Factors Affecting Coarse Fish Recruitment

Institute of Freshwater Ecology,
International Fisheries Institute
(Hull), SGS Environment,
Uninersity of Hertfordshire

R&D Technical Report W75

Further copies of this report are available from:

FWR

Foundation for Water Research, Allen House, The Listons,
Liston Rd, Marlow, Bucks SL7 1FD. Tel: 01628-891589, Fax: 01628-472711

Factors Affecting Coarse Fish Recruitment

LCV Pinder, RHK Mann, M Ladle, I Cowx, K O'Hara, GH Copp,
P Garner, AW Bark

Research Contractors:
Institute of Freshwater Ecology, International Fisheries Institute
(Hull), SGS Environment, Uninersity of Hertfordshire

Environment Agency
Rio House
Waterside Drive
Aztec West
Almondsbury
Bristol
BS12 4UD

R&D Technical Report W75

Publishing Organisation
Environment Agency
Rio House
Waterside Drive
Aztec West
Almondsbury
Bristol BS12 4UD

Tel: 01454 624400 Fax: 01454 624409

NW-04/97-15-B-AYKI

Dissemination status
Internal: Released to regions
External: Public Domain

Statement of use
This scoping study was aimed at identifying what factors affect recruitment in riverine coarse fish populations and quantifying their impact and the mechanism(s) by which they operate. The report will help the Coarse Fisheries Technical Group define the terms of reference of phase two of the project.

Research contractors
This document was produced under R&D Project W2/023 by:

Institute of Fresh Water Ecology
Monks Wood
Abbots Ripton
Huntingdon, PE17 2LS
Tel: 01487 773381

International Fiseries Institute
University of Hull
Hull, HU6 7RX
Tel: 01482 466 427

SGS Environment,
Yorkshire House,
Chapel Street,
Liverpool, L3 9AG
Tel: 0151 255 1115

Dept of Environmental Sciences,
Univ of Hertfordshire,
College Lane,
Hatfield, AL10 9AB
Tel: 01707 28 5563

Environment Agency's Project Manager
The Environment Agency's Project Manager for R&D Project W2/023 was:
Miran Aprahamian - North West Region

EXECUTIVE SUMMARY

For the Environment Agency to effectively manage fisheries there is a requirement to understand what factors, both biological and environmental, affect the abundance of fish populations and the mechanisms by which these factors operate. In order to do this the Agency asked four contractors to scope out a study aimed at identifying what factors affect recruitment in riverine coarse fish populations and quantifying their impact and the mechanism(s) by which they operate. The contractors were: the Institute of Freshwater Ecology (IFE), University of Hull International Fisheries Institute (HIFI), SGS Environment (SGS) and a consortium (UH) from the University of Hertfordshire, The Freshwater Biological Association and Kings Environmental Services.

The contractors were required to outline and justify independently, wherever possible:

a) where the study(s) should be carried out;
b) the target fish species;
c) the biotic and abiotic factors to be measured and the precision with which they should be determined;
d) the method(s) to be used to sample the population(s), the frequency of sampling and the level of precision;
e) over what time period should the study be carried out;
f) how the data are to be analysed;
g) the cost of the programme in terms of planning, sampling, analysis and reporting; and
h) how the studies relate to management issues and how they might influence best practice within the Agency.

The conclusions from the various contractors have been presented in separate sections of the report, and have been summarised in the three tables below.

Table 1: The main species identified, with the numbers referring to priority (1 = the highest) and letters indicating the species which should be chosen as representative of a particular group.

Species	Roach	Dace	Chub	Barbel	Bream	Silver Bream	Tench	Pike	Perch	Bleak	Gudgeon	Rudd	Eel
HIFI	1	1	1		1			2A	2A				
IFE	1A	1B	1B	1B	1C	1C	1C	1D	1D	2	2		
SGS	1	5	3	4	2			8	6	9	7		
UH	1A	1B	1B	2	1A	1D		1C	2			1D	2

Table 2: The main locations (choice of river).

RIVER	Gt. Ouse	York. Ouse	Severn	Trent	Dee	Thames	Frome	Hamp. Avon	Canals	Stillwaters
HIFI	✓	✓	✓	✓	✓					
IFE	✓	✓					✓	✓		
SGS			✓	✓		✓			✓	✓
UH										

Table 3: The main components of the studies (Mvts - movements, Disp. - Dispersion, Hybrid. - Hybridization, Dist. - Distribution, Antho - Anthropogenic).

	Iden. keys	Habitat	Mvts	Disp.	Growth	Diet	Mortality - incl. over wint. surv.	Hybrid.	Repr. Bionomics	Dist.	Antho. effects	Sampling
HIFI		✓	✓	✓	✓	✓	✓		✓	✓	✓	
IFE	✓	✓	✓	✓		✓		✓				
SGS		✓			✓		✓					✓
UH		✓	✓	✓	✓	✓	✓		✓		✓	✓

In addition IFE proposed a detailed analysis of the Great Ouse & Frome data, SGS suggested sampling at 40 sites in the bream & barbel zone to look at the relationship between juvenile and adult abundance and the effect of flow and temperature and UH included a programme which involved sampling at circa 40 sites to estimate density, biomass, growth rates, fecundity, mortality, diet, parasites & habitat requirements.

All four contractors suggested long term projects (>10 years).

The four reports were used to assist the Agency in formulating an investigation into identifying and quantifying factors affecting recruitment in riverine coarse fish, the studies helped identify the priority areas and the resources that must be secured to ensure successful completion.

CONTENTS

The Institute of Freshwater Ecology
L C V Pinder, R H K Mann and M Ladle

EXECUTIVE SUMMARY

(i) **TARGET SPECIES** should be selected to represent the range of major ecotypes inn British lowland rivers. The core group of species should include **roach**, as an example of a eurytopic (generalist) species, rheophilic, gravel spawners (**dace, chub, barbel**) phytophilous spawners (**bream, silver bream, tench**) and a predator (**pike or perch**).

(ii) **A MINIMUM OF 3 RIVERS** is required for most aspects of the research, to ensure that conclusions and models are based on an appropriate range of environmental conditions. Individually, and collectively the selected rivers should allow access to as many as possible of the selected, target species. The **Great Ouse** is recommended as an example of a slow-flowing, highly managed and regulated lowland river, with the **Dorset Frome** and **Hampshire Avon** as contrasting, relatively unperturbed lowland rivers. The **River Swale** or another of the tributaries of the Yorkshire Ouse is suggested as a good example of an upland catchment, supporting a good coarse fishery. All have a history of research and data collection and / or are within resaonable distance of established fisheries research organisations.

(iii) Long-term data sets (10 years or more) are required to provide a holistic interpretation of environmetal factors influencing year class strengths in coarse fish. Such information probably does not exist in the form of discrete data sets and would be extremely expensive and time-consuming to generate. It is recommended that **EXISTING DATA** should be examined more carefully with a view to gaining added value from combining data from various sources. Examples are suggested for initial study.

(iv) A prerequisite to research on recruitment of coarse fish is the ability to identify accurately the larval and juvenile stages. priority should be given to the production of accurate **DESCRIPTIONS AND KEYS** for the identification of larvae and small juveniles based on bothe hatchery reared and "wild" fish.

(v) There is a lack of detailed understanding of coarse fish **SPAWNING BEHAVIOUR** and and of the factors influencing choice and suitability of **SPAWNING SITES**. Research on spawning, associated behaviour, egg development and rates and causes of mortality of embryos, in relation to local environmental conditions is considered to deserve high priority.

(vi) The significance of **BARRIERS TO COARSE FISH MOVEMENTS AND MIGRATIONS, ESPECIALLY IN RELATION TO SPAWNING,** is not understood. Research on this topic, using a combination of radio-tracking and physical tagging is recommended, with attention initially focussed on dace and common bream, in the Dorset Frome and Great Ouse respectively, with subsequent extension of the research to other rivers and species..

(vii) Reduced habitat diversity, resulting from river management in some instances is likely to lead to a breakdown in the behavioural mechanisms that maintain the genetic integrity of populations of some coarse fish species. High rates of **HYBRIDISATION** that result are likely to pose a threat to the survival of species populations or subpopulations that are already depleted through degraded habitat conditions. This problem should be investigated with emphasis on highly managed and modified rivers and species that are believed to have sufferd significant local

declines in population size.The question of common bream in the Great Ouse is highlighted as an example.

(viii) There is a need for further research on a range of rivers to compare temporal and inter-specific differences in **DIETS OF LARVAL AND YOUNG JUVENILE CYPRINIDS** and to establish the conditions under which food may become limiting to growth and survival.

(ix) **DOWNSTREAM DISPLACEMENT**, especially of young fish, by high current velocities potentially has a significant impact on coarse fish populations. This may be especially important in channelized rivers where refugia from high velocities are few and in impounded rivers where weirs and sluices restrict the possibility of compensatory upstream migration. There is a need to establish the conditions under which downstream displacement may be significant and its significance, if any, in to coarse fish populations.

(x) There is evidence that **CONNECTION OF RIVER CHANNELS TO ADJACENT WATER BODIES, SUCH AS DISUSED GRAVEL PITS**, can have a beneficial impact on the river fishery. This may be brought about through creation of a better food supply, protection from high velocities or creation of additional spawning habitat for phytophilous species. Research on the benefits to fish populations of connecting river channels with such lateral habitats and of the mechanisms underlying any such benefits required in order to provide the information necessary for appropriate management in situations where this possibility exists.

(xi) Estimated **COSTS** are intended to be indicative only and will vary according to the contractor, and the precise details of any agreed programme or project.

1. INTRODUCTION

The objective of the present contract is ;

" To scope out a study aimed at identifying what factors affect recruitment in riverine coarse fish populations and quantifying their impact and the mechanism(s) by which they operate".

In general terms, the critical steps that are involved in determining recruitment success among fish populations are;

- Extent and availability of spawning habitat
- Viability and survival of eggs
- Growth / survival during immediate post-hatching period
- Growth / survival to end of first summer
- Survival over first winter.
- Subsequent survival and age at maturity
- Size and fecundity of breeding stock

The relative importance of each step in determining year class strength will vary according to species and river conditions. However there is a good deal of evidence that variations in year class strengths are predominantly influenced by spawning success and survival of young over the first year. The early developmental stages are particularly vulnerable and this draft scoping report therefore concentrates on these early stages and the factors likely to influence them. It is essential that river managers are provided with the necessary fundamental understanding of the biological, and physical interactions influencing these processes that will allow them to manage rivers and fisheries in a holistic and sustainable manner. This is nowhere more important than for the larger rivers where regulation and channel simplification have produced substantial reductions in habitat diversity with a drift towards communities that are dominated by a small number of eurytopic species, notably roach. A thriving and diverse fish community is desirable not just for its own sake but also as an indicator of a generally healthy and diverse ecosystem.

Cowx et al. (1995) make a useful contribution to the understanding of factors influencing coarse fish populations in rivers but inevitably fails to take account of some of the ongoing work, much of it being carried out at the IFE River Laboratory (Wareham, Dorset) and Eastern Rivers Laboratory (Monks Wood, Cambridgeshire). Specific reference will be made to aspects of this research at appropriate points in this report, but the work on the Great Ouse has been particularly concerned with the habitat requirements (including food) and growth / survival of larval and juvenile cyprinids and so is of particular relevance in the present context. The following general comments are made in response to the summarised conclusions from Cowx et al.(1995), contained in the initial brief for this contract.

(1) *"Little is known about the early life history of coarse fish and the factors influencing individuals at this stage, which have profound implications for recruitment to adult fish populations and subsequent year class strengths".*

Recent research on the Great Ouse has supplemented the available information on factors influencing larval and juvenile cyprinids particularly in terms of diet (Mann et al., 1997), growth rate in relation to diet (Mann,1997; Garner, 1995), the factors influencing food availability (Bass et al., 1997a, 1997b; Marker & Collett, 1997a, 1997b), current velocity tolerances and preferences (Garner, 1995; Mann and Bass, 1997) and general habitat selection (Copp, 1992; Garner 1995; Garner & Mann, 1996). Unpublished Environment Agency (Anglian Region) data on the reach-related size distribution of young-of-the-year fish in the Ely Ouse system provides additional insights into localised variation in early growth and annual variations in recruitment success. Much of this work is biased towards roach which are the dominant species, but more limited data are also available for other cyprinids.

(2) *"Temperature may exert an overriding influence on the growth of fry, but the way it does this has not yet been ascertained. It is possible that three consecutive months of high temperatures are required, or that there is a threshold level above which strong year-classes will result."*

Research on the Great Ouse indicates that the quantity and quality of available food also plays an important part in determining growth rates and by implication may also affect survival, independently of temperature (Mann, 1997; Environment Agency, unpubl. data).

(3) *"The supply of food and its variability at critical stages of development has been recognised as a significant factor in the growth of fry. However there appear to be little or no empirical (Environment Agency) data to justify this hypothesis and further work is required to clarify the situation. This is considered fundamental to evaluating the underlying factors influencing the survival of coarse fish in their early life stages."*

A substantial quantity of relevant data has arisen from the work on the Great Ouse. Availability of suitable prey during the immediate post-hatching period may be especially critical and, because it is susceptible to substantial and rapid changes in abundance (Bass et al., 1997) may affect coarse fish species differentially - favouring good year classes in some species but not in others, depending on spawning and hatching times.

(4) *"The growth of coarse fish in their first year of life is important in determining year class strength. However in rivers, years of good growth do not always convert to strong year classes, suggesting that other factors are therefore responsible."*

This serves to emphasise the importance of adopting an holistic approach to fish research, taking account especially of physical habitat conditions (channel geomorphology and hydrology in particular) and their role in determining overwintering success. It also serves to emphasise the need for data to be available for a series of rivers so as to encompass a range of characteristics, from the relatively "natural" to the highly managed and regulated.

"It was evident from R&D Note 460 that there was a general absence of any long-term data sets on fish numbers together with any environmental data, except temperature, and biological data. Therefore if the Environment Agency are to obtain an understanding of the factors affecting year-class strength in coarse fish a wide ranging holistic approach is required with data needed on habitat, food supply, predators and water quality. In the absence of any suitable data sets in the Environment Agency a programme needs to be put together to collect the relevant data over an appropriate time scale."

The need for a properly coordinated "holistic" programme of research to provide the data required for improved and sustainable management of riverine coarse fisheries is apparent. However additional value is also likely to be derived through investigation of existing data bases, singly and in combination. New research programmes, taking a holistic approach, as defined, would require to run for a minimum of 10 years to provide data of value to river management and would probably be prohibitively expensive.

2. THE TARGET SPECIES

To provide maximum benefit and cost efficiency target species need to be selected to be representative of the range of major ecotypes in British lowland rivers.

The core group should include broad generalist (eurytopic) species (roach), rheophilic, gravel-spawning species (dace, chub, barbel), phytophilous spawners (bream, silver bream, tench) and a predator (pike or perch).

Bleak and gudgeon though not regarded as being of highest priority might also be considered because of their interest to match-fishermen, while carp and zander are now abundant in a number of rivers and are also of potential interest, principally in view of their interactions with other species.

3. THE CHOICE OF RIVERS

A number of criteria need to be considered in selecting rivers for any future research programme.

- Several (a suggested minimum of three) rivers need to be studied in order to allow initial models to be robustly based on a broad range of environmental characteristics.
- The existence of a significant amount of historical background data and fisheries related research, especially where this has been directed towards the factors influencing recruitment success, would add significantly to the value of any additional data that are gathered.
- The rivers should individually and collectively provide access to as many of the desirable target species as possible, to maximise the strategic value of the research programme.
- The rivers should be readily accessible to established laboratories or research groups to keep costs at an acceptable level.

Smaller rivers have advantages for study in that they are relatively easy to sample quantitatively and may permit direct observation of spawning habitats and behaviour. Monitoring of movements, including spawning migrations is also easier to accomplish in smaller rivers. Most will support only a limited number of species which limits their usefulness, however. Larger rivers, are more likely to support a larger number of species and hence are potentially more productive of relevant data and in general it is the larger rivers that are most affected by management and regulation and which thus give most cause for concern..

Eastern England - The Great Ouse

A substantial amount of research has been carried out since 1989 on the middle reaches of the Great Ouse, as an example of a highly managed and regulated lowland river, by the Institute of Freshwater Ecology. The fish community of the Great Ouse is now dominated by small roach, a generalist species in terms of feeding and spawning behaviour - traits that have enabled it to thrive in the simplified habitat conditions created by channelization and regulation. Less versatile species such as bream, chub and barbel have declined in numbers and are much more restricted in their distribution. The progress that has been made in elucidating the ecological requirements and habitat characteristics of species of larval and juvenile cyprinids, together with the relatively long run of Environmental Agency data on fish populations in rivers of the Anglian Region provides a sound basis on which to develop further research on factors influencing recruitment. recent Environment Agency projects associated with recruitment in the Great Ouse have included habitat restoration, deployment of artificial reefs and application of "soft engineering" techniques for bank stabilisation.

Chalk streams and rivers of southern England

The Great Ouse is an extreme example of a slow-flowing, managed river and research needs to be pursued on other rivers as well. The chalk streams and rivers of southern England provide a striking contrast and also have the advantage of close proximity to the IFE River Laboratory with its long history of research on fish and freshwater ecology in general. Studies on movements of cyprinids, using radio tracking have been developed over several years in the Dorset River Frome while data on dace populations in the East Stoke Mill Stream extend over 30 years. The coarse fish fauna of the River Frome is however fairly restricted, mainly comprising dace, roach, pike and grayling. Research would need to be extended to a larger river, such as the Hampshire Avon.which supports a more diverse coarse fishery. The middle and lower reaches of the Avon are highly regarded as a coarse fishery with many species growing to a large size. There has however been a widespread feeling for a humber of years that the catchment of the Hampshire Avon has deteriorated in various respects, including the quality of the fishery, and research on factors affecting recruitment would be highly appropriate not only to the management of this river but as a further contribution to establishing wider principles of sustainable, holistic river management.

The northern, upland catchments.

It will be important to include at least one river with a predominantly upland catchment to contrast with the lowland rivers that are suggested. Several strong contenders exist among the rivers feeding into the Yorkshire Ouse. The River Swale, for example, supports a substantial and varied coarse fishery with good populations of lithophilous species, such as barbel and chub in particular. The flashiness and power of these rivers will provide a strong contrast with the hydrology of the lowland rivers of the south and east. Although there is no long term history of research on these fisheries, specific projects on juvenile cyprinids (fry surveys) have been undertaken recently and these rivers are are relatively close to established centres of fishery research in the University of Hull and the IFE Windermere Laboratory.

Environmental data

Basic environmental data required for each river are discharge, temperature and oxygen concentration, all of which need to be recorded continuously. Background chemical data, nutrients, pH, conductivity etc., for which monthly data would be sufficient. Chlorophyll *a* concentration, weekly during spring, monthly at other times.

4 THE RESEARCH PROGRAMME

4.1. A holistic view of the influence of environmental factors on year class strengths- better use of existing data

Cowx et al. (1995) indicate a lack of any long-term data sets suitable for comparing year-class strengths with environmental data, other than temperature. If this is the case, and such data are needed to tackle the problem holistically, then a long term study, of at least 10 years, is required. Such a prospect, especially if it involves a range of river types is probably unrealistic, but a short term (3 year) study on fish populations and environmental variables is unlikely to provide useful answers to management problems. We therefore recommend that existing Environment Agency data bases, which now extend back over a number of years, and any other long-term data bases are examined for evidence of frequency and level of year-class-strength variation and that interpretation should be enhanced through the addition of data from other suitable sources. The latter need not necessarily have been collected over the same time scale so long as they are sufficient to allow the development of retrospective models of environmental conditions, such as food availability at critical stages.

Strategy
(i) The Great Ouse data

Anglian Region has collected data, that should allow comparisons of year class strengths, as a 3 year rolling programme of sampling since the early 1980s, for the Great Ouse and other rivers in the Anglian Region.. In conjunction with data derived from research, carried out by the Institute of Freshwater Ecology since 1989, this provides the possibility of relating year class strengths to a suite of environmental conditions in the Great Ouse over a period of roughly 15 years.

In addition to temperature the important environmental factors likely to influence between year variability in recruitment success are discharge and food availability, especially during the early stages of development when fish are able to feed on a very restricted size-range of prey.. Daily discharge data are readily available from the National Surface Water Archive. Water temperature data are probably available within the Environment Agency over the necessary period but if not then it will be possible to derive a relationship between air and water temperatures. This leaves the problem of data on variation in food supply which we believe is soluble, at least for the vulnerable early post hatching period, using IFE data for the Great Ouse.

Mann (1997) has shown that year to year variations in length increments of 0+ roach in relation to temperature appear to be a result of changes in food availability. Under similar temperature conditions, between-year differences in growth trajectories occurred during the summer at the same site, even though the final mean sizes of fish at the same site in different years were not very different. Mann concluded that this phenomenon has important implications for recruitment success, since it is known (e.g Mills & Mann, 1985) that the growth of many cyprinid species in the first few weeks after hatching largely determines their survival rate over the first year, and hence the subsequent survival strength of that year class. Broughton and Jones (1978) also concluded, from studies of 0-group roach in the River Hull that water temperature, acting through the food supply, is the dominant factor affecting fish growth.

The principal food of cyprinids during their first few weeks after hatching is planktonic rotifers (Mann et al, 1997). Bass et al. (1997) showed that densities and patterns of abundance of planktonic rotifers in the Great Ouse varies substantially between years, in response to a combination of phytoplankton dynamics and variation in discharge. Since numbers can fluctuate dramatically over the period of cyprinid hatching it is possible for initial feeding conditions for fish species with different hatching times to differ substantially even in the same year.

Data on rotifer and phytoplankton populations are available for the Great Ouse from 1989 until 1993. These data are capable of being used to develop a model of trends in rotifer dynamics in relation to discharge, which would permit hindcasting of trends in feeding conditions for young cyprinids in the river over the period of years for which Environment Agency data on fish population are available, thus permitting a more detailed analysis of environmental influences on year class strengths than has hitherto been possible. If successfully applied to the Great Ouse the methodology could be extended subsequently to other slow-flowing lowland rivers for which suitable data on year class strengths are accessible.

(ii) Long-term dace populations data, River Frome

Data on dace populations from the Mill Stream (R. Frome) at East Stoke, have been collected over a period of about 30 years. These data have not been accompanied by other detailed biological data, notably food supply. The data do offer the opportunity, however, of: (a) establishing the strength of the relationship between size at age 1 and year class strength, through back-calculation of body length; (b) establishing the strength of the relationship between water temperature and year class strength, using a long run of data.

Anticipated results and benefits to Environment Agency

A substantial improvement in understanding of the factors influencing coarse fish recruitment success using existing data at a relatively modest cost to the Agency. More precise identification of areas in need of further research, resulting in improved targeting of resources.

Costs

The cost of the study associated with the Great Ouse data is estimated as **£20k**

The cost of analysing and interpreting the data on dace from the East Stoke Mill Stream would be about **£10k.**

4.2 Identification of larval and juvenile coarse fish.

A major hindrance to research on the young stages of coarse fish, and hence to research on factors influencing growth and survival, is the absence of adequate descriptions or "keys" for their identification. This is particularly a problem with the very young fish, prior to full development of their fins. Development of "tools" for the identification of young fish is therefore considered to merit high priority.

Strategy

Larval fish pass through a range of developmental stages and each will need to be considered. A primary source of material for study would be the Environment Agency's hatchery at Calverton, Notts. Small samples from as many species as possible would need to be collected on a daily basis from hatching until the completion of fin-development However this material would need to be supplemented for comparative purposes with additional samples from a range of river sites. the Institute of Freshwater Ecology already has some suitable material available from the Thames, Great Ouse and Tees, for example and has staff skilled in the identification of young fish.

It is unlikely that all species of coarse fish could be dealt with at once and initial attention should be concentrated on more common and recreationally important species, with other species being added in later phases of the project.

Outline methodology

Existing literature on identification of larvae would be reviewed and critically assessed through comparison with larvae of known provenance at the full range of developmental stages. Larvae of as many species as possible would be obtained from the Environment Agency's hatchery at Calverton. Small samples would be required to be taken at daily intervals, in order to take account of the full range of intraspecific variation during development. The conditions of sampling and subsequent treatment of material would be carefully controlled in order to take account of natural variation within a developmental stage, and variability in appearance mediated through differences in handling of material. Additional material for comparative purposes would be obtained from a variety of other sources. Some would be available from sampling programmes associated with other phases of the programme to be developed from the present scoping study, and other material could be available from other independent sampling programmes.

Descriptions and keys would be based on a critical reassessment of the literature and an independent assessment of the new material from both hatchery reared and "wild" stock. Although juvenile fish are less of a problem for identification we believe that there would be practical advantage in including descriptions and keys for small juveniles as well as larvae. It is essential that the "tools" arising from this study are well illustrated, with both photographs and line drawings.

Anticipated results and benefits to Environment Agency

Well illustrated keys and detailed descriptions, potentially on CD ROM as well in the form of conventional reports or publications, will facilitate accurate identification of larval and juvenile fish and hence improved ability to assess initial habitat utilisation, recruitment success and survival, and provide essential tools for further research on factors influencing coarse fish recruitment.

Costs

The initial cost of producing keys and descriptions for the common coarse fish species, including photographs and good quality line drawings is estimated as **£15k**. This assumes that material will be provided free of charge by the Environment Agency's hatchery and that additional material arising from other sampling programmes, such as those of the IFE would be made available free of charge. It does not include the cost of any publications arising from the project. Additional work, involving species not available during the initial phase is likely to be concerned mainly with smaller, recreationally less important species and those which are more sparsely distributed. These would be the subject of subsequent, supplementary projects, and additionally costed projects as appropriate.

4.3 Spawning habitats and behaviour associated with spawning

In respect of their spawning behaviour riverine fish may broadly be classified, using the terminology of Balon (1975,1981) as phytolithophils., lithophils and phytophils. Phytolithophils include species such as bleak, roach and perch that normally spawn on submerged macrophytes but which will utilise alternative substrata, such as gravel, when plant surfaces are not available. Common bream are often regarded as phytolithophils but Mann (1996) points out that while they may use alternative substrata in still waters, in rivers they have only been reported as spawning on macrophytes and in this situation at any rate they are more properly regarded as phytophilous. Typical lithophils include barbel, dace and chub, all of which spawn on areas of clean well oxygenated gravel. Siltation of gravels may have a significant impact on egg survival (e.g. Mills, 1981). Phytophils, tench, carp, rudd, silver bream (and in rivers also common bream) rely entirely on aquatic macrophytes as spawning substrata, which in heavily managed rivers, where plants are restricted, may limit their distribution to reaches with less intensively managed backwaters and side-channels (e.g. Copp, 1997).

Strategy
Spawning areas and habitats would be identified within defined reaches for selected species within each of the 3 or 4 rivers selected for study and detailed data on habitat conditions would be collated. Similar data would be gathered for other potential habitats, not selected for spawning. Egg development and mortality would be monitored and causes of mortality evaluated where possible.

Outline methodology
Reaches selected for study would be carefully surveyed to provide information on habitat structure and diversity. Habitats would be classified into categories and their distributions would be mapped.

Use of habitats for spawning within the selected reaches would be determined by a combination of radio-tracking (this would be restricted in extent by the amount of equipment available and would be linked with studies of spawning migrations and impacts of barriers to fish movement Section 4.3) and, where possible, direct observation, together with direct sampling of substrata and any associated eggs which would then be hatched and identified in the laboratory.

Spawning habitat and associated environmental conditions would be described in detail (flow, oxygen, temperature, plant species and structure (in the case of macrophyte spawners), particle type and size distribution, siltation characteristics (in respect of bottom spawners). Similar data would be assembled for other apparently suitable but unutilised areas of habitat for comparison.

