Carline and Klosiewski, 1985; Spillett et al., 1985). Swales (1982a) and Kern (1992) immediately followed such observation with a detailed morphological assessment of the river in order to determine an appropriate restoration strategy, an approach that has been surprisingly rare but which has been strongly recommended by Lyons and Courtney (1990) and Kern (1992).

Lyons and Courtney (1990) forcibly make the point that, while restoration structures can often be placed in small salmonid streams by eye, the greater complexity of most coarse fish sites means that such an approach is courting disaster. Thus, the proper placement of structures in coarse fish rivers requires a detailed planning phase involving a quantitative evaluation of stream physical characteristics and dynamics.

They consequently recommend that detailed channel morphology and flow data be collected and analysed before modification of the habitat commences. In particular, the properties and effects of flood flows at the proposed location should be simulated using computer hydraulic and geomorphologic models.

Kern (1992) also proposed the Leitbild concept of planning, which probably represents restoration planning and execution at its most elaborate. The Leitbild approach involves a thorough description of the desirable properties of the restored stream regarding its natural potential, but not considering the economic or political aspects that influence the realisation of the scheme. Clearly, before this can be implemented, a thorough planning stage is required to gather information on the stream history and its present condition. Kern (op. cit.) recognizes five key topics involved in such planning:

a) land use
b) habitat assessment
c) description of channel morphology and stream type
d) hydrological and hydraulic data
e) limnology including fish populations

The Leitbilt approach was used by Kern (1992) in the restoration of two small lowland streams in south-west Germany. The planning phase of the restoration of a lowland stream involved the detailed assessment of the cyprinid-dominated fish community in terms of species and life stages, followed by the generation of the desired community based on detailed knowledge of the stream and its environment. Planning for the restoration of an upland stream was carried out in a similar detailed manner, gathering information on water temperature, dissolved oxygen, pH, conductivity, major ions, macroinvertebrates, fish populations, riparian and floodplain vegetation, and the ecomorphology of the stream bed.

Initial recognition of the problem has also been made by the results of routine scientific surveys in the case of cyprinid fisheries in the Anglian NRA Region (Linfield, 1985; Jordan, 1987). The details of these surveys indicated consistent recruitment failures, information that directly influenced the nature of subsequent experimental restoration work (Jordan, 1987) towards the provision of suitable cyprinid spawning and rearing habitats as known from fundamental studies of the ecology of these species.

Finally, many restoration programmes have undoubtedly been initiated in response to problems first identified through angler-perceived declines in fishery performance, although the literature does not provide details. The Anglian NRA problems considered by Linfield (1985) and Jordan (1987) were also identified by the poor performance of cyprinid-based match fisheries. The quantification and use of angling records to monitor fish population status is currently the subject of much research (e.g. Cowx, 1991).

3.3.2.3 Specificity of the restoration

Almost all of the coarse fish restoration schemes described in the literature have been aimed at producing a general increase in habitat diversity, in particular compensating for the typical loss of the pool:riffle system following drainage work. The habitat requirements of young and adult coarse fish, as noted earlier, are generally less well known than are those of salmonids. Thus, much restoration has usually been aimed at the community in general. As a consequence, most restoration work has been of a general nature, as compared with the more specific projects associated with the restoration of salmonid habitats.

Exceptions to this general trend do exist. For example, the planning of restoration work for chub described by Swales and O'Hara (1983) took into account the observation that instream structure is particularly important for the distribution of this species, while the experimental provision of spawning and nursery areas for cyprinids (Jordan, 1987) represented the application of a detailed fundamental knowledge of the requirements of such species.

3.3.2.4 Scale of restoration

All coarse fish habitat restorations reported in the literature have been carried out with local terms of reference, rather than as part of an overall catchment plan. However, Lyons and Courtney (1990) in their review of North American experiences note that poor-quality habitat is often caused by catchment-wide problems rather than by localised instream or riparian factors. Consequently, they recommend that individual stream habitat improvement should always be considered in the context of the management of the entire catchment.

3.3.3 Methodology

3.3.3.1 General

Various methods have been used to restore coarse fish habitats, though they have been less extensive and varied than those employed for salmonid habitats. This doubtless arises from the lesser research effort devoted to coarse fishes, and to the fact that their habitats are typically larger and less tractable than those of stream salmonids. As noted above, the methodology of coarse fish habitat restoration is still in its infancy, even in North America (Lyons and Courtney, 1990).

This review considers methodologies in four broad categories:

a) instream structures,
b) substratum restoration,
c) channel restoration ,
d) off-river supplementation units (ORSUs).

Note that some methodologies fall into more than one category and that ORSUs verge on the fringe of aquaculture.

3.3.3.2 Instream structures

The demands of other river users, particularly drainage and navigation, significantly limit the use of instream structures in coarse fish habitats (Swales, 1982a).

Weirs or low dams were used by Swales (1982a) and Spillett et al. (1985). As noted above, the positioning of the low dams (Swales, op. cit.) was largely determined by drainage considerations. The dams were constructed of small sacks (30 x 20 cm) filled with a mixture of rubble and quick-setting cement, which facilitated their rapid removal in case they caused drainage problems, and the adjacent banks were protected against erosion by rubble and concrete sacks. Swales and O'Hara (1983) showed that large numbers of dace and chub were often present in the pools that formed above each dam, whereas numerous benthic species such as the gudgeon and stone loach congregated in the riffle below each dam. On the River Cole, Spillett et al. (1985) made similar temporary weirs using sand bags, but they were washed away with winter floods. This study also used two stone gabion weirs, O.5 m high, which were more permanent.

Spillett et al. (1985) employed two groynes in the River Cole and in the River Thame, made from woven hazel saplings and used singly and in combinations. Subsequent evaluation indicated that these structures had a beneficial effect on the fish populations by affording instream cover and acting as foci for macroinvertebrate colonisation, particularly by caddis-fly larvae. A similar increase in macroinvertebrate populations following the installation of artificial reefs including brushwood substrata is reported for the tidal part of the River Bure (Taylor et al., unpublished ms) though the effect on the fish community was unassessed.

In Poland, Penczak and Mann (1990) found that rock and tree branches installed along the banks of the Pilica River to prevent erosion provided important refugia for fish and invertebrates.

Current deflectors have been used on several occasions. Spillett et al. (1985) used them on the River Cole, where they were made from stone and consisted of elongate crescent-shaped gabions designed to create a sinusoidal pattern of flow. They were low enough to be covered by winter floods, had cavities in the trailing edge to give shelter to fish, and created scour patterns that enhanced erosion and undercutting. In addition, deeper depressions were excavated and filled with gravel behind the deflectors to act as foci for macrophyte and invertebrate colonisation.

Swales (1982a) constructed current deflectors by extending a wall across one third to one half of the river width and a few centimetres above the water surface, and angled at 45 degrees to the bank. Swales and O'Hara (1983) did not usually find large numbers of fish in the vicinity of current deflectors, but dace did favour the region of high velocity immediately downstream of the tip of the deflector. The area of almost still water behind each deflector contained large numbers of dace, chub and roach fry.

In North America, current deflectors (single- or double-wing) in two small Ohio streams (Carline and Klosiewski, 1985) were made of 15 to 20 cm diameter rock, roughly triangular in cross-section, which just broke the water surface at base flow. Significant increases in the diversity and density of the 32 fish species community were evident one and three years after restoration.

