The Status of Headwater Stream Fish Populations and Their Tolerance to Low-Level Habitat Degradation

WRc plc

R&D Technical Report W58

Further copies of this report are available from:

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

The Status of Headwater Stream Fish Populations and Their Tolerance to Low-Level Habitat Degradation

C P Mainstone, N Morgan and R Wyatt

Research Contractor:
WRc plc

Environment Agency
Rivers House
Waterside Drive
Aztec West
Bristol
BS12 4UD

R&D Technical Report W58

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

Tel: 01454 624400 Fax: 01454 624409

HO-07/97-B-AXQY

Dissemination status

Internal: Released to Regions
External: Public Domain

Statement of use

This report summarises the scoping study work which will be used as a basis for a further phase of experimental fieldwork

Research contractor

This document was produced under R&D Project i691 by:

WRc plc
Henley Road
Medmenham
Marlow
Buckinghamshire
SL7 2HD

Tel: 01491 571531 Fax: 01491 579094

WRc Report No.: EA 4270/1

Environment Agency's Project Manager

The Environment Agency's Project Manager for R&D Project i691 was:
Dave Bird, South West Region

CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

Page

EXECUTIVE SUMMARY

Headwaters are highly vulnerable habitats that generally constitute a large proportion of the total water area and riparian length in river catchments. Whilst being an important fishery habitat in their own right, they contribute to the well-being of the whole catchment fishery resource by providing spawning habitat and nursery areas for juvenile fish. The degree of monitoring and management attention afforded them is at odds with their importance to proper catchment functioning. This report documents the findings of an initial review of available literature and easily accessible data on headwater fish populations, their vulnerability to the wide variety of threats to their status, and the nature and extent of impacts upon them.

Headwaters have always been loosely defined, owing to the continuous nature of change in riverine communities and the consequent lack of clear ecological transition zones that can be used to define a meaningful downstream boundary. No objective definition has been used in this report; instead, information has been presented in relation to a number of parameters that relate to stream size and location in the river network.

Preliminary analysis using historical data suggests that their contribution to the total standing stock in the catchment can be substantial, although the extent to which juvenile fish in headwaters contribute to adult stocks in larger rivers downstream is less clear. Phase 2 work will concentrate on the collection of data that will provide more comprehensive answers to these two questions.

Headwaters are intrinsically vulnerable to a range of impacts by virtue of their small size and location in the river network. Key factors are their numerous but individually insignificant nature, the low dilution capacity afforded to polluting inputs, their small gathering grounds, their remoteness from the main river network in many instances, and the frequent lack of accessibility to fish from other areas.

The impacts to which headwater fish populations are subjected are many and varied, including physical habitat degradation, organic pollution, acidification, the siltation of spawning substrates, alterations to flow regime, the imposition of artificial barriers to movement, mine drainage, pesticide contamination and genetic introgression. Whilst the nature of most of these impacts is largely understood, the extent of impact nationally is generally little known.

Considering that the principal driving force for this project is the difference in protection afforded to classified and unclassified river reaches, it has been recommended that Phase 2 concentrates on all 'minor' streams, defined as those falling into Environment Agency Flow Category 1 (coinciding with the guideline definition of unclassified watercourses), aiming to divide them into sensible groupings on the basis of fish communities. Recommendations for Phase 2 are presented at the end of this document, relating to a national assessment of the nature of fish populations in minor streams, and a purpose-built assessment of their contribution to the catchment fishery resource and their vulnerability to perturbations in catchment function. Recommendations for separate studies on specific impacting activities have also been made.

KEY WORDS

Headwaters, small streams, fish, vulnerability, impacts

1. INTRODUCTION

1.1 Background

A large proportion of the total length of river network in England and Wales consists of small streams that drain into the main river system, loosely termed 'headwater streams'. Although the contribution of such streams will vary greatly depending on catchment characteristics, it has been calculated that first order streams alone constitute 61% of the total stream length in the Conwy catchment, North Wales, with second order streams constituting a further 22% (Milner *et al.* 1991) This represents a large component of the total riparian habitat available in the catchment. Owing to their small widths, the contribution of first order streams to total water area in the catchment is generally lower than their length contribution, amounting to just less than 20% in the Conwy catchment. However, this contribution is still highly significant in ecological terms, particularly considering the role such streams play in the well-being of migratory salmonid populations and fish populations in the wider catchment. Second order streams can contribute a greater proportion of total water area by virtue of their greater width, constituting just over 30% of the total in the Conwy catchment.

Such figures show that, when considered together, headwaters represent a considerable proportion of the total riverine habitat in England and Wales. When considered in isolation, however, they appear as insignificant watercourses that are too small, and often too remote, to warrant monitoring and management attention. This situation creates a practical dilemma in terms of catchment management that needs to be resolved if headwaters are to be adequately protected in the future. Owing to their small size and large numbers, few headwaters feature in the Agency's routine river quality monitoring programme and relatively little surveying of headwater fish populations is undertaken.

From a broad ecological perspective, headwaters play host to diverse biological communities that not only constitute a highly valuable source of biodiversity in their own right, but also act as important sources of individuals for populating the river network further downstream. This continual downstream trickle of both vertebrate and invertebrate colonists is of great importance to the biological functioning of the whole river system. The interaction between headwaters and the rest of the catchment is not purely one-way, however, since headwaters often rely on the upstream migration of adult individuals (that have matured in larger watercourses) to maintain their juvenile populations.