Egg development and mortality in relation to habitat characteristics, would be monitored by rpeat sampling of eggs from a selection of locations.

Key species would be:-
All rivers: roach, a generalist spawner (phytolithophil).
Dorset Frome: Dace, grayling, (lithophilous species), pike.
Hampshire Avon: Chub, barbel (lithophilous species), perch..
Great Ouse: Common bream, silver bream, rudd (phytophils), perch.
Yorkshire Ouse system: barbel, chub (lithophils).

Anticipated results and benefits to Environment Agency
Identification of habitat conditions required for successful spawning by species of coarse fish, leading to improved ability to manage fisheries; through habitat creation and maintenance and avoidance of damaging management activities during critical periods.

Costs
In total the programme would cost about **£50k** which could be spread over a period of 3 years, with different rivers being studied each year.

4.4 Spawning migrations among coarse fish and the impact of barriers to movement on spawning success

It is not uncommon, for the same sites to be used for a number of years and by several generations of spawners, often involving associated spawning migrations (e.g. Diamond, 1985; Baras & Cherry,1990). Little is known in detail about the movements of coarse fish in relation to spawning. The significance of barriers to migration in relation to spawning success is a question that needs to be addressed urgently, especially in relation to regulated lowland rivers, which may have several barriers within a short reach of river. Techniques for radio-tracking of fish have been developed at the River Laboratory over several years. The technology is now sufficiently well developed for application in high conductivity waters like those of the Great Ouse where low signal strength from submerged radio-tags had previously posed some difficulty.

Strategy
Target species would initially be restricted, probably to dace in the River Frome for which some information on movement patterns is already available and common bream in the Great Ouse. The equipment is expensive but already exists within the Institute of Freshwater Ecology and additional equipment costs would be restricted to purchase of radio-tags. Later consideration could be given to extending the methodology to other species and / or rivers. Initial studies would be carried out on dace in the River Frome since some data are already available and there are no significant barriers to movements that would complicate interpretation of the data. There are preliminary indications that spawning migrations are undertaken separately by males and females and that females arrive at the spawning sites in advance of the males.

In the Great Ouse common bream appear to be restricted to spawning in large numbers to a small number of sites, which tend to be susceptible to disruption through weed cutting, although shoals do exist in other parts of the system where spawning appears to have low success. Shoals of bream from areas known to support high densities of young fish and from adjacent low-density spawning areas would be located by a combination of angling "intelligence" and echo-sounding. A subsample of fish from the shoals would be fitted with radio tags and movements of the marked fish before and during the spawning period would be monitored in relation to spawning activity and response to the various sluice and lock systems that create barriers to migration.

Outline methodology
Studies on the dace and bream would be carried out in subsequent years.

During year 1, dace movements would be monitored from late winter until after spawning in the Dorset Frome. Sexes are distinguishable from each other by late winter. A total of 10 fish, 5 males and 5 females, from 2 or 3 shoals within a short reach of the main river and an adjacent mill stream would be fitted with radio tags. A proportion of other fish in the shoals would be sexed and fitted with individually recognisable physical tags, either using visible, numbered implants or elastomer tags applied to the fins.

The radio tagged fish would be tracked using hand held receivers and fixed monitors from mid-January until after spawning was completed. On two to three occasions the shoals associated with the radio-tagged fish and any other shoals detected within the reach would be sampled. Data would be analysed to assess the timing and extent of spawning migrations; the extent to which males and females segregate during pre-spawning migrations; the extent to which shoal integrity is maintained or to which there is mixing during spawning.

A similar approach would be applied to a study of bream movements in the Great Ouse during year 2 but in this case the impact of sluices and weirs as barriers to migration would be included as part of the study. Two reaches would be selected, one with a high density of bream, where recruitment is known to be good and a second where recruitment is poor although shoals of bream still occur. Up to 10 fish would be radio-tagged in shoals at each site in February. Since Bream spawn later than dace it is not anticipated that movements associated with spawning will occur earlier than this. Other fish would be visibly tagged as in the case of dace and a similar sampling strategy will be adopted. Tagged fish would be located at 3 to 4 day intervals using hand-held devices and where possible fixed monitoring stations would be installed in the vicinity of barriers to movement.

Radio tags would be replaced or new individuals fitted with tags as necessary over the course of each of the studies.

Anticipated results and benefits to Environment Agency
Evaluation of the role of migration in relation to spawning and of the impact of barriers to migration on spawning success, leading to a better ability to manage fisheries through habitat creation and avoidance of disruptive management activities during critical periods.

Costs
£18k per year for 2 years with the option of extending the research to other species and a northern river at a later stage.

4.5 Potential for species extinctions through hybridisation

In a recent review, Rhymer & Simberloff (1996) drew attention to the possibility of species extinctions being brought about through hybridization. They were primarily concerned with hybridization resulting from introduction of non-indigenous species but habitat modification may also break down reproductive isolation between native species. The consequences are likely to be much more severe for "rare" species than for common ones. The potential for loss of species from rivers as a result of such mechanisms acting through habitat simplification has rarely been considered. However, there is evidence that in reaches of the Great Ouse lacking ideal spawning habitat, the already depleted populations of bream spawn in close proximity to roach (e.g. on submerged roots of *Salix* spp) resulting in a high incidence of hybrids which may of itself be detrimental to the long-term survival of bream in such areas. Creation of better spawning habitat or facilitation of migration through the provision of fish-passes could be necessary to overcome this problem. A comparison of the incidence of hybrids among juveniles in reaches where bream spawn successfully with those where spawning is restricted is needed to establish the scale of this problem. Sufficient data and samples already exist to allow a start to be made on assessing the extent of hybridisation problem but addittional samples would need to be taken, both from areas where bream spawn successfully and where spawning is restricted, as well as from other rivers for comparison.

Strategy

The proportion of bream hybrids among 0+ and 1+ fish would be compared at sites on the Great Ouse where bream have become uncommon in recent years and those isolated sites where they continue to be relatively abundant. The data would be examined for any evidence of a higher incidence of hybridisation in reaches where spawning habitat or habitat diversity generally is depleted.

Outline methodology

A series of reaches on the Great Ouse would be selected for study, including situations where bream are relatively uncommon and those where they continue to be relatively abundant. Surveys of instream habitat structure and diversity would be conducted for each reach in May.

Samples of 0+ and 1+ fish would be collected in August and September and bream and hybrid bream would be identified and separated. Any doubtful hybrids would be confirmed by examination of the pharyngeal teeth and if necessary by electrophoresis. The proportion of bream:hybridbream would be determined for each reach. Surveys of spawninh habitats would be carried out within each reach and the data would be analysed for any evidence that a depletion in habitat diversity through management, or loss of a specific types of habitat, results in higher than expected rates of hybridisation. If this is the case the implications for the future of affected populations will be assessed and appropriate management actions indicated.

Anticipated results and benefits to Environment Agency

Hybridisation is a potential problem that has not previously been given serious consideration as a factor in the population dynamics of coarse fish. It appears to have the potential to push species with populations already reduced in size through habitat depletion to local extinction and needs to be further investigated so that remedial measures of habitat improvement can be implemented urgently if necessary.

Costs
One year **£13k**

4.6 Comparative studies of the diets and growth rates of larval cyprinids in contrasting rivers.

As a result of the dominance of roach in the Great Ouse most data from the river relate to that species, although limited data are also available for others. Larval roach, like other cyprinids are initially restricted in the size of prey they can ingest by the size of the gape, which determines that their diet during the early stages of development consists almost entirely of rotifers and diatoms; the latter being more important when rotifer abundance is low. Once they are large enough they begin to feed on larger animals. Cladocera initially figure prominently with other invertebrates, notably Chironomidae becoming more important as the fish develop. In the river channels Cladocera and chironomid larvae are mainly grazed from plant surfaces, although in marinas fish continue to consume planktonic invertebrates, predominantly Cladocera..

The quality of the food source associated with plants in the Great Ouse varies substantially between years. (Bass et al., 1997b) When invertebrate numbers are low roach ingest "aufwuchs" unselectively and, although their guts are generally found to be full, growth rates are reduced when they are feeding on this evidently poor quality food (Mann & Bass, 1997). In marked contrast to roach some other species, notably common bream and chub feed selectively on invertebrates and when numbers are low their guts are often empty.

Poor growth rates among roach and the lack of suitable food organisms for more selective feeders has obvious implications for survival. There is a need for more research on a range of rivers to establish the conditions under which food may be limiting and the impact on year class strengths of key species.

Strategy
These studies would need to be carried out over several years in order to establish the extent of seasonal and inter-annual variability in food and growth rates under a range of conditions of flow and temperature. Initially a 3 year programme is suggested followed by a review which will determine whether sufficient added value would be obtained by continuing for a further period. A similar study has already been carried out on the Great Ouse with additional data available for the River Thames (commissioned by the Environment Agency, Thames Region). Future studies are therefore recommended to be carried out on the Hampshire Avon and an upland river such as the R Swale.

Outline methodology
Young fish would be sampled at weekly intervals from late April until mid-July and at fortnightly intervals thereafter until late autumn or until river conditions make sampling impossible. Initially, for the first week or two after hatching, samples are most easily obtained by using a hand net. Later samples can be taken using a micromesh seine-net.
Fish will be identified accurately and suspected hybrids will be separated for further investigation

in relation to Issue 4.5. All fish will be individually weighed, measured (standard length) and a subsample of each species will be retained for determination of lipid content.

Dietary analysis will be carried out on fish from alternate samples (i.e. fortnightly frequency). Small larvae may be mounted beneath cover slips in dimethyl hydantoin formaldehyde solution, or other suitable mountant without dissection, but the guts of larger fish must be removed and the contents spread to allow individual items to be identifiable.
Prey items should be identified by, or under the guidance of persons experienced in invertebrate identification.

Initially prey are expected to be mainly taken from the drift. Rotifera and perhaps algae are likely to predominate and as far as possible will be identified to genus. Later in the summer the fish will begin to feed on larger organisms and switch their behaviour to grazing from plants and stones and taking drifting terrestrial invertebrates. All organisms would be counted and identified as far as possible to a level that will allow an assessment of their probable origin (e.g., drift, plant surface, stony substrate, silt).

Data will be analysed for evidence of temporal and between-species differences in quantity and quality of food in relation growth rates and condition. Where possible inferences will be drawn concerning differences in feeding behaviour, for example, in relation to food and feeding sites.

Anticipated results and benefits to Environment Agency
Appreciation of the extent to which food for larval and juvenile fish may be limiting to growth and survival in some species and the circumstances in which this may occur. Management guidelines for measures that can be taken to improve the situation where necessary.

Estimated annual cost.
£20K per annum for each river

4.7 Downstream displacement of larvae, juveniles and adults and their significance for coarse fish populations.

Habitat simplification (channelization, restriction of macrophyte growth, reduced interaction of rivers with flood plain features) leading to a reduction in the extent of refugia from elevated current velocities has been implicated as an important constraint on coarse fish populations. It may be particularly significant in rivers with barriers to compensatory upstream migrations of coarse fish and may be a significant factor influencing the overwinter survival of juveniles. There is a need to establish the extent to which downstream displacement especially of young stages occurs in rivers of different types and of the environmental conditions that give rise to it. Recent unpublished investigations by the Environment Agency (Anglian Region) have indicated that lower rates of discharge through the Great Ouse Relief Channel have promoted increased survival of young roach by reducing displacement to the sea.

Strategy
Sampling would be carried out on the full range of rivers recommended for study. This encompasses the northern, upland rivers that are very responsive to rainfall over the short term;

southern rivers with a significant groundwater input, which are managed with a relatively low intensity and are less flashy; and a highly regulated lowland river, which while slow flowing for most of the time is subject to high velocities with few refugia for fish, during periods of high rainfall.

Outline methodology

Drifting larval and juvenile fish would be captured using drift nets or traps adapted from those commonly used in studies of invertebrate drift. A preliminary study would determine the optimum type and design of trap for sampling young fish.

Traps would be deployed in groups of 3, across the river over the period of a spate. Bridges, sluices or similar structures would be used from which to deploy the traps. Samples would be taken during the period of increasing discharge, at the peak of the hydrograph and over the subsequent fall. If possible 5 samples would be taken over a fixed time period in association with each "event". It would be important to sample the first major spate after the summer and 2 or 3, according to opportuniy over the winter period. Additional samples would be taken during normal flows to act as "controls". The suggested period for each sample is 30 minutes but in some rivers this might be impractical and a greater frequency of samples, of shorter individual duration might be preferrable

Anticipated results and benefits to the Environment Agency

Downstream losses of juvenile coarse fish may be an important constraint on fish populations in some rivers, that needs to be taken account of in the management of habitat and flow.

Cost

£12k for each river

4.8 Gravel pits and marinas as potential surrogates for flood plain features in degraded lowland rivers.

Loss of habitat marginal habitat diversity and interaction between rivers and their floodplains, through channelization and regulation are frequently cited (e.g. Petts et al., 1989; Stalnaker et al., 1989) as important contributory factors to the decline of fisheries in lowland rivers. Constraints on management of river channels imposed by the need for flood control, land drainage and navigation severely limit the extent to which this problem can be mitigated through changes in management of the river channels themselves. However, lateral features such as gravel pits / marinas are widespread along the valleys of many lowland rivers and have the potential to serve as surrogates for the depleted natural flood plain features. There is a good deal of evidence that connection of gravel pits to river channels can have beneficial effects for populations of some species and in the research on the Great Ouse it has been shown that feeding conditions within marinas, some of which are modified gravel pits, are often better than in the main river and that growth of juvenile fish is faster in such situations. Furthermore such structures can serve as refugia from high current velodities and provide valuable "dead zones" that allow phytoplankton and zooplankton populations to persist and recolonise the river after periods of high discharge.

Strategy
This work is most relevant to large lowland rivers such as the R. Trent, R. Thames, and R. Great Ouse.

Identify 3 lowland, river-reaches connected with gravel pits or large marinas. Compare growth rates and diets among 0+ fish within the gravel pits and adjacent river with those of fish in comparable reaches not associated with gravel pits. Monitor the degree of movement of adult and juvenile fish between the river and the marinas using a combination of mark / recapture techniques and radio-tracking. Establish, the extent to which gravel pits are utilised for spawning, especially by phytophilous species such as bream. Establish the extent to which such situations are used as refugia during periods of high discharge.

Outline methodology
Samples of 0+ fish would be taken at monthly intervals from each of 6 reaches (3 with gravel pits / marinas and 3 without) from June to October and then at two-monthly intervals through the winter and into the following spring, using hand nets and / or micro-mesh seines. All 0+ fish would be identified to species. Growth rates and condition of each species and in each sample would be assessed using the methods outlined in Issue 4.6

At one marina / gravel pit site only, a group of 5 adult common bream, or other appropriate species, some from within the marina/gravel pit and some from the adjacent river would be equipped with radio-tags and movements monitored over a one year period, Tags would be replaced or attached to new fish as necessary. A fixed monitoring station would be installed at the entrance to the marina if feasible. Special attention during tracking would be paid to periods associated with spawning and high discharge.

Spawning sites within the marina / gravel pit would be identified by a combination of direct observation, tracking of radio-tagged fish and substrate sampling. Eggs would be collected and hatched for positive identification. Egg development and mortality rates would be monitored as in Issue 4.3.

Anticipated results and benefits to Environment Agency
Assessment of the value of gravel pits and similar flood plain features in enhancing riverine coarse fisheries and guidance on management to maximise beneficial impacts

Costs
Estimated cost **£20k** for one year.

REFERENCES

Balon, E.K.(1975). Reproductive guilds of fishes: a proposal and definition. J. Fish.Res. Bd Can. 32: 821-964.

Balon, E.K. (1981). Additions and amendments to the classification of reproductive styles in fishes. Env. Biol. Fish. 6: 377-389.

Baras,E. & Cherry, B. (1990). Seasonal activities of female barbel *Barbus barbus* (L.) in the River Ourthe (Southern Belgium) as revealed by radio-tracking. Aquatic Living Resources, 3: 283-294.

Bass, J.A.B., Pinder, L.C.V. & Leach, D.V. (1997a) temporal and spatial variation in zooplankton populations in the Great Ouse. - an ephemeral food source for larval and juvenile fish. Reg. Rivs: Res. Mgt. 13: (in press).

Bass, J.A.B., Leach, D.V. & Pinder, L.C.V. (1997) The invertebrate community of submerged *Nuphar lutea* (L.) leaves in the River Great Ouse. Reg. Rivs: Res. Mgt. 13: (in press).

Broughton, N.M. & Jones, N.V. (1978) An invetsigation into the growth of 0-group roach (*Rutilus rutilus* L.) with special reference to temperature. J.Fish Biol., 12: 345-357.

Copp, G.H. (1992) An empirical model for predicting habitat use of juvenile fishes in a lowland river catchment, Oecologia, 91: 338-345.

Copp, G.H. (1997) Microhabitat use of fish larvae and 0+ juveniles in a highly regulated section of the River Great Ouse. Reg. Rivs: Res. Mgt., 13 : (in press)

Cowx, I.G., Pitts, C. S., Smith, K.L., Hayward, P.J. & van Breukelen, S.W.F. (1995). Factors influencing coarse fish populations in rivers. National Rivers Authority, R&D Note, 460.

Diamond, M. (1985). Some observations of spawning by roach and bream and the implications for management. Aquaculture and Fisheries Management, 16: 359-367.

Garner, P. (1995) Habitat use by 0+ fishes in a regulated river. PhD Thesis, University of Birmingham.

Garner, P.G. & Mann, R.H.K. (1996). Modelling the habitat suitability for 0+ roach *Rutilus rutilus* in a regulated river; The Great Ouse, England. Fisheries Management & Ecology

Mann, R.H.K. (1996). Environmental requirements of European non-salmonid fish in rivers. Hydrobiologia, 323: 223-235.

Mann, R.H.K. (1997). Temporal and spatial variations in the growth of 0 group roach *(Rutilus rutilus)* in the River Great Ouse, in relation to water temperature and food availability. Reg. Rivs: Res. Mgt. 13: (in press)

Mann, R.H.K., Bass, J.A.B., Leach, D.V. & Pinder, A.C. (1997) Temporal and spatial variations in the diet of 0 group roach (*Rutilus rutilus*) larvae and juveniles in the River Great Ouse in relation to prey availability. Reg Rivs: Res. Mgt. 13: (in press).

Mann, R.H.K. & Bass, J.A.B. (1997) The critical water velocities of larval roach (*Rutilus rutilus*) and dace (*Leuciscus leuciscus*) and implications for river management. Reg. Rivs : Res. Mgt. 13: (in press)

Marker, A.F.H. & Collett, G.D. (1997a). The spatial and temporal characteristics of algae in a slow-flowing, regulated river in south-eastern Britain. 1. The phytoplankton populations during both wet and dry years. Reg Rivs: Res. Mgt. 13: (in press)

Marker, A.F.H. & Collett, G.D. (1997b) The spatial and temporal characteristics of algae in a lowland, slow-flowing, regulated river in south-eastern Britain. II. The epiphytic algal flora. Reg. Rivs : Res. Mgt. 13, (in press)

Mills, C.A.. (1981) Egg population dynamics of naturally spawning dace *Leuciscus leuciscus*

(L.). Env.Biol. Fish. 6: 151-158.
Mills, C.A. & Mann, R.H.K. (1985). Environmentally induced fluctuations in year-class-strength and their implications for management. J. Fish Biol. 27 (suppl. A) ; 209-226. 1996)
Petts, G.E., Imhof, J.G., Manny, B.A., Maher, J.F.B. and Weisberg, S.B. 1989, Management of Fish Populations in Large Rivers : A Review of Tools and Approaches, Canadian Special Publication of Fisheries and Aquatic Sciences, 106: 578 -588.
Rhymer, J.M. & Simberloff, D. (1996). Extinction by hybridization and introgression. Annu. Rev. Ecol. Syst. 27: 83-109.
Stalnaker, C.B., Milhous, R.T. & Bovee, K.D. (1989). Hydrology and Hydraulics Applied to Fishery Management in Large Rivers, Canadian Special Publications on Fisheries and Aquatic Sciences, 106, 13-30.

CONTENTS

University of Hull International Fisheries Institute
I Cowx

Contents | Page No

1. INTRODUCTION

1.1 Background

Under Section 114 of the Water Resources Act 1991, the Environment Agency has a statutory duty to maintain, improve and develop freshwater (i.e. including coarse) fisheries.

The coarse fish populations of England and Wales have great social and economic importance since they provide a vast and valuable recreational resource, enjoyed by over 1 million coarse fish anglers (NOP 1981). In many areas of the country there is concern about large-scale variations in the performance of the coarse fisheries within major river systems, as many rivers experienced marked decline in their status in the late 1980s and early 1990s. Although natural fluctuations may account for some of the variability, these fisheries are under pressure from a range of factors. Unless these can be identified and strategies formulated to ameliorate their effects, riverine coarse fish resources may exhibit long-term decline. The importance of these coarse fisheries make it imperative that the interactions between the fish and their environment are properly understood, so that management strategies can be formulated based on sound technical and scientific knowledge.

A complex array of interacting natural, physical, chemical and biological factors are important in influencing the distribution and abundance of fish populations. These have been identified in a previous literature review (Cowx *et al.* 1995). Impacted on these factors are the effects of human manipulation of the river environment including:

- loss of physical habitat, e.g. through channel engineering;
- the resultant changes in flow regime arising from such impacts;
- the effects of acute and chronic pollution;
- the activities of river users;
- the impact of river management activities, e.g. weed-cutting and dredging.

Recent and on-going research in these area has tended to focus on specific issues in localized situations, and hence failed to assess fully the factors influencing coarse fish populations, particularly recruitment. There is, thus, a need to conduct primary research into the factors, both biological and environmental, that affect the abundance of fish populations and the mechanisms by which these factors operate. The objective of this scoping study is to identify the various options available and propose projects to implement this primary research.

1.2 Specific Objectives

The overall concept of recruitment in fisheries is a complex problem involving many independent and interacting factors. The complexity is best explained in Figure 1 which shows the magnitude and diversity in issues that must be understood to get a handle on the factors affecting coarse fish recruitment. Furthermore is shows the key areas where research must be targetted.

The problems can be broken down into three key areas which are probably inter-linked and cannot be treated as separate issues. These are:

- role of reproductive strategies in regulating larval recruitment;

x

- role of habitat in regulating the carrying capacity of the fish stock;

x

- abiotic and biotic factors affecting the survival (mortality) of fish and the subsequent year class strength.

It is considered that the overall problem is too complex to be treated as a whole and the project should be broken down in a suite of manageable components with the following specific objectives.

- To determine the basic habitat requirements of all life stages of coarse fish in rivers, and the seasonal habitat changes required to maintain sustainable recruitment.

x

- To understand the impact of reproductive strategies on the recruitment dynamics of fish populations.

x

- To determine the factors needed for the successful spawning and juvenile recruitment of the dominant coarse fish species in rivers.

x

- To determine the critical factors affecting the early life stages of various coarse fish species in rivers, and identify the causes and rates of mortality under various ecological and environmental scenarios.

x

- To establish the causes and rate of mortality in post-one year coarse fish.

x

- To determine how fish populations and individuals respond to environmental change and the implications this has on stock dynamics.

x

- To determine the impact of river management activities on the recruitment dynamics of the dominant coarse fish populations and assess the underlying causes for any changes observed.

To achieve these specific objectives a number of projects are recommended. Although each project appears self-standing they are inter-dependent and all contribute towards elucidating the factors controlling coarse fish recruitment.

2. PROJECT ACTIVITIES

2.1 Habitat requirements

2.1.1 *Micro-habitat requirements*

For the purposes of integrated river and fisheries management it is vital to understand the critical factors which affect the distribution and abundance of coarse fish species. Multivariate models have been developed which show different groupings of fish species, coinciding with classical upstream-downstream fish communities, and identify key environmental factors that relate to these different groupings. Habitat suitability index models have also been developed to determine the key habitat factors which limit the abundance of different species. Unfortunately these models are still crude, but can be used as a tool to provide an overview of factors influencing the distribution and abundance of the main coarse fish species in lowland rivers. Ultimately the information will be usefully for understanding the habitat and environmental factors that influence recruitment success. However, at present the models do not account for seasonal variation in distribution and abundance or the habitat requirements for all life stages, in particular models generated for juveniles are generally weak or absent. The models are also not sufficiently robust to be used for management purposes. There is therefore an urgent need to upgrade these HSI models to support analysis about the critical habitat features which constrain coarse population recruitment.

To carry out the modelling activities specific field exercises will have to be carried out. These should adopt a modification of the point abundance sampling strategy forwarded by Persat and Copp (1990). The modification involves the use of quantitative electric fishing such as described in the sampling methods (Section 4.2.3). However, the data can be analyzed using the Canonical analysis procedures described by Persat and Copp (1990) and the multivariate and HSI methods described by Cowx *et al.* (1995)

Data collected from the various surveys will be used to model spatial and temporal variations in the community structure and population parameters. These will then be examined in relation to habitat and environmental characteristics of the different river systems. These data will also be analyzed to evaluate the habitat needs of the index fish species at various life stages (i.e. spawning, fry, juvenile and adult) and thus highlight the factors regulating population recruitment. Particular emphasis will be placed on:

- assessing the influence of environmental parameters on species abundance, distribution and performance;

x

- optimal habitat conditions for various life stages of the major coarse fish species;

x

- assessing the impact of man's activities and river management practices on habitat and physicochemical characteristics and their consequent effects on coarse fish populations;

x

- development of models which link habitat requirements to the potential usable area to predict the outcome of mitigation and restoration activities on fisheries.

These analyses will allow a better understanding of the underlying factors influencing coarse fish populations and permit development of management strategies to improve their status and performance.

2.1.2 *Macro habitat evaluation*

In addition to micro habitat preferences of juvenile fish, a broader-scale approach is needed to identify macro habitat needs, such as the importance of bays, tributaries, marinas, backwaters. These are key features which probably aid the overwinter survival of juveniles and afford refuge during periods of inclement flow conditions.

This study should be intrinsically related to any investigations on fish dispersal although it is recognized the latter will be difficult to assess. The basic aim should be to assess habitat usage under various environmental and climatic conditions. It is necessary to undertake this work on a macro scale because long reaches of river need to be surveyed to show distribution patterns of juveniles in relation to key habitat features. To this end, boom-mounted electric fishing surveys over several kilometres of rivers are necessary if the study is to show distribution patterns. The sections of river selected much have a wide range of features, to discriminate between regions heavily utilized and those not occupied by juveniles. Change in habitat usage with season, particularly to avoid adverse flow conditions is another factor that needs to be investigated.

These macro habitat studies will complement the micro habitat studies and aid in focussing where sampling effort for the former should concentrate.

This type of study has intrinsic value for river management because rehabilitation measures usually target macro changes in habitat, e.g. provision of backwaters, alteration of flow dynamics, etc. They should also identify the importance of lateral connectivity to side channels, off river lakes etc., in supporting recruitment to the catchable cohorts. This is a much neglected area of research and fundamental to rehabilitation activities.

2.2 Determination of juvenile recruitment success

2.1.1 *Quantifying year class strength (YCS)*

One fundamental problem in evaluating juvenile recruitment is defining recruitment success. The classical way of illustrating this is the use of YCS indices. Unfortunately the most precise measures (Mann 1973) require samples of adult fish to be taken from three or more years for a comparative assessment to be made. The alternative is to use percentage contribution of each age group to the overall population but this is biased against juvenile and older fish because of gear selectivity and age-dependent mortality. A new measure of YCS has been developed by HIFI which gives an absolute measure of YCS based on a single representation sample of the population. This method, which uses a modified cohort analysis, is currently being field tested but looks a promising and more precise index of YCS.