Swales (1982a) reported a novel form of instream structure, described as floating artificial cover devices, which were designed to simulate the shelter of undercut banks and overhanging riparian vegetation. These temporary structures were made by linking, end-to-end, sheets of marine plywood (2 m x 0.75 m x 0.5 cm), which were then anchored to stakes in the bank but allowed to float freely to allow for changes in water level. In all 40 square metres of cover was provided by these structures, which attracted large numbers of dace, chub and roach, possibly by the reduced light level.

In their extensive review of North American techniques, Lyons and Courtney (1990) catalogued instream structures used in warmwater streams. These included: bank cribs, live cribwells, bulkheads, current deflectors, fence barriers or retards, groynes, 'lunker' structures, and wing dams or jetties. All these had been used and proven effective in small streams, but only bulkheads and wing dams had been used on larger rivers. Information on instream structures designed to act as fish attractors and spawning structures, and the modification of wing dams, are given by Schnick et al. (1982).

Finally, a note may be made of 'instream' structures constructed by Irvine et al. (1990) in their experimental restoration of a Norfolk broad. These structures consisted of bundles of alder (Alnus glutinosa) twigs, polypropylene ropes, parallel strips of netting or a netting box, and were intended to hinder the feeding of young coarse fish in order to enhance zooplankton populations. However, the authors concluded that they also formed suitable habitats for young perch and rudd, but not roach, in an otherwise structureless habitat. This interpretation is certainly supported by laboratory observations of the feeding behaviour of these species amongst a variety of artificial structures (Winfield, 1986; Diehl, 1988). Thus, such techniques may be of value in the restoration of slow-flowing riverine habitats.

3.3.3.3 Substratum restoration

Substratum restoration has been employed rarely in coarse fish habitats, although it is widely practised in salmonid streams. The three slow-flowing, lowland streams restored by Spillett et al. (1985) all shared the common feature of drainage works resulting in the exposure of a clay substratum, which is particularly difficult to renovate because of its inert nature. On one stream, the River Ock, the substratum was restored by the addition of sections of reject flint gravel
(> 4 cm) alternating with sections of crushed limestone (10 to 15 cm). The results were still being evaluated at the time the paper was written, but they indicated a more abundant and diverse community of macroinvertebrates on the gravel and limestone than on the clay.

A more common substratum problem, as in salmonid streams, arises from the excess deposition of silt. In Europe, Kern (1992) installed a sediment trap in a lowland stream, although no further details are given. In North America, Lyons and Courtney (1990) noted that sediment traps constructed simply as large holes in the channel were generally successful, although they required heavy machinery to build them and they needed periodic emptying. They also noted that fine sediments can be directly removed from a section of stream by hydraulic jets, or by mechanical cleaning of coarse substrata with sieves and pumps. However, expensive machinery is again required and the process needs to be repeated at intervals, and the moved sediments may cause problems elsewhere.

3.3.3.4 Channel restoration

While many of the above techniques result in some minor form of channel restoration, more complete works have been used in some coarse fish habitats outside the U.K. The extensive restoration work of Kern (1992) in lowland streams in Germany involved the addition of an artificial oxbow and greater variation in channel width, but precise details of the manipulation and subsequent evaluation are not given.

In North America, Edwards et al. (1984) restored part of the channelised Olentangy River, Ohio by creating an artificial riffle:pool series. Five equally-spaced riffles, each 6.2 m long and extending 36 m from bank to bank, were constructed by layering boulders over earthern fill. The pools below each riffle were 250 m long, with a maximum depth of 2.5 m at mean discharges. This extensive restoration programme, which involved a community of 36 fish species, produced increases in the restored sections in fish abundance, diversity and condition, macroinvertebrate abundance and diversity, and improvements to the fishery as evidenced by angler counts and a creel survey. However, the use of current deflectors and artificial riffles in the River Styx by Carline and Klosiewski (1985) did not significantly affect the community of 29 fish species.

Of North American experiences in general, Lyons and Courtney (1990) confirmed that, while several restoration schemes involved riffle construction, the direct building of pools was less common. In any situation involving extensive restoration of channel morphology, they warned that such manipulations often have effects upstream and downstream of the restoration site. In the complex environment of relatively large warmwater or coarse fish streams, the proper placement of structures thus requires a detailed planning phase involving a quantitative evaluation of stream physical characteristics and dynamics.

Information on the limited U.S.A. experience of side channel modification to improve their performances as spawning grounds and nursery areas is given by Schnick et al. (1982).

3.3.3.5 Off-River-Supplementation-Units (ORSUs)

While ORSUs may be viewed as a form of low-intensity aquaculture, they do represent an aspect of coarse fish riverine habitat restoration in that they are intended to substitute for spawning and nursery habitats that have been typically lost through drainage work (Linfield, 1985). Consequently, they are covered briefly in this review, though a detailed account of their management will not be given.

ORSUs have only been developed and employed in the Anglian Region of the U.K., although they have potential application in many other regions. Yorkshire NRA are considering modifications of the method to provide 'fish havens' in their region (letter from Dr D.G.Hopkins, 16.4.1992).

Jordan (1987) describes the concept and development of ORSUs, to which reference may be made for further details. In essence, the ORSU is a small water body closely connected to a main river channel that has been channelised, or in some other way has lost its natural floodplain backwaters, which form spawning and nursery grounds for many European non-salmonid fishes.

Originally, an ORSU was conceived as consisting of two parts: a holding area for adult broodstock (5 m x 5 m x 2 m deep) and a spawning and fry rearing pond (20 m x 5 m x 2 m deep). However, research has shown that the system can be operated more efficiently if controlled spawning and fertilisation is carried out in aquaria and the subsequent eggs put into the ORSU in protective cages. After one or two growing seasons, the fry are released directly into the adjacent river through a sluice, thereby avoiding handling and changes of their physico-chemical environment at this vulnerable stage in their life cycle.

Following several years of research, ORSUs have been built at several sites in the Anglian Region and, in addition to the original target species of common bream, they now produce chub , dace, barbel, carp, tench and grayling. While the present strategy for bream still involves a low stocking density of less than 10 larvae per square metre, those for other species utilise more intensive management regimes. Further details of these developments are given by Brighty and Jordan (1988).

In North America, some work has been done on nursery ponds, coves and marshes to provide a secure and productive environment for fish during their vulnerable early life (review by Schnick et al., 1982), which has some parallels with the ORSU research in the U.K. In a similar way, remedial measures in the lower River Danube (Bacalbasa-Dobrovici, 1985; Bacalbasa-Dobrovici et al., 1990) entailed connecting the river to off-river water bodies, such as flood-plain lakes and fish ponds. Both measures are claimed to have maintained high levels of fish production despite the widespread development of hydraulic works.

3.3.4 Evaluation

3.3.4.1 General

Relatively few of the coarse fish habitat schemes reported in the literature have been adequately evaluated. This is surprising and important, given that such restoration technology is still in its infancy in Europe, as it is in North America (Lyons and Courtney, 1990). These authors argue that the restoration community needs to learn from each project undertaken, and this can be done only with an adequate evaluation, which they admit is often difficult as it requires control sections and/or before-and-after surveys. Indeed, a proper evaluation may take longer and cost more than the original restoration work, but it must be done if the field is to develop.

The few evaluations that have been carried out on coarse fish habitats have covered the fish populations themselves, fishery performance, macroinvertebrates, and habitat morphology. This section is concerned with the methodology of evaluation, rather than the actual results obtained by the various studies. Where appropriate, such findings are reported earlier alongside the restoration techniques involved.