This two-way interaction may be seen to provide riverine communities with their fundamental resilience to cope with perturbations in environmental conditions, be they natural or anthropogenic in origin. The depopulation of a stretch of main river by (for instance) an acute pollution incident may be rectified by recolonisation from headwaters, whilst the loss of headwater populations, due to (for instance) extreme drought, can be resolved through egg-laying by adults migrating upstream. Long-term disruptions to this interaction, brought about by permanent physical disruption to habitats or chronic contamination, can interfere with the resilience of communities catchment-wide.

In terms of fish populations specifically, headwaters support a significant (but as yet unquantified) proportion of the total standing stock in river catchments, whilst contributing to fish populations in the wider catchment by providing spawning habitat for adults migrating upstream and acting as nursery areas for juveniles that are eventually recruited into downstream populations. The degree to which headwaters are relied upon varies between fish species and between different types of headwater, from those running off lowland chalk to those draining upland moorland.

Headwater populations are at risk from a variety of anthropogenic activities that lead to chemical and physical degradation of the habitat, a situation often made worse by their individually insignificant and often remote nature, the lack of upstream sources of colonists, and their limited capacity for dilution of contaminants. Factors such as land drainage activities, water abstraction, organic pollution, acidification and mine drainage are all key influences on the quality of headwater streams, although the extent of impact on fish populations nationally is unclear.

Under the Water Resources Act 1991, the Agency has a duty to maintain, improve and develop the salmon, trout, freshwater and eel fisheries under its jurisdiction. In addition, it has a duty to regulate and protect fisheries as defined in the Salmon and Freshwater Fisheries Act 1975 and the Salmon Act 1986. In nature conservation terms, the Environment Act 1995 requires all Agency Functions (including fisheries) to further conservation, thereby imposing a need to give greater consideration to fish species of little or no angling interest. Fulfilment of all of these duties relies to a large extent on the proper functioning of headwaters, which can by no means be taken for granted.

In recognition of the importance of headwaters to the catchment fishery resource and the limited attention as yet afforded them, the Environment Agency is funding a two-phase research project aimed at improving the current level of understanding. This document presents the work undertaken during Phase 1 of the project, comprising a review of available information and the development of a programme of fieldwork to generate new data in the second phase.

1.2 Objectives

1.2.1 Overall project objective

To provide a quantifiable basis for the strategic management of headwater stream fish populations, by assessing their contribution to catchments and their sensitivity to impacts.

1.2.2 Specific objectives

(a) To review existing information concerning the importance of headwater stream fish populations in relation to the catchment as a whole.

(b) To review existing information to provide a national overview of the type, effects and extent of various impacts on headwater stream fish populations.

(c) To plan case studies in different ecological types of catchment to validate literature findings on the relative importance of headwater stream fish populations and their sensitivity to impacts.

1.3 Method of working

A search of published literature (on headwaters, their fish populations and human impacts upon them) was conducted using relevant databases on the DIALOG host (such as BIOSIS and Aquatic Science and Fisheries Abstracts), WRc's AQUALINE database and the FBA's library catalogue. A written request for relevant information was also made to the Agency Regions, asking for reports that would help to characterise headwater fish populations, quantify their contribution to the catchment fishery resource, and assess the impact of different human activities. Appendix A provides a list of Agency staff who helped to supply information.

The mapping package MAPINFO was used in selected catchments to provide illustrations of different possible definitions of headwater (see Section 2) and to estimate the contributions of different sizes of stream to the total fishery resource (see Section 4.2). Catchment selection was dictated by the availability of adequate fishery data for small streams, but attempts were made to cover contrasting environmental conditions. The 1:50 000 scale digitised river network was supplied for each selected catchment by the Institute of Hydrology, allowing the production of data stream order and distance from source. Grid-based data on altitude and Base Flow Index (an indication of groundwater influence) was extracted from databases held at WRc. MAPINFO was used to assign values for each of these parameters to each reach in the catchment (a reach being the distance between two confluences, and the attribute value assigned being that relating to the reach mid-point). Using available stream width and fishery data, models were then built using Genstat V to simulate variation in wetted area and fish density in the catchment according to these parameters. These models were then applied to all reaches in the catchment in order to extrapolate wetted areas and fish densities to reaches without sites. Multiplication of the fish density in each reach by the total wetted area in the reach then allowed the total fish stock in the catchment to be estimated and apportioned across the river network.

2. DEFINING HEADWATER STREAMS

2.1 Introduction

The term ‘headwater stream’ can conjure up different images to different people, particularly people working in different disciplines and in different geographical locations. In order to ensure that future research and management policies are based on a clear understanding of the term, an objective definition is required that is acceptable and understood by all. Such a definition should have ecological relevance and also be relevant to the operational activities of the Agency. Since it will be applied to innumerable small streams, it should not require the use of parameters that are difficult or time-consuming to measure. It is also important to note that a definition is already being used in research into macroinvertebrate communities in headwater streams, also funded by the Agency (R&D Project 242). A common definition must be reached if confusion is to be avoided.