Unfortunately determination of recruitment success using YCS is restricted because the cohort has to have existed in the adult population for several years before it can be determined. This puts restrictions on the type of analysis that can be carried out based on YCS, primarily because information on the juveniles, except in a few cases, was not collected. Consequently an alternative rapid measures is required.

2.2.2 *Factors regulating year class strength*

It has been demonstrated that temperature is a key factor in regulating year class strength in coarse fish populations through growth in their first year of life, i.e. the larger the fish at the end of the first year the greater the chance it has of surviving the winter. However, this does not account for all the variation. In some rivers, years of high temperatures and good growth do not always convert to strong year classes, suggesting that other factors are responsible. This was particularly evident from the 1989-1991 year classes in many UK rivers which, if temperature was the key regulating factor, should have consistently produced three successive strong year classes. However, the general observations were that 1989 was strong, 1990 average and 1991 slight above average (see Cowx *et al.* 1995). It is proposed that several other factors were heavily influencing the recruitment processes in the later years. Of particular importance may have been the flow regime, particularly in the early summer and autumn winter periods. It is possible heavy floods could have had a flushing effect on the juvenile stocks. It should therefore be possible to use river discharge data in a similar manner as to that proposed for temperature for rivers where good data on fry recruitment are available to evaluate this effect of discharge. Much of this analysis can be carried out on historical data but the assessment should also be included in any further studies.

Alternatively, and possibly more likely, biotic factors are having an heavy influence on YCS. It appears that two or three successive strong year classes are rare. This is possibly because the high density of juvenile fish from one cohort may be successfully competing for food resources with the next cohort. This may lead to reduced food resources and increased mortality amongst O-group fish. How this mechanism operates also needs to be determined.

2.2.3 *Critical period/critical size concept*

It has often been postulated that juvenile fish mortality is linked to three primary factors.

- growth of larval food match mis-match theory;
- critical size to avoid predation;
- critical size to survive overwinter.

All these factors can be elucidated using proper experimental design.

The food match-mismatch theory states that adequate food resources must be available for larvae within a short period of hatching so the fish can move from endogenous to exogenous foods quickly and avoid starvation. Thus hatching must be timed to coincide with explosions of plankton or epibenthic food resources. Comparison of the dietary intake of fry against available food resources will help to quantify this issue. During the spawning/hatching/early development period, the food intakes of fish needs to be assessed and compared with natural availability. Aspects that must be measured are:

- abundance and size of available foods;
- optimal size of food in diet;
- food preferences;

- ontogenic shifts in diet.

These data can be incorporated into an optimal foraging theory model to illustrate cost benefit relationships between food availability, food intake and growth rates. It should also be useful to discriminate the critical periods in the development of the fry when predation pressure and natural mortality are at their highest.

Several issues need to be examined to assess whether there is a critical size that the fish must reach to survive over winter. In its simplest form correlation between fish length and YCS suggests this may be true, with temperature exerting an over-riding influence on the fry growth. However, the mechanism by which the temperature influence the growth has yet to understood. There is evidence to suggest that three consecutive months of high temperatures are required or that there is a threshold level of degree days above which strong year classes will result. Further in-depth studies, using databases of fry length at the end of the summer with YCS, are needed to improve the understanding of this relationship. Exist and new databases on fisheries through the UK will be used to examine any relationship. This will be achieved by running a Monte Carlo analysis on various temperature profiles generated randomly from monthly temperature records against growth and YCS. This should help to confirm the critical periods when temperature influences growth and subsequent mortality.

A further complication of the effect of temperature was found for barbel by Baras (in Welcomme and Cowx 1997), which will probably be applicable for other cyprinid species. He was able to show that juvenile fish growth was influenced by subtle changes in water temperature in the margins of rivers, where the fry concentrate, brought about by boat wash. The exchange of water (influshing of mid stream water) caused by the boat wash effectively lowered the temperature in the margins by approximately one degree for several minutes after a boat went by, until the water warmed up again. The cumulative affect of intense boat traffic was to reduce the growth quite substantially. This whole problem needs further investigation but considerable expenditure will be required to provide the water temperature records for such a study.

Notwithstanding, this relationship is probably an over-simplification of the issues. It is probable that it is not so much the length but the weight, and more specifically the fat/lipid content, of the fish which is the controlling factor. It is therefore necessary to investigate the relationship between lipid/fat stores in fish and their survival prospects. This can be achieved in two ways. Firstly, biochemical analysis can be undertaken to determine absolute lipid content of fish at the end of the summer (growing season). Second, morphometric relationships between various body characteristics have been shown to correlate well with body fat content in salmonids. If similar relationships can be developed for cyprinid, this approach can be utilized.

If this study is undertaken, fish should be intensively sampled from the three index rivers and if possible a range of other rivers across England and Wales in late September each year. The size distribution and fat content relationship will be determined and related to YCS assessed during surveys in future years.

The main benefit accrued from these studies is that it should be possible to predict, with a reasonable degree of precision, the year class of each cohort. This can then be related to future potential of the fishing in the system.

2.3 Mortality schedules

A second mechanism of examining recruitment success can be gained from analysis of natural mortality at different life stages. This can be achieved by using mortality schedules and key factor analysis based on $N_t = N_o \exp -Zt$, where the independent components of the total mortality (Z) are discriminated. The various components that need to be evaluated are outlined in Fig. 2. Total mortality can be represented by the equation $Z = M + F$ where M is the natural mortality (egg viability, failure to develop, predation, disease and starvation) and F is the fishery mortality which is assumed to be zero in this study.

The data derived from this study can be integrated using Leslie Matrix and key factor analyses. The method discriminate where the highest levels of mortality occur and focus on the cause. These are important factors that can be built into an overall population model to describe recruitment dynamics from egg deposition number to survival beyond the fry stage.

A Monte Carlo simulation programme can also be used to derive confidence limits for the component values of Z. This model generates known distributions about each of the model parameters and then randomly samples each to provide a single estimate of Z for each river during a given time using iterative procedures. This programme effectively generates the distribution of natural mortality through each life stage and sums the parameters to give to total mortality with confidence limits. It should provide a realistic estimate of proportion of the stock which survives to the end of each life stage and thus predict the future status of the fishery.

Unfortunately, it many be difficult to discriminate between various key factors and the analysis may have to be based on gross natural mortality through the first year of life. The value of this approach is that a measure of survival can be determined for each year and this information linked to reproductive potential of the population and recruitment.

2.4 Reproductive bionomics

Recruitment of cyprinids is also dependent upon the reproductive success of adult fish. Few studies have been carried out to evaluate variations in the reproductive bionomics of coarse fish species, particularly fecundity. Cowx (1988) found considerable inter-annual variation in the fecundity and egg size of roach and dace of a similar size and age. It was suggested that this was linked to food availability and competition, but empirical evidence was not available to confirm this hypothesis. In addition, Bagenal (1969) also showed that larger eggs resulted in larger larvae which had an improved chance of survival.

These two studies raise a fundamental issue which needs elucidating. The reproductive bionomics of fish populations appears to vary between years, and this will probably influence the number and quality of eggs deposited. This will have direct implications on the development of each cohort because the starting population size (number of eggs deposited) and survival of the larvae (size of eggs) contribute to the recruitment dynamics of the population. The main issues that need addressing are:

- What are the factors that influence the reproductive bionomics of coarse fish?

x

- How do food and density-dependent interactions regulate the reproductive success of the population?

On top of this issue there is a compounding problem associated with spawning habitat availability and success. Although the reproductive potential of the adult population may be high, the spawning success, and thus recruitment, can be low because of: i) lack of availability of suitable spawning habitat; and ii) environmental conditions may not conclusive to spawning.

The first issue, spawning habitat, can be resolved by modelling the habitat needs of spawning fish and identifying its availability in the study rivers. This can be carried out by surveying the rivers and identifying spawning locations of the target species. These data can then be used to identify if availability of spawning habitat is a bottleneck in the recruitment process, an issue that has been proposed for many fisheries in degraded rivers. The value of this study is that it will provide fundamental information on the spawning habitat needs of each species and a baseline for rehabilitation actions to ameliorate the problem.

The issue of environmental factors is more difficult to evaluate and is linked to the studies on early development of larvae. Optimal conditions which stimulate spawning and egg development may not be suitable in certain years and these may lead to inadequate spawning activity and reproductive success. In particular, spring and summer periods which have protracted periods of low temperature may lead to reduced or delayed spawning activity, which in turn leads to low egg deposition rates and poor growth and survival of larvae.

Compounded within the problem is the role of batch or serial spawning to improve the reproductive success of the population. It has long been thought that serial spawning is a mechanism to ensure at least a proportion of the eggs and larvae are laid and hatch under optimal conditions to guarantee a contribution to the cohort development. How this mechanism influences year class strength and sustainability of the population has yet to be identified, but it is a fundamental issue in the recruitment process that needs to be teased out.

2.5 Migration and dispersal behaviour

One of the main issues that has been identified by EA staff and data analyses from other projects (Cowx *et al.* 1995)is that coarse fish populations are extremely mobile and appear to exhibit breeding, feeding and overwintering migrations. However, little is known about this behaviour and its importance in the recruitment, survival and mortality processes. Similarly, little is known about the dispersion and displacement patterns of coarse fish populations at all life stages. Information of this nature is fundamental to the management of river fisheries because various anthropogenic activities are known to impede movement of fish. These may have considerable influence on reproductive and feeding behaviour of fish, and, ultimately, sustainability of the stocks.

It is suggested that two main aspects of movement behaviour should be considered if resources allow.

i) Downstream displacement of individual fish during their early life stages is known to occur, but the magnitude, frequency and causes are little understood. These aspects of the dispersion mechanisms should be examined, in conjunction with studies on the juvenile stages to identify the time of the movement and, if possible, the underlying cause and effect. It is possible to discriminate the timing of the dispersion from examination of length frequency distributions of fry, which, in the past, has been suggested (personal observation) to indicate this type of behaviour.

ii) There is also the need to examine the migratory behaviour of mature fish is with a view to ascertaining the extent of movements between spawning, feeding and overwintering habitats. The studies must compare migration behaviour on a river where movements are restricted by man-made features (Great Ouse) and a river where movement is relatively unrestricted (Yorkshire Ouse). These comparative data can be used to evaluate whether man-made obstructions are influencing recruitment success by impeding movements to spawning and feeding areas, and whether passage facilities should be considered to ameliorate the effect.

The problem with studies of this nature is that they are extremely difficult to undertake on juvenile fish because of the problems of marking. As indicated, it may be possible to use size or body morphology as a discriminating mechanism but this type of work is unlikely to lead to any conclusive result. It is therefore recommended that these studies are given low priority and an opportunistic approach to assessment is adopted whereby any interpretation of data from other studies is utilized to the benefit of this component.

2.6 Anthropogenic activities

Gross changes in fish community structure have been clearly linked to changes in the aquatic environment brought about by anthropogenic activities, but the underlying mechanisms for these changes have not been clearly identified. Consequently, one of the critical components of this project must be to differentiate the impact of various anthropogenic activities on recruitment processes in river coarse fish populations.

A similar approach to that adopted for the habitat modelling can be used for this study and data for this component will come from the same sources as those for the habitat modelling exercises. The index rivers are considered to represent the major anthropogenic activities so they should provide sufficient baseline data on which discriminate the underlying causes. Standard methods of assessing population parameters can be applied to the main fish species subject to the anthropogenic impacts.

HSI and multivariate models can be used to relate the changes in environment caused by the anthropogenic impact to the fish community. The ABC Index, utilized by Cowx *et al.* (1995), can be used as a tool to demonstrate the shifts in population structure and changes in life history strategy adopted by species in response to the stressor. Impacts on the early life stages of fish will be evaluated by studies of juvenile growth and recruitment in populations in close proximity to various anthropogenic activities.

The activities which should be investigated include:

- maintenance weed cutting;
- removal of instream features e.g. desnagging;
- rehabilitation/mitigation measures;
- regrading of rivers for flood alleviation;
- stocking.

Close liaison will need to be maintained with EA fisheries staff to identify when and where such activities take place so pre- and post-implementation surveys can be carried out. An essential part of these surveys will be to quantify the effects of carrying out the various activities at different times of the year on the physical habitat, recruitment success and fishery performance.

This component, in conjunction with outputs from the other activities, will allow a better understanding of the underlying effects of man's activities on habitat, and fish population and community dynamics.

3 PROJECT IMPLEMENTATION

3.1 Target species

Ideally, all coarse fish species present in the rivers of England a Wales should be studied because the reproductive strategies, habitat needs at various life stages and overall population dynamics are different. However, resource constraints make it necessary to concentrate on a few index species. It is recommended that only 4 species are studied. These are roach (*Rutilus rutilus* (L.)), dace (*Leuciscus leuciscus* (L.)), bream (*Abramis brama* (L.)) and chub (*Leuciscus cephalus* (L.)) These species are representative of the main species caught by anglers and represent the main ecological zones and trophic levels in riverine fish communities. The species also represent the different spawning habitat requirements of coarse fish species, they have different spawning and reproductive dynamics, and are the most widely studied species in the UK. In addition habitat suitability models for these species are available (Cowx *et al.* 1995) for the adult life stages.

It would be useful to add a piscivorous species to this list, such as pike (*Esox lucius* L.) or perch (*Perca fluviatilis* L.), but it will probably be difficult to collect the quality and quantity of data needed to elucidate the various issues required. Consequently, undue effort may be expended to achieve the desired sample size which would detract from the remainder of the study.

3.2 Study rivers

The field programme to support the studies proposed should be carried out on a number of rivers, exhibiting a representative array of topographical and habitat characteristics, including rivers where natural conditions have been altered by man. They should preferably be undertaken at sites where previous studies have been, or existing studies are being, undertaken, as there is a need to access long-term databases to resolve several of the issues identified. These rivers, which should be considered as index rivers, must also provide a wide geographical coverage of English catchments. Unfortunately, constraints on resources dictate that study sites must be restricted and it is therefore recommended that only three study rivers are used. These must display a diverse array of the characteristics as well as being capable of covering the issues. The three rivers proposed and the reasons for their selection are given below.

1) Yorkshire Ouse This river has considerable information on the growth and year class strength of O+ fish collected by the EA and HIFI over the past 10 years. The Yorkshire Ouse also has a range of problems relating to water quality, habitat degradation and is subject to considerable development through water resource schemes.

2) Great Ouse This river has been the subject of considerable research by the IFE Eastern Rivers Group, particularly by Mann, Bass, Copp and Garner. The channel form and habitat have been heavily altered so that and the flow is regulated, thus presenting a number of issues that are directly related to fish recruitment.

3) The third river is a little more difficult to select because no one river has been intensively sampled to the level of the other selected. However, it is recommended that either the River Trent, River Dee or the River Severn is used. The former is perhaps the best because it has to be the subject of some research in the past (Jacklin PhD) and it is also being studied as part of the MAFF fish eating birds project so the information database is growing. The Severn has the advantage of being more westerly and subject to less degradation than the other rivers so it could be used as a control. The River Dee was the subject of intensive study in the late 1970s and 1980s (Liverpool University & Hodgson) and this may be used for comparative purposes. It is also a heavily modified river with recruitment problems so it may be difficult to obtain sufficient material to elucidate some of the primary issues.

The actual location of the sampling on the river will depend on the issue being examined and will have to be selected prior to the work being initiated.

3.3 Sampling methods

A number of methods are available to sample juvenile fish populations, however, each suffers from inherent problems and the sampling method will have to be tailored to the specific needs of the study.

Ichthyoplankton trawls, inflatable lift nets, trawl traps and drift traps have been used with limited success and are inefficient when sampling amongst vegetation, a location where juveniles are frequently found. It is recommended that these gears are not employed.

Perhaps the best method for sampling is micromesh seine netting. These are efficient in river margins where weed growth is minimal and can be operated safely by two persons. They can be used when topographical conditions permit and/or large samples of fish for length, weight and dietary analysis are required. It may be possible to use the techniques to provide a quantitative or semi-quantitative estimate of the population size if the net can be deployed without problems.

This technique can be used quantitatively if the area of the sweep is determined and no obstructions prevent the net being drawn in, i.e. where a suitable a substrate and shoreline is present.

The alternative method is to use electric fishing techniques. The boom mounted electric fishing equipment designed by HIFI for the NRA (EA) catches fish down to 20 mm so it can be used when distribution patterns of fish in long reaches of river are to be assessed. Point abundance sampling techniques, using the modification of the electrode is described by Persat and Copp (1990) can also be used. However, it should be pointed out that the small electrode head employed reduces field size and thus the area being sampled. The method is also not quantitative and relies on numerous replicates to remove sampling variance. It is probably best used when evaluating the relationship between habitat variables and fish abundance or preferences. However, the method is still considered to have severe limitations in efficiency and may underestimate the populations parameters.

An improvement on this gear is the juvenile electric fishing apparatus designed by HIFI which provides a quantitative assessment of fry/juvenile density. The gear consists of a metal frame (cathode), which represents the outer extremity of the electric field which stuns fish, and can be placed on the river bottom (including over weeds) or suspended from a boom area in open water. Because the field dimensions are known, and specifically designated, the number of fish per unit volume can be calculated. The gear can be used to determine the density of fish in various habitats and elucidate more effectively the relationships between habitat characteristics and fish preferences, two key issues in the project.

3.4 Sampling strategy

A sampling strategy that covers such a multi-facetted project is complex and will have to use an adaptive approach. It is unlikely that many of the questions being posed will be answered by a short term low intensity programme. Consequently a long-term (3-5 years minimum) project is required. This is deemed necessary to ensure inter- and intra-annual variation in biotic and abiotic factors regulating recruitment success are addressed satisfactorily.

The strategies for deployment of the gears vary between the main components of the overall project and are identified in relation to each proposed projects in Table 1. This shows that the preferred sampling gear and the intensity of sampling considered necessary to meet the objectives of the individual projects. It should be noted that the sampling programme is likely to be dynamic and will have to be adjusted to account for variation in spawning season between species and between years. It will also be adjusted from year to year to improve the precision of the data required to answer specific objectives. For example, it will be necessary to first identify approximately the critical period in the early development of the larvae when heavily mortality occurs and the critical period/size beyond which the fish are less susceptible to intense predation from invertebrates, etc. Once this has been identified the sampling programme can be intensified to improve the precision of the data used to elucidate these issues.

Table 1 - Proposed sampling programme to meet objective of individual projects

Project	Preferred gear/precision	Sampling frequency
Juvenile mortality schedules	electric fishing frame; quantitative	In the first year June and July. Every 2 weeks from 1 May-15 July and monthly thereafter to identify the critical periods in the programme will be adjusted in subsequent years to intensify sampling during critical periods
Juvenile growth studies	electric fishing frame; semi-quantitative	as above
Juvenile feeding studies	electric fishing frame; semi-quantitative	as above
Relationship between size and over winter survival	micro mesh seine; semi-quantitative	intensive sampling throughout river in mid - late September
Reproductive bionomics	boom electric fishing; semi-quantitative	Prior to spawning season of species + post spawning season + September
Distribution mapping	boom electric fishing; semi-quantitative	July, late September, January
Habitat preferences	electric fishing frame or point abundance gear; quantitative	In early stage of larval development, July, late September + January (in conjunction with above)

4 COSTS

The complexities of the project as proposed make it necessary for a full time person to be engaged. There is considerable time devolved to the field sampling programme (minimum of four times per year plus intensive sampling period in early summer), and this will generate a considerable data base for collation and subsequent analysis. As indicated earlier the project should be run over a minimum of three years, and preferably five years, to resolve intra- and-inter annual variation in environmental characteristics.

Several options are available to meet the resourcing needs of the project. These are based on experience of the main person involved in the sampling and analysis. It should also be noted that it is assumed the project is operate without support from the Environment Agency in the field sampling and analysis. However, assistance will be necessary to access the various water quality and hydrology data required to underpin the project.

The project can be implemented either by a Post doctoral Research Assistant or a postgraduate Research Assistant, preferably registered for a PhD. The PhD registration is necessary because it will encourage the person to see out the duration of the project and reduce salary costs. The project costs for the two options are outlined in the following schedules.

Schedule 1a - Postdoctoral Option

	Year 1	**Year 2**	**Year 3**
Postdoctoral Research Assistant	27000	27000	27000
180 man days per year			
Field technician	4200	4200	4200
60 man days per year @ ??			
Project leader	3000	3000	3000
10 man days per year			
Travel + subsistence	6500	6500	6500
Gear micromesh seine net	600		
electric fishing	300	300	300
Computing	600	600	600
Reporting (based on 10 copies per report)	400	400	400
	42600	42000	42000
Overheads 30% on staff costs	10260	10260	10260
Total	52860	52260	52260

Schedule 1b - Postgraduate Option

	Year 1	**Year 2**	**Year 3**
Postgraduate Research Assistant	9000	9000	9000
PhD Registration fees	3000	3000	3000
Field technician	4200	4200	4200
60 man days per year @ ??			
Project leader	3000	3000	3000
10 man days per year			
Travel + subsistence	6500	6500	6500
Gear micromesh seine net	600		
electric fishing	300	300	300
Computing	600	600	600
Reporting (based on 10 copies per report)	400	400	400
	27600	27000	27000
Overheads 30% on staff costs	4860	4860	4860
Total	32460	31860	31860

Note: These costs are indicative of the minimum budget required to undertake the programme described. They must not be considered for tender purposes.

All costs are exclusive of VAT and are subject to inflation at the Retail Price Index. Staff costs would also be subject to annual increments should the project extend beyond one year duration which in recent years has approximated to the RPI.

Costs identified are to service the project as identified in this report. If the overall programme is reduced, costs will only be marginally less because it is difficult to achieve any of the objectives without the full field programme. Difficulties are also likely to occur if staff are allocated part-time to the project as it demands links to other projects which presents a risk.

Costs could be reduced considerably if EA staff are made available to support the field programme, thus eliminating the need for additional technical support (savings in salaries and subsistence estimated at £6400) for sampling.

5. ASSUMPTIONS AND RISKS

The project, as designed, is a complex integrated package which is aimed at determining the known primary factors influencing recruitment. The programme is made up of a number of small projects which interface to meet the overall objective. It is possible that certain outputs from the projects may be inadequate to meet the input requirements of the overall evaluation but these will not necessarily detract from the output. However, the cumulative effect of several components not producing the necessary output could put an unacceptable level of uncertainty on the overall project output. It is anticipated the rigorous nature of the project design has minimized any potential problems but the study may be influenced by the vagaries of the climatic conditions. For example, if the project period is dominated by cold wet or warm dry years this will prevent any overall discrimination of survival under different climatic conditions. This is the reason why a minimum of three years, and preferably a five-year, study period is recommended.

It is assumed that the angling clubs/associations will grant the necessary permission for carrying out the intensive and ad hoc sampling programmes on their waters.

6. BENEFITS

Riverine coarse fisheries are under pressure from a range of factors. At present management of these resources is based primarily on experience and qualitative evaluation. Those factors which are considered constraints on coarse fish populations in flowing waters will be investigated to quantitatively determine the mechanism of impact on fish population dynamics. It should then be possible to formulate strategies to ameliorate the effects of these critical factors, thus leading to improved management of coarse fish resources. This will help to alleviate pressures on the fisheries and help their recovery/improvement. This would have beneficial implications for their capital value and improve the recreational benefits enjoyed by large numbers of anglers in England and Wales.

The development of management strategies will enable informed advice to be given in a number of areas where there is uncertainty at present. For example:

- recommendations on the timing of river engineering activities (river maintenance) with a view to minimizing the impact on spawning, and post-larval development and subsequent growth stages, and to enhance beneficial effects;

x

- recommendations as to the form of regulated flow regimes which will minimize impacts and enhance benefits;

x

- recommendations on stocking policies and other stock management practices to limit displacement of both stocked and natural populations and improve the outcome of stocking activities;

x

- empirical information on which to formulate management plans for the maintenance, improvement and development of coarse fisheries;

x

- recommendations on the optimum habitat requirements for coarse fish species to maximize diversity and standing crop in rehabilitation practices;

x

- predictions of the potential outcome of rehabilitation and habitat improvement schemes;

x

- forecasting the status of angling in different river systems through use of the recruitment models;

x

- empirical evidence to enable the Environment Agency to provide its customers with informed advice and services based on sound technical/scientific knowledge.

Whilst it is difficult to justify the benefits of the project in economic terms, the improved understanding will enable future management practices to be more efficient and cost-effective, and to be designed to minimize the detrimental impacts and maximize benefits to coarse fish populations.

10. REFERENCES

Bagenal, T.B. (ed.) (1978) *Methods for assessment of fish production in fresh waters.* IBP Handbook No. 3 (2nd edition). Blackwells Scientific Publications Oxford. 365 pp.

Cowx, I.G., Pitts, C.S., Smith, K.L., Hayward, P.J. and van Breukelen, S. (1995) Factors influencing coarse fish populations in lowland rivers. R&D Report, NRA R&D Project DO2(91)3, R&D 0429/6/N&Y, Bristol: NRA 125pp.

Mann, R.H.K. (1973) Observations on the age, growth, reproduction and food of roach (*Rutilus rutilus*) in two rivers in southern England. *Journal of Fish Biology* **5**,

NOP (1981) National Angling Survey, 1979-80. National Opinion Poll Market Research Ltd, London.

Persat, H. & Copp, G.H. Electric fishing and point abundance sampling for the ichthology of large rivers. In I.G. Cowx (ed.) Developments in electric fishing. Fishing News Books, Blackwell Science, Oxford, pp. 197-210.

Welcomme, R.L. & Cowx, I.G. (1997) Rehabilitation of rivers for fish. Fishing News Books, Blackwell Science, Oxford.