3.3.4.2 Fish populations

In their experimental work on the River Perry, Swales and O'Hara (1983) carried out a comprehensive but short-term evaluation by surveying the fish community for one year before and one year after the restoration. Sampling was carried out bimonthly by electrofishing from a boat within sections of river isolated by stop nets, although estimates of numbers and standing crop were made only for dace and chub more than 10 cm in length. A qualitative mapping of fish distribution in relation to restoration structures was also made. The population estimates were characterised by high levels of variation, but they did demonstrate the success of the various instream structures described earlier. However, Swales and O'Hara (op. cit.) noted that such a short-term study really assessed the scheme only in terms of its effects on fish distribution rather than in increasing the carrying capacity of the habitat.

Spillett et al. (1985) examined the fish populations of the River Thame over five years, including a pre-restoration survey. They also electrofished the River Cole regularly before and after the experimental manipulation, although assessment of the scheme was complicated by restocking and by mortalities following pollution.

In North America, Edwards et al. (1984) comprehensively evaluated their restoration of the Olentangy River, including before-and-after electrofishing surveys. These were carried out monthly through most of the summer and early autumn in each of three years, and were quantified by catch-per-unit-effort by time, and by the use of a mark-recapture technique. Shannon-Weaver diversity indices were also calculated for fish numbers and biomass.

Also in the U.S.A., Carline and Klosiewski (1985) employed single catch electrofishing assessments in June, one and three years after their restoration of Chippewa Creek, while on the River Styx they electrofished in May, July and September of the year before and after habitat manipulation.

3.3.4.3 Fishery performance

As noted above, the quantification and use of angling records to monitor coarse fish population status is currently the subject of much research (see Cowx, 1991), and is likely to be used increasingly in the future as a means of evaluating restoration programmes. At present, the only study to have used this technique is that by Edwards et al. (1984) in their restoration of the Olentangy River, Ohio. Angler counts and a creel survey gave data on catch rate, catch composition and fishing methods. These provided an assessment of the restoration work, which was in good agreement with direct fish population and macroinvertebrate surveys.

3.3.4.4 Macroinvertebrates

Assessment of changes in macroinvertebrate populations, which form a major food supply for many riverine coarse fish, has been used occasionally as a restoration evaluation technique. Spillett et al. (1985) used this approach in the River Ock, following restoration of the substratum by the addition of reject flint gravel alternating with sections of crushed limestone. After the restoration, macroinvertebrates were assessed by a combination of semi-quantitative kick-sampling, quantitative Surber sampling, and more precisely by artificial substrate samplers retrieved after 4, 10, 20 and 26 weeks (see Section 3.3.3.3).

Macroinvertebrate populations were also assessed by Edwards et al. (1984) in the Olentangy River, Ohio. The drift and benthos communities were sampled by drift net and Surber sampler during the summer months of a three year period covering the restoration. Identification to family was found sufficient for the purposes of the assessment, which was based on modified Shannon-Weaver family diversity indices, using biomass rather than numbers.

3.3.4.5 Habitat morphology

Rather than directly surveying the fish or other biological aspects of a restoration, some schemes have been assessed by examination of the habitat morphology. Swales (1982a) used this approach on the River Perry following a detailed morphological assessment of the site prior to the restoration work. Examination of the environmental characteristics of flow, water depth etc., produced by low dams showed that they produced conditions similar to those of natural pool:riffle sequences. The same was true of a current deflector positioned in a shallow, fast-flowing section, but the one placed in deeper, slower-flowing water did not reproduce desirable natural conditions.

Habitat morphology was also assessed in some detail by Kern (1992) during the extensive restoration of streams in Germany, but no details are given. In North America, Kinsolving and

Bain (1990) have described a novel method of counting plant and debris surfaces as a measure of cover complexity in two Alabama warmwater streams.

The development of habitat suitability index models for coarse fish has not progressed to the same extent as for salmonids. However, Inskip (1982) gives detailed information for pike, based on a review of information from North America, the U.K. and Europe. Similar criteria are required for other major coarse fish species to facilitate consideration of their habitat needs in the planning of future engineering projects, and the work by Copp cited in Section 2.5 provides an important starting point.

3.3.5 Cost/benefit analyses

Cost/benefit analyses for coarse fish restorations are even rarer than evaluations. Spillett et al. (1985) considered that one of the most important features of their study was that it enabled the calculation of the costs of the various ameliorative measures. This facilitated the inclusion of fisheries costs into the cost/benefit calculations of some drainage schemes. As an example, these authors noted that ameliorative measures in one planning study amounted to more than 10 % of the total engineering costs, and thus had a significant effect on the overall assessment. Costs of mitigation at this stage of a project contrast favourably with those that can be incurred in having to restore damaged habitats.

3.4 SUMMARY

3.4.1 GENERAL

A number of specific points regarding riverine restoration came out strongly from the review. In general, there were very few documented examples of U.K. work compared with numerous examples from North America, though the latter mostly comprised work on salmonid streams. A good example is the publication of the Proceedings of the 5th Trout Stream Habitat Workshop (Miller et al., 1986). This contains many examples of small scale trout habitat restoration, including some that were unsuccessful.

Throughout the literature there was a dearth of long-term studies showing the pre- and post-restoration status of fisheries in relation to natural year-by-year variations. In many cases the status of a fishery (or fish population) was confined to a single pre-restoration survey. Similarly the effect of a restoration project was determined by a single post-project survey.

There were few discernible differences between restoration programmes for salmon and trout (and other salmonid species), except that the creation of fish passes formed an important part of salmon restoration activities. In general, differences between projects appeared to result more from habitat differences than from variations between the habitat needs of the different fish species.

The techniques of restoring coarse fish habitats are based largely on those developed for salmonid fisheries. However, the application of these techniques has a shorter history, and the choice of appropriate techniques is inhibited by the less detailed knowledge of coarse fish habitat requirements.

Comprehensive handbooks from the North American literature exist that detail specific techniques for riverine restoration. Not all of these are appropriate in all U.K. rivers, but copies of the best handbooks in the 10 NRA Regions would be valuable.

Coarse fish: Schnick et al. (1982).

Salmon and trout: Parkinson and Slaney (1975)
Maughan et al. (1978)
Finnigan et al. (1980)
Gore (1985)
Hunt (1988)
Hunter (1991)

3.4.2 DESIGN AND PLANNING - RECOMMENDATIONS

1. To state as precisely as possible the aim of the restoration project, including identification of the target fish species.

2. To design restoration projects within the needs of the whole catchment. This is recommended by several authors, but there are examples of small independent projects that benefitted fish populations on a local scale.

3. To create a database of habitat requirements of target fish species to enable appropriate restoration work to be instigated.

4. To fully document all restoration projects, even those that are not successful. Lack of such documentation inhibits dissemination of experience and, hence, slows down the learning process.

5. To evaluate the results of the restoration work in terms of its physical effect on the river and the changes to the fishery or fish population. Without such evaluation, cost/benefit assessments are not possible.

B. QUESTIONNAIRE

4. INTRODUCTION

A questionnaire seeking information on restoration work was compiled by IFE in collaboration with Dr J.S.Wortley. This was circulated on 29-30 August 1991 to 54 NRA Fisheries Managers, Officers and Scientists (list of names provided by Dr Wortley). A request was made that the forms should be completed and returned by 31 October 1991.

4.1 COMPILATION AND CIRCULATION

The questionnaire (Appendix A) comprised two sections.

Section I requested information on the lengths of fisheries (salmon, trout , coarse) in each NRA Region/Division and an assessment of the lengths that would benefit from physical restoration. It was accepted that the assessment of restoration potential would be subjective, and would be based on the knowledge and experience of NRA staff. A covering letter sent with the questionnaire emphasised this point.