In broad terms, it is accepted that headwater streams are small (in terms of physical dimensions and flow) and are located ‘near’ to their source. In placing such vague statements on an objective footing, the key questions are therefore: ‘how small?’ and ‘how near?’. It is also generally accepted that a headwater stream can rise at any point in the catchment, be it in the highest gathering grounds or near the river’s mouth, as long as the above-mentioned criteria are satisfied. This gives rise to a wide variety of headwater habitats that need to be acknowledged if sensible comparisons between headwaters are to be made.

It is worth briefly considering classical definitions of headwaters in terms of their relevance to the debate. The term ‘headstreams’ used by Carpenter (1928) is based on an idealised catchment which rises in the uplands, and the term is only used to describe small upland streams. In addition, no objective criteria are proposed for identifying such habitats. The work of Huet (1959) is more useful in that it relates habitat zones to the key variables channel width and gradient, these being inter-correlated with a wide variety of other channel characteristics such as flow and current velocity. He defines four zones, with associated fish communities, comprising the trout, grayling, barbel and bream zones. Although he does not make use of the term ‘headwater’, he defines the ‘brook’ as streams less than 5 metres in width, and acknowledges that such streams can give rise to any of his four fish zones, depending upon the position of the brook in the catchment (Figure 2.1). The Huet model provides the type of framework necessary for an informative definition of headwater streams, comprising a boundary for the downstream limit of headwaters (in this case using channel width) with sub-divisions (using a combination of gradient and width) that aim to account for major ecological differences between headwaters. The Fisheries Classification Scheme (Mainstone *et al.* 1994a) uses the same two parameters to characterise habitat type, albeit in a slightly different context.

The River Habitat Survey methodology provides a possible basis for defining headwaters and headwater types, providing a classification of watercourses into 11 different segment types (Table 2.1). Within the classification there is a division of watercourse types into ‘streams’ and ‘rivers’, although the nature of the boundary between the two is unclear. The relevance of these divisions to fish populations has not been fully evaluated, although recent attempts have been made by the Environment Agency North West Region to predict trout numbers using RHS.

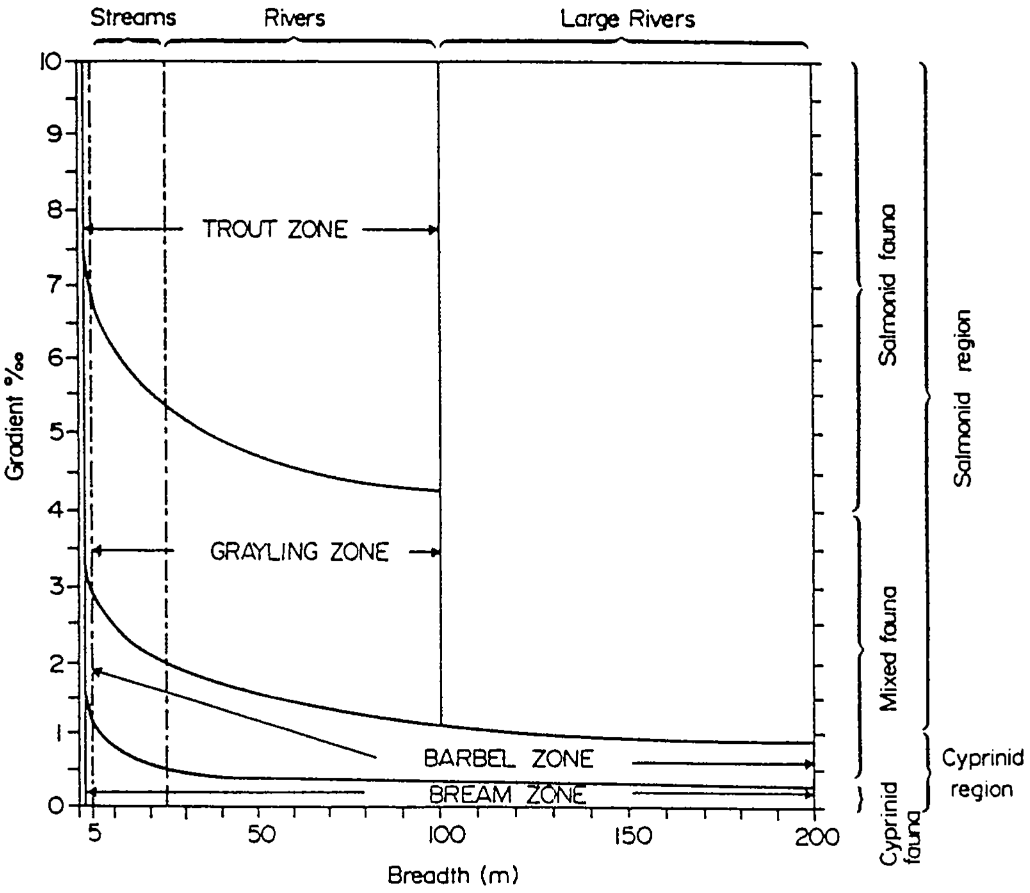


Figure 2.1 The relationship between gradient, river width and fish faunal zones (after Huet 1959).

Table 2.1 River segment types used in the River Habitat Survey methodology (NRA 1996).