Figure 1 Model to illustrate the complexity of factors that need to be addressed to identify the factors influencing coarse fish populations From Cowx *et al* (1996)

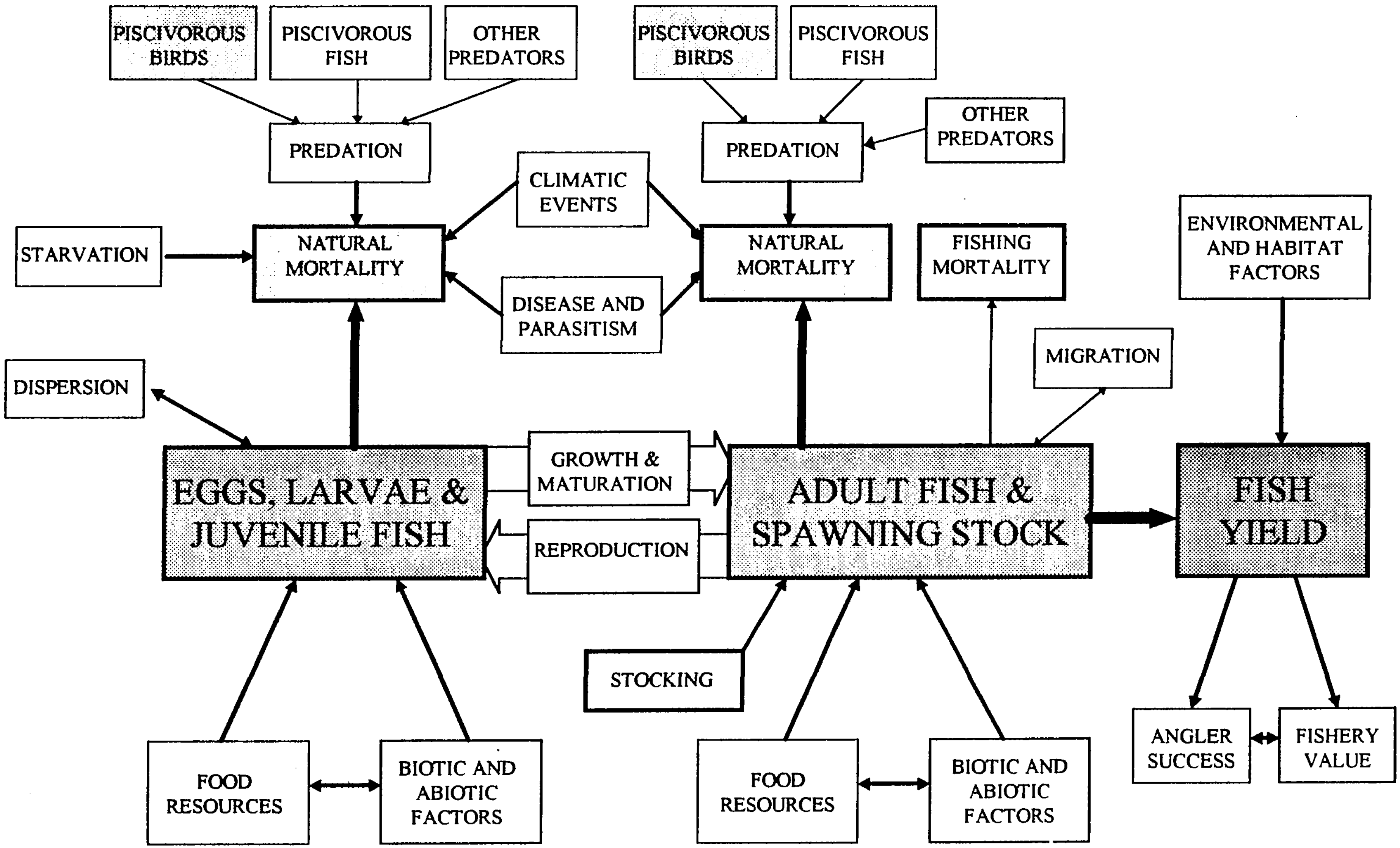
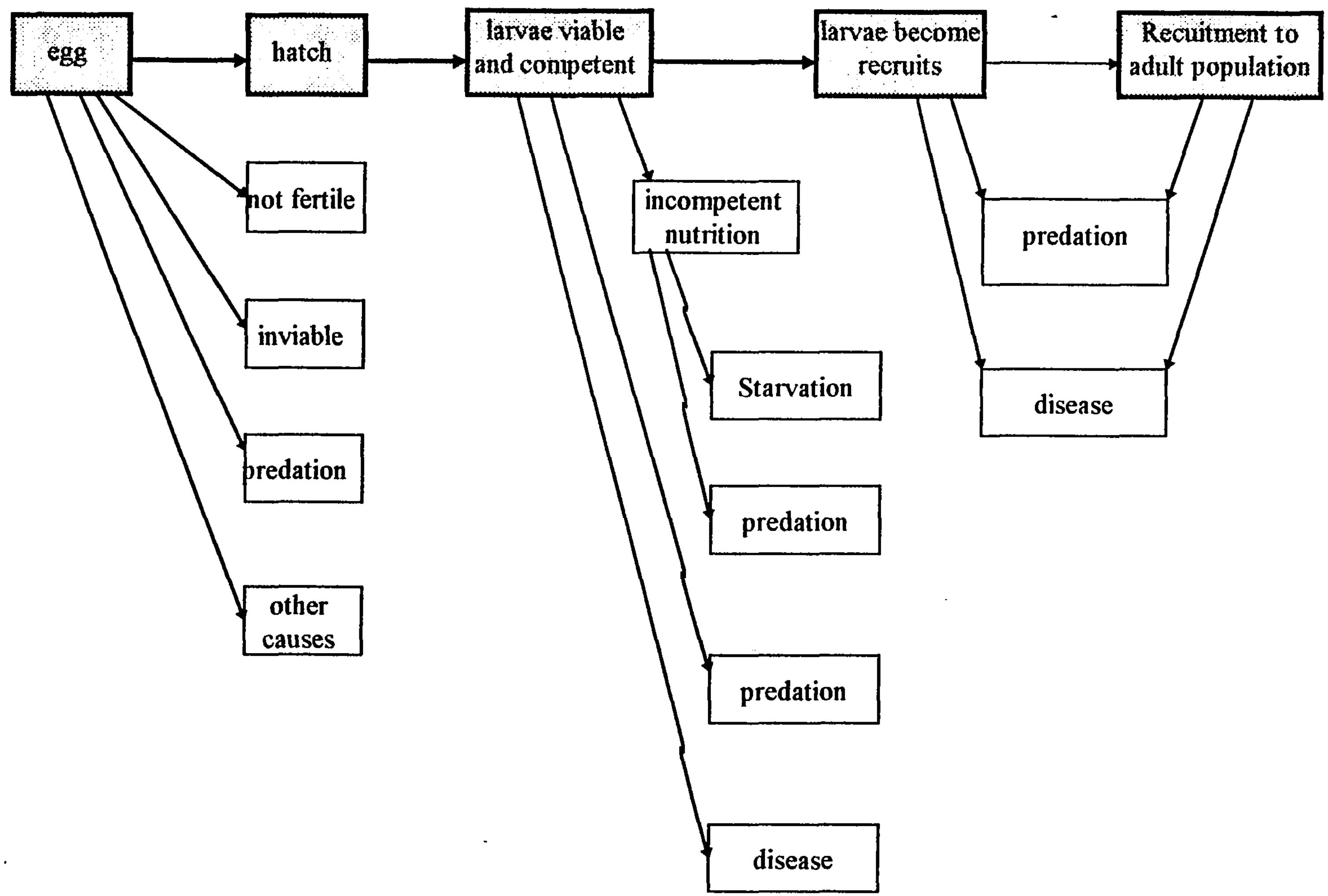


Figure 2 Factors influencing mortality in juvenile life stages of coarse fish



CONTENTS

SGS Environment
K O'Hara

1.0 INTRODUCTION, INTERPRETATION AND RATIONALE

1.1 Introduction

1.1.1 SGS Environment were commissioned by the Environment Agency to undertake a project entitled *'Factors affecting coarse fish recruitment - R&D Project Proposal W2B(96)8*. The objective of this work was to scope out, including experimental design, methods of analysis and costs, a study aimed at identifying what factors affect recruitment in riverine coarse fish populations, quantifying their impact and the mechanisms by which they operate. We take recruitment in the project brief to mean survival of the 0+ stage to the end of the first summer of life.

1.1.2 There are four areas where further study on coarse fish recruitment was recommended from R&D Note 460. These are:

i) There are few data on the factors influencing the early life-stages in coarse fish which may ultimately be important for determining year class strength.

ii) There are uncertainties on the impacts of temperature on fry growth and development in riverine systems

iii) The availability of food and its importance in determining growth and subsequent survival.

iv) Other factors which may be responsible for reducing year class strength when good growth rates and abundance were present in the previous year.

1.2 Interpretation

1.2.1 The scoping study brief intimates that the younger stages of coarse fish are not well understood in Britain. Whilst this may be true with regard to some elements, we would suggest that the recent review by Mann (1996) indicates that in fact more information may be lacking on sub-adult and adult stages. Most of the useful studies that have been undertaken on coarse fish e.g. IFE Windermere studies and River Laboratory studies, Severn-Trent Region studies, Yorkshire rivers have required long-term data sets to demonstrate trends. It should be stressed that we consider the long term consistent collection of data to be an essential component to the development of successful coarse fish studies.

1.2.2 It is assumed, but not known, that there has been a decline in species such as bream and roach on many of the large lowland rivers in Britain. What are the causes of such declines, if they exist, remain unknown but the problems are usually ascribed to a loss of habitat.

1.2.3 We would suggest that it is not coincidence that the rivers that have retained their reputations as fisheries are those in which the species present are those of the barbel zone. In particular we would identify the middle Severn, the Trent, the Wye and some of the Yorkshire rivers such as the Swale. Thes middle reaches of these named rivers have not suffered too greatly from the effects of channelisation and river regulation.

1.2.4 It is the highly regulated rivers and the bream zones of the large lowland rivers that we would hypothesise are the areas that have been most subject to complaints of poor fishing.

1.2.5 The project brief suggests that restrictions to recruitment are based at the juvenile level. However, there are known examples when high numbers of juveniles do not translate to an abundant stock of adult coarse fish (i.e the Shropshire Union Canal) . Anecdotal evidence and preliminary discussions indicate that this is thought to occur on some rivers. This suggests that 'bottle necks' may be present within the population, at the sub-adult or adult levels. There is little information available on the habitat utilisation by these later stages for recreationally important coarse fish species on large low land rivers (c.f Mann). To proceed on the basis of mainly assessing juvenile stages could lead to errors in interpretation on assessing recruitment into adult stocks.

1.2.6 For spawning, hatching, larval and fry stages, temperature and flow appear to be particularly important determinants. The studies of Copp and his co-workers (e.g Copp 1992) on the continent and Mann in the UK (e.g Mann 1995) we would suggest strongly show the importance of habitat structure both for spawning and fry survival. The last decade in Britain has demonstrated some of the warmest summer conditions on record which may have resulted in good fry production but it remains unknown if this has translated to a high adult YCS as there has been no routine sampling programme. Therefore, there is a requirement to be able to follow cohorts of fish through their life-history to determine important factors in limiting recruitment success such as absence of particular habitats for all life history stages. This will be difficult to achieve in fine detail due to sampling difficulties on large lowland rivers and may need to be studied on smaller systems where effective sampling can be carried out.

1.2.7 The work of Mann and his co-workers suggest that growth during the first year may be important in determining YCS. However, growth may not be a predictor of YCS. This may result from the fact that it is quite possible to have a warm summer and good growth but if the initial density of fish is low then density dependence would be expected to allow good growth rates. There is a requirement to develop some index of year class strength in the first year of life i.e density combined with length / condition measured on a wide range of rivers.

1.2.8 An additional difficulty we face in the UK is actually finding large rivers in which the habitat recorded in some French rivers (c.f Copp) and some other European rivers, is still present. Most studies in the UK have either taken place in relatively small rivers or in the barbel zone (where reasonable habitat still remains in some UK rivers) or else has been conducted on the bream zone of rivers such as those in East Anglia, the Welsh Dee and the Yorkshire Ouse where the rivers are already severely degraded in terms of the physical habitat and regulation of the flow. The importance of the utilisation of the flood plain may be an important factor in the bream zone of large lowland rivers. The importance of this flood pulse concept and how it applies to UK rivers has received relatively little attention.

1.2.9 We therefore suggest that in terms of habitat many of the theoretical requirements for juveniles are understood. What is therefore needed is that these requirements are translated into an appraisal of the large lowland coarse rivers of the UK to assess the degree of degradation that is present.

1.2.10 We are not at this stage convinced that if a problem of juvenile recruitment were identified as one of the main problems , which it undoubtedly is for example for roach on the Welsh Dee that this river would necessarily show a marked improvement in the bream zone if juvenile recruitment were improved because recruitment to the angling stock may not take place. Therefore we believe that there is a need to study to other life history stages coincident with the juvenile studies

1.3 Rationale

1.3.1 We consider that the essential part of the project is to demonstrate how juvenile recruitment relate to recruitment to the adult stock for angling and conservation purposes. There are a several potential hypotheses that need to be considered when addressing the study.

These are:

- **that populations are expected to show variability over time.**
- **there may be geographical differences in the recruitment and growth of coarse fish.**
- **a high abundance of 0+ fish may not translate to a high year class strength.**

To address these problems there is a need to consider the following approaches:

- **in order to detect long-term trends sampling of sequential years will be required. It is unlikely that the current 3 year rolling programme appraisal undertaken on adults will provide sufficient detail to examine factors which influence variability in juveniles.**
- **as many sites on a study river and as many rivers as are practicable need to be examined to produce statistically valid comparisons.**
- **the fish need to be sampled qualitatively or semi-quantitatively at all life history stages but particularly 0+ and adult stock, because these stages are vulnerable to present capture methods that are available for large rivers.**

1.3.2 Experimental studies will be required to examine those factors which may influence recruitment and cannot be successfully determined from a field sampling programme. The large number of variable associated with juvenile coarse fish growth and survival are likely to make interpretation of the important factors difficult and these need to be examined on an experimental basis.

2.0 MANAGEMENT ISSUES AND AGENCY PRACTICE

2.1 The results of the studies will provide important information for the development of coarse fish planning strategy. It is anticipated that the field studies will provide an understanding of recruitment of coarse fish and habitat utilisation on large lowland rivers which we suggest are the main riverine sites of angling interest. It is important that the results generated are developed into a simple monitoring system which will provide the results which will allow Agency staff to develop fishery management and improvements strategies. It is considered that the studies should provide:

i) **An ability to predict from early life history stages the likelihood of future adult YCS.**
ii) **An ability to enhance coarse fish habitat for all life stages in lowland rivers.**
iii) **Provide fisheries guidelines for water resources particularly for flow and temperature regimes on regulated rivers.**
iv) **Assist in developing further value from other R&D projects and regional programmes**
v) **Fish species and community conservation value for enhancing populations of particular species in selected rivers by enhancing particular habitats**

3.0 NEED TO DEVELOP AND AGREE SAMPLING METHODS

3.1 Juvenile fish

3.1.1 There is a requirement to develop a standard sampling methodology which can be used on a National basis and provide estimates of juvenile density. There are two methods which appear most practical from published studies. These are:

a) The point sampling electric fishing method

b) Micromesh seine netting

3.1.2 Both are quick and easily applied techniques which would allow many sites to be surveyed within a day. The point sample method has the additional advantage of being able to sample all shallow water habitats but the catch rate appears to be generally low and the question of the ability of the technique to estimate abundance needs to be answered. **We therefore propose that the efficiency of the point sampling method is assessed by enclosing a site with a micromesh seine net followed by fishing within this area with many point samples and then retrieving the net.** At the present time the point sampling technique is restricted in the UK to hand-held electrodes because the throwing electrode is unapproved. **We therefore propose that a throwing anode technique should be developed.** The ability to produce statistically robust data from the different sampling methods should be established in this preliminary work.

3.1.3 In the barbel zone of rivers it is possible that an electric fishing survey approach can yield good results for 0+ coarse fish. There would be a need for agreement of the most efficient equipment and the fine detail of the technique before it is applied on a national basis. It has recently come to our attention of the ability of different electric fishing gears to capture 0+ fish may vary considerably. It appears that it may be possible to catch 0+ fish effectively using standard kit in the barbel zone and edge habitat of large rivers. This method should be assessed in conjunction with point sampling and micromesh seine netting

3.2 Adult fish

3.2.1 There are difficulties associated with sampling adult fish stocks in large lowland rivers and producing quantitative data may not be possible at many sites. **We proposed that the sampling could be undertaken by the use of angling catches supplemented by standard sampling methods, where these are shown to be more appropriate, in providing YCS for adult stages.** This could be undertaken by organising and monitoring large angling competition or using small set number of anglers.

There is potential to use angling as the equivalent of point sampling to determine sub-adult and adult habitat use. Hydroacoustic surveys may also be useful in this respect.

3.2.2 The recording of adult catches could be undertaken using the tray photographic technique developed in the Catch Statistics R&D Contract.

3.3 Validation and agreement of survey methods

3.3.1 A suite of survey methods for the sampling of both juvenile and adult coarse fish lifestages needs to be identified. Development and validation of the sampling methods should be undertaken on three rivers such as the Tees, Severn and Thames. these methods would then be applied on a national survey basis. It is important that these sampling methods are fully agreed, standardised and shown to produce statistically valid results due to the long timescale over which the main study will have to run to be meaningful.

4.0 GENERAL SURVEY STRUCTURE PROPOSALS

4.1 Design

4.1.1 The overall project can be considered as two areas:

- **A National survey programme which will be needed to be undertaken with annual samplings.**
- **Specific R&D projects examining areas such as experimental studies and detailed areas of study where specialised expertise will be required.**

4.1.2 There are several areas that need to be considered before any programme is implemented. The survey design for the project must be simple in its structure if it is to be run over the long time period. The project may need to run for a period of 10 years as a minimum before sufficient data is generated to allow conclusions to be drawn up. Therefore the project must be set up with a view to long term data collection, after method validation studies have provided a simple, practical approach.

4.1.3 The R&D Projects need to be based on a structured research programme seeking to answer questions to individual problems rather than as general question projects. Such R&D projects therefore will require to be highly specific in the questions being set and the outputs required.

4.2 Suggested study projects

4.2.1 National Studies:

a) National annual sampling programme of numerous sites of angling importance on as many rivers as possible for juvenile and adult abundance in bream and barbel zones. This should be combined with abiotic measurements of flow and temperature.

4.2.2 Regional Studies:

a) Specific type river studies in the North, Midlands and South where all life stages of coarse fish species may be effectively sampled.

b) Assessment of the habitat availability, including overwintering habitat, for all life history stages of coarse fish on selected large rivers to include barbel and bream zones (cf. Northcote 1978).

4.2.3 Suggested R&D Experimental Studies:

a) Larval and juvenile coarse fish growth and temperature.
b) Larval and juvenile coarse fish growth and density.
c) Larval and juvenile coarse fish survival and food resource particularly examining the importance of lipids.
d) Habitat usage by different life history stages of coarse fish.
e) Hatching success in relation to water temperature.

4.3 Target Species

4.3.1 The target species for study should be those which are considered to be recreationally important in the barbel and bream zones of large lowland rivers (Huet 1947). The species list resolves itself, in order of importance to:

- roach
- bream (bronze)
- chub
- barbel
- dace
- perch
- gudgeon
- pike
- bleak

4.4 Selection of survey sites

4.4.1 General matters: The types and numbers of sites selected will depend on whether the project is within the national, regional or R&D category. For rivers selected for sampling habitat criteria for each study reach should be identified. There will be a need to sample both the barbel and bream zones after applying Huet's classification scheme. Each zone should be considered separately within the studies. It is likely that there are relatively few, if any, bream zones present on many UK rivers which have not undergone major habitat degradation due to flood defence schemes and channel modifications. The bream zone identified by slope would then be sampled regardless of its condition of habitat degradation. Collaboration may be necessary with European countries where rivers are present which display the natural features of the bream zone. Sampling programmes could be established on 2 selected European rivers to provide comparative data to those collected in the UK rivers.

4.4.2 National Studies: A range of large lowland rivers will need to be selected for the study of juvenile and adult abundance. As many rivers and sites as is practical should be identified for monitoring on an annual basis over a long time scale. The number of sites that will be required to produce statistically valid results will depend on the initial validation of sampling methods. As a guideline it is suggested that possibly 20 sites would need to be selected in each of the barbel and bream zones for juvenile sampling. The sampling of these sites for juvenile fish would be undertaken in August to capture 0+ fish when the main criteria for selection of these sites are:

- **The sites must be considered to represent suitable habitat for 0+ fish which can be effectively sampled.**
- **The sites would preferably be located on popular recreational angling areas to allow sufficient anglers to be present to assist in the monitoring of adult stocks.**
- **If the sites are not considered as popular recreational fisheries they should be suitable for sampling by electric fishing.**
- **It may be necessary to consider the possible effects of cormorant predation when sites are selected due to the potential impacts these birds may have on adult stocks which would act as a confounding factor in the study of YCS.**
- **The same sites should be sampled each year to allow comparison of the results.**

The sampling could be repeated the next June to determine overwinter survival rates. Adult fish should be sampled in areas co-incident with the juvenile fish.

4.4.3 Regional Studies: Selected type rivers should be chosen in the North / Midlands and South of the UK for more intensive studies. An important criteria is that the selected sites can be effectively sampled for all life history stages. For example a selection may include the River Trent or Severn and the Thames. Sampling sites could then be identified on the main river stem and larger tributaries. Canals and still waters may also provide useful additional sites as they can be effectively sampled.

A similar methodology to the national survey should be pursued on the regional studies of the type rivers selected in the north and south of the country but on a more intensive basis. The work undertaken by Mann on small chalkstream rivers has been of great value. However, the studies may be considered unrepresentative of many course fish rivers because of their chalkstream nature. Similar studies could be repeated on a regional basis but designed to include all habitats and all life history stages. This will provide more precision to the data and detailed information on recruitment for the type rivers. These data may then be extrapolated and incorporated into the interpretation of the National sampling results.

4.4.4 R&D Studies: The selection of sites for the R&D components will be highly specific depending on the particular study. The R&D contracts are likely to be on an experimental basis and require experimental ponds or fluvaria for the study of growth and habitat preferences. Field study sites may be required as part of the R&D contracts and contractors would need to co-ordinate with the manager of the National long-term sampling programme.

4.5 Biotic and abiotic measurements

4.5.1 General matters: Temperature, flow, dissolved oxygen and food availability were highlighted as possible factors influencing YCS for juvenile cyprininds on lowland rivers. These parameters are therefore obvious data to collect alongside the sampling programme. However, we would suggest that it is not practical to include food studies as part of a national programme. Temperature has been demonstrated to be a particularly important parameter but is normally only monitored as a spot reading associated with dissolved oxygen recording during water quality sampling. The level of collection of these data tends to vary between regions at present and the is a need for the standardisation of data collection on a national basis The value of using 15 minute temperature loggers along the length of the river was demonstrated in the NRA Tyne Dace contract.

4.5.2 National Studies: The national study will need to be address:

Sampling Programme: In conjunction with the extensive fish sampling programme it is suggested that 15 minute temperature and oxygen loggers are installed at a range of sites identified for fish sampling. The use of 15 minute loggers is considered vital to allow the fluctuations which are likely to be important to be examined. Flow data should also be available for all study rivers.

This would allow, over a long time scale, the influence of these parameters on YCS to be established. We feel that this may be all that could be practically measured at a National level.

4.5.3 Regional Studies: There are two aspects of the regional studies that need to be addressed:

Sampling Programme: The measurement of abiotic and biotic parameters in regional studies on the type rivers could be undertaken on a more intensive basis to provide greater detail than can be practically collect in the National study. This information will provide important additional information that can be considered when the national survey results are being analysed. This could include detailed microhabitat logging of flow and temperature and dissolved oxygen. The importance of flood events to the bream zone, the flood pulse concept, on recruitment success should be investigated. This flow information could be compared to data collected from the bream zone of European rivers.

Habitat Assessment: From the National sampling programme sites would need to be identified which were productive for different life history stages of the target species, including winter habitat for juveniles. The summer habitat requirements of juvenile coarse fish have been fairly well studied but there is a general lack of information on the winter habitat requirements for juveniles and the habitat requirement of sub-adult and adult fish particularly in bream zone reaches. The habitat of these sites could then be examined on a more detailed basis to include measurements such as temperature logging, flow logging, depth, cover and substrate. This information can then be compiled to provide parameters for assessing the coarse fish habitat availability on rivers.

4.5.4 R&D Studies: The measurements undertaken for the R&D studies will be specific to each project. Details of the type of project recommended are presented in section 5.0.

4.6 Data Analysis

4.6.1 General matters: A National Officer should be appointed by the Agency to collate and analyse the data from the National Surveys and ensure the co-ordination of regional surveys. Data should be stored on a suitable software package which allows large databases to be manipulated and analysed. This information should be available to the Agency as an annual report to the fishery officers of all regions.

4.6.2 National Surveys: The National surveys applied over a long time scale can be used to follow year classes (see Figure 1) and determine YCS. From this study a YCS density index may be developed which is likely to be on a logarithmic scale (e.g 0-1 fish.m^{-2}, 1-10 fish m^{-2}, 10-100 fish.m^{-2} etc).

This can be combined with data collected from temperature loggers to determine the importance of this parameter on year class strength. Non-parametric statistics could be applied to this data set and may be the most appropriate technique for some elements.

4.6.3 The recommended approach will allow the densities and growth of coarse fish to be examined throughout the UK. The use of ANOVA, ANCOVA and regression analysis will also provide useful statistical technique for examining the temporal and spatial differences in the data for comparing river systems over a long timescale. The interpretation of the data should be considered at fisheries, ecological and conservation levels.

4.6.4 Regional Surveys: The regional fish surveys on the selected rivers may be analysed using similar techniques to the National survey. The techniques and analytical methods previously applied to survey data sets obtained by Anglian region are also likely to be applicable. The analysis of habitat data many be approach using the multi-variate approach of correspondence analysis. This should allow the important habitat features associated with different life history stages to be identified from-which assessment criteria may be developed. This information can then be used to map, in a similar way to river corridor surveys, the habitat availability on the study rivers. A GIS system can be used to record and update this information. If this approach is demonstrated to be successful then it is proposed that a national habitat survey is undertaken using the techniques developed.

4.6.5 An annual review of the results of the national studies may allow the sampling regime to be reduced after a several years data have been collected.

4.7 Costs

4.7.1 It is difficult to determine the costs for the project as it depends on the degree to which the project is undertaken in-house and incorporated into the rolling programme of stock assessment.

4.7.2 The following is an example of the personnel requirement for annual juvenile sampling of a river for the national survey:

To survey 1 river: i.e.	**20 sites in the barbel zone** **20 sites in the bream zone**
Personnel required:	**2 - 3 people**
Time required for sampling:	**5 days (river dependant)**
Processing of catches in laboratory:	**10 days (depending on sample size)**
Data analysis:	**5 days**
Reporting	**5 days**
Total time requirement	**40 days / river**

4.7.3 Additional time requirements will be necessary, for example, for the selection of sites, meetings and analysis of abiotic factors. It is proposed that that the validation and development of sampling methods is undertaken as a specific R&D project.

5.0 SUGGESTIONS FOR EXPERIMENTAL R&D STUDIES

5.1 General Matters

5.1.1 A range of experimental R&D contracts should be arranged to provide specific data on the growth and survival of coarse fish juvenile life stages. The most cost effective method for undertaking these studies is by the use of PhD studentships at research institutions. The applications for the PhD studies should be made in a similar manner to the system for applying for Research Council projects.

5.2 Coarse fish Growth and Temperature

5.2.1 This R&D contract should be set up to specifically examine the growth of the target coarse fish species in relation to a range of temperature regimes. Tank experiment would be suitable for this project which should be pursued with a similar method to that undertaken by Elliott *et al.* (1996). This would allow growth models and optimum growth temperatures to be established for each species. It is currently assumed that overwinter survival is partially related to good growth rates of juvenile fish during the summer period. This information could then be compared to data obtained from the long-term national survey to examine geographical differences in growth rates for the target fish species.

For example it may be shown that the recruitment of some species is limited to slower growth in northern regions and thus effect recruitment to the fishery.

5.3 Coarse fish growth and density

5.3.1 It can be hypothesised that on natural systems 'bottle-necks' may occur at the juvenile stage due to limited availability of nursery habitat areas. This may result in density dependant factors exerting an important effect on growth and survival. This R&D contract is likely to be set-up in pond or tank or fluvaria systems where different densities of fish of the target species are introduced. Frequent sampling of the experiment systems can then be used to examine the influence of stock density on growth and survival.

5.4 Coarse fish survival and food resource

5.4.1 This R&D study should aim to examine the importance of food availability and survival. Both pond and tank experiments may be used for this study.

Pond studies may involve fertilisation of particular ponds, chemical treatment to remove zooplankton, or the use of supplementary feed ration to examine growth and survival over 2 or 3 years. The condition of fish, possibly as a result of lipid accumulation, has been highlighted as a potentially important factor in determining overwinter survival. The relationship to growth, condition and lipid accumulation should be examined as part of this project.

5.5 Habitat usage by different life history stages of coarse fish

5.5.1 To provide detailed information for the development of the national habitat assessment of large lowland rivers it is recommended that an R&D project is set up to investigate the habitat usage by different life history stages of the target coarse fish species. This work is likely to involve a combination of ponds, fluvaria, laboratory flowing water systems and field site studies. The use of habitat in terms of temperature, depth, flow, structure, macrophyte cover, substrate, and time of day should be examined. Observation studies and underwater video equipment may provide a useful technique in examining behaviour. This may be a difficult project to undertake and should be carefully set up with clearly defined objectives. Supplementary samplings at field sites on large lowland rivers are likely to be important. Comparing catch to habitat will be important for determining the habitat requirements of the different life-history stages in the field. This data may then be applied to developing a method for the national habitat assessment and compared to data obtained from the national sampling programme.