Section II requested detailed information on individual restoration projects.

In addition to the questionnaire, a short article (Appendix B) publicising the project was published by the Institute of Fisheries Management journal 'FISH'. The article included a request for information on restoration work that had been carried out by riparian owners, angling clubs etc., and not by the WA/NRA.

4.2 RESPONSE TO THE QUESTIONNAIRE

Very few replies to the questionnaire were received by 31 October 1991, and telephone calls and letters were required to prompt returns. The last returns were not received until January 1992. No information was received as a result of the article in the IFM journal 'FISH'.

12 Section I replies were received, which covered 9 of the 10 Regions. Full coverage was obtained for 6 Regions and part coverage for 3 Regions. No reply was received from the Southwest Region despite a follow-up request.

Information on 75 individual projects was obtained by Section II of the questionnaire, though some forms were submitted containing more than one project per form. Thames NRA staff felt that the form of the questionnaire was not appropriate to the type of restoration work they carried out. Hence Mr Mann visited the East and West divisions on separate dates to obtain information pertaining to the project. As a result , information for Section I and three projects for Section II was obtained. Other information on Thames NRA restoration work will be summarised in a separate section.

4.3 SECTION I - ANALYSIS OF REPLIES

Tables 2 to 10 summarize the Section I information received from the 9 Regions, and Table 11 gives an overall summary. For most of the Regions, the total lengths of fisheries do not include very small tributaries. Also, the percentage lengths of streams that would benefit from restoration work relate principally to major schemes and not to the very many small ad hoc activities that are often carried out in conjunction with river engineering works.

There were considerable differences between Regions but, overall, rivers supporting coarse fisheries were deemed to require more restoration work than those with salmonid fisheries (coarse fish 34%, salmon 10%, trout 19%).

Bearing in mind that full returns were not received from all Regions, the lengths (km) of rivers plus the lengths needing restoration were:

Salmon 9260 (935); Trout 38 056 (7182); Coarse 61 312 (12 598)

On a percentage basis, the Thames and Yorkshire Regions were the areas requiring most restoration work (about 50%) and the Southern and Welsh Regions requiring the least (about 10%). However,the value of 10% for the Welsh NRA represented the largest distance (3457 km) needing restoration work in all the Regions.

Table 2. Details of the available lengths (km) of salmon, trout and coarse fisheries and their potential for physical restoration.

Division	Salmon	Trout	Coarse	Totals
Northern	0	261	977	1238
%	0	22	4	7
Central	0	296	1522	1818
%		49	32	35
Lincoln	0	83	731	814
%	0	48	50	50
Norf. Suffolk &	0	200	652	852
Essex %	0	50	42	44
Totals	0	840	3882	4722
%	0	41	30	32

Table 3. Details of the available lengths (km) of salmon, trout and coarse fisheries in the Northumbrian Region and their potential (%km) for physical restoration.

Division	Salmon	Trout	Coarse	Totals
Southern	1191	2382	467	4040
%	14	34	14	25

Note: No data from the Northern Division

Table 4. Details of the available lengths (km) of salmon, trout and coarse fisheries in the Northwest Region and their potential (%km) for physical restoration.

Division	Salmon	Trout	Coarse	Totals
Central	161	241	105	507
%	10	7	0	6
Southern*	0	350	1550	1750
%	0	0	52	46
Totals	161	591	1655	2257
%	0	3	48	37

* = Includes 150 km of the same mixed trout/coarse fisheries

Note: No data from the Northern Division

Table 5. Details of the available lengths (km) of salmon, trout and coarse fisheries in the Severn-Trent Region and their potential (%km) for physical restoration.

Division	Salmon	Trout	Coarse	Totals
Lower Severn	40	90	600	730
%	0	38	12	15
Upper Severn	772*	772*	233	1005
%	10	10	14	11
Lower Trent	0	152	1797	1949
%	0	59	18	21
Totals	812	1014	2630	3684
%	10	20	17	17

* = Same mixed salmon/trout fisheries

Note: No data from the Upper Trent Division

Table 6. Details of the available lengths (km) of salmon, trout and coarse fisheries in the Southern region and their potential (%km) for physical restoration.

Division	Salmon	Trout	Coarse	Totals
Hants & IOW	16	97	40	153
%	50	66	0	47
Kent	0	32	805	837
%	0	0	0	0*
Totals	16	129	845	990
%	50	50	0	7

* = Fish passes needed over most weirs

Table 7. Details of the available lengths (km) of salmon, trout and coarse fisheries in the Thames Region and their potential (%km) for physical restoration.

Division	Salmon	Trout	Coarse	Totals
East	0	1600*	1600*	1600
%	0	50	50	50
West	0	500	900	1400
%	0	50	50	50
Totals	0	2100	2500	3000
%	0	50	50	50

* = Same mixed trout/coarse fisheries

Table 8. Details of the available lengths (km) of salmon, trout and coarse fisheries in the Welsh Region and their potential (%km) for physical restoration.

Division	Salmon	Trout	Coarse	Totals
North	755	4094	121	4970
%	20	10	26	12
Southwest	2506	5393	0	7899
%	12	6	0	8
Whole Region	7000	27000	570	34570
%	10	10	10	10

Note: Separate data not available for all the Divisions

Table 9. Details of the available lengths (km) of salmon, trout and coarse fisheries in the Wessex Region and their potential (%km) for physical restoration.

Division	Salmonid* (EC designated)	Coarse	Totals
Avon & Dorset	1178	298	1476
%	18	36	21
Bristol Avon	377	139	516
%	13	28	17
Somerset	214	263	477
%	17	30	25
Totals	1769	700	2469
%	17	32	21

* = Combined salmon/trout fisheries

Table 10. Details of the available lengths (km) of salmon. trout and coarse fisheries and their potential (%km) for physical restoration.

Division	Salmon	Trout	Coarse	Totals
Whole Region	80	4000	1500	5580
%	63	50	67*	55

* = This represents 100 km; a further 800 km have the potential for physical restoration if water quality is improved sufficiently for fish to return there.
Note: Data not available for the separate Divisions.

Table 11. Summary of Tables 2 to 10, inclusive, showing the available lengths (km) of salmon, trout and coarse fisheries in the NRA Regions and their potential (%km) for physical restoration.

Region	Salmon	Trout	Coarse	Totals
Anglian	0	840	3882	4722
%	0	41	30	32
Northumbrian	1191	2382	467	4040
%	14	34	14	25
Northwest	161	591	1655	2257
%	10	3	48	37
Severn-Trent	812*	1014*	2630	3684
%	10	20	17	17
Southern	16	129	845	990
%	50	50	0	7
Thames %	0	2100^^	2500^^	3000
	0	50	50	50
Welsh	7000	27000	570	34570
%	10	10	10	10
Wessex	--- 1769** ---		700	2469
%	17		32	21
Yorkshire	80	4000	1500	5580
%	63	50	67	55
Totals	9260$	38056	14749	61312
%	10	19	34	21

* = Includes 772 km same mixed salmon/coarse fisheries
** = Mixed salmonid fisheries
^^ = Includes 1600 km same mixed trout/coarse fisheries
$ = Totals exclude the Wessex combined salmonid data
Note: No data available from the Southwest Region

4.4 SECTION II - ANALYSIS OF REPLIES

Details of 75 projects were completed on the questionnaire forms, although two were filled in by Mr Mann, based on information received from Thames NRA.. The total of 75 included separation of a number of forms from Southern NRA on which the same type of restoration was described for two rivers.