River segment type	Description
1	Low altitude, low gradient rivers on soft geology
2	Low altitude, low gradient rivers on mixed geology
3	Low altitude, low gradient streams on soft geology
4	Low altitude, steep gradient streams on mixed geology
5	Medium altitude, low gradient rivers on soft geology
6	Medium altitude, moderate gradient rivers on mixed geology
7	Medium altitude, moderate gradient streams on soft geology
8	Medium altitude, steep gradient streams on mixed geology
9	High altitude, moderate gradient rivers on mixed geology
10	High altitude, steep gradient streams on mixed geology
11	High altitude, very steep gradient streams on hard geology

Although it is necessary for the purposes of this scoping study to provide indications of what might constitute a headwater (dealt with later in this section), it is important that a permanent definition is arrived at through an iterative process, taking into account the views of a range of people and linking with the parallel Agency research on macroinvertebrate communities. To this end, a discussion of the key parameters that might be used is considered valuable, together with some implications of their use in different situations. This discussion, and work within R&D Project 242, should be used as the basis for producing a consensus on a definition. Parameters are divided into those that may be used to provide the broad definition, and those that might be of value in providing ecologically relevant sub-divisions.

It should be noted that the definition applied by R&D Project 242 is now quite well-entrenched in Agency thinking in the Water Quality Function. This means that, if a downstream limit is decided upon that does not coincide with this definition, it would be sensible to use a different term to 'headwater' in order to avoid confusion. If, as may be the case, it is decided that the Fisheries Function requires a broader definition (i.e. a boundary set further downstream), the most pragmatic solution may be to use a different term (such as 'minor stream') and to have the Project 242 definition of 'headwaters' as a sub-division. For the purposes of this scoping study, the term headwater is used in its broadest sense and not in relation to the Project 242 definition.

2.2 Parameters of use in defining the downstream limit

The ecological basis for defining a distinct boundary between headwater streams and the rest of the river network will always be tenuous, since it is widely accepted that rivers represent a continuum of ecological change (Vannote *et al.* 1980) with no clear boundaries (or ecotones) between different habitats and their associated communities. Nevertheless, a definition must be made if protection policies for headwaters are to be developed. Key parameters that are of potential use in setting the downstream limit of headwaters, in terms of stream size and proximity to source, are:

- Stream order;
- Distance from source;
- Flow;
- Channel width;
- Catchment area.

a) **Stream order** is a valuable parameter in that it is easily accessible (from maps and increasingly from GIS) and changes in its value are the closest thing to ecotones in a river network. It should be noted that, since stream order is dependent upon the scale of observation, it is necessary to specify a map scale - 1:50 000 scale is in widespread use across the Agency and is sensible for use in this context. There are various definitions of stream order but the one in most widespread use is that of Strahler (1957). Shreve's stream order (or Link Number) is also of value in certain instances (Section 2.3) and is used in the HABSCORE model. The main drawback with stream order is that its relationship to other key variables, particularly distance from source, is largely dependent upon drainage density. In catchments of high drainage density, first order streams join up quickly to become second order, whereas first order streams in catchments of low drainage density can persist for much longer distances downstream. This means that stream order is a very useful and relatively consistent descriptor of stream size in individual catchments or over areas with homogeneous physiography, but less informative in a broad definition covering a large heterogeneous area.

An illustration of the problem is given by our contrasting case study catchments in Figures 2.2 and 2.3. In the Western Cleddau and the eastern half of the Colne, where the drainage density is high, first order streams (Strahler) are largely contained within 2.5 km of source. On the western half of the Colne, where watercourses are chalk streams and the drainage density is very low, first order streams can continue for tens of kilometres and build up to a reasonable size. The only practical option of linking stream order to other key variables is to classify catchments or parts of catchments The question then has to be asked as to whether it would be easier to use other key variables directly. The possibility of classifying catchments prior to defining the downstream boundary of headwaters will be discussed further, later.

b) **Distance from source** is a valuable parameter in that it provides a direct geographical linkage with the outer extremities of the drainage system. The range of values that might be used to define the downstream limit of headwaters is wide; three possible definitions (2.5 km - the value used in R&D Project 242 - 5 and 10 km) are illustrated in Figures 2.2 and 2.3 by reference to our case study catchments. As with stream order, distance from source is dependent upon the scale of observation - 1:50 000 scale is the standard used in the Agency and elsewhere and is used in our illustration. It is relatively easily accessible from maps, and increasingly so from GIS. It should be noted that the Project 242 definition of headwaters is based on the observation of a range of macroinvertebrate species that are found almost exclusively within 2.5 km from source (map scale undefined but presumably 1:50 000). The relevance of this definition to fish populations is unclear, and it may be that reaches downstream of this distance (which many would still term 'headwaters') are more important in the catchment fishery context in that they generally provide larger habitats and are generally more accessible to fish residing in the main river network (see Section 3).

Table 2.2 and Table 2.3 show the relationship between stream order and distance from source in our case study catchments. In the Western Cleddau, there is a strong coincidence between the 2.5 km cut-off and first order streams in terms of both stream length and stream area. The predominance of chalkstreams in the western half of the Colne catchment means that no such relationship exists, with a larger proportion of wetted stream area occurring in the >10 km-from-source category than the <2.5 km category.