5.6 Hatching success and abiotic factors

5.6.1 This study should aim to evaluate the relationship between abiotic factors and ova hatching success in the target coarse fish species. The importance of post-hatching conditions in determining survival and early growth could also be studied as part of this work.

6.0 TIMETABLE

6.1 Suggested timetable

The following is a suggested timetable for development of the project:

1997	Set up R&D contract on developing fish sampling methodology
1998	Test sampling methodology and survey technique on three selected rivers
1999	1) Implementation of national survey (to be reviewed every year and undertaken for a 10 year period)
	2) Implementation of regional programme
2000	Advertise PhD studentships on an annual basis.

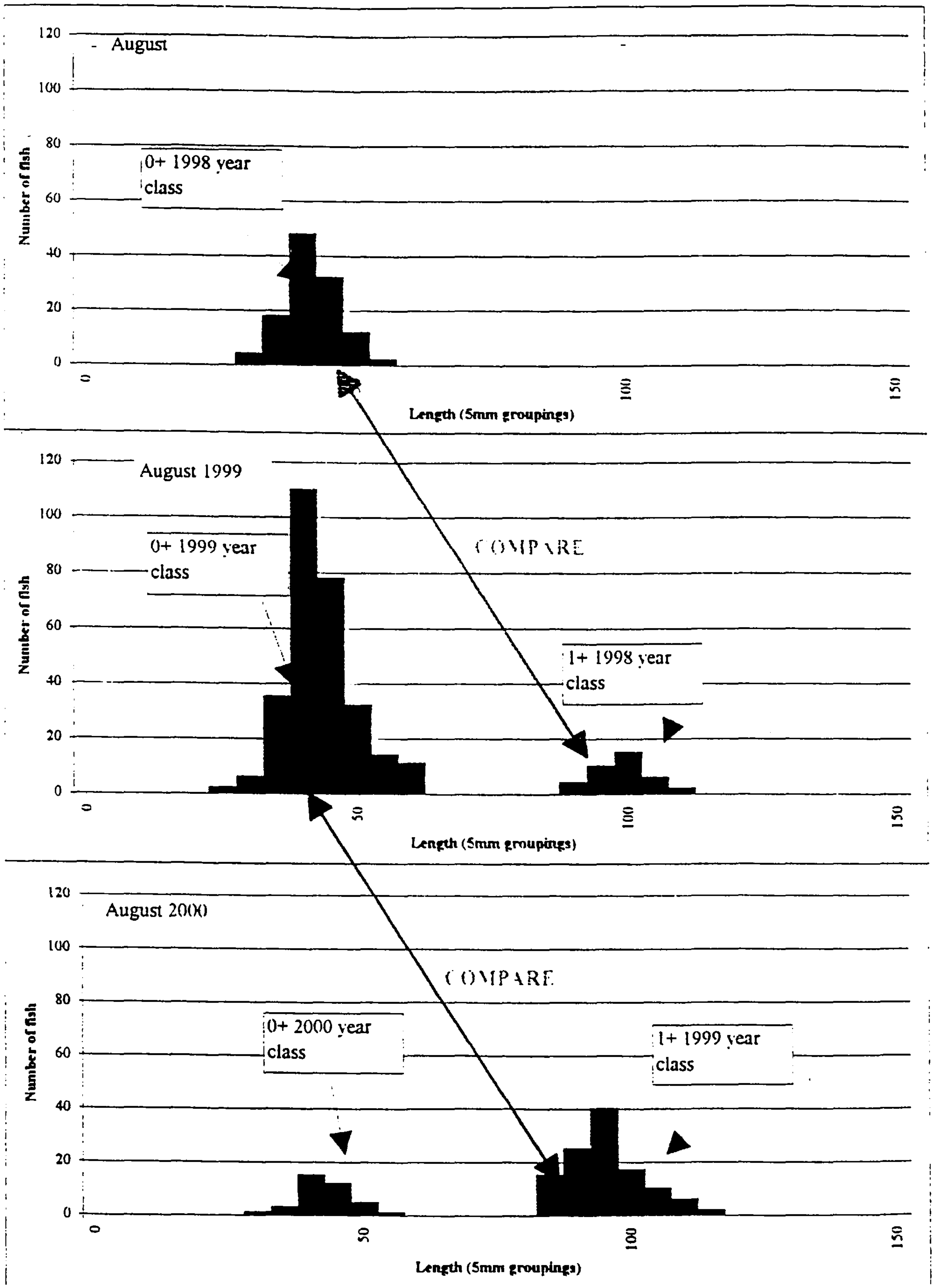


Figure 1: Length frequency histograms to examine year class strength

CONTENTS

University of Hertfordshire
GH Copp, P Garner, AW Bark

Contents — Page No

1. INTRODUCTION

Unlike marine fisheries, relatively less is known of the factors influencing the recruitment of freshwater fish species (Houde 1994). For the Environment Agency to manage fisheries effectively, it will be necessary to understand which factors, both biological and environmental, affect the abundance of fish populations as well as the mechanisms by which these factors operate. To identify these factors and mechanisms, the Environment Agency (the then NRA) commissioned an R&D study (NRA 1995), which provided a number of recommendations under the nine subject areas given here below:

Habitat requirements of coarse fish in lowland rivers

1) Habitat requirements for all life stages of coarse fish and seasonal habitat changes are included in habitat suitability index (HSI) models.

2) The responses of fish species to a sudden change in habitat caused by human activities, particularly as a result of habitat restoration projects also need to be monitored in detail, so that more insight is gained into habitat requirements.

Natural factors affecting recruitment success

3) Considerable effort should be put into collecting 0+ fish growth and environmental data to examine further the relationships between these variables. Once the individual factors that regulate recruitment have been evaluated, it is recommended that a dynamic recruitment model should be developed in conjunction with habitat information defined from the HSI models.

Human activities

4) HSI models and multivariate analyses should be used to focus attention on how human activities modify fish habitat, and the influence this has on fish population dynamics.

5) The abundance/biomass comparison (ABC) index should be refined, as it is expected to play a vital role as a supportive tool in the use and testing of the HSI models and multivariate analyses to help discriminate the factors responsible for the various changes observed.

Spawning and nursery habitats

6) Each spring, index rivers should be surveyed to identify the spawning habitats of the major angling species.

Life History strategies

7) Attention should be focused on general autecology to examine how fish populations and individuals respond to environmental change, and the implications this has on stock dynamics.

Mortality schedules

8) Life tables should be set up for the main coarse fish species in the main rivers surveyed to identify the rates of mortality at different stages of their life history and establish which factors contribute towards this mortality.

Migration and dispersal behaviour

9) Aspects of the dispersion mechanisms should be examined, in conjunction with studies on the juvenile period, to identify the time of the movement and, if possible, the underlying cause and effect.

10) The migratory behaviour of mature fish should be examined in order to ascertain the extent of movements between spawning, feeding and overwintering habitats.

River/fisheries management project appraisal

11) More detailed studies of the impact of management activities should be carried out.

12) Baseline fish population/community studies (species composition, biomass, growth parameters, reproductive bionomics, movements), combined with habitat assessments, should be carried out over extended reaches of river adjacent to impacted areas.

13) All river management schemes that may have a potential impact on fisheries should include pre- and post-project evaluation phases to upgrade knowledge about the impact of different activities.

Data collection and analysis

14) The EA should give consideration to their routine monitoring programme and the objectives of this activity.

15) The data collected during routine coarse fish surveys should be standardised between regions.

16) EA fisheries departments should initiate a policy of collecting appropriate environmental data at the time each fish survey is conducted.

17) Implicit in these recommendations is the need to standardise data archiving, analysis and reporting.

Long-term data sets with the necessary information on riverine fisheries and environmental conditions, in particular water temperature and biological data, are generally lacking in the UK (Cowx et al. 1986, NRA, 1995). Therefore, if the Environment Agency is to obtain an understanding of the factors affecting year-class strength in coarse fish, a programme needs to be put together using a wide-ranging, holistic approach that will provide the necessary data over an appropriate time scale on fish habitat, food supply, predators, and water quality in the variety of riverine environments in the UK.

1.1 Aims and Objectives

Within this context, the aim of the present report is to scope out a study, including the experimental design, methods of analysis, costs, etc., in order to identify which factors affect the recruitment of riverine coarse fish populations, and quantify their impact and the mechanism(s) by which they operate. The general objectives of the proposed protocol will be to provide the necessary data to:

- identify the factors and mechanisms influencing recruitment, and
- address the management goals of the Agency

In doing so, our underlying approach will be to build upon existing good practice in the Environment Agency, incorporating new elements to existing appropriate practice, replacing those less appropriate with others that provide the necessary information, and proposing new practices to acquire information not provided in any way by existing practices. The protocol proposed, in line with the Agency's move towards holistic, integrated catchment management (e.g. Gardiner 1988), is presented within a river catchment context. As such, the present scoping study is an initial step in addressing recommendations 14, 15, 16 and 17 in R&D Note 460 (NRA 1995).

2. SAMPLING PROTOCOL

2.1 Study sites

2.1.1 The effect of spatial scale

The effect of spatial scale has been infrequently studied in fisheries research. Fish populations tend to be comprised of sub-populations representing mobile and sedentary components (Stott 1967, Linfield 1985). This has a selective advantage, allowing the colonisation of new habitats while maintaining a high rate of recruitment from suitable sites. This has important implications to the determination of the minimum spatial scale required for a population to function in a manner that requires the minimum of management. For example, many species undertake upstream migration (Baras 1994, Hughes & Reynolds 1994) which appears to counteract the effect of downstream displacement of the offspring in a similar manner to that described for aquatic invertebrates (Hynes 1970, Peterson & Vanderkoog 1995). If such upstream migration is blocked, not only may this separate the spawning population from suitable spawning habitat (Baras 1994) but it may also reduce the area available for downstream colonisation by the progeny. This may act as an additional control upon recruitment, particularly in habitats where the availability of flow refugia has already been reduced (Linfield 1985, Mann 1995a). More information concerning the ability of drifting fish to locate suitable habitat is needed before any conclusions as to their fate can be made.

Stability of populations is commonly related to the spatial scale and habitat diversity present in the environment (Rahel 1990, Kolasa & Weber 1995). Thus, increasing the size of the conserved area tends to stabilise the populations present owing to an increase in habitat variability (Webb & Thomas 1994). This will reduce the effect of rare events and reduce the strength of biotic interactions by increasing the range of habitats available in the conserved area, allowing the formation of distinct sub-populations (May 1972, 1979, Taylor 1991, Sutcliffe et al. 1995). The advantage of increasing habitat size can be maximised if the form of the habitat is taken into account (Webb & Thomas 1994, Sutcliffe & Thomas, pers comm.). Not only should the diversity of the physical habitat be considered but also the distribution and connectivity of the different mesohabitats, as rates of colonisation and extinction will effect the stability of the habitat mosaic (Webb & Thomas 1994). This is particularly so in aquatic systems, where natural colonisation is only possible between connected patches.

In line with the Agency's move towards an integrated, holistic approach to river catchment management, the study of riverine fish populations should be hierarchical, both in terms of how the river catchment is perceived (e.g. Lastochkin 1943, Frissel et al. 1986, Amoros et al. 1987, Malavoi 1989, Wasson 1989, Bengen et al. 1992, Cortes et al. 1995) and how the data are analysed (Pialot et al. 1984, Persat et al. 1985, Chessel et al. 1987, Dolédec 1988, Juhász-Nagy 1992, Copp et al. 1994). Therefore, sampling effort within a given catchment should ideally be of equal intensity, with sampling techniques applied at the micro, meso and macrohabitat scales. However, given the range of environments present in river catchments, such a hierarchical sampling approach, designed to address the current gaps in fishery knowledge, would prove prohibitively expensive. Therefore, we suggest a hierarchical sampling strategy that incorporates the following components to reduce the effort required (Fig. 1):

1) **Key** sites within the upstream (rhithron), mid-stream (upper potamon), and downstream (lower potamon/tidal river) 'sections' of the catchment where regular, i.e. seasonal, and specialised sampling will provide precise data on life history, habitat use, etc..

2) **Complementary** sites within each catchment section will complement the key sites, allowing the results collected at the key sites to be viewed within a wider perspective. Complementary sites should be sampled on an annual basis, subsequent visits to a site being in the same season as in previous years.

3) **Additional** sites with each catchment section would be sampled on an occasional basis either to complement routine sampling of the Key and/or Complementary sites or as part of an Impact Assessment Protocol (IAP).

This protocol is similar to elements of the protocols currently used by EA staff in various regions, but incorporates the intensive study of a limited number of sites in order to acquire an understanding of the seasonal framework of patterns within which the data from annually or occasionally sampled sites can be assessed. This sampling protocol will provide the information necessary to address in whole or in part the recommendations 1, 2, 3, 4, 5, 7, 8, 9, and 12 given in R&D Note 460 (1995); it should be complemented by a number of satellite projects, which will consist of specific studies that generate the information required to address in whole or in part the recommendations 3 - 11 given in R&D Note 460 (1995). The Impact Assessment Protocol, will provide the information necessary to carry out recommendations 11 - 13.

2.1.2 Site choice

In general, reaches of the river encompassing biological and geomorphological break-points are best avoided because of the large variability encountered. In addition, areas affected by human activities should also be avoided because these may be affecting the biota in an indeterminate manner. Bovee (1980) recommends the following proceedure for determining the choice of key study reaches of rivers:

1) produce topographical, land cover and geological maps of the catchment;
2) indicate major changes in flow (>15%), changes in sinuosity, permanent passage barriers and other human changes to river form, point sources of pollution, areas of land use change, areas where access is poor or cannot be obtained;
3) remove all river reaches containing the features in item 2 and determine reaches within similar geomorphology;
4) from each geomorphic type, select five representative reaches at random.

Location of complementary and additional study sites can be undertaken on a more ad-hoc basis. Complementary sites should avoid the features listed under item 2. Correspondingly, Additional sites will be chosen because they contain those features outlined under item 2.

2.2 Material & Methods

2.2.1 Natural and human factors affecting recruitment success

Data on fish relative abundance, relative biomass, frequency of occurrence, life-history data (age, diet, fecundity, mortality, growth), and habitat availability/suitability should be collected using sampling approaches appropriate to the information required and the environmental circumstances, as no one sampling approach is appropriate to all situations.

Casselman et al. (1990) list a total of 57 sampling techniques that have been used to varying degrees to sample fish in large rivers. These can be divided into those which are designed for studying fish at the individual level (i.e. direct observation, spear fishing) and those which are designed for studying fish at the assemblage level (i.e. netting, trawling). A great deal of overlap occurs between these two groups. Historically, most studies of fish, particularly in Europe, have concentrated upon the quantification of population parameters, such as growth and mortality. Conventionally, three main sampling strategies have been used to sample fish at the assemblage level: successive removal strategy (De Lury 1947), absolute abstraction strategy (Mahon

1980) and mark-recapture strategy (Petersen 1896). All of these techniques are labour intensive and generally require that a large proportion of the population of the study reach can be removed efficiently (Hankin & Reeves 1988). In large rivers, this often requires the removal of an extremely large number of fish, increasing the processing time. The taking of a small number of relatively large samples also tends to yield data with low statistical power (Cyr et al. 1993), requiring increased sampling effort or alternatively a reduction in the accuracy of population statistics. What is required is an increase in the number of samples taken with a reduction in the effort expended per sample.

Quantitative estimates of fish density and biomass should be acquired using the single depletion catch per unit effort (CPUE) sampling strategy, which would be calibrated using the conventional three-depletion approach (Zippin 1958, Seber & LeCren 1967, Carle & Strub 1978). The fish should be captured either by electrofishing or seine netting, depending upon their suitability to the environmental conditions.

2.2.2 Sampling the early stages of fish

Microhabitat-based sampling techniques tend to have less impact upon the biota and also tend to be less labour intensive, allowing a larger number of samples to be taken. This greatly enhances statistical robustness and may also allow the data to be used at several spatial scales, from a single microhabitat patch to hydrosystem (Copp et al. 1994, sensu Petts & Amoros 1997). Yet, the smaller number of fish captured may limit the usefulness of the technique for examination of specific traits, such as diet, where larger sample sizes are required.

Sampling of small fish, particularly the 0+ group, has received considerable attention during the last two decades owing to the recognition of the importance of this life stage. Most research carried out upon 0+ fishes has focused upon habitat use (Copp 1992a, 1992b, Watkins et al. 1997), growth (Mark et al. 1987, Mooij & Van Tongeren 1990; Kubecka 1994) and diet (Mann 1995a). Few published data are available detailing the estimation of population parameters for 0+ cyprinids because of the difficulty in sampling in a quantitative manner, obtaining estimates of reasonable statistical power and of determining size-related capture efficiency. From the point of hatching, the growth of fish is extremely rapid, with a thousand-fold increase in weight during the first summer (Tong 1986), rapid morphological development (Prokes & Honrakova 1988; Copp 1990a, Kovác & Copp 1996), and changes in habitat use (Copp 1990a, 1992a, 1992b, Copp & Kovác 1996). These specific factors mean that most sampling techniques are not suitable for sampling 0+ fish throughout this period.

Of all sampling techniques currently in use, electrofishing is one of the most popular for shallow water situations. Yet, electrofishing was rarely used (e.g. Dauble & Gray 1980) previous to the last decade for capturing small fish because of the difficulties of sampling short fish using electricity (Copp & Penáz 1988, Persat & Copp 1989). As a result it has been necessary to adapt present electrofishing equipment to increase the efficiency of capture of small fish (Copp 1989a Copp & Garner 1995).

2.2.3 The point abundance sampling strategy

Point Abundance Sampling (PAS, Nelva et al. 1979) was adapted from ornithological research (Blondel et al. 1970; Blondel 1975) and combined with electrofishing to address the problems of sampling fish in complex river ecosystems. Although this approach has gained some acceptance, few studies have quantitatively evaluated the ability of this technique to provide reliable, reproducible results (Copp & Garner 1995, Garner 1997).

PAS is suitable for sampling 0+ fish because it provides a rapid means of collecting a large number of relatively small, random samples, which will be less biased by the contagious distribution of the fish. This will increase the statistical robustness of the data (Blondel et al. 1970; Blondel 1975; Downing & Anderson 1985), as uncommon events will have a relatively small effect on the results. Personnel requirements and equipment costs are small and data analysis can be carried out at spatial scales ranging from a single sampling point (microhabitat) up to the catchment scale (Copp et al. 1994).

PAS is ideal for capturing fish in diverse habitats, yet it requires a suitable sampling method. Previously electric fishing (Bain et al. 1985, Copp & Penáz 1988, Copp 1991, 1992a, Scheidegger & Bain 1995), dip nets (Carrel 1986, Copp 1987), hand seines (Carrel 1986, Copp 1987), buoyant nets (Bagenal 1974), rod & line (Abell & Fisher 1953, Robson 1960, 1961) and visual observation (Grossman et al. 1987) have been used with the PAS of one form or another. Of all sampling methods currently in use, electrofishing is one of the most popular for shallow water situations (Copp & Garner 1995). However, any sampling method can be used in conjunction with the point sampling strategy if it:

1) offers a high rate of data acquisition relative to time expenditure;
2) produces comparable replicate samples;
3) allows random samples to be taken.

Thus, estimates of relative density and biomass, in particular those of small and young fishes, should be collected using PAS by electrofishing, which would be controlled using seine netting. The CPUE/depletion approach will be appropriate in most circumstances to the up- and mid-stream sections of the river catchment. In the downstream sections of the catchment, where CUPE/depletion methods are not applicable, the combined use of echosounding and elector/conventional trawling should be used to obtain the estimates.

2.2.4 Satellite project I - comparison of sampling techniques

All sampling gears are selective for a certain size range and species of fish (Reynolds 1983). Although a large number of different sampling techniques have been developed, these are often limited to specific conditions of fish size, water depth, water transparency and the absence of snags (Casselman et al. 1990). Whatever gear is used, the efficiency must be calibrated so that comparisons between sampling occasions, the effect of species composition and the effect of habitat type can be compared. Calibration of efficiency generally requires that a known population is sampled. This is difficult to achieve, owing to the lack of boundaries in river systems, thus the population under study may well be in a continual state of flux. More applicable is the comparison of the gear with others of known efficiency over short time intervals. This does not require that the population should remain static as the sampling duration is relatively short, but it does require that the first sampling strategy does not adversely affect later sampling (Garner 1997).

2.2.5 Habitat recording and measurement

As with fish sampling, a hierarchical sampling design should be used for collecting environmental data, thus providing an assessment of habitat requirements at the micro, meso, and macrohabitat levels, and permitting comparisons within and between river catchments. At the macrohabitat scale the following variables should be recorded: distance from tidal limit, stream order, link number, site altitude, site gradient, stream flow, catchment area, mean conductivity, catchment gradient, mean wetted width and mean depth. At each point the following variables should be measured: water column depth, water velocity, substratum roughness, cover density, temperature. Macrohabitat data should be collected on each occasion when CPUE/depletion sampling takes place, with the microhabitat data of young and small fishes collected in conjunction with the PASE (Copp & Garner 1995)

Because of the lateral and longitudinal changes in habitat available at each site, it will be necessary to record habitat availability during each sampling occasion. Habitat variables will be recorded at a minimum of twenty points along a minimum of three transects placed perpendicular to the line of flow.

2.2.6 Water quality characteristics

The water quality variables worthy or measurement have been listed in R&D Note 460 (NRA 1995): water temperature (°C), hardness, suspended solids ($mg{\cdot}l^{-1}$), conductivity ($\mu g{\cdot}cm^{-1}$), alkalinity, acidity (pH), the concentrations of oxygen ($mg{\cdot}l^{-1}$), ammonia ($mg{\cdot}l^{-1}$), phosphate ($mg{\cdot}l^{-1}$), the levels of biological oxygen demand (BOD; $mg{\cdot}l^{-1}$) and total oxidized nitrogen (TON; $mg{\cdot}l^{-1}$). These variables would be measured at the precision currently being employed by the EA. Coordination between fisheries,biology and water quality sections within the EA would minimise the costs of obtaining water quality information of use to fisheries and conservation.

2.2.7 Transect placement

Even on small channels, recording habitat variables in a quantitative manner will require at least one man hour per transect. It is thus essential to balance the trade-off between adequately describing the study reaches and resource limits. Large trapesoidal channels are relatively homogeneous and require less sampling effort. Trapesoidal channels may be adequately described using only three transects (Garner 1997).

Less regulated channels, particularly those containing a number of hydraulic controls, such as riffle-pool sequences require more sampling effort. Bovee (1980) suggest a minimum of five transects per riffle - pool cycle. Transects should be placed at any hydraulic controls in the study reach (i.e., at the head and tail of riffles), within each mesohabitat (i.e., riffles, runs and pools) and in transition zones between mesohabitats.

2.2.8 Target species

Certain groups of target species should be identified for special consideration, in particular the rheophilous cyprinids in upstream sections (e.g. dace *Leuciscus leuciscus* and chub *L. cephalus*), larger-bodied shoaling cyprinids (e.g. roach *Rutilus rutilus*, bream *Abramis brama*) and piscivorous fishes (pike *Esox lucius*) in the mid-stream sections, and limnophilous species (e.g. silver bream *Blicca bjoerkna*, rudd *Scardinius* *erythropthalmus*) in the downstream sections of the catchment. In some catchments or parts of catchments, some species such barbel *Barbus barbus*, as eels *Anguilla anguilla* and perch *Perca fluviatilis* may be locally abundant and could require special consideration.

2.2.9 Habitat satellite project II - Spawning habitat

Spawning and nursery habitats should be evaluated using PHABSIM modeling and the development of habitat suitability indices (e.g. Pouilly & Souchon 1994), in particular for up- and mid-stream sections of the river, though this approach may be applicable to some downstream locations.

In May/June, the survival of embryo's on the spawning grounds will be monitored for individuals held in *in situ* traps (Raddum & Fjellheim 1995). The traps will be located so that a large range of physical habitats are included. At each point the water conductivity, pH and oxygen concentration will be monitored daily, and water velocity, bottom shear stress and substratum composition (particularly the contribution of silt) recorded upon removal of the traps. Each trap will be stocked with 800 fertilised eggs. Hatching date will be determined using the formula of Penaz (1973), after which time the traps will be removed. The number of remaining eggs and the number of free-embryo's present in each trap will be determined. Owing to the rapid disintegration of infertile eggs (Raddum & Fjellheim 1995) the difference between the initial and final counts will be ascribed to egg mortality. Habitat suitability curves will then be produced for the intragravel period of the life history. These data will be compared to similar studies undertaken upon salmonids.

2.2.10 Habitat satellite project III - Dispersal

The migration and dispersal behaviour of the fish should undertaken by way of an intensive fish tagging programme (Satellite project IV), complemented by radio-tracking (Satellite project V) and drift sampling, the latter in particular for the downstream dispersion of fish eggs and larvae. With some species, such as barbel, which is both a popular angling fish and an indicator of river integrity (Copp et al. 1991, Roux & Copp 1996), the rhythm and behaviour of emergence of free-embryos and the downstream dispersion of larvae is important to recruitment success. This behaviour can be investigated using *in situ* emergence/dispersion traps (Bardonnet & Gaudin 1990), with fertilised eggs stocked at 800 per in situ emergence/displacement trap (daily sampling until first emerging/drifting larvae observed, then once every 2 h over 48 h). The behaviour of drifting individuals will be determined by releasing a known number of free-embryo's marked with tetracycline (immersion stained for two hours at concentration of 100 $mg \cdot l^{-1}$) just above the surface of the substratum. These will be sampled at progressive distances below the release point to determine the rate and distance of movement, relative to the morphology of the river. Also, the intensity and rhythm of natural emergence and downstream dispersion by barbel larvae will be investigated with drift nets (mornings until the first specimens are captured, then over a 48-h period, then once per day weekly).

2.3 Frequency of sampling

The key sites within the upstream, midstream, and downstream sections of the catchment should be sampled in a manner commensurate the with the key periods in the development of fish. For coarse fishes, several key developmental periods can be identified. Initially, suitable spawning sites must be available. Spawning habitat can be interpreted as the habitat chosen by the adult fish upon which to lay their eggs (Shirvel 1989, Sempeski & Gaudin 1995). Survival of the eggs in a given habitat also needs to be modelled. (White 1942, Raddum & Fjellheim 1995). Although both measurements may be important, there is no a priori reason to presume that fish lay their eggs in the most suitable habitat available. In regulated rivers, characterised by rapid changes in habitat conditions, suitable habitats may rapidly become unsuitable (Mills 1981a, Hvidsten 1985, Mann 1995a). It is thus important to consider both the habitat choice by the adults and also the survival of the eggs.

Upon hatching, most species of cyprinid fish remain close to the site of egg deposition and habitat suitability will, for a short period of time, be similar to the spawning habitat (El-Fiky & Wieser 1988, Copp 1989). After a period of 2-10 days (El-Fiky et al. 1987) the fish start actively selecting the habitat available in an (supposed) optimal manner (Copp 1990b). This period corresponds to the development of the musculature and sensory organs (Blaxter 1986). During this period the fish often drift downstream (Copp & Cellott 1988, Pavlov 1994) owing to intraspecific competition and lack of essential resources (Elliott 1984, 1987). Roles of competition and passive movement in determining the drift of cyprinids remains to be quantified. This second distinct period of habitat selection thus, coincides with the progression of the fish to developmental step L2 (Copp 1990b).