Table 12. Project details separated according to type of fishery (dominant fishery indicated), though many rivers included minor angling activity for other fish.
S = Salmon fishery, T = Trout fishery, C = Coarse fishery, S/T = Equal status Salmon & Trout fishery, T/C = Equal status
Trout and Coarse fishery.

Region	S	T	C	S/T	T/C	Totals
Anglian	0	8	9	0	2	19
Northumb.	0	1	1	0	0	2
Northwest	1	0	0	0	0	1
S-Trent	1	0	1	0	0	2
Southern	5	4	2	0	0	11
Southwest	8	0	0	1	0	9
Thames	0	1	2	0	0	3
Welsh	0	4	0	0	0	4
Wessex	0	1	10	0	0	11
Yorkshire	1	6	6	0	0	13
Totals	16	25	31	1	2	75

For most of the remaining analyses, the categories S, T, S/T are combined under 'Salmon', and T and T/C are combined under 'Trout'.

Letters were received from a number of NRA areas, indicating that no restoration work had been carried out:

Severn-Trent Region: lower Severn and lower Trent,
Anglian Region : Essex division.

REASON FOR THE RESTORATION

There was a wide variety of reasons why the restoration work was initiated. For salmon, most was concerned with improvement of the spawning gravels, mostly because of gravel concretion and siltation. This was important also in trout fisheries, but many other restorations involved increase in cover and in the frequency of pool:riffle sequences. The reasons given for coarse fish habitat restoration were more diverse, but covered the general field of low water levels and lack of habitat diversity. Many of the reasons for both salmonids and coarse fish related to the effects of major works (e.g. land drainage, flood protection, channel re-alignment). Although the inclusion of information of fish passes was not originally intended for this R & D Project, a number of project replies were received that referred to fish passes. These included passes for salmon and coarse fish (but not trout), and opportunity for some of the works arose during routine maintenance of existing weirs.

Table 13. Reasons for restoration work. More than one reason is given for some projects and percentage values are based on the total number of projects in each category: Salmon 17. Trout, 27, Coarse 31, Total 75.

Reason	Salmon		Trout		Coarse		Totals	
	No.	%	No.	%	No.	%	No.	%
Low fish nos.	0		4	14.8	2	6.5	6	8.0
Low depths	0		3	11.1	8	25.8	11	14.7
Poor cover	0		8	29.6	4	12.9	12	16.0
Riffle:pool	2	11.8	6	22.2	3	9.7	11	14.7
Poor spawning	9	52.9	5	18.5	2	6.5	16	21.3
Experimental	0		0		3	9.7	3	4.0
Major works	0		4	14.8	8	25.8	12	16.0
Fish passage	5	29.4	0		4	12.9	9	12.0
Bankside veg.	1	5.9	3	11.1	0		4	5.3
Wide channel	0		0		1	3.2	1	1.3
New channel	0		3	11.1	0		3	4.0

TYPE OF RESTORATION WORK

Installation of low level weirs were the most common restoration technique for trout and coarse fisheries, but were not used at all in salmon fisheries. For salmon, the principal concern was the restoration of spawning beds, mostly using mechanical means to counteract gravel concretion or siltation.

Table 14. Restoration techniques used in salmon, trout and coarse fisheries. More than one method was used for some projects and percentage are based on the total number of projects in each category: Salmon 17, Trout 27, Coarse 27, Totals 75.

Restoration	Salmon		Trout		Coarse		Totals	
	No.	%	No.	%	No.	%	No.	%
Weirs	0		10	40.7	10	32.3	21	28.0
Riffles	0		3	11.1	2	6.5	5	6.7
Groynes	2	11.8	6	22.2	3	9.7	11	14.7
Artif. reefs	0		0		5	16.1	5	6.7
Gravel	8	47.1	6	22.2	2	6.5	16	21.3
Fascine mats	0		0		2	6.5	2	2.7
Deflectors	0		2	7.4	0		2	2.7
Bank cover	0		6	22.2	2	6.5	8	10.7
Berms	0		1	3.7	1	3.2	2	2.7
Deeper channel	0		6	22.2	0		6	8.0
B/water havens	1	5.9	0		5	16.1	6	8.0
Boulders	0		6	22.2	2	6.5	8	10.7
Fish passes	5	29.4	0		5	16.1	10	13.3
Clear debris	2	11.8	0		0		2	2.7
Gabions	0		0		2	6.5	2	2.7
Fencing	0		2	7.4	0		2	2.7
Powdered chalk	0		1	3.7	0		1	1.3

WHO CARRIED OUT THE RESTORATION WORK ?

The previous Water Authorities and the current NRA were responsible for the majority of projects either on their own (64%) or in conjunction with other parties (20%). Only 16% of projects had no recorded WA/NRA involvement, but presumably permissions were received from them for some of the work. It should be noted that this small percentage may be an underestimate as the questionnaire was sent only to NRA personnel. A letter inviting information from other (private) sources was published in 'FISH', the Institute of Fisheries Management Newsletter, but there was no response.

It is worth noting that riparian owners/angling organisations with salmon or trout interests had a greater direct involvement with remedial activities than those with coarse fish interests.

Table 15. Number of restoration projects for which various organisations were responsible.

Authority	Salmon		Trout		Coarse		Totals	
	No.	%	No.	%	No.	%	No.	%
WA/NRA only	7	41.2	16	59.3	25	80.6	48	64.0
WA/NRA & others	6	35.3	6	22.2	3	9.7	15	20.0
Riparian owners	4	23.5	5	18.5	3	9.7	12	16.0
Totals	17		27		31		75	

WIDTH OF THE RIVER AT THE RESTORATION SITE

River width was used as an indication of the size of the river at the restoration site. The majority (61.3 %) of rivers were between 6 and 15 metres wide. Only 3 of the 75 sites were wider than 30 metres, and these were all coarse fisheries.

Table 16. River width in metres at the restoration site.

Width category (m)	Salmon No.	Salmon %	Trout No.	Trout %	Coarse No.	Coarse %	Totals No.	Totals %
0 - 5	5	29.4	0		2	6.5	7	9.3
6 - 10	7	41.2	13	48.1	10	32.2	30	40.0
11 - 15	4	23.5	4	14.8	6	19.4	14	18.7
16 - 20	0		7	25.9	3	9.7	10	13.3
21 - 30	1	5.9	3	11.1	4	12.9	8	10.7
> 30	0		0		3	9.7	3	4.0
Not stated	0		0		3	9.7	3	4.0

LENGTH OF RIVER BENEFITTING FROM THE RESTORATION

Answering this question caused some problems through the clear difficulty in knowing how far the fisheries upstream and downstream of a local restoration was affected. The longest distances given are those resulting from the construction of fish passes that opened up new areas for exploitation by migratory salmonids. However, most replies referred to lengths of improved riverine habitat and did not include the possible improvement to fisheries outside these areas.

Table 17. Length (km) of river benefitting from the restoration.

Length (km)	Salmon No.	Salmon %	Trout No.	Trout %	Coarse No.	Coarse %	Totals No.	Totals %
0.0 - 0.5	7	41.1	8	29.6	9	29.0	24	32.0
0.6 - 1.0	2	11.8	5	18.5	5	16.1	12	16.0
1.1 - 5.0	0		12	44.4	6	19.4	18	24.0
> 5.0	8	47.1	0		3	9.7	11	14.7
Not stated	0		2	7.4	8	25.8	10	13.3

DATE OF COMMENCEMENT OF THE RESTORATION PROJECT

As several restoration projects took more than a year to complete, the following table gives the date that the work commenced. There was no major difference in pattern between salmon, trout and coarse fisheries. For all fisheries, over 50 % of projects had been carried out in past 5 years and only 2 (in the 1920's) before 1970. In view of the general lack of historical documentation of rehabilitation work, it is likely that many of those who replied could include only those projects of which they had personal knowledge.