Table 2.2 The relationship between distance from source and stream order in the Western Cleddau catchment

Stream order	Distance from source (km)				
	<2.5	2.5-5	5-10	>10	**Total**
Percentage breakdown by stream length					
1	51.4	3.4	0.0	0.0	**54.7**
2	9.4	10.6	5.0	0.0	**24.9**
3	0.4	2.5	7.1	1.5	**11.5**
4	0.0	0.0	1.1	7.8	**8.9**
Total	**61.1**	**16.4**	**13.1**	**9.3**	**100.0**
Percentage breakdown by wetted stream area					
1	27.9	4.3	0.0	0.0	**32.3**
2	5.6	9.8	6.5	0.0	**22.0**
3	0.3	2.5	10.7	3.5	**17.1**
4	0.0	0.0	1.7	27.0	**28.7**
Total	**33.9**	**16.7**	**18.9**	**30.5**	**100.0**

Table 2.3 The relationship between distance from source and stream order in the western half of the Colne catchment

Stream order	Distance from source (km) <2.5	2.5-5	5-10	>10	**Total**
Percentage breakdown by stream length					
1	16.4	5.2	8.7	9.5	**39.8**
2	2.2	2.0	1.8	18.6	**24.6**
3	0.0	0.8	0.8	8.2	**9.8**
4	0.0	0.0	0.2	25.6	**25.7**
Total	**18.6**	**8.0**	**11.5**	**61.9**	**100.0**
Percentage breakdown by wetted stream area					
1	8.2	2.9	5.6	10.4	**27.2**
2	1.1	1.1	1.2	18.6	**22.1**
3	0.0	0.5	0.5	14.8	**15.7**
4	0.0	0.0	0.1	34.9	**35.1**
Total	**9.4**	**4.5**	**7.4**	**78.7**	**100.0**

c) **Flow** provides a direct indication of physical size for small streams and is extremely valuable in this respect. The only indication of river flow that is available across England and Wales is the crude flow categorisation used by the Agency. The threshold for the lowest flow category is an average annual flow of less than 0.31 $m^3 s^{-1}$, which is also used as the guideline for the upstream boundary of classified waters in the GQA scheme (with an additional guideline of a natural summer flow of less than 0.05 $m^3 s^{-1}$). Unless a definition in line with this lowest flow category is used, the implications of using a definition based on flow will be difficult to visualise. Such an operationally linked definition would certainly be useful, since it would highlight the differences in monitoring and management attention that have led to concern over small streams. However, it must be pointed out that the threshold between classified and unclassified stretches is not simply a matter of flow. Any watercourse can also be designated on the basis of high conservation or local importance.

Figures 2.4 and 2.5 show the classified river network in our case study catchments, illustrating the extent and distribution of headwaters if the boundary between classified and unclassified reaches (assumed to be broadly equivalent to an average flow of 0.31 $m^3 s^{-1}$) were to be used as a definition. Distances from source have also been added to the figures to show how possible definitions based on this parameter relate to the extent of unclassified streams. In the Western Cleddau, unclassified streams generally extend down to 8-10 km from source, which leaves a large length of small stream in limbo between the Project 242 definition and the upstream limit of classified watercourses. In the eastern half of the Colne catchment (which has a similar drainage

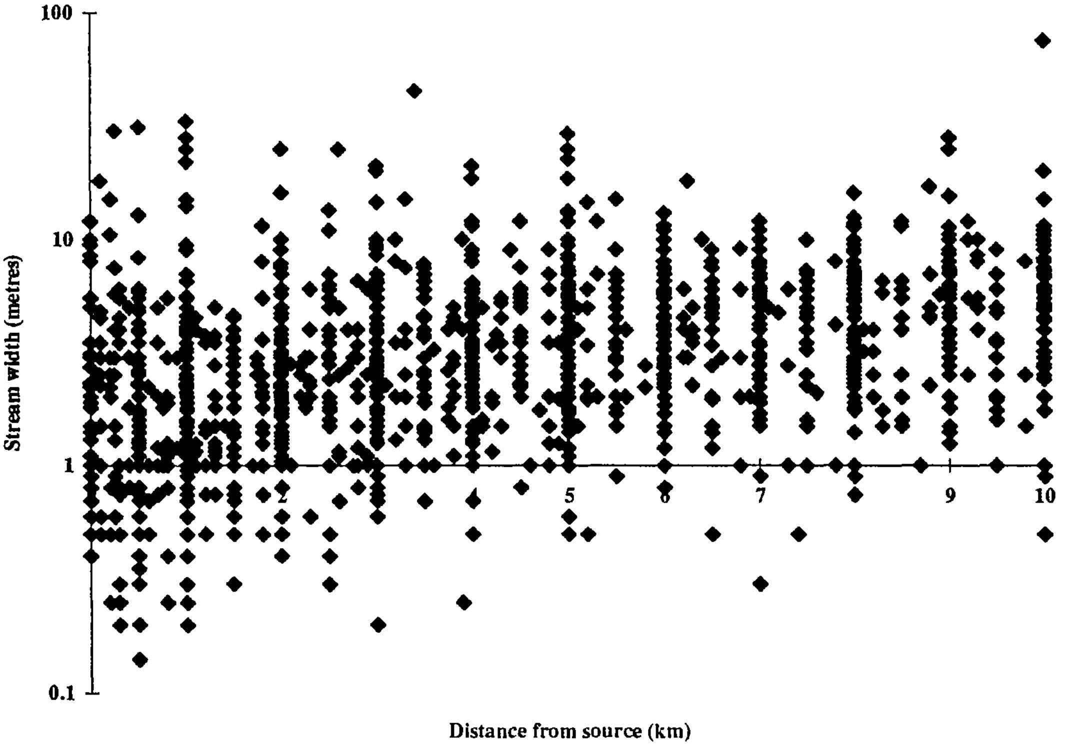


Figure 2.8 The relationship between stream width and distance from source at sites less than 10 km from source in the River Habitat Survey database (1994 and 1995 data).