Once the fish reach the L2 step, they are able to choose the habitat that they use from that available. This appears to develop at two levels: habitat that is always unsuitable, owing to the morphology and physiology of the fish (i.e. fast flowing currents and dense macrophyte stands) and habitat that is suitable depending upon the physiological state of the organism (i.e., velocities close to the critical swimming speed and areas of high predation risk). As long as a certain quantity of habitat remains within these established physiological limits, then it is physically possible for the species to support a viable population (Bovee 1986). The relationship between the members of the population, i.e., the degree of inter-individual tolerance, will determine the relationship between habitat availability and fish density (Elliott 1984; Bovee 1986). It is unlikely that such a relationship will remain static, particularly in complex habitats where obstacles, such as macrophytes and coarse woody debris, may act as a partial refuge, thereby increasing inter-individual tolerance. In cyprinid fishes, tolerance is generally high (unlike salmonids for which habitat models were originally developed) and the fish often form shoals. In this instance there may be a minimum size to each functional unit greater than one (Allan & Pitcher 1986). Hence, the use of individual-based measures of habitat suitability, including density, may be inappropriate. In view of the highly contagious distribution of 0+ cyprinids (Copp 1992a, 1992b, 1993a, 1993b, Copp et al. 1994, Garner 1996a, 1996b, Watkins et al. 1997), it is unlikely that density-based models would provide unbiased results.

The late larval period represents the next period of habitat use, owing to differentiation of the the finfold and development of the musculature, mouth parts and lateral line (Balon 1956, 1986). Often during this period the fish utilise shallow water close to the bank (Copp & Juradja 1995), which it as been hypothesised acts as a refugia from aquatic predators (Eklov et al.1994).

Although habitat use may change as the fish grow in weight over several orders of magnitude, the juvenile-adult (non-spawning) period can be considered as a single interval owing to the similar morphology and behaviour of the fish (Balon 1986, Copp & Kovác 1996). The final period returns the fish to the spawning habitat and reflects the choice of spawning site by the adult, rather than the suitability for the progeny.

Sampling each site several times per year will also reveal gross movement of adult fish between reaches.

The **complementary** sites should be sampled once each year, some sites in each season, with consecutive visits to a site always being in the same season as in previous years. It will be possible to gauge the effect of season of sampling from the multiple sampling visits of the key sites.

The **additional** sites would be sampled on an occasional basis, either to complement routine sampling or as part of an Impact Assessment protocol, which would be used to assess management practices and unexpected human alternations to the environment.

In order to obtain the long term data necessary to achieve the Agency's objectives of adequate fisheries assessment and management, the study should be implemented for a minimum of 25 years, with the intention of continuing the monitoring and assessment of the fish populations for an equal period thereafter. Reviews of progress could be carried out each five-to-ten years on the data derived from adult fishes and over shorter intervals with the data on 0+ fishes, which provide a more rapid barometer of environmental change (Copp et al. 1991).

2.3.1 Satellite project IV - Displacement of coarse fish using PIT tags

One of the main concerns regarding any long term study of coarse fish populations is the degree to which the data are biased by mass movements of the fish. This is obviously less of a problem in lake situations but in large river systems fish may move considerable distances (Linfield 1985). Although there has been a long history of using tagged fish to follow the movements of fish populations, most tagging methodologies have an impact upon the behaviour of the fish as they are relatively large. Alternatively, the tags are kept small, minimising tag bias but which are then difficult to read. The recent development of small transponder and visible implant tags has solved many of the technical problems associated with standard tagging techniques.

Passive Integrated Transponders (PIT Tags)

Passive Integrated Transponders, (PIT tags) are tiny implantable tags, each containing an individual code which can be read remotely. They consist of a tiny glass encapsulated transponder which can be programmed at the time of manufacture with any one of almost 500 billion unique codes. Once programmed, the code cannot be changed, and because the tags have no power source they have an unlimited lifespan.

PIT tags are 12 mm by 2 mm cylinders weighing around one tenth of a gram, and work equally well in air or water, and at temperatures from -20 to 80 oC. The tags are read from up to 30 cm away using a hand held reader emiting a low frequency magnetic field, which activates the passive transponder. Once activated the transponder transmits its unique code.

Visible implant (VI Tags)

There are currently two types of visible implant tags, or VI tags available, Alpha Numeric Tags and Elastomer tags. Elastomer is a coloured solution which sets into a pliable solid at room temperature. It can be injected into any clear tissue on the fish, for example between the fin rays, where it hardens. The resulting tag can usually be clearly seen with the naked eye but fluoresces brightly when illuminated with an ultra violet light. There are currently five different colours available and they can either be used to batch mark lots of individuals, or by carefully choosing different colour and position combinations you can apply individually recognisable marks to a smaller number of fish. A recent study of the retention of elastomer marks in dace has shown that nearly all the marks applied were visible two months after tagging, and elastomer marked dace released into the wild have been recovered a year later still carrying the coloured tags (S. Clough pers. comm.).

Alpha numeric visible implant tags are tiny pieces of plastic film that, like elastomer, can be injected into clear tissue sites on a fish. Unlike elastomer, each alpha numeric tag carries an individual code consisting of a three character code made up of both letters and numbers. The code contained on the two and a half millimetre long tags can be read in situ, at least by those with good eyesight, and it individually identifies the fish that carries it. This allows fishery managers to monitor the movements of the fish as well as keep a check on their growth. There are several different colour combinations of both background and lettering, allowing the individual marking of thousands of fish before the need to repeat a code arises.

If a percentage of the fish captured during the routine sampling of the study sites were marked with (preferably) PIT tags or VI tags then it would be possible to follow the fate of individual fish as they moved around the system. This would allow a much greater understanding of the movements of coarse fish in rivers and enable better estimation of between site variation in population parameters and population exchange.

2.3.2 Satellite project V - Telemetry of coarse fish movements

The use of radio and sonic tags allows the behaviour of individual fish to be monitored This can provide data of varying resolution; from the microhabitat inhabited by a fish at a point in time to the home range of a population. Unlike the passive tagging methodologies outlines in satellite project IV, telemetric methods are not reliant upon the recapture of marked individuals. Thus, there is potentially a greater yield of information per individual fish. Unfortunately, equipment costs for telemetric studies are relatively high. The combination of a small number of radio tagged fish with a much larger number of passively tagged fish provides a means of following the movement of fish around the system at a number of temporal scales.

2.4 Data analysis & Interpretation

2.4.1 Habitat

Recent development in multivariate analysis have begun to bridge the gap between the purely descriptive approach to interpreting the patterns observed in the environment and the modelling of natural populations (ter Braak 1986, Copp 1992b, Oberdorff et al. 1993, Copp et al. 1994, ter Braak & Verdonschot 1995). Amongst the most powerful of the empirically-based multivariate approaches is canonical correspondence analysis (CCA), which allows the scientist to examine the relationships between a wide range of environmental variables and species distributions. CCA was developed so that species or species assemblages could be related directly to a group of environmental variables. In the analysis, a biplot is generated, a diagram that illustrates the main pattern of variation in community composition as accounted for by the environmental variables, as well as the species distribution along each environmental gradient. The biplot presents the linear combinations of the variables from the unit variance table (from principal components analysis of the environmental variables) that maximize the variation of the column means from the correspondence analysis table for species (Chessel et al. 1987). The measure of goodness of fit, $100 \times (l_1+l_2)$/(sum of all eigen values), expresses the percentage variance of the weighted averages accounted for by the two-dimensional diagram. The length of an arrow representing an environmental variable is equal to the rate of change in the weighted average as inferred from the biplot, and is therefore a measure of how much species distributions differ along that environmental variable (ter Braak 1986), thus effectively providing a form of niche analysis based on statistics related to multiple regression analysis (ter Braak & Verdonschot 1995). CCA can be used over a range of scales of perception, from microhabitat (e.g. Copp 1992b, 1993, 1993a, 1993b, 1997a, Copp et al. 1994), mesohabitat, macrohabitat (e.g. Pilcher & Copp 1997), and probably larger, e.g. between basin. Thus, CCA could be a powerful form of empirical modelling for use by the Environment Agency at local, regional and national levels.

Whilst offering a predictive element, CCA remains primarily empirical. Similarly, other the Habitat Suitability Index (HSI) and the Physical HABitat SIMulation (PHABSIM) methodologies (e.g. Armitage & Ladle 1990) are empirically based, but provide quantitative models to aid in the prediction of available and exploitable fish habitat.

Modelling the habitat use behaviour of fish is an imprecise science because of the variable response of fish to their environment. Cyprinid fish display a great deal of phenotypic plasticity (Wieser 1991), resulting in a variable response to the habitat available (Copp 1990a). Although a similar scenario has been found with the more intensively studied salmonids, the restricted range of these fishes limits the habitat variability that they encounter. As a result, the existing methodologies developed for salmonid fishes may not simply be transposed to other fish taxa without due consideration of the ecology of the fish in their environment (Orth 1987).

2.4.2 The Instream Flow Incremental Methodology

The IFIM is designed to relate changes in habitat availability, owing to fluctuating discharge, to the capacity of the channel for the target species. This can be summarised as a series of assumptions, implicit in the methodology:

1) the target species exhibits preferences within a range of habitat conditions that it can tolerate and which can be defined numerically,

2) the area of stream providing suitable conditions can be quantified and modelled as a function of discharge and channel structure,

3) the target species reacts to changes in available habitat by altering its abundance in the stream (Bovee 1982).

2.4.3 Levels of habitat use and measurement

Some variables affect the distribution of a species differently at several different spatial scales. Initially, individuals of a species must have gained access to the site for colonisation to occur. Thus, species such as the barbel which has been introduced to rivers geographically separate from its original range by humans have become successful. Original absence of this species from the river was not owing to a lack of suitable habitat but was owing to the lack of suitable immigration. Similarly, young stages of a species may be absent from habitats where the adults are common owing to the lack of suitable spawning habitat (Baras 1994). This is often the situation following the introduction of adult stock when insufficient account has been made of the requirements of the whole life history of the species (Cowx 1994).

For a species to survive and flourish the chemical environment must suit the species. For example, oxygen, pH and temperature must be within the tolerance range of the species (Knights et al. 1995, Pinder & Morgan 1995). Chronic effects of poor water conditions such as slow growth, poor swimming ability and low fecundity may all result from poor water conditions (Wells & McNeil 1970, Orth 1987). Such effects are often difficult to determine, owing to the inter-dependence of many variables. Laboratory studies may provide a clearer definition of the role played by a specific factor on long- term survival but, owing to the long life - span of cyprinid fishes, such chronic relationships have only recently been studied in detail, as it may be many years before the effect of a specific stressful event are determined.

Availability of suitable physical habitat is also essential for survival. This is the focus of most studies of the relationship between the riverine biota and habitat (Shirvell 1986, Moore & Gregory 1988). Often superimposed upon physical habitat availability are biotic factors, such as, competition, predation, parasitism, which may alter the relationship between the target species and its environment (Baltz et al. 1982, Orth 1987, McMahon & Hartman 1989, Greenberg 1992, Tyler 1993). All of these factors must be taken into account when developing accurate and reproducible habitat suitability models if the model is expected to perform well over a range of habitats. Alternatively, relationships may be developed for specific conditions, most commonly for individual reaches which, although they do not include all possible variables, allow for fish behaviour to be approximated in the study reach and similar reaches. Limitations of such models must be explicitly stated and the abiotic and biotic conditions recorded. In general, models developed for individual systems perform better than generic indices (Mathur et al. 1985, Morin et al. 1986, Waite & Barnhart 1992). Three possible explanations for this can be proposed:

1) the generic index is less biased by the availability of specific habitat conditions than the local index (e.g., sampled site(s) were not pristine or the fish population was not at the carrying capacity of the channel; Bovee 1986, Thomas & Bovee 1993);

2) the generic index is less precise because abiotic and / or biotic variables acting at the local scale are not taken into account;

3) conditions in the study reach are outside the scope of the index (e.g., high velocities, deep water).

It is important to distinguish between these causes of disparity because in the first instance the generic index may better reflect the conditions present than the local index, whereas in the other scenarios the specific index may better reflect habitat suitability. In Europe, pristine conditions are rare, thus it is not possible to collect data from unimpacted sites. Instead, analysis of habitat use at impacted sites must be supplemented by critical analysis of the conditions present and be combined with experimental data pertaining to the target species. A knowledge of the historical changes in the system is thus useful in determining the degree of disturbance to which the study sites have been exposed.

2.4.4 Calculation of habitat suitability

Quality of habitat for the target organism can be quantified at several resolutions. At its simplest, the researcher may use previous knowledge of the target organism to determine the relationship with habitat (Type I curve, Bovee 1986). This type of model requires no field work and hence costs can be minimised. Although this technique may not be as legally defensible as more field based techniques, relationships can be produced rapidly and, if a number of experts are included in the analysis the results can provide habitat use relationships over a wide range of conditions (Chaveroche & Sabaton (1989).

Although expert curves offer a means of developing habitat - biota relationships without the need for investigation, the available data may be insufficient for producing accurate predictions for many species. Also, plasticity of response and variety of conditions in river systems often limit the use of expert curves. Most studies designed to develop habitat suitability relationships are based upon empirical evaluation of habitat use by the target organism (Bovee 1986). This requires the sampling of the biota and the habitat and, in more complex studies, the quantification of the relationship between the two.

At its simplest, the position of fish in the study reach may be recorded and used to define the habitat use of the fish by measuring the habitat present at each point (Type II curve, Bovee 1986). This technique offers no indication of the effect of habitat availability upon habitat use, hence the most suitable habitat may be used only rarely because it is in short supply. More complex relationships between habitat availability and use, referred to as habitat suitability relationships (Type III curves, Bovee 1986), have been widely used to overcome this potential bias. Such techniques tend to be of the form:

$$S = P_i/A_i$$

Where P_i = the amount of habitat category i used by the fish as a proportion of all habitat used by the fish and A_i = the amount of habitat i available as a proportion of all habitat available. Although several forms of this relationship have been used for different organisms (e.g. presence/absence, relative density, biomass), all assume that all habitat patches are equally available to the organism, that the Ideal Free Distribution is obeyed and that the density of fish present is equal to the channel carrying capacity, so that all available habitats are used relative to their suitability (Bovee 1986). In practice these assumptions are rarely met (Mathur et al. 1985). Channel form may limit the availability of certain peripheral habitats (i.e., ox-bow lakes), shoaling behaviour often negates the ideal free distribution, particularly in complex habitats where it is difficult to predict habitat value, often fish density is controlled by factors other than habitat availability (i.e. predation) so that the channel is not at its carrying capacity.

It is also possible to measure habitat use (and hence suitability) in several manners. Historically fish habitat use has tended to be measured as presence / absence in IFIM studies (Bovee 1986). Yet in reach - scale relationships between the biota and habitat both biomass and density of individuals have been used to define suitability. This is also the case in studies of habitat suitability for invertebrates carried out using the IFIM (Gore & Judy 1981). As the output of PHABSIM is expressed as weighted usable area per unit reach area, it has been preferable to determine fish abundance numerically. This may prove extremely difficult though, owing to the variation in the intraspecific behaviour of the fish (Allan & Pitcher 1986). In shoaling fishes, such as 0+ cyprinids, the use of density based estimators should yield poor quality results owing to the aggregation of the fish (Ibbotson et al. 1994). For such studies to be truly successful the fish must be responding to the environment available in accordance to the ideal free distribution. Thus, the density of fish found in a given habitat will be directly proportional to its relative suitability. A more suitable index for shoaling fish may be the use of frequency of use as a relative measure of habitat suitability.

The ability of any model generated by the IFIM to adequately describe habitat availability is dependent upon the quality of the raw data (Gore & Nestler 1988). Several techniques have been used to collect habitat use data, which include: successive removal of fish at the reach scale using electricity, rotenone, or netting (Conder & Annear 1987, Parsons & Hubert 1988, Layher & Brunson 1992), observation of individual fish from the bank using scuba equipment (Moyle & Baltz 1985, Theilke 1985, Waite & Barnhart 1992, Barrett & Maughan 1994) and radio telemetry (Gerhardt & Hubert 1990), and the use of fixed point samplers such as drop nets and fixed point electric shockers (Belaud et al. 1989). Although all of these techniques have been used with some success, most are unsuitable for small (<7 cm long) fish, particularly in complex habitats such as high-order stream margins.

Habitat suitability indices will vary throughout the life of fish, both as a result of morphological development and skeletal growth and as a result of changing abiotic conditions (Bovee 1986; Copp 1990b). To produce a high resolution habitat suitability model, effects of both these sets of factors must be taken into account. In the present study a series of models has been developed covering the first year of life of the roach. Although it can be argued that it would also be necessary to include models of older larval habitat suitability these have been found to be similar to those of the juveniles (Copp 1990b). As well as incorporating different developmental stages into the model framework, both summer and winter juvenile habitat use were modelled. The main physical difference between the two is the lower winter temperatures and reduced macrophyte cover. The resulting models were found to differ, reinforcing the need for the additional models.

2.4.5 HABSCORE : Multiple regression techniques.

HABSCORE (Milner et al., 1985; NRA 1991) can be used as a complementary approach to the IFIM. This approach is particularly well suited to the reach level data (i.e., cpue, water quality, transect habitat data) collected routinely as part of the proposed sampling regime. Until now, HABSCORE has been mainly applied to upland salmonid streams, although it is equally applicable to lowland, coarse fish dominated, environments. Although HABSCORE only explains the variance in the densities of fish populations at a number of sites, by incorporating data from a wide range of environments the results, the resulting model can be used to predict the idealised fish population at new sites (Barnard 1992; Barnard et al. 1995). Such a prediction of fish density can then be compared to that actually found, or used to ascertain the effect of proposed impacts.

Data should be collected from sites as near to pristine as is feasible, covering the largest range of environmental and biological variability possible (Barnard 1992). The proposed Key sites will act as the initial data set for producing the HABSCORE model. Incorporation of seasonal data will enable variance attributable to seasonal fish movements to be identified. Samples collected at the complementary sites will provide additional base-line data for inclusion in the model. The additional sites will allow the testing of the models developed on sites which have been impacted, thus allowing an additional analysis of the robustness of the model.

Local site and catchment features (Barnard et al 1995), recorded as part of the regular sampling regime, should be checked for independence using correlation analysis. If the variables are not independent then they can be included as a set of derived variables, based on the joint occurrence of the habitat variables. When independence of the variables has been established, they can be inputted into a forward stepwise regression of population data on habitat variables. This procedure will allow the production of a multiple linear regression explaining the largest proportion of the variance in the population data possible. Once a model has been obtained stepwise removal of variables in the model can be used to see if any models with better fit could be obtained.

2.4.6 Cohort and Recruitment modelling

Cohort analysis

Developments in multivariate techniques have provided useful tools for cohort analysis in ichthyology, such as size-class ordination of length-frequency data (Persat & Chessel 1989). Size-class ordination incorporates two different perspectives, which result from the original applications of correspondence analysis to ecology: the analysis of contingency tables by numerical coding of the lines and columns, and as an ordination technique for large data matrices (Persat & Chessel 1989). Persat & Chessel's (1989) application of size-class ordination, involves three steps.

1) The data matrix is subjected to Correspondence analysis, which takes a matrix N, consisting of I lines (samples) and J columns (size classes) where one finds, at line i (notation after Greenacre 1984) and the column j, the value N_{ij} of individuals of the size class j in the sample i (Persat & Chessel 1989). From the analysis, one obtains two matrices of ordination scores, which are F (ordination scores for lines) and G (ordination scores for columns) and a list of eigenvalues (l_1, l_2, ...l_K, where K = Min (I - 1, J - 1)). The ordination scores may be considered as numerical codes attache to the lines (F) or to the columns (G). To

know which amongst these codes [factors] should be taken into consideration (this question is very important and subject to much discussion), the simple method is to trace the quantities l_K ($K \geq k \geq 1$) as a function of the numerical order of k and thus obtain a graph of the eigen values. In most cases, in the graph on can observe a rupture between two groups of eigen values. The first group of values correspond to the structure part of the matrix, and the second group, which constitutes the weakly decreasing values, indicates the ensemble of individual variations amongst the size classes and the samples (Persat & Chessel 1989).

2) After the pertinent factors have been retained for analysis, it is usual to present the relevant factors graphically, both singly and in two dimensions as an ordination diagram. A gradual separation between the modes of the different histograms generally provokes the well-known phenomenon called the 'Guttman' or 'horse-shoe' or 'arch' effect, which is quite marked. Because the ordination scores are numerical codes, one can also represent them as a function of the central value of the size class, i.e. the graphs are a 'functional representation' of the factors, which is frequently used to ordinate vegetation samples when they are ordinated spatially by transect (Hill 1973). This practice is not only empirical (Persat & Chessel 1989), assigning numerical values to alternatives, or categories (size classes), so as to discriminate optimally amongst the objects (samples) in some sense, which is usually the least-squares sense (Nishisato 1980). Two principal cases can result. The weak variations of ordination scores indicate large overlaps of histograms, whereas brutal variations between two contiguous size-classes reveal the groups of non-overlapping histograms. Between these two typical models, some other arrangements are possible, which reoccur in several ordination scores. This proposition is a return from the numerical coding ('scaling') point of view towards the analysis of contingency tables (Persat & Chessel 1989).

3) To reveal the inner structure of the population, i.e. a graphical representation that separates overlapping histograms and aligns the temporally and spatially associated histograms (i.e. cohorts), the data matrix is reconstructed. The lines (samples) are arranged according to the ordination scores of the factor that best reveals the population's inner structure, whereas the columns (size-classes) retain their natural order (Persat & Chessel 1989). The resulting graph is an adapted version of Hill's (1973) 'multidimensional scaling' point of view, or the simultaneous linear regression perspective of Hirschfeld (1935), which was clarified by Greenacre (1984). The lines traced on the reconstructed data matrix reveal the structure coded by the initial factors (Persat & Chessel 1989).

One of the principal advantages of size-class ordination is that it can be used with data sets that consist of partial or missing histograms, which would otherwise affect either the spatial or temporal continuity of the data (Persat & Chessel 1989, Copp 1990b). Such discontinuity occurs both because of operator error (i.e. sampling errors) and as a result of natural variations in fish populations. For example, the young larvae of many riverine species of fish are strongly clumped in their distribution (e.g. Copp 1992a, 1993a, 1997a), which results in some groups of sub-cohorts (a sub-cohort group is a collection of individuals emanating from one spawning event) being missed when a random-stratified sampling strategy is used (e.g. Copp 1990b). Although one can sample more intensively in order to ensure that sub-samples are collected from all sub-cohort groups, this usually results in entire sub-cohort groups being eliminated (Carrel 1986). Discontinuities in length-frequency distributions are also commonly found in those adult fishes that shoal intensively, such as the common bream *Abramis brama* and the silver bream *Blicca bjeorkna*; during routine sampling of lowland rivers, these species are often either in high abundance, when a shoal is found in the study stretch, or not at all (J. Adams, EA-Anglian Central, personal communication; M. Pilcher, EA-Thames East, personal communication). Thus, size-class ordination could be of particular use in the analysis of suitable EA data sets, both those previously collected and those to be collected in the future, for revealing gaps in the recruitment of longer-lived species of fish (Persat & Chessel 1989).

Recruitment modelling

Recruitment modelling involves both empirical descriptive and empirical predictive approaches, the former tending to describe patterns in short or long-term data sets upon which to generate hypotheses that can be tested using mathematically-based predictive models. The bulk of recruitment modelling has addressed marine fisheries (e.g. Miller et al. 1988, Howbowy 1989, Fogarty et al. 1991). Freshwater fisheries modelling has primarily addressed the modelling of the effects of environmental variables on ontogenetic characters such as growth, habitat and development (e.g. Weatherley et al. 1988, Hostetler 1991), though some have tried to predict year-class strength, either in terms of numbers (Koonce et al. 1977, Mills & Mann 1985) or tonnage (Holcík & Kmet 1986). Amongst the most commonly used in marine fisheries are the density-independent, the Ricker overcompensatory and the Beverton-Holt models. The density-independent mode for change in cohort size during the prerecruit phase is: $N_t = N_0 \exp(-\mu t)$, where N_t is the number of surviving to recruitment, N_0 is the initial number in the cohort and t is the time interval between spawning and recruitment. The linkage between the initial cohort size and the mature stock is made by specifying the relationship between fecundity, sex ratio and the total egg production. In the overcompensatory model, the rate of change of cohort size for the Ricker model is: $N_t = N_0 \exp[\mu_1 + \mu_2 N_0) t]$, where$\mu_1$ is a density-independent morality term, μ_2 represents compensatory mortality and N_0 is the initial number in the cohort. In the Beverton-Holt model, which is appropriate for the case of intracohort cannibalism or competition, the rate of change of cohort size is: $N_t = \{(1/N_0 \exp(\mu_1't) + (\mu_2'/\mu_1')[\exp(\mu_1't)-1]\}^{-1}$, where μ_1' is density-independent mortality and μ_2' is density-dependent mortality. The distinction between the Ricker and Beverton-Holt models is that in Ricker's, mortality during the prerecruit phase increases linearly with the initial number in the cohort, whereas in Beverton-Holt's model, mortality increases linearly with the number in the cohort at each point in time (Fogarty et al. 1991). Such predictive models need to be developed for riverine fishes, based on long-term data sets of both local and climatic environmental variables in order to help forecast the influence of natural and human-generated variations in environmental conditions on fish recruitment. The protocol proposed here will provide the necessary information, as data from both quantitative and CPUE sampling can be used to develop recruitment models.

2.4.7 Controls upon recruitment success in lowland rivers

For small ectotherms, over-winter survival tends to be positively related to size at the onset of winter (Mills & Mann 1985, Conover 1992). In 0+ cyprinids, the availability of suitable habitat during the winter period has been suggested as a possible mechanism by which size-dependent selection could occur, owing to the greater capacity for habitat utilisation of larger fish within a developmental phase (Mann & Bass 1997). Although the lack of suitable habitat may have the potential to limit the success of a given cohort, this does not explain the observed response of fish under all conditions. During winter, when discharge is often at its peak and temperature is at its lowest, swimming ability of 0+ fishes is severely reduced. Over the size range of fishes present at the end of the summer (25 - 55 mm SL) it is unlikely that a significantly greater amount of habitat will be available to the larger individuals of a species than is available to their smaller siblings. In this case, lack of habitat suitability may reduce numbers of young fish, irrespective of length. Thus, habitat availability may not act as a size selective force owing to the availability of suitable habitat.

Availability of suitable habitat may have an indirect influence upon the survival of a cohort by increasing fish densities in the suitable habitat above the threshold at which density-dependent growth occurs (Mills 1982). Fish size at the end of the growing season may thus be partially controlled by conspecific density in the suitable habitat available, rather than in the channel as a whole, with the knock-on effect of reduced winter survival for fishes subjected to high levels of intraspecific competition. Such a scenario is unlikely to occur in salmonids, which tend to defend territories with sizes inversely proportional to prey density, thereby stabilising energy budgets (Bovee 1986). For cyprinids, which do not demonstrate aggressive behaviour, such a mechanism may be operating. Evidence for stunted growth related to elevated levels of competition can be found in the literature (Mills 1982). Data from a survey of 19 sites on the River Great Ouse, situated in close proximity, revealed significant deviations in mean length at the end of the growing season that could not be explained by the effect of temperature (Garner 1997b). Similar results were encountered at the catchment scale during a survey of the Great Ouse during 1992 (Kovác & Copp 1996) Although prey availability may vary between sites, the data do suggest that density-dependent growth may be occurring and also that the 0+ fish form discrete populations at the reach scale.