Table 18. Year of commencement of restoration project.

Year	Salmon		Trout		Coarse		Totals	
	No.	%	No.	%	No.	%	No.	%
Before 1970	0		2	7.4	0		2	2.7
1970 - 75	0		0		2	6.5	2	2.7
1976 - 80	4	23.5	1	4.9	7	22.6	12	16.0
1981 - 85	0		6	22.2	4	12.9	10	13.3
1986 - 90	3	17.6	12	44.4	10	32.3	25	33.3
1991 onwards	8	47.1	4	14.8	6	19.4	18	24.0
Not stated	2	11.8	2	7.4	2	6.5	6	6.0

COSTS OF RESTORATION PROJECTS

36 % of projects had no costings attached to them, and others referred to material costs and did not include labour costs. A few were rated as zero costs as they did not involve any expense to the NRA Fisheries section, but were included in the costs of major engineering works, e.g. land drainage and flood protection. This was particularly so for those projects that seemed to be more mitigation of planned engineering works rather than restoration of previous activities. About 45 % of projects were costed at less than £5K.

Table 19. Estimated costs (£K) of restoration projects.

Cost category (£K)	Salmon No.	%	Trout No.	%	Coarse No.	%	Totals No.	%
0.0- 0.5	1	5.9	5	18.5	4	12.9	10	13.3
0.6- 1.0	5	29.4	0		2	6.4	7	9.4
1.1- 5	3	17.6	3	11.1	10	32.3	16	21.3
6 - 10	0		0		3	9.7	3	4.0
11 - 20	0		1	3.7	2	6.4	3	4.0
21 - 30	1	5.9	2	7.4	1	3.2	4	5.3
31 -100	2	11.8	2	7.4	0		4	5.3
> 100	1	5.9	0		0		1	1.3
Not stated	4	23.5	14	51.9	9	29.0	27	36.0

EXISTENCE OF LONG-TERM (> 5 YEARS) FISH DATA RECORDS

Almost half (34/75) of the projects had no long-term records of the fish populations from either rod catches or scientific surveys. Salmonid fisheries had better records of rod catch data than coarse fisheries, and one salmon fishery had a long record of redd counts. Electrofishing surveys provided the bulk of the scientific records, but netting surveys were used for some coarse fisheries.

Table 20. Details of long-term (> 5 years) records of fish population. Some projects had fish records from more than one source and percentages are based on the total number of projects in each category: Salmon 17, Trout 27, Coarse 31, Total 75.

Capture method	Salmon No.	%	Trout No.	%	Coarse No.	%	Totals No.	%
Electrofishing	8	47.1	9	33.3	10	32.3	27	36.0
Netting	0		0		5	16.1	5	6.7
Rod catches	5	29.4	7	25.9	2	6.5	14	18.7
Redd counts	1	5.9	0		0		1	1.3
No records	3	17.6	15	55.6	16	51.6	34	45.3

SPECIFIC FISH SURVEY PRIOR TO THE RESTORATION

A very high percentage (62.7) of projects did not include an examination of the fish populations prior to the commencement of the restoration work. This was more so for salmon and trout fisheries (76.5% and 70.4%, respectively) than for coarse fisheries (48.4 %). Where surveys were carried out, capture by electrofishing was the most common method employed. Usually only one survey was carried out, but there were a few notable exceptions (Table 22).

Table 21. Capture methods used for a specific fish survey prior to the start of the restoration project. Some projects used more than one method, percentages are based on the total number of projects in each category: Salmon 17, Trout 27, Coarse 31, Total 75.

Capture method	Salmon		Trout		Coarse		Totals	
	No.	%	No.	%	No.	%	No.	%
Electrofishing	4	23.5	8	29.6	12	38.7	26	34.7
Netting	0		0		4	12.9	4	5.3
Rod catches	0		0		1	3.2	1	1.3
Redd counts	1	5.9	0		0		1	1.3
No survey	13	76.5	19	70.4	15	48.4	47	62.7

Table 22. Number of repeat surveys carried out before commencement of the restoration project.

No. of surveys		1	2	3	5	10	30
Electro - fishing	Salmon	4	0	0	0	0	0
	Trout	5	0	2	1	0	0
	Coarse	6	2	0	0	1	2
Netting	Coarse	1	1	1	0	0	0
Rod	Coarse	1	0	0	0	0	0
Redds	Salmon	1	0	0	0	0	0
Totals		18	3	3	1	1	2

SPECIFIC FISH SURVEY AFTER RESTORATION

A high percentage (66.7) of projects did not include any specific fish survey after the completion of the restoration work, the percentages for salmonid fisheries (68.2) being similar to that for coarse fisheries (66.7).

Table 23. Capture methods used for specific fish surveys after completion of the restoration project. More than one method was used for some of the projects and percentages are based on the total number of projects in each category: Salmon 17, Trout 27, Coarse 31, Total 75.

Capture method	Salmon		Trout		Coarse		Totals	
	No.	%	No.	%	No.	%	No.	%
Electrofishing	4	23.5	10	37.0	7	22.6	21	28.0
Netting	0		0		4	12.9	4	5.3
Rod catches	0		0		1	3.2	1	1.3
Snorkel	0		0		1	3.2	1	1.3
No survey	13	76.5	17	63.0	20	64.9	50	66.7

As with the 'Before' surveys, electrofishing was the most common method, and usually involved one survey. However, comments attached to some of the more recently completed projects indicate that more surveys are planned for the future.

Table 24. Number of repeated surveys after completion of the restoration project.

No. of surveys:		1	2	3	4	5	6	10
Electro-fishing	Salmon	4	0	0	0	0	0	0
	Trout	4	1	3	0	1	1	0
	Coarse	4	1	0	1	0	0	0
Netting	Coarse	2	1	0	0	0	0	1
Rod	Coarse	1	0	0	0	0	0	0
Snorkel	Coarse	1	0	0	0	0	0	0
Totals		16	3	3	1	1	1	1

OTHER ENVIRONMENTAL IMPACT ASSESSMENTS

Table 25. Details of environmental impact assessments (other than fish surveys) before and after the restoration project. More than one method was used for some of the projects and percentages are based on the total number of projects in each category: Salmon 17, Trout 27, Coarse 31, Total 75.

Survey method a) = Before b) = After	Salmon No.	Salmon %	Trout No.	Trout %	Coarse No.	Coarse %	Totals No.	Totals %
Riv. corr. a)	0		3	11.1	3	9.7	6	8.0
b)	0		1	3.7	0		1	1.3
Invert. a)	1	5.9	6	22.2	5	16.1	12	16.0
b)	1	5.9	7	25.9	7	22.6	15	20.0
Macrophyte a)	0		0		0		0	
b)	0		1	3.7	1	3.2	2	2.7
Other a)	1	5.9	1	3.7	1	3.2	3	4.0
b)	0		0		1	3.2	1	1.3
No survey	15	88.2	17	63.0	23	74.2	55	73.3

WHAT CHANGES OCCURRED TO THE FISH POPULATION AS A RESULT OF THE RESTORATION ?

In view of the low frequency of specific before-and-after studies, it is no surprise to find a high percentage (61.3 overall) of projects for which no information is available on the effect of the restoration. No projects were recorded as having caused no change to the fishery or as having caused it to deteriorate.