One possible method of defining a downstream boundary of headwaters that varies with catchment size would be to use catchment area and set the boundary at a fixed percentage of the total area of the river catchment in question. However, this type of approach leads to the possibility of having two stream sections of identical stream order, distance from source, flow characteristics and channel width, and terming one a headwater and the other a non-headwater due to the size of catchment to which they belong. Even worse, one stream section could be termed both a headwater and a non-headwater, depending upon what is considered to be the most downstream point of the catchment. This paradox raises the question of whether defining the downstream limit of headwaters needs to be preceded by a classification of catchments in England and Wales, in order to fix one's perception of the river catchment.

2.3 Parameters of use in discriminating between headwater types

Whilst any of the four parameters listed above may be used to sub-divide headwaters, a number of other key parameters are also of potential use, as below. It should be noted that there are intercorrelations between some of these parameters (and the parameters in Section 2.2) that would make their combined use unnecessary.

- altitude;
- stream gradient;
- downstream 'link number';
- soil type and geology.

Altitude is a widely used parameter due to its accessibility from maps and GIS, and is related to key factors such as climate and stream gradient that greatly influence fish communities. **Gradient** is also accessible from maps, and additionally from GIS with some programming. The **downstream 'link number'** or Shreve's stream order, is extremely useful for indicating the position of the stream in relation to larger rivers in the network, with remote headwaters being assigned low values and small tributaries directly connected to main river being assigned high values. The relative position of a stream in the river network has been found to play an important role in the composition of fish communities, since it greatly influences the accessibility of the headwater to adult fish in the main river network. For instance, Osborne and Wiley (1992) found that the proximity of the tributary sampling location to the downstream main channel was more important than local habitat structure in determining species richness in tributary streams. Downstream link number has been found to be an extremely good predictor of salmonid abundance in the Agency's HABSCORE model (Wyatt *et al.* 1995).

Soil type and **geology** have important influences on riverine habitat and may prove useful in discriminating between headwater types. However, existing classifications are not particularly amenable to use within this context. A new classification is currently being developed by WRc for the DoE that aims to improve the situation and may be useful in the future. In the meantime, simple parameters such as soil permeability or Base Flow Index may provide useful discrimination. Two basic influences of soil type/geology may be identified: the influence of the catchment area of a river reach, which shapes the basic water chemistry and flow regime, and the influence of the drift/solid geology of the reach itself, which shapes the instream physical habitat.

Development of meaningful sub-divisions of headwaters is some way off and needs to be arrived at through a comprehensive analysis of the characteristics of fish populations in headwater streams, which should be gained from Phase 2 of this project.

2.4 Interim solution to the problem of a definition

Whilst it is recognised that the development of a suitable definition for headwaters needs to evolve, a means of dealing with the issue was needed for this scoping study in order to direct data collation efforts and to place the existing information into context. In terms of the data request sent to Agency Regions, a loose description was needed that enabled Agency fisheries staff to focus their search. This was given as streams that were less than 3 metres in width and generally not classified under the GQA scheme, a description that was easily interpretable using available information. Wherever possible in this report, data on streams are referenced in relation to information on distance from source, stream order and channel width, so that the position in the river network is described without imposing a rigid definition of headwaters. Information in the report should therefore be as interpretable as possible in relation to any definition that is subsequently decided upon.

3. UTILISATION OF HEADWATERS BY SPECIES

Anthropogenic influences aside, a variety of factors influence the ability of fish species to utilise headwater streams, amongst which the most important are current velocity, water depth and temperature. These factors are related and are intercorrelated with a range of other ecologically importance variables, such as substrate type. The tolerance of each species, and age classes within each species, to such factors determines the extent to which headwaters, and different types of headwaters, may be exploited and at which stages of the life cycle.

In general, the age structure of fish populations in headwater areas shifts from juveniles upstream to older age classes downstream, with a smaller-scale segregation into juveniles in riffle areas and older fish in pool habitat (Schlosser 1982). During low flows, older fish seek out deeper habitats, which are invariably downstream. During high flows and periods of higher food availability, older fish migrate upstream to feed and/or spawn. However, behaviour of age classes varies greatly from species to species, such that generalisations of this nature must be treated with caution. Salmonid species demonstrate this behaviour most strongly, even making use of ephemeral streams for spawning during the winter period of high flows (Mann *et al.* 1989, NRA South Western Region 1992).

Even where major fish species are the most visually obvious members of a headwater fish community, minor species may well far exceed them in terms of productivity and therefore play an extremely important ecological role. Mann (1967) discovered that, although brown trout was the most conspicuous member of the fish community in the River Tarrant, the annual production of bullhead was four times as great.

Although the extent of utilisation of headwaters by different species will ultimately depend upon the exact definition used, and will also vary between different types of headwater, it is useful to make a broad assessment of the key species in headwaters by reference to published descriptions of general habitat preferences. Brief notes have been made on each species of potential relevance, and the likely extent of utilisation in different life stages has been summarised in Table 3.1. In the table, a mixture of two criteria have been used to gauge the extent of utilisation by each species:

1. the perceived frequency of occurrence in headwaters across all types;
2. the dependence on headwaters (i.e. in relation to the perceived frequency of occurrence outside of headwaters).