Several hypotheses have been proposed for the selection of specific sizes and species of fish during the early period of the life history. Physical conditions must be suitable both before and after spawning has taken place. Increases in the time of development will increase the risk of predation upon the ova (Diamond & Brown 1984) and may also increase the rate of malformation, resulting in increased mortality (Cerny 1975). Lack of suitable food for the newly emerged larvae may have an important contribution to mortality (Blaxter & Hempel 1963, Dabrowski 1976). Peak densities of planktonic organisms tend to be correlated with the emergence of larval fish; yet if conditions are unfavourable, densities may rapidly fall to below the levels required for optimal feeding (Mann 1995a, b). Few studies have examined this relationship in freshwater ecosystems and so its impact upon cyprinid fishes cannot be quantified.

Predation pressure may affect fish populations in a size-dependent manner, owing to increased capture efficiency of small fishes (Werner et al. 1983, Werner & Hall 1988). However, for a significant effect to be apparent, large numbers of fish must be consumed. In regulated rivers, predator densities are unlikely to be high enough to have a significant effect upon cyprinid densities. Observation of diet of a small number of 0+ and 1+ pike, the major piscivore of 0+ fishes in the River Great Ouse revealed that the pike fed primarily upon perch. Perch grow more rapidly than the cyprinids and, although it inhabits areas of dense macrophytes where pike predation efficiency is reduced, and it is cryptically coloured and possesses protective spines (Bean & Winfield 1995), perch was found in almost all pike guts examined. Although only qualified evidence (i.e., small sample size) is available, pike may be preferentially predating the largest fish rather than the smallest.

The period during which water temperatures are below the critical growth threshold is long for many cyprinids in the UK. For example, the thermal minima for roach (12 °C, Mann 1973) is exceeded only from May until October. During this period no skeletal growth occurs and there is a tendency for condition (weight - length ratio) to decrease (Griffiths & Kirkwood 1995, Mann 1995a). This indicates that the fish may be unable to obtain sufficient food during the winter period. Yet, observations in the River Great Ouse revealed that roach had similar length-weight relationships both before and after the winter period and were feeding well. Hence, although starvation may occur in other environments and in other species, this does not appear to be the case in the River Great Ouse. Effects of reduced growth, caused by insufficient prey, may limit recruitment.

There is a large body of evidence supporting the determination of year class strength in fish populations during the first and possibly the second years (refs ????).

2.5 Fish population & river integrity/Assessment of management practices

2.5.1 The Abundance/Biomass Comparison Index

An index based on the average of the difference between cumulative biomass and abundance has been proposed, the Abundance/Biomass Comparison (ABC) index (Meire & Dereu 1990, Coeck et al. 1993):

$$\text{ABC index} = B_i - A_i / N$$

where B_i - is the percentage dominance of species i (ranked from the highest to the lowest biomass), and A_i is the percentage dominance of species i (ranked from the most to the least abundant species), and N is the total number of species.

The ABC index has been shown to be a useful tool in assessing the stress affecting fish populations yielding positive values associated for fish assemblages existing under non-stressed conditions and negative values for those under stressed conditions. Fish assemblages existing under non-stressed conditions are expected to be near carrying capacity and dominated by so-called K-selected species (long-lived, large-bodied species), whereas fish assemblages under stressed conditions are expected to be below carrying capacity and dominated by r-selected species (short-lived, small-bodied species). A shift towards r-selected species can be found in fish assemblages impacted by human activities (Mann et al. 1984, Cowx 1990, Copp 1990d), and preliminary analyses of some English fish assemblages using the ABC index (NRA 1995) have demonstrated that the index provides an initial step towards assessing such impacts. However, a more comprehensive assessment method that includes information on species composition and 0+ abundance will be required if a river integrity is to be assessed more accurately (Copp 1991b).

2.5.2 The Index of Biotic Integrity (IBI)

Although indices based solely on fish abundance and biomass, such as the ABC index, are useful tools in attempting to assess the integrity of riverine fish populations, a more comprehensive index, such as the Index of Biotic Integrity, IBI, (Karr 1981) have the potential of providing a more comprehensive fish assemblage integrity (Oberdorff & Hughes 1991). The IBI provides a numerical score derived from assessments of the species richness/composition, the trophic composition, and the condition/abundance of fishes at sites in North American streams and rivers. The first adaptation of the IBI to European rivers was carried out by Oberdorff & Hughes (1991) for the River Seine in France, and this model is currently in the process of being adapted to rivers throughout France (T. Oberdorff, personal communication). The IBI relies on CPUE data, which temporally and spatially comparable, though spatial comparisons need to be carried out with some caution. Fractional sampling strategies, such as meso-habitat level single depletions as well as PAS, provide such data. The European adaptation of the IBI (Oberdorff & Hughes 1991) stresses the need to consider the functional aspects of the fishes (% lithophily, rheophily, limnophily, phytophily, etc.), however, a more substantial consideration of the reproductive requirements of riverine fishes and the inclusion of 0+ fish abundance and diversity would improve the predictive and assessment power of this index (Copp 1991b) and lend itself more towards assessing river integrity (Copp et al. 1991).

2.5.3 Impact Assessment Protocol

In order to assess both unexpected and planned impacts on river ecosystems, both an impact assessment protocol and appropriate analytical methods will be required. As a complement to the routine sampling protocol, we suggest that an Impact Assessment Protocol (IAP) be established, based on the same sampling approach used in routine sampling of the Key and Complementary sites, for both the emergency evaluation of impacts due to unexpected incidents (i.e. disasters) and for the pre- and post-impact assessment of expected human activities (e.g. management practices, alterations to river environment, etc.). This will provide an organised, routine procedure that will provide the necessary information for impact assessment, even when implemented rapidly in the case of an unexpected incident.

3. RECOMMENDATIONS ON IMPLEMENTATION

The study of riverine fish populations should be hierarchical, both in terms of how the river catchment is perceived and how the data are analysed. We suggest a hierarchical sampling strategy that incorporates the following components to reduce the effort required (Fig. 1):

1) **Key** sites within the upstream (rhithron), mid-stream (upper potamon), and downstream (lower potamon/tidal river) 'sections' of the catchment where regular, i.e. seasonal, and specialised sampling will provide precise data on life history, habitat use, etc..

2) **Complementary** sites within each catchment section will complement the key sites, allowing the results collected at the key sites to be viewed within a wider perspective. Complementary sites should be sampled on an annual basis, subsequent visits to a site being in the same season as in previous years.

3) **Additional** sites with each catchment section would be sampled on an occasional basis either to complement routine sampling of the Key and/or Complementary sites or as part of an Impact Assessment Protocol (IAP), which will be used to appraise management practices and planned alterations (expected impacts) as well as disasters (unexpected impacts) to the river environment.

The type of sampling method used routinely to capture the fish will vary depending upon the information required and the environmental conditions characteristic of that part of the river catchment. In general, catch-per-unit-effort (CPUE) sampling and point abundance sampling (PAS), in conjunction with suitable calibrations (i.e. depletion, etc.), should be used in the middle and upper sections of the catchment. In the lower, deeper and wider sections, trawling and echosounding methods are expected to provide the necessary results where conventional electrofishing and seine netting are inappropriate.

For the implementation of this protocol, we suggest a twelve-step procedure:

Step 1 Create a multi-disciplinary committee, representing the Fisheries, Biology, Water Quality, and Hydrology departments with the task of developing a complementary data collection strategy that provides the necessary information for all parties.

Step 2 Set up and implement a data cataloguing and analysis procedure, with a modern national database (Fig. 2) that is:

- user friendly
- easily accessible for downloading of raw data
- conversant with standard file formats (Excel, Claris, StatView, Lotus, etc.)
- includes all fisheries, water quality, river flow and other relevant data
- permits cross analysis
- the final destination of ALL relevant data collected by EA staff of all regions

This step should include: 1) a nation-wide collation of existing data, which should be added to the new national data base, and 2) the development of a 'FishPacs' predictive modelling package similar to that for invertebrates (i.e. RivPacs).

Step 3 Select the river catchments, preferably those for which data already exist.

Step 4 Select a number of Key sites (reaches) within the catchment, using the following criteria:

- should be characteristic of that part of the catchment
- avoid areas of extremely variable flow
- should be near flow gauging stations and permanent water quality (°C, etc.) stations

Step 5 Identify the placement of transects

Step 6 Carry out river habitat surveys where necessary, beginning the procedure described by Bovee 1980)

- Produce topographical, land cover and geological maps of the catchment.
- Indicate major changes in flow (>15%), changes in sinuosity, permanent passage barriers and other human changes to river form, point sources of pollution, areas of land use change, areas where access is poor or cannot be obtained.
- Remove all river reaches containing the features in item 2 and determine reaches within similar geomorphology.
- From each geomorphic type, select five representative reaches at random.

Step 7 Implement at Key sites:

- Seasonal sampling, spring, summer, autumn (CPUE/depletion) at each site, which will provide information on density, biomass, length-weight relationships, length and weight at age (hence growth rates), fecundity, mortality/survivorship, visible parasites and deformities (pollution, predators), meso and macrohbitat use

- PAS for 0+/1+ fish at each site, which will provide data on microhabitat, relative density and biomass, growth, indirect/direct evidence of reproduction
- Pit-tagging of target species at all Key sites during all routine seasonal sampling operations, which will provide information on the displacement, mortality/survivorship, and age-specific growth of individual specimens.
- Sub-sampling and sacrifice of a representative number of specimens from target species, which will provide information on diet and predation
- Drift sampling during the spawning and post-spawning periods
- Determine and study where possible the spawning sites of target species.

Step 8 Implement annual sampling at **Complementary** sites (CPUE, PAS, trawler, echosounding)

Step 9 Implement the occasional sampling of **Additional** sites

Step 10 Set up and implement the Impact Assessment Protocol (IAP), which should consist of annual sampling of the impacted sites either with pre- and post-impact assessment (expected impacts) or as soon after the impact as possible (unexpected incidents). The sampling should include stretches of river both up- and downstream of the impacted stretch.

Step 11 Implement at the end of the first year of sampling:

- Report on current river habitat quality
- Calculate initial integrity indices (ABC, IBI, etc.)
- Report on calibration of sampling (e.g. depletion to CPUE)
- Examine initial species-habitat relationships, length and weight at age, etc.
- Report on any drift and spawning site studies

Step 12 Implement a review schedule (Fig. 3):

- **Annual reviews** — 0+/1+ densities/biomass, integrity indices (ABC, IBI), PHABSIM, IAP results on impacted sites

- **Five-year reviews** — Initial trend analysis of abundance/biomass, dispersion/migration, mortality/survivorship, density-dependent growth rates, environmental conditions related to growth, influence of predators on survivorship, initial ontogenetic trends in habitat use, and over-winter success.

Review the IAP results, in particular to assess management practices on fisheries. Review results of Satellite projects and their objectives. Implement new or continuation Satellite projects to complement routine sampling data.

- **Ten-year reviews** — Examine cyclical trends in fish movements, species-habitat relationships, fish abundance/biomass, etc. Begin the development of predictive models of recruitment success. Review the impact of management practices on fisheries. Implement Satellite projects to complement data from routine sampling. Carry out review of national strategy (i.e. are the intended objectives being met ?). Review and implement Satellite projects to complement routine sampling data.

- **Fifteen-year reviews** — Review the results from the IAP of sites receiving expected and unexpected impacts. Continue trend analysis of abundance/biomass, dispersion/migration, growth rates, mortality/survivorship, ontogenetic trends in habitat use, development of predictive models of recruitment success, over-winter success. Review and implement Satellite projects to complement routine sampling data.

- **Twenty-year reviews** — Review the effectiveness of management practices on fisheries and carry out assessment of the long-term impacts on river and fish population integrity. Carry out a review of the national strategy. Begin testing the predictive models developed for recruitment/survivorship forecasting, review the selection of parameters, etc. Analysis of the migration/dispersion data for long-term patterns. Review and implement Satellite projects to fill gaps.

- **Thirty-year reviews** — Review the effectiveness of management practices on fisheries and carry out assessment of the long-term impacts on river and fish population integrity. Carry out a review of the national strategy to assess the effectiveness of river management practices on fish recruitment in particular and river integrity in general. Continue the testing of the recruitment forecasting models, including the evaluation of climatic effects on year-class strength. Analysis of the migration/dispersion data for long-term patterns. Review and implement Satellite projects to fill gaps.

4. COSTING

4.1 Costing strategy and assumptions

Steps 1 and 2 (establishment of multi-disciplinary steering committee and establishment of a unified national data base) are regarded as important components of the long term strategy for achieving the overall objectives of this and many related projects. These proposed steps also have implications for the manner in which much routine fisheries data is collected and archived. These steps have therefore been highlighted as important considerations within the context of the Coarse Fish Recruitment R&D project but have not been costed because of their much wider operational implications. Costings have been limited to the catchment based aspects of the project.

It is assumed that river systems/catchments can be selected that have routine biological, chemical and flow monitoring at a substantial number of sites and that the routine physicochemical/biological monitoring and the fisheries programmes can be spatially and temporally coordinated. There would therefore be no significant project costs for the collection of background physicochemical/biological data.

The number of survey sites will clearly depend on the number of catchments included within the study and the size and nature of each individual catchment. The costings assume 40 survey sites within a catchment, comprising:

12	**Key** sites	(sampled seasonally)
24	**Complementary** sites	(sampled annually)
4	**Additional** sites	(sampled annually/occasionally)

Costs can therefore be scaled up or down *pro rata* depending on the number of catchments included in the study and the number of sites per catchment.

Semi-quantitative sampling has been proposed, either single run electric fishing or single haul seine netting for larger fish and point abundance sampling (50 samples per site) for 0+/1+ juveniles. Semi-quantitative sampling is more cost effective as it allows a greater number of sites to be sampled more frequently per unit of effort.

Semi-quantitative sampling methods will need to be calibrated against quantitative methods within each catchment. It is assumed that this will be done at the 12 key sites in year one and again in year 5. Thus Satellite Project I - Sampling calibration becomes an integral component of the main project.

4.2 Costing of satellite projects

As already indicated, Satellite Project I - Sampling Calibration is an integral component of the main project and has therefore not been costed as a separate item..

Habitat Satellite Project II - Spawning Habitat and Habitat Satellite Project III - Dispersal are costed in terms of time commitment, which represents the major cost involved.

Satellite Project IV - Displacement of Coarse Fish using PIT Tags, carries negligible cost implications in terms of time commitment, as fish can be tagged, and subsequently monitored during the routine survey programme. . There will however be a substantial capital cost if the equipment (tagging and reading equipment and tags) is not available to the project team. Satellite project IV has not therefore been costed.

The inclusion of Satellite project V - Telemetry, is deemed desirable but as with Satellite project 2, there are substantial capital cost implications if equipment.is not already available to the project team.Satellite project V has not therefore been costed. Projected coats for Satellite Project V exclude potential equipment costs.

4.3 Core Project costs - Annual time commitment per catchment.

4.3.1 Year 1

Steps 3-6	Project planning, catchment selection, macro habitat survey, site selection etc	20 days
Steps 7-10	Quantitative fish (and habitat) surveys of 12 Key sites, 3 times per year. One site per day with 4 person field team	144 days
	Semi-quantitative fish (and habitat) surveys of 24 Complementary sites, once per year. Two site per day with 4 person field team	48 days
	Semi-quantitative fish (and habitat) surveys of 4 Additional (occasional) sites, once per year. Two sites per day with 4 person field team	8 days
	Point abundance sampling (including habitat measurements of 12 Key sites, 3 times per year. Two sites per day with 2 person field team	36 days
	Point abundance sampling (including habitat measurements of 24 Complementary sites and 4 Additional sites, once per year. Two sites per day with 2 person field team	28 days
Steps 11-12	Data analysis addressing all proposed objectives, reporting and full review of all project strategies	120 days
	Total time commitment for year 1 core programme	**404 days**

4.3.2 Year 2

Steps 7-10	Semi-quantitative fish (and habitat) surveys of 12 Key sites, 3 times per year. Two sites per day with 4 person field team	72 days
	Semi-quantitative fish (and habitat) surveys of 24 Complementary sites, once per year. Two site per day with 4 person field team	48 days
	Semi-quantitative fish (and habitat) surveys of 4 Additional sites (location of Additional/occasional sites may vary from year to year), once per year. Two sites per day with 4 person field team	8 days
	Point abundance sampling (including habitat measurements of 12 Key sites, 3 times per year. Two sites per day with 2 person field team	36 days
	Point abundance sampling (including habitat measurements of 24 Complementary sites and 4 Additional sites, once per year. Two sites per day with 2 person field team	28 days
Steps 11-12	Data analysis addressing all proposed objectives and reporting. Data analysis and reporting is simpler than in year one as procedures are set up and primary task is to build long term data base	50 days
	Total time input for years 2-4 of core programme	**242 days**

4.4 Satellite Project costs - Annual time input per catchment.

4.4.1 Satellite project II - Spawning Habitat

Mapping of spawning and juvenile habitat within catchment based on survey of 1 km lengths of river around each of 12 Key sites.	12 days
Monitoring of embryonic survival in *in situ* traps in selected spawning grounds. Three traps per site and 5 sites, with satellite project to run over three months to cover several key species would require a two person team full time, including reporting, for three months.	120 days
Total time commitment in 1 year	**132 days**

4.4.2 Satellite Project III - Dispersal

To be carried out during May to July over 10 weeks to cover a range of species. Based on 2-3 sites on river system with three drift nets per site. Satellite project III would fully occupy a 2 person team for 3 months including data analysis.	120 days
Total time commitment in 1 year	**120 days**

4.4.3 Satellite Project V - Telemetry of coarse fish movements

Fish would be radio tagged during the normal sampling programme. Time commitment for monitoring diel/seasonal dispersal and migrations would depend on specific objectives which are likely to develop over the course of the main project. A notional time commitment of 60 days per year has been allocated	60 days
Total time commitment in 1 year	**60 days**

4.5 Monetary costs of proposed programme

Monetary costs may vary considerably depending on which aspects of the programme are conducted in-house by the Environment Agency, or contracted out, and if contracted out, the nature of the contracting organisation. The following costs are based on an average daily staffing costs of £150 per day, assuming that staff costs range from £100 - 300 per day for individual team members. Costs are exclusive of any equipment costs which, depending on availability, could add significantly to some aspects of the proposed programme.

Main project year 1 404 days at £150 per day	**£ 60,600**
Main project annual cost for years 2-4 242 days at £150 per day	**£ 36,300**
Satellite project II - Spawning habitat repeated annually or as required 132 days at £150 per day	**£ 19,800**
Satellite project III - Dispersal repeated annually or as required 120 days at £150 per day	**£ 18,000**
Satellite project V - Telemetry repeated annually or as required 60 days at £150 per day	**£ 9,000**

It should be noted that research programmes of this type, especially when of a longer term nature, provide excellent scope for one or more PhD programmes. These provide excellent value for money, engender major personal commitment to the work and can significantly reduce overall costs.

5 REFERENCES

Abell, D.D.L. & Fisher, C.K. (1953). Creel census at Millerton Lake, California, 1945-1952. *Calif. Fish Game* 39, 463-484.

Allan, J. R. and Pitcher , T. J. (1986). Species segregation during predator evasion in cyprinid fish shoals. *Freshwater Biology.* 16, 653-659.

Amoros C., Roux A.L., Reygrobellet J.L., Bravard J.P. & Pautou G. (1987). A method for applied ecological studies of fluvial hydrosystems. *Regul. Rivers: Res. & Mgmt.* 1, 17-36.

Armitage, P.D. & Ladle, M. (1990). Habitat preferences of target species for application in PHABSIM testing. In: A. Bullock, A. Gustard & E.S. Grainger (eds.) *Instream flow requirements of aquatic ecology in two British Rivers - application and assessment of the Instream Flow Incremental Methodology using the PHABSIM system.* Wallingford: Institute of Hydrology.

Bagenal, T. B. (1974) A buoyant net designed to catch freshwater fish larvae quantitatively. *Freshwater Biology.* 4, 107-109.

Bain, M.B., Finn, J.T. & Booke, H.E. (1985a). A quantitative method for sampling riverine microhabitats by electrofishing. *N. Amer. J. Fish. Mgmt.* 5, 489-493.

Balon, E.K. (1956). Spawning and post-embryonic development of roach (Rutilus rutilus ssp.). *Biol. Prace* 2 (13), 7-60. (in Slovak)

Balon, E. K. (1986). Types of feeding in the ontogeny of fishes and the life-history model. *Environmental Biology of Fishes* 16, 11-24.

Baras, E. (1994). Constraints imposed by high densities on behavioural spawning strategies in the barbel, Barbus barbus. *Folia Zoologica* 43, 255-266

Baras, E. Nindaba, J. & Philippart, J.C. (1995). Microhabitat used in a 0+ rheophilous cyprinid assemblage: Quantitative assessment of community structure and fish density. *Bulletin Francais de la Peche et la Pisciculture* 337/9, 241-247.

Barnard, S. (1992). *HABSCORE development.* Report to NRA No. 338/3/W, 109p.

Barnard, S., Wyatt, R. J. & Milner, N. J. (1995) The development of habitat models for stream salmonids, and their application to fisheries management. *Bull. Fr. Peche Pisc.* 337/338/339, 375-386.

Blaxter, J.H.S. (1986). Development of sense organs and behaviour of Teleost larvae with special reference to feeding and predator avoidance. *Transactions of the American Fisheries Society* 115, 98-114.

Blaxter, J. H. S. & Hempel, G. (1963) The influence of egg size on herring larvae (Clupea harengus L.). *Journal Cons. perm. int. Explor. Mer.* 28, 211-240.

Blondel, J. (1975) L'analyse des pleuplements d'oiseaux elements d'un diagragnostic ecologique. I. La methode des echantillonages frequentiels progressifs. (E.F.P.). *Terre et Vie.* 29, 533-583.

Blondel, J., Ferry, C. & Frochot, B. (1970). La methode des indices ponctuels d'abondance (I.P.A.) ou des releves d'avifaune par "Stations d'ecoute". *Alauda* 38, 55-71.

Bovee, K. D. (1986) *Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology.* US Fish and Wildlife Service Biological Report 86, Instream Flow Information Paper No. 21.

Carle, F.L. & Strub, M.R. (1978). A new method for estimating population size from removal data. *Biometrics* 34, 621-630.

Carrel, G. (1986). *Caracterisation physico-chimique du Haut-Rhone francais et de ses annexes; incidences sur la croissance des populations d'alevins.* These de Doctorat, Universite Claude Bernard, Lyon I, France. 185 pp.

Casselman, J. M., Penczak, T., Carl, L., Mann, R. H. K., Holcik, J. & Woitowich, W. A. (1990) An evaluation of fish sampling methodologies for large river systems. *Polskie Archiwum Hydrobiologii.* 37, 521-551.

Coeck, J. Vandelannoote, A. Yseboodt, R. & Herheyen, R.F. (1993). Use of the abundance/biomass comparison method for comparison of fish communities in regulated and unregulated lowland rivers in Belgium. *Regul. Rivers* 8, 73-82.

Chessel, D. Lebreton, J.D. & Yoccoz, N. (1987). Propietes de l'analyse canonique correspondences. Une utilisation en hydrobiologie. Revue de statistiques appliquees 35, 55-72

Copp, G.H. & Penaz, M. (1988). Ecology of fish spawning and nursery zones in the flood plain, using a new sampling approach. *Hydrobiologia* 169, 209-224.

Copp, G.H. & Cellot, B. (1988). Drift of embryonic and larval fishes, especially Lepomis gibbosus (L.), in the Upper Rhone River. *J. Freshwat. Ecol.* 4, 419-424.

Copp, G.H. (1989a). Electrofishing for fish larvae and 0+ juveniles: equipment modifications for increased efficiency with short fishes. *Aquacult. & Fish. Mgmt.* 20, 177-186.

Copp, G.H. (1989b). The habitat diversity and fish reproductive function of floodplain ecosystems. *Environ. Biol. Fish.* 26, 1-26.

Copp, G.H. (1990a). Shifts in the microhabitat of larval and juvenile roach *Rutilus rutilus* (L.) in a floodplain channel. *J. Fish. Biol.* 36, 683-692

Copp, G.H. (1990b). Recognition of cohorts and growth of larval and juvenile roach Rutilus rutilus (L.), using size class ordination of developmental steps. *J. Fish. Biol.* 36, 803-819

Copp, G.H. (1990d). Effect of regulation on 0+ fish recruitment in the Great Ouse, a lowland river. *Regul. Rivers* 5, 251-263

Copp, G.H. (1991a). Typology of aquatic habitats in the Great Ouse, a small regulated lowland river. *Regul. Rivers* 6, 125-134.

Copp, G.H. (1991b). Sampling strategies and capture methods in the fisheries management of larger river systems. pp. 261-270 in: Proceedings of the IFM conference, Fisheries to the year 2000. Institute of Fisheries Mgmt., Nottingham, UK. ISBN: 0-9508194-3-3. (invited communication)

Copp, G.H., Olivier, J.-M., Penaz, M. & Roux, A.-L. (1991). Juvenile fishes as functional describers of fluvial ecosystem dynamics: Applications on the River Rhone, France. Regul. Rivers 6, 135-145.

Copp, G.H. (1992a). Comparative microhabitat use of cyprinid larvae and juveniles in a lotic floodplain channel. *Environ. Biol. Fish.* 33, 181-193

Copp, G.H. (1992b). An empirical model for predicting the microhabitat of 0+ juveniles in lowland streams *Oecologia* 91, 338-345.

Copp, G.H. (1993a). Microhabitat use of fish larvae and 0+ juveniles in a small abandoned channel of the upper River Rhone, France. *Folia Zool.* 42, 153-164.

Copp, G.H. (1993b). The upper River Rhone revisited: an empirical model of microhabitat use by 0+ juvenile fishes. *Folia Zool.* 42, 329-340.

Copp, G.H. & Mann, R.H.K. (1993). Comparative growth and diet of tench Tinca tinca (L.) larvae and juveniles in river floodplain biotopes in France and England. *Ecol. Freshwat. Fish* 2, 58-66.

Copp, G.H. & Jurajda, J. (1993). Do small fish move inshore at night? *J. Fish. Biol.* 43 (Suppl. A), 229-241.

Copp, G.H., Guti, G., Rovny, B. & Cerny, J. (1994). Hierarchical analysis of habitat use by 0+ juvenile fish in the Hungarian/Slovak flood plain of the River Danube. *Environ. Biol. Fish.* 40, 329-348.

Copp, G.H. & Garner, P. (1995). Evaluating microhabitat use of fish larvae and juveniles with Point Abundance Sampling. *Folia Zool.* 44, 145-158.

Copp, G.H. & Kovac, V. (1996). When do fish with indirect development become juveniles? *Can. J. Fish. Aquat. Sci.* 53, 746-752.

Copp, G.H. & Bennetts, T.A. (1996). Short-term effects of removing riparian and instream cover on barbel (Barbus barbus) and other fish populations in a stretch of English chalk stream *Folia Zool.* 45, 283-288.

Copp, G.H. (1997a). Microhabitat use of fish larvae and juveniles in a highly regulated section of the River Great Ouse. *Invited paper for special issue of Regul. Rivers* (in press) 13 (3)

Copp, G.H. (1997b). Importance of marinas and off-channel water bodies as refuges for young fishes in a regulated lowland river. *Invited paper for special issue of Regul. Rivers* (in press) 13 (3)

Cortes, R., Graca, M.A.S., Vingada, J.N. & Varandas de Oliveira, S. (1995). Stream typology and dynamics of leaf processing. *Annls Limnol.* 31, 119-131.

Cowx, I. (1990). Gorwth and reproduction tactics of roach, Rutilus rutilus (L.), and dace, Leuciscus leuciscus (L.), populations in the Rivers Exe and Culm, England. Pol. Arch. Hydrobiol. 37, 1/2, 195-210.