Table 26 The impact of the restoration project on fish populations.

Degree of change	Salmon No.	Salmon %	Trout No.	Trout %	Coarse No.	Coarse %	Totals No.	Totals %
Considerable improvement	7	41.2	4	14.8	6	19.4	17	22.7
Moderate improvement	0		7	25.9	5	16.1	12	16.0
No change	0		0		0		0	
Deterioration	0		0		0		0	
Not known	10	58.8	16	59.3	20	64.5	46	61.3

HOW WAS THE CHANGE ASSESSED

This question was similar to that relating to specific before-and-after studies, but the replies showed that changes to the fisheries were based also on subjective assessments. These included hearsay evidence from anglers, visual inspection of the habitat and, on occasion, of the fish in the water by NRA scientists and bailiffs.

Table 27. Methods used to assess the change to the fishery as a result of restoration. More than one method was used for some projects and percentages are based on the total number of projects in each category: Salmon 17, Trout 27, Coarse 31, Total 75.

Method	Salmon		Trout		Coarse		Totals	
	No.	%	No.	%	No.	%	No.	%
Electrofishing	3	17.6	4	14.8	3	9.7	10	13.3
Rod catches	2	11.8	5	18.5	5	16.1	12	16.0
Anglers hearsay	0		2	7.4	3	9.7	5	6.7
Netting	0		0		1	3.2	1	1.3
Redd counts	3	17.6	0		0		3	4.0
Visual	1	5.9	5	18.5	0		6	8.0
Not assessed	11	64.7	15	55.6	21	67.7	47	62.7

COMMITMENT TO MAINTENANCE OF THE RESTORATION

As the WA/NRA were responsible for most of the restoration projects (see Table 15), it is no surprise that they had taken responsibility for maintaining the changes carried out. Even so, almost half of the 75 projects were deemed to be maintenance free or included no commitment for maintenance. Marginally more riparian owners associated with salmonid fisheries than with coarse fisheries were directly involved with maintenance work.

Table 28. Commitments to maintain restored habitat.

Authority	Salmon No.	Salmon %	Trout No.	Trout %	Coarse No.	Coarse %	Totals No.	Totals %
WA/NRA only	12	70.6	8	29.6	14	45.2	34	45.3
WA/NRA & others	1	5.9	1	3.7	0		2	2.7
Riparian owners	2	11.8	2	7.4	2	6.5	6	8.0
Maintenance free	0		8	29.6	7	22.6	15	20.0
No commitment	2	11.8	7	25.9	5	16.2	14	18.7
Not stated	0		1	3.7	3	9.7	4	5.3

AVAILABILITY OF REPORTS

The majority (61.3 %) of projects were not documented in any way, more so for salmonid fisheries (68.2 %) than for coarse fisheries (51.6 %). Many of the internal NRA fish reports were not not specific to the restoration project but were part of routine reports on fish surveys. In the table below, the category 'Other' includes reports from universities (including a PhD thesis), a book and an angling newsletter.

Table 29. Reports available from the 75 restoration projects. More than one type of report is available for some projects and percentages are based on the total number of projects in each category: Salmon 17, Trout 27, Coarse 31, Total 75.

Report	Salmon No.	Salmon %	Trout No.	Trout %	Coarse No.	Coarse %	Totals No.	Totals %
Fish	2	11.8	6	22.2	7	22.6	15	20.0
Engineering	0		2	7.4	6	19.4	8	10.7
Invert.	0		2	7.4	1	3.2	3	4.0
Photos.	6	35.3	0		0		6	8.0
Other	0		2	7.4	5	26.3	7	9.3
None	12	70.6	19	70.4	16	51.6	16	62.7

4.5 INFORMATION FROM OTHER SOURCES

4.5.1 General

Initially no Section I and only one Section II reply was received from the Thames Region. The Senior Fisheries Officers for the two component areas (West and East) considered that the way that restoration work was carried out in Thames NRA made it impossible to identify specific projects as required by the questionnaire. This is because most of the work comprises relatively small-scale, day-to-day exercises, rather than larger, discrete projects.

Therefore Mr Mann visited the two Officers concerned (Mr A.Butterworth, Thames West and Mr J.Reeves, Thames East) and some of their staff on 21.11.91 and 28.11.91, respectively. As a result of the extensive amount of information received, Mr Mann was able to complete Section I and two projects in Section II.

4.5.2 Thames NRA

It was clear that much of the restoration work in Thames consisted of mitigation of proposed works, or resulted from on-site agreements between Fisheries staff and engineers during ongoing work. Documentation of such work is minimal, and often the work is not costed directly to the fisheries budget.

Both Divisions have rolling programmes of fish stock assessment (c. 5 years in the West and up to 10 years in the East), but Thames East considered that the details of such surveys were usually not sufficiently precise to assess the effects of particular restoration schemes. Thus, there were very few specific evaluations of changes to fish populations resulting from habitat restoration. Instead, both Divisions used the knowledge and experience of their fisheries staff to assess the environmental changes needed at particular river sites to improve the fisheries (or enhance the fish populations). Thus their decisions were based on the concept that the fish populations will be adequate if the environment is satisfactory.

Examples of the type of work carried out are:

Trout fisheries -

a) Low level weirs to offset the effect of low flows
b) Channel re-alignment to improve habitat diversity

Coarse fisheries -

a) Stabilization of unstable sandy river bed with groynes and boulders
b) Re-profiling a trapezoidal channel
c) Creating meanders in a straight channel

Often such restoration work was followed by fish stocking, which adds to the problem of evaluating the work.

Nearly all the restoration work in the Thames Region is carried out on the tributaries and not on the main channel of the River Thames. Similarly, information from the Severn-Trent Region showed that no restoration work was carried out on the larger river channels of the lower Severn and lower Trent.

Recently, small scale experimental restoration work has been initiated in the Thames Region in order to test methods that are simple and cost/effective. Methods that prove successful will be incorporated into larger schemes and larger budgets. Other NRA Regions carry out similar experimental restorations, some of which are indicated in the Questionnaire replies.

It was clear from the discussions that Thames NRA have an effective working relationship with engineering and angling interests regarding habitat restoration. However, the effectiveness of their operations in improving the fisheries (or enhancing the fish populations) is difficult to assess in view of the scarcity of long-term background data on fish stocks. Similarly, the difficulty of costing the many small-scale habitat improvements make cost/benefit assessments difficult.

It is important to note that most other NRA Regions carry out similar types of restoration work, so that these problems are not specific to Thames NRA. They are relevant also to restoration work carried out in other countries (see the summary of the Literature review).

4.6 SUMMARY

4.6.1 General

Within the context of this R & D project it is important to distinguish between 'restoration' of degraded riverine habitat, and the 'mitigation' of proposed engineering schemes to minimize such degradation.

From the questionnaire replies and from discussions with NRA staff, it is clear that with concepts are regarded within the NRA as 'restoration'. However, mitigation techniques often involve procedures that are quite different from restoration techniques. Often they simply involve modification of proposed engineering works, rather than inclusion of specific structures that enhance the habitat.

4.6.2 Review of NRA restoration projects

In all types of fishery, a high proportion of projects were poorly documented and there was little information about their impact on the fish populations, either in the short-term or in the long-term. Specific 'before and after' fish surveys were reported for less than half of the projects, and were generally less evident for salmonid fisheries. Some of these surveys were part of the normal routine fish population surveys. Long-term records on fish populations were available for about half of the projects.