On the basis of work to be undertaken in Phase 2, it should be possible to refine this table by disentangling these two criteria and determining the importance of different headwater types to each species and life stage.

Table 3.1 Perceived extent of utilisation of headwaters by fish species native to England and Wales.

Species	Spawning/egg development	Maturation	Adult growth
Brown trout (*Salmo trutta*)	***	***	***
Atlantic salmon (*Salmo salar*)	***	***	-
Bullhead (*Cottus gobio*)	***	***	***
Stone loach (*Noemacheilus barbatulus*	***	***	***
Minnow (*Phoxinus phoxinus*)	***	***	***
Three-spined stickleback (*Gasterosteus aculeatus*)	***	***	***
Nine-spined stickleback (*Gasterosteus pungitius*)	***	***	***
Brook lamprey (*Lampetra planeri*)	***	**	N/A
River lamprey (*Lampetra fluviatilis*)	**	*	-
Sea lamprey (*Petromyzon marinus*)	**	*	-
Eel (*Anguilla anguilla*)	-	**	**
Dace (*Leuciscus leuciscus*)	**	**	*
Spined loach (*Cobitus taenia*)	*	*	*
Grayling (*Thymallus thymallus*)	*	*	*
Chub (*Leuciscus cephalus*)	*	*	*
Gudgeon (*Gobio gobio*)	*	*	*
Barbel (*Barbus barbus*)	*	*	-
Roach (*Rutilus rutilus*)	*	*	*
Perch (*Perca fluviatilis*)	*	*	*
Pike (*Esox lucius*)	*	*	*

Brown trout are extremely widespread in both upland and lowland headwaters of good quality. Self-sustaining populations can be found in extremely small and remote streams, whilst other more accessible streams provide spawning and juvenile-rearing habitat for both sea trout and non-migratory trout from larger rivers downstream.

Headwaters provide important spawning and juvenile-rearing habitat for **Atlantic salmon**, although this species does not penetrate as far up the river network as the brown trout. Observations on the distribution of juvenile salmon in West Wales (Clark *et al.* 1987, Wightman 1988, Wightman 1989, Wightman and Jones 1992) suggest that salmon usage of upland streams declines considerably at channel widths of below 3 metres, such that headwaters might be seen to be more important to trout populations than salmon (depending upon the definition applied). It is not clear how these observations relate to other parts of England and Wales.

Headwater streams are heavily utilised by minor species for their whole life cycle, and are often the sole representatives when water depths are low and significant pool habitat is unavailable. The **bullhead** is probably the most widespread minor species in headwaters in England and

Wales, with **stoneloach** largely being restricted to streams with high dissolved oxygen levels. **Minnows** and the **three-** and **nine-spined sticklebacks** all utilise headwater streams heavily, particularly in lowland locations. **Spined loach**, though restricted in distribution, occurs in small streams (Perrow and Jowitt 1997) to a greater extent than has been previously thought (particularly by Mann 1995).

All three species of lamprey migrate upstream to spawn in stony/gravelly reaches of rivers, which will include streams small enough to be termed headwaters. Larvae drop downstream to slack water, where they burrow in silt until metamorphosis. Following metamorphosis, the **sea lamprey** and **river lamprey** migrate to the coast to feed, whilst the brook lamprey does not feed in the adult form but migrates upstream once more to spawn (Maitland and Campbell 1992). The most likely lamprey species to find in headwater habitats is the **brook lamprey**, which can be found in the absence of the two anadromous species above impassable falls. A survey has recently been conducted on the distribution of lamprey species in selected catchments in England, which has confirmed a strong association with headwaters (pers. comm. Mary Gibson, English Nature).

Eels penetrate into headwaters if there are no obstacles to migration, and are frequent members of headwater fish populations. In the Thames catchment, Naismith and Knights (1993) found that eels penetrating into the small streams of the catchment were invariably large and female, although it is not known how this relates to other parts of England and Wales.

In terms of major cyprinids, limnophilic species are unlikely to make heavy use of headwaters at any stage in the life cycle unless the habitat has been impounded/impeded to provide an adequate depth of slow-flowing water. These species tend to seek out weedy backwaters with negligible flow for spawning so that eggs and fry are protected against wash-out. Spawning migrations into headwaters are therefore unlikely to be important to such species, unless the watercourse is extremely slow-flowing and suitable habitat in the main river is in short supply. Rheophilic cyprinids, such as **dace**, **chub**, **barbel** and **gudgeon**, are more likely to utilise headwaters significantly, owing to their tolerance to swifter currents and their use of coarse substrates for spawning. Dace, chub and barbel generally inhabit the middle and lower reaches of swift-flowing rivers, but may make use of smaller streams for spawning and juvenile development, particularly if such habitat is connected directly to the main river. Dace are well-known for their upstream spawning migrations (Maitland and Campbell 1992), and are likely to make more use of headwaters than chub or barbel. The gudgeon is most likely to live out its full life cycle in headwaters owing to its smaller size, although the adult does have a preference for deeper water (Zweimuller 1995). This species is also known to exhibit upstream migrations (Stott 1967), so headwater habitat is likely to be more important for spawning and juvenile development than for adult feeding.