Cowx I.G., Wheatley G.A. & Mosley A.S. (1986). Long-term effects of land drainage works on fish stocks in the upper reaches of a lowland river. *J. Environ. Mgmt.* 22, 147-156.

Cowx, I. G. (1994) Stocking strategies. *Fisheries Management and Ecology.* 1, 15-30.

Cyr, H., Downing, J. A., Lohoade S., Baines, S. B. & Pace, M. L. (1992) Sampling larval fish populations: choice of sample number and size. *Transactions of the American Fisheries Society.* 121, 356-368.

Dauble, D.D. & Gray, R.H. 1980. Comparison of a small seine and a backpack electroshocker to evaluate nearshore fish populations in rivers. *Prog. Fish Cult.* 42, 93-95.

De Lury, D. B. (1947) On the estimation of biological populations. *Biometrics.* 3, 145-167.

Doledec S. (1988). Les analyses multi-tableau en ecologie factorielle. II. Stratification longitudinale de l'Arceche a partir des descripteurs physicochimiques. *Acta Oelogica Oecol. Gener.* 9, 119-135.

Downing, J. A. & Anderson, M. R. (1985) Estimating the standard biomass of aquatic macrophytes. *Canadian Journal of Fisheries and Aquatic Science.* 42, 1860-1869.

Eklov, A. G., Greenberg, L. A. & Kristiansen, H. (1994) The effect of depth on the interaction between perch (Perca fluviatilis) and minnow (Phoxinus phoxinus). *Ecology of Freshwater Fish.* 3, 1-8.

El-Fiky, N. & Wieser, W. (1988) Life stages and patterns of development of gills and muscles in larval cyprinids (Cyprinidae, Teleostei). Journal of Fish Biology. 32, 135-146.

El-Fiky, N. Hinterleiner, S. & Wieser, W. (1987) Differentiation of swimming muscles and gills, and development of anaerobic power in the larvae of cyprinid fish (Pisces, Teleostei). *Zoomorphology.* 107, 126-132.

Elliott, J. M. (1984) Numerical changes and population regulation in young migratory trout Salmo trutta in a Lake District stream 1966-83. *Journal of Animal Ecology.* 53, 327-350.

Elliott, J. M. (1987) The distances travelled by downstream-moving trout fry, Salmo trutta, in a Lake District stream. *Freshwater Biology.* 17, 491-499.

Fogarty, M.J., Sissenwine, M.P. & Cohen, E.B. (1991). Recruitment variability and the dynamics of exploited marine populations. TREE 6, 241-246.

Frissel C.A., Liss W.J., Warren C.E. & Hurley M.D. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Env. Mgmt.* 10 : 199-214.

Gardiner J.L. 1988. Environmental sound river engineering: examples from the Thames catchment. *Regul. Rivers* 2, 445-469.

Garner, P. (1995) Suitability indices for juvenile 0+ roach (Rutilus rutilus (L.)) using point abundance sampling data. *Regul. Rivers* 10, 99-104.

Garner, P. (1996a) Microhabitat use and diet of 0+ cyprinid fishes in a lentic, regulated reach of the River Great Ouse, UK. *J. Fish. Biol.* 48, 367-382.

Garner, P. (1996b) Diel behaviour of juvenile 0-group fishes in a regulated river: The Great Ouse, England. *Ecol Freshwat. Fish* 5, 175-182.

Garner, P., Bass, J. A. B. & Collett, G. D. (1996). The effects of weed cutting upon the biota of a large regulated river. Aquat.Conserv. 6, 21-30.

Garner, P. & Clough, S. (1996). Habitat use by adult dace (Leuciscus leuciscus (L.)) in a side channel of the River Frome, England. *Fish. Mgmt.& Ecol.* 3, 349-352.

Garner, P. (1997a). Determination of length bias and calculation of minimum sample sizes required for length and density estimation when using point sampling by electrofishing. *J. Fish. Biol.* 50, 95-106.

Garner, P. (1997b) Spatial variability in the habitat available for 0+ Rutilus rutilus in a regulated river channel. Aquat. Conserv. (in press).

Greenacre, M. (1984). *Theory and Applications of Correspondence Analysis.* Academic Press, London. 364 pp.

Grossman, G.D., Sostoa, A. de, Freeman, M.C. & Lobon-Cervia, J. (1987). Microhabitat selection in a Mediterranean riverine fish assemblage. I. Fishes of the lower Matarrana. *Oecologia 73*, 490-500.

Hankin D.G. & Reeves G.H. (1988). Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. *Can. J. Fish. Aquat. Sci.* 45, 834-844.

Hill, M.O. (1973). Reciprocal averaging: an eigenvector method of ordination. *J. Ecol.* 61, 237-249.

Hirschfeld, H.O. (1935). A connection between correlation and contingency. *Proc. Camb. Ph. Soc.* 31, 520-525.

Holcik, J. & Kmet, T. (1986). Simple models of the population dynamics of some species from the lower reaches of the Danube. *Folia Zool.* 35, 183-191.

Horbowy, J. (1989). A multispecies model of fish stocks in the Baltic Sea. *Dana* 7, 23-43.

Hostetler, S.W. (1991). Analysis and modeling of long-term stream temperatures on the steamboat creek basin, Oregon: implications for land use and fish habitat. *Wat. Resour. Bull.* 27, 637-647

Houde, E.D. (1994). Differences between marine and freshwater fish larvae: implications for recruitment. *ICES J. Mar. Sci.* 51, 91-97.

Hvidsten, N. A. (1985) Mortality of presmolt Atlantic salmon, Salmo salar L., and brown trout, Salmo trutta L., caused by fluctuating water levels in the regulated river Nidelva, central Norway. *Journal of Fish Biology.* 27, 711-718.

Juhasz-Nagy, P. (1992). Scaling problems almost everywhere: an introduction. *Abstracta Bot.* 16 : 1-5.

Karr, J.R. (1981). Assessment of biotic integrity using fish communities. *Fisheries* 6, 21-27.

Koonce, J.F., Bagenal, T.B., Carline, R.F., Hokanson, K.E.F. & Nagiec, M. (1977). Factors influencing year-class strength of Percids: A summary and a model of temperature effects. *J. Fish. Res. Board Can.* 34, 1900-1909.

Kovac, V. & Copp, G.H. (1996). Ontogenetic patterns of relative growth in young roach Rutilus rutilus (L.): within-river basin comparisons. *Ecography* 19, 153-161.

Krause, J. (1993) Positioning behaviour in fish shoals: a cost-benefit analysis. *Journal of Fish Biology*. 44(Suppl. A.), 309-314.

Kubecka, J. (1994) Night inshore migration and capture of adult fish by shore seining. *Aquaculture and Fisheries Management*. 24, 685-689.

Lastochkin, D.A. (1943). A plain river subdivision into geomorphological and biological districts on the basis of its structural and biological unity. *CR (Doklady) Acad. Sci. URSS* 41 : 347-350.

Linfield, R.S.J. (1985). The effect of habitat modification on freshwater fisheries in lowland areas of eastern England. In: J.S. Alabaster (ed.) *Habitat Modification and Freshwater fisheries*. London: Butterworths, pp. 147-155.

Mahon, R. (1980) Accuracy of catch-effort methods for estimating fish density and biomass in streams. *Environmental Biology of Fishes*. 5, 343-360.

Malavoi, J.R. (1989). Typologie des facies d'ecoulement ou unites morphodynamiques des cours d'eau a haute energie. *Bull. Fr. Peche Piscic.* 315 : 189-210.

Mann, R.H.K., Mills, C.A. & Crisp, D.T. (1984). Geographical variation in the life-history tactics of some species of freshwater fish. In; G.W. Petts & R.J. Wootton (eds) *Fish Reproduction: Strategies and Tactics*. London: Academic Press. pp. 171-186.

Mann, R. H. K. (1995a) Natural factors influencing recruitment success in coarse fish populations. In: *The Ecological Basis for River Management* (ed: Harper, D. M. & Ferguson, A. J. D.) Wiley, Chichester. pp339-348.

Mann, R. H. K. (1995b) Temporal and spatial variations in the growth of 0 group roach (Rutilus rutilus (L.)) in the River Great Ouse in relation to water temperature and food availability. *Regulated Rivers: Research & Management*. (in press).

Mann R.H.K. & Bass J.A.B. (1997) The critical water velocities for larval roach (Rutilus rutilus) and dace (Leuciscus leuciscus) and implications for river management. *Regul. Rivers* (in press).

Mark, W., Hofer, R. & Wieser, W. (1987) Diet spectra and resource partitioning in the larvae and juveniles of three species and six cohorts of cyprinids from a subalpine lake. *Oecologia*. 71, 388-396.

Meire, P.M. & Dereu, J. (1990). Use of the abundance/biomass comparison method for detecting environmental stress: some considerations based on intertidal macrozoobenthos and bird communities. *J. Appl. Ecol.* 27, 210-223.

Miller, T.J., Crowder, L.B., Rice, J.A. & Marchall, E.A. Larval size and recruitment mechanisms in fishes: towards a conceptual framework. *Can. J. Fish. Aquat. Sci.* 45, 1657-1670.

Mills, C.A. & Mann, R.H.K. (1985). Environmentally-induced fluctations in year-class strength and their implications for management. *J. Fish Biol.* 27 Suppl. A, 209-226.

Mills, C. A. (1981a) Egg population dynamics of naturally spawned dace, Leuciscus leuciscus (L.). *Environmental Biology of Fishes*. 6, 151-158.

Milner, N. J., Hemsworth, R. J. & Jones, B. E. (1985) Habitat evaluation as a fisheries management tool. *J. Fish Biol.* 43 (Suppl. A), 103-119.

Mooij, W. M. and Van Tongeren, O. F. R. (1990) Growth of 0+ roach (Rutilus rutilus) in relation to temperature and size in a shallow eutrophic lake: comparison of field and laboratory observations. *Canadian Journal of Fisheries and Aquatic Science*. 47, 960-967.

Nelva, A., Persat, H. & Chessel, D. (1979). Une nouvelle methode d'etude des peuplements ichtyologiques dans les grands cours d'eau par echantionnage ponctuel d'abondance. *CR Acad. Sci. Paris t. 289, Serie D*, 1295-1298.

Nishisato, S. (1980). *Analysis of categorical data: Dual scaling and its applications*. Univ. Toronto Press, London. 276 pp.

NRA (1991) *HABSCORE software manual (Version 2.1)* NRA, 28 p.

NRA (1995). *Factors influencing coarse fish populations in rivers*. R&D Note 460, National Rivers Authority, Rivers House. Almondsbury, Bristol, BS12 4UD, UK. 125 pp.

Oberdorff, T. & Hughes, R. (1991). Modification of an Index of Biotic Integrity based on fish assemblages to characterize rivers of the Seine Basin, France. *Hydrobiologia* 228, 117-130.

Oberdorff, T., Guibert, E. & Lucchetta, J.C. (1993). Patterns of fish species richness in the Seine River basin, France. *Hydrobiologia* 259, 157-167.

Pavlov, D.S. (1994). The downstream migration of young fishes in rivers (mechanisms and distributions). *Folia Zool.* 43, 193-208.

Persat, H. & Copp, G.H. (1989). Electrofishing and Point Abundance Sampling for the ichthyology of large rivers. pp. 203-215 In: *Developments in Electrofishing* (ed. by I. Cowx), Fishing News Books, Oxford.

Persat, H. & Chessel, D. (1989), Typologie de distributions en classes de taille: interet dans l'etude des populations de poissons et d'invertebres. *Acta Oecol. Oecol. Gen.* 10, 175-195.

Persat, H., Nelva, A. & Chessel, D. (1985). Approche par l'analyse discriminante sur variables qualitatives d'un milieu lotique, le Haut-Rhone francais. *Acta Oelogica Oecol. Gener.* 6, 365-381.

Petersen, C. G. T. (1896) The yearly migration of young plaice into the Limfjord from the German sea. *Reports of the Danish Biological Station.* 6, 1-48.

Petts, G.E. & Amoros, C. (eds.) (1996). *Fluvial Hydrosystems*. Chapman & Hall, London. 322 pp.

Pialot, D., Chessel, D. & Auda, Y. (1984). Description de milieu et analyses factorielle des correspondances multiples. *CR l'Acad. Sci., Paris* 298 (III, 11), 309-314.

Pilcher, M. & Copp, G.H. (1997). Winter distribution and habitat use of fish in a regulated lowland river system of South-East England. *Fish. Mgmt & Ecol.*, 4 (3)

Pinder, M. J. & Morgan, R. P. (1995) Interactions of pH and habitat on cyprinid distributions in Appalachian streams of Maryland. *Transactions of the American Fisheries Society.* 124, 94-102.

Ponton, D. (1994) Sampling neotropical young and small fishes in their microhabitats: An improvement of the quatrefoil light-trap. *Archive fur Hydrobiologi.* 131, 495-502.

Pouilly, M. & Souchon, Y. (1994). Simulation de l'habitat physique du barbeau fluviatile (Barbus barbus, L. 1758): choix des modeles biologiques et sensibilite de la reponse. *Bull. fran. Peche Piscicul.* 334, 213-225.

Prokes, M. & Honrakova, M. (1988) The course of spawning, early development and longitudinal growth of the nase carp, Chondrostoma nasus, in the Rokytna and Jihlava rivers. *Folia Zoologica.* 27, 269-278.

Raddum, G. G. & Fjellheim, A. (1995) Artificial deposition of eggs of Atlantic salmon (Salmo salar L.) in a regulated Norwegian river; Hatching, dispersal and growth of the fry. *Regulated Rivers: Research & Management.* 10, 169-180.

Reynolds, J. B. (1983) Electrofishing. In: Fisheries Techniques (ed: Nielsen, L. A. & Johnson, D. L.) American Fisheries Society, Bethesda, Maryland, 147-163.

Robson, D.S. (1960). An ubniased sampling and estimation procedure for creel censuses of fishermen. *Biometrics* 16, 261-277.

Robson, D.S. (1961). On the statistical theory of a roving creel census of fishermen. *Biometrics* 17, 415-437.

Roux, A-L. & Copp, G.H. (1996). Fish assemblages. Chapter 8, pp. 167-183 In: *Fluvial Hydrosystems.* (eds. G.E. Petts & C. Amoros) Chapman & Hall, London. 322 pp.

Scheidegger, K.J. & Bain, M.B. (1995). Larval fish distribution and microhabitat use in free-flowing and regulated rivers. *Copeia* 1995, 125-135

Seber, G.A. & LeCren, E.D. (1967). Estimating population parameters from catches large relative to the population. *J. Anim. Ecol.* 36, 631-643.

Sempeski, P. & Gaudin, P. (1995) Habitat selection by grayling - I. Spawning habitats. *Journal of Fish Biology.* 47, 256-265.

Shirvel, C. S. (1989) Ability of PHABSIM to predict chinook salmon spawning habitat. *Regulated Rivers: Research & Management.* 3, 277-289.

ter Braak, C.J.F. (1986). Canonical Correspondence Analysis. A new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67, 1167-1179

ter Braak, C.J.F. & Verdonschot, P.F.M. (1995). Canonical Correspondence Analysis and related multivariate methods in aquatic ecology. *Aquat. Sci.* 57, 255-289.

Tong, H.Y. (1986). A qualitative and quantitative description of the early growth of roach, Rutilus rutilus, in the laboratory. *Env. Biol. Fish.*15, 293-300.

Wasson, J-G. (1989). Elements pour une typologie fonctionnelle des eaux courantes : 1. Revue critque de quelques approches existantes. *Bull. Ecol.* 20, 109-127>

Watkins, M.S., Doherty, S. & Copp, G.H. (1997). Microhabitat use by 0+ and older fishes in a small English chalk stream. *J. Fish. Biol.* 50 (in press)

Weatherley, A.H., Gill, H.S. & Lobo, A.F. (1988). Recruitment and maximal diameter of axial muscle fibres in teleosts and their relationship to somatic growth and ultimate size. *J. Fish Biol.* 33, 851-859.

White, H. C. (1942) Atlantic salmon redds and artificial spawning beds. *Journal of the Fisheries Research Board of Canada.* 6, 37-44.

Zippin, C. (1958). The removal method of population estimation. *J. Wildl. Mgmt.* 22, 82-90.

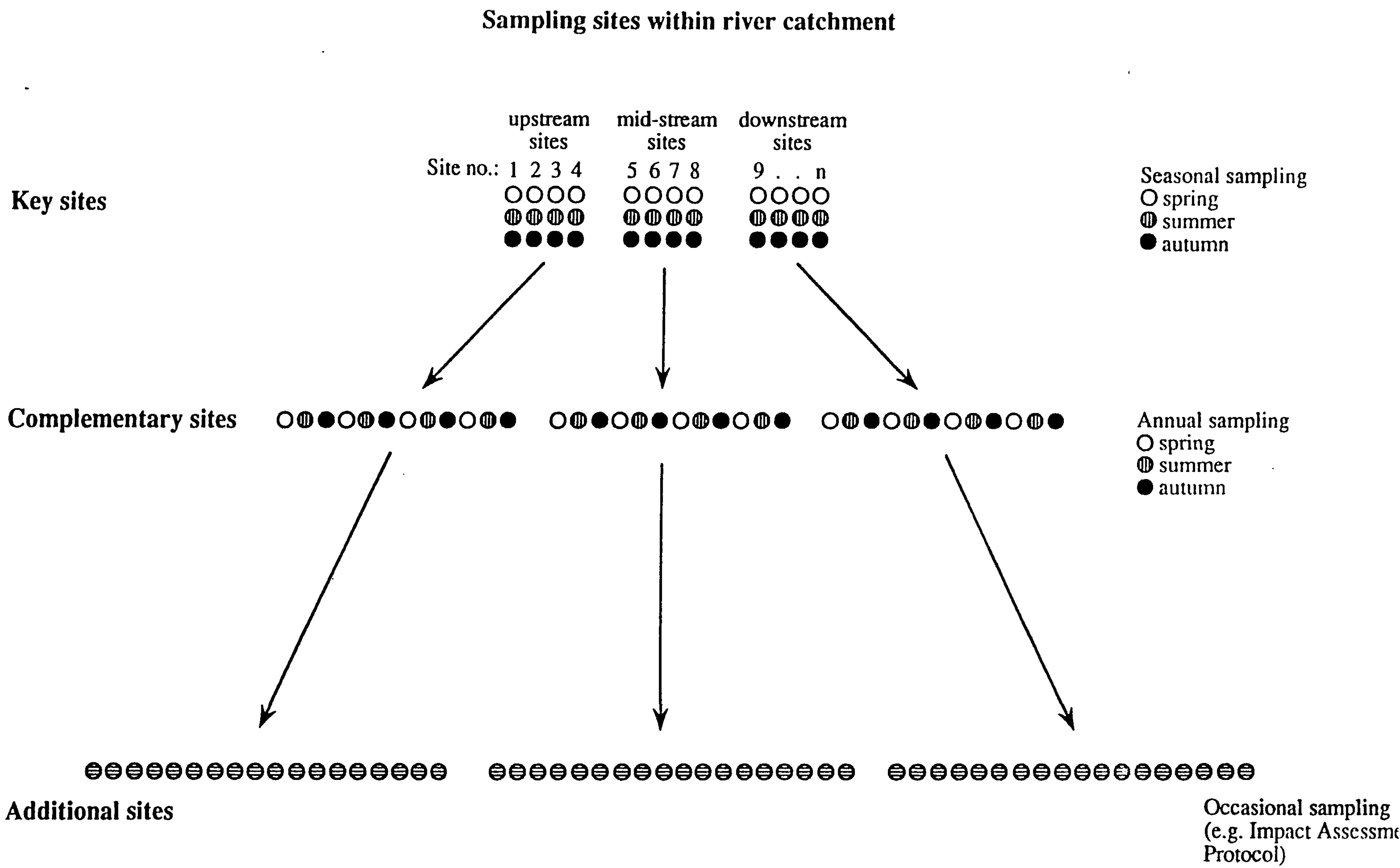


Figure 1. Schematic of the frequency and timing of sampling in a river catchment, for illustrative purposes only, this figure is based on four Key sampling sites per river section: upstream, mid-stream, downstream.

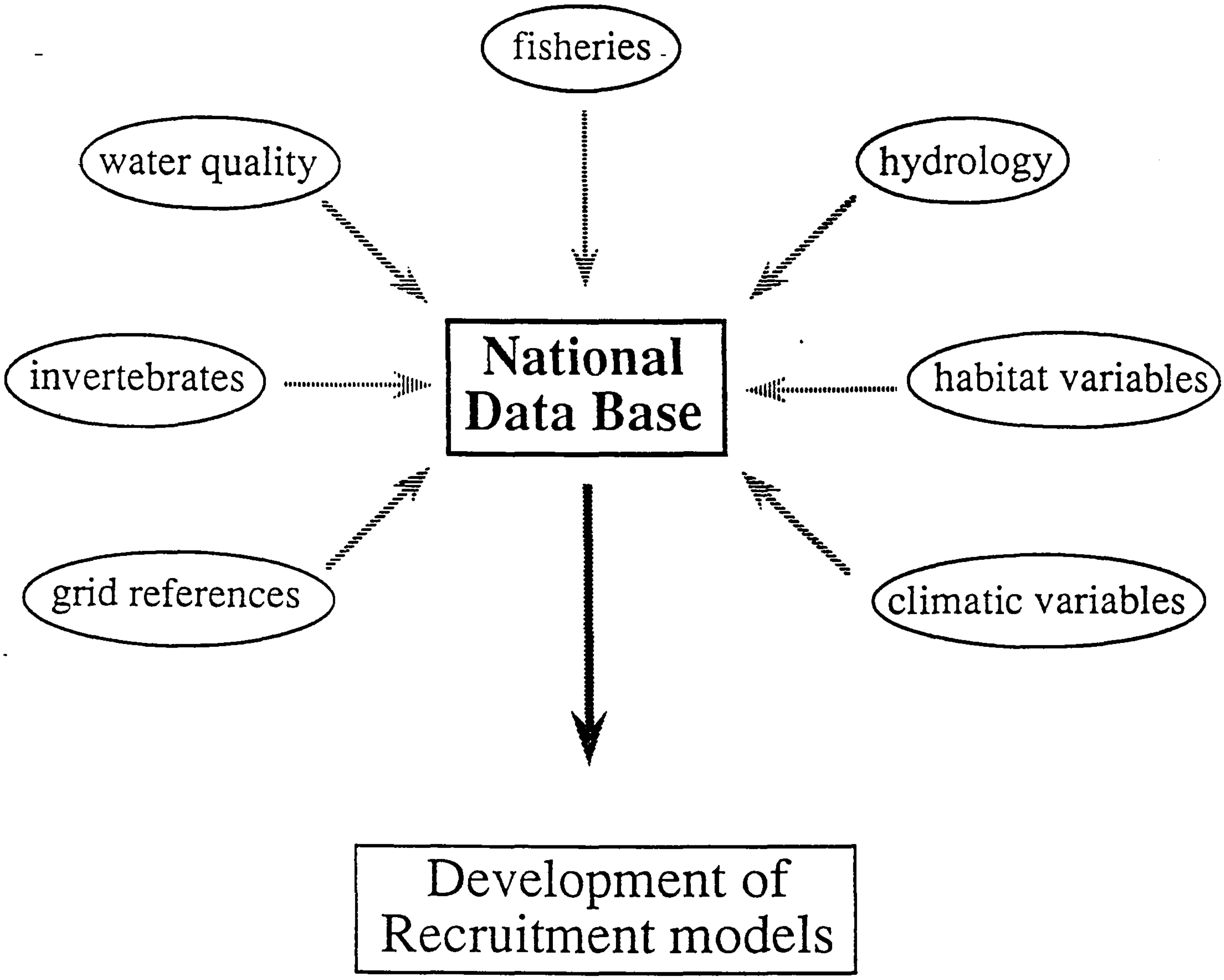


Figure 2. National data-base schematic

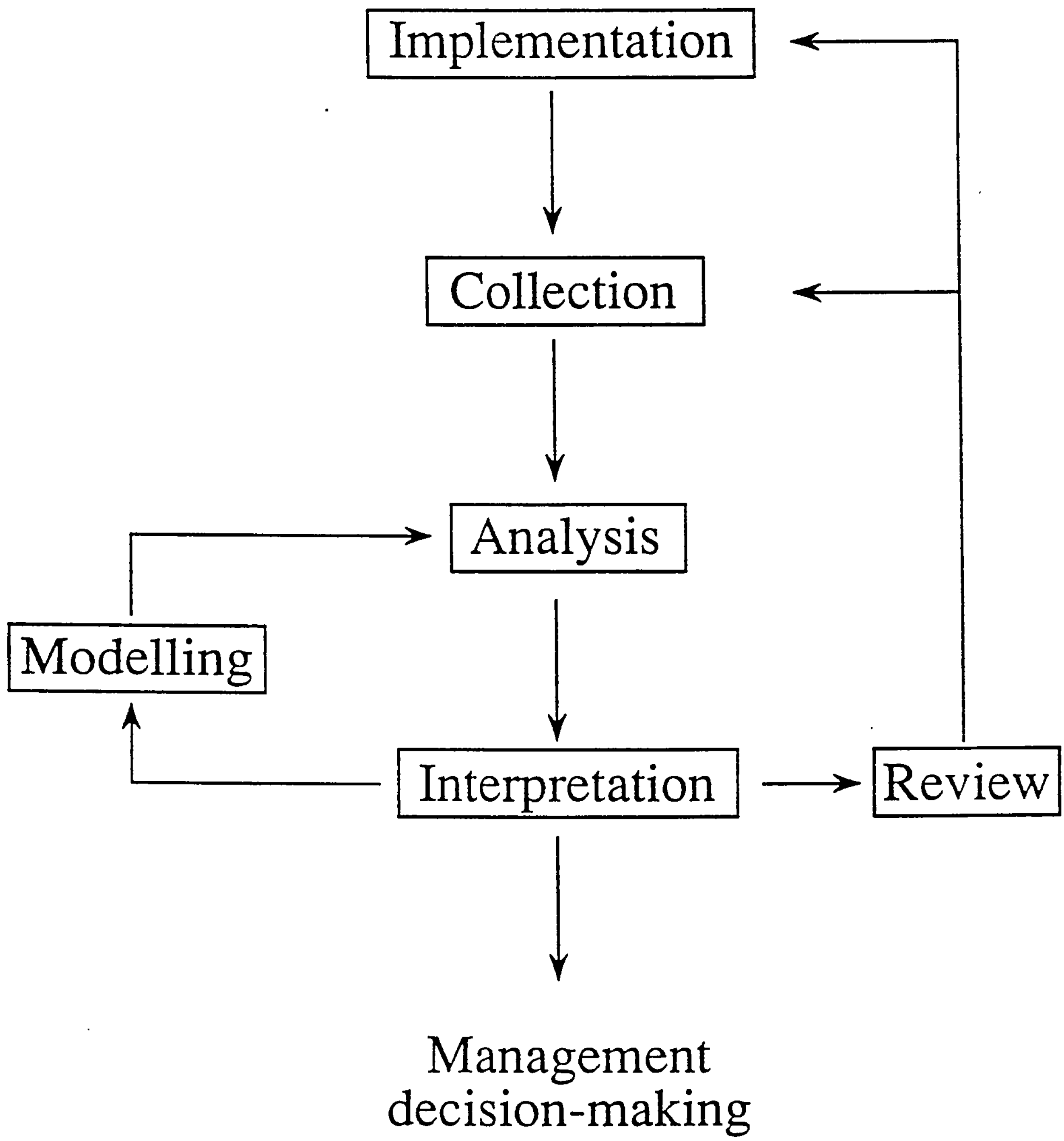


Figure 3. Information acquisition and processing flow chart