This lack of basic information suggests that many of the reasons given for carrying out habitat restoration were based upon subjective assessments by NRA staff and/or anglers and riparian owners. Most projects appeared to be designed to give a general increase in habitat diversity, rather than to rectify a particular habitat defect. Particular defects that were identified (e.g. low river depth, compacted spawning gravel) were often assumed to be detrimental to the fishery without apparent examination of other, more serious factors that could be limiting the population. Natural year-by-year variation in fish populations appeared not to be considered in assessing the current status of a fishery.

There was no information about the durability of actual restoration structures, though there was some commitment to maintain about 60% of the schemes, mostly by the WA or NRA. Information on project costings were meagre. and often non-existent. Hence, cost/benefit assessments were impossible.

4.6.3 Recommendations for assessing restoration schemes

a) Define factors limiting the status of a particular fishery. This could include a survey (preferably several surveys) of the pre-restoration fish population(s).

b) Design the restoration project to offset these limiting factors, with particular reference to the habitat requirements of the target fish species. Note that these requirements can change during the life of the fish, and with the type of river habitat. Specify the 'Success conditions' for the scheme.

c) Assess the result of the scheme (i.e. were the pre-determined conditions of success fully met (or partly, or not at all).

d) Fully document all aspects of the project, including engineering and fishery aspects. This is as equally important for unsuccessful projects as it is for successful ones.

C. RECOMMENDATIONS FOR PHASE 2

TO BE ADDED

APPENDIX A

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APPENDIX B

Details of the Questionnaire circulated to NRA staff.

Note that the spacing between questions has been reduced; the circulated questionnaire gave more space for answers.

SECTION I

1. NAME:

2. NRA REGION (or subregion)

3. HOW MANY MILES OF RIVER ARE THERE IN YOUR REGION/SUB REGION UNDER THE FOLLOWING CATEGORIES ?

   SALMON FISHERY

   TROUT/SEA TROUT FISHERY

   COARSE FISHERY

   In the case of mixed fisheries please fill in more than one category.

4. IN YOUR OPINION HOW MANY MILES OF RIVER IN YOUR REGION/SUBREGION WOULD BENEFIT FROM HABITAT IMPROVEMENT UNDER THE FOLLOWING CATEGORIES:

   SALMON FISHERY

   TROUT/SEA TROUT FISHERY

   COARSE FISHERY

SECTION II (Please use one form per restoration project)

1. NRA REGION:

2. NAME OF RIVER:

3. LOCATION (MAP REF):

4. TYPE OF FISHERY (Please tick: more than one if necessary,but encircle the principal fishery):

   SALMON TROUT/SEA TROUT   COARSE FISH

5. REASON FOR THE RESTORATION:

6. TYPE OF RESTORATION (i.e. physical modification, including any changes to the river gradient, channel morphology, banks etc.)

7. WHO CARRIED OUT THE RESTORATION (Please tick)

   WATER AUTHORITY/NRA

   OTHER (Please specify)

8. RIVER WIDTH AT RESTORATION SITE:

9. LENGTH OF RIVER BENEFITTING FROM THE RESTORATION:

10. DATE OF RESTORATION - MONTH(S) YEAR:

11. APPROXIMATE COST OF RESTORATION: £

12. WERE LONG-TERM (>5 years) RECORDS OF THE FISH POPULATIONS AVAILABLE ?

    YES   NO   (Please tick)

    IF YES - WHAT TYPE OF RECORDS (Please tick)

    ANGLERS' CATCHES
    } - NETTING
    POPULATION ESTIMATES } - ELECTRO-FISHING
    } - OTHER (Please specify)

13. WAS A SPECIFIC FISH SURVEY CARRIED OUT BEFORE THE RESTORATION?
YES NO (Please tick)

IF YES - HOW MANY SURVEYS:

DATES - MONTHS/YEAR:

WHAT TYPE OF SURVEY (Please tick):

} - NETTING
POPULATION ESTIMATES } - ELECTRO-FISHING
} - OTHER (Please specify)

14. WAS A FISH SURVEY CARRIED AFTER RESTORATION ?

YES NO (Please tick)

IF YES - HOW MANY SURVEYS:
DATES - MONTHS/YEAR:

WHAT TYPE OF SURVEY (Please tick):

} - NETTING
POPULATION ESTIMATES } - ELECTRO-FISHING
} - OTHER (Please specify)

15. WERE ANY OTHER ENVIRONMENTAL IMPACT ASSESSMENTS MADE CONJUNCTION WITH THE RESTORATION ? Please tick:

	BEFORE	AFTER
RIVER CORRIDOR		
INVERTEBRATE SURVEY (E.G. RIVPACS)		
OTHER (Please specify)		

16. HOW DID THE FISHERY CHANGE AS RESULT OF THE RESTORATION ? Please tick:

CONSIDERABLE IMPROVEMENT:

MODERATE IMPROVEMENT:

NO CHANGE:

DETERIORATED:

UNKNOWN:

17. HOW WAS THE CHANGE IN THE FISHERY ASSESSED ?

18. WHAT WAS THE COMMITMENT CONCERNING MAINTENANCE OF THE RESTORATION (Please tick)

RESTORATION IS MAINTENANCE FREE:

COMMITMENT BY WATER AUTHORITY/N.R.A.:

NO COMMITMENT:

OTHER (Please specify):

19. IS A REPORT(S) OR UNPUBLISHED PAPER(S) AVAILABLE CONCERNING THE RESTORATION PROJECT ?
Please tick:

ON THE ENGINEERING ASPECTS:

ON THE FISHERIES ASPECTS:

ON OTHER ASPECTS (Please specify):

20. PLEASE GIVE ANY FURTHER DETAILS OR COMMENTS THAT WILL CONTRIBUTE TO THIS STUDY:

21. NAME OF NRA CONTACT CONCERNING THE ENVIRONMENTAL (FISHERIES) ASPECTS OF THE RESTORATION PROJECT

NAME:

ADDRESS:

TEL. NO.

FAX. NO.

Thank you for your cooperation..

APPENDIX C

Contents of the article that appeared in FISH, Issue No. 24, October 1991, page 33.

Restoration of Riverine Fisheries Habitats

Many schemes have been carried out in recent years to improve fisheries by physically restoring riverine habitats. The techniques used include the installation of gabions and low level weirs, increasing river meanders and altering the pool/riffle sequences. But how effective are these and similar remedial measures - and how should their effectiveness be assessed ?

To address these and related questions the NRA has commissioned an R & D Project on fisheries habitat improvement schemes. The first, one-year, phase started in July 1991, the work being carried out by the NERC Institute of Freshwater Ecology led by Mr Richard Mann, with Dr Jonathon Wortley acting as the NRA co-ordinator. The study seeks to examine current and recent restoration schemes throughout the NRA regions and to quantify future needs in the regions for habitat improvement of rivers. Information will also be collected on the procedures used in other countries.

Fisheries for salmon, trout and coarse fish are being examined separately and an initial questionnaire has been sent already to over 50 NRA Fisheries Managers, Officers and Scientists regarding restoration schemes in their area. By close consultation with the biologists and engineers responsible for designing and carrying out restoration projects, it is hoped to identify the criteria needed to implement successful schemes, and to recommend where they may be more widely applied.

It may be that there are some schemes that have had little or no Water Authority/NRA involvement and Richard Mann would be pleased to receive information about them. His address is: I.F.E., Eastern Rivers Laboratory, c/o Monks Wood Experimental Station, Abbots Ripton, Huntingdon, Cambs. PE17 2LS (tel. 04873-381).