Grayling tend to inhabit larger river sections in the adult form, although they may well be present in larger headwaters. They undergo upstream migrations into fast-flowing tributaries, laying eggs in gravel redds (Maitland and Campbell 1992). Their use of headwaters for egg and juvenile development is therefore likely to be greater than for adult feeding.

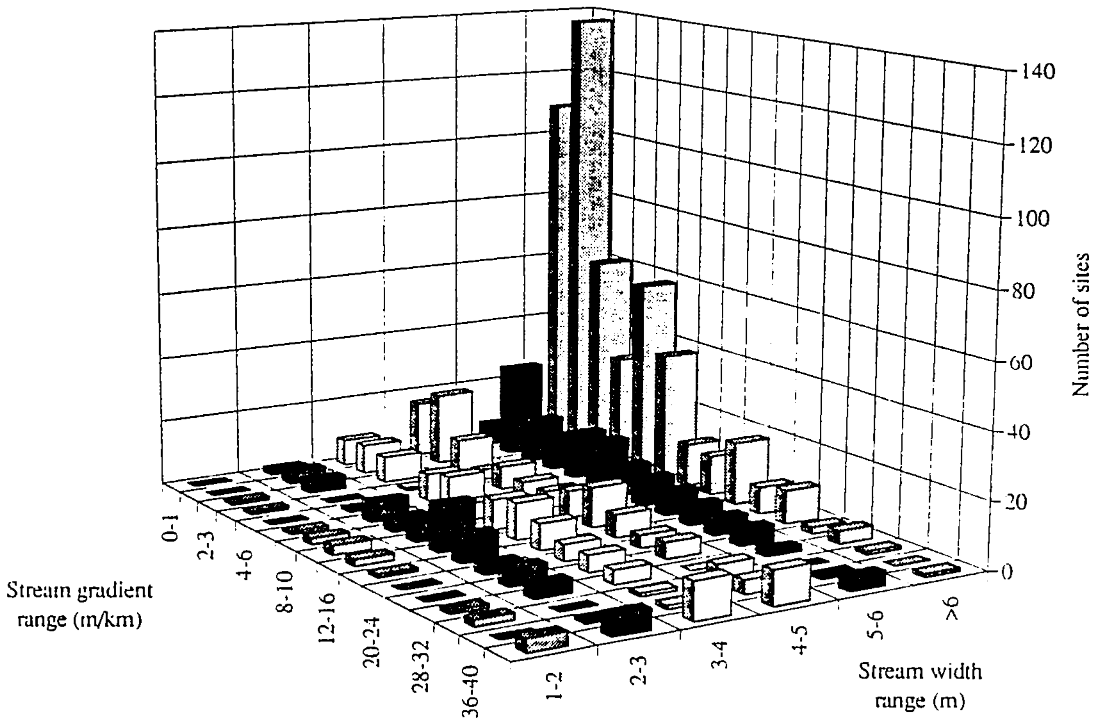
More tangible evidence of the use of small streams by different species can be gleaned from data collated from the NRA (as was) for the development of the national Fisheries Classification Scheme, which can be presented on the basis of presence/absence in relation to stream width and gradient (Figures 3.1 to 3.12). In each figure, the number of sites for which data are available on the species is given in part (a), whilst part (b) shows the percentage occurrence. It is immediately evident that there are relatively few sites in the original fishery classification database that are less than 3 metres in width. The lack of geographical representativeness of the database should also be borne in mind when considering results, there being few sites on small streams in lowland (southern and eastern) areas of England (see Mainstone *et al.* 1994b). However, it is still possible to glean some general information on the extent of utilisation, whilst the trend towards increasing or decreasing use with stream size and gradient is often very apparent.

For brown trout, utilisation appears to be very high even in the smallest streams (<1 metre), whilst the occurrence of salmon becomes very patchy below the 2-3 metre class. Dace, chub and gudgeon all exhibit good utilisation of streams down to 2-3 metres, but are absent above gradients of 5 m km^{-1}. Grayling appear to be restricted to larger streams, although there were comparatively few sites at which the species was found at all. Roach appear to have a similar pattern of utilisation to dace, chub and gudgeon at this coarse level of analysis. Eels make use of the full range of stream sizes, with 100% utilisation down to 1-2 metres.

Although all sites in part (a) of each figure should theoretically contain observations of presence/absence on the species in question, the patchy nature of utilisation shown in Figures 3.9 to 3.12 brings into question the reliability of the data for minor species. This is particularly apparent for minnow and to a lesser extent three-spined stickleback, although the preference for lower gradient watercourses is evident. However, the picture for bullhead shows a realistic picture of high occurrence across a wide range of stream widths and gradients. The pattern for lampreys (which cannot be distinguished into species and will be a mixture of observations on river and brook lampreys) is difficult to interpret, since the true pattern of utilisation is likely to be patchy but this is confounded by probable under-recording.

Figures 3.13 to 3.24 combine the above data from the fishery classification database with data from case study catchments and other easily accessible data to indicate the geographical distribution of species occurrence in relation to stream width. As they stand, the distribution of sites across England and Wales is very patchy; even so, some trends are readily apparent. As might be expected, both brown trout and salmon exhibit high utilisation in western and upland areas, with trout becoming more patchy and salmon almost absent in lowland areas. It is interesting to note that trout are the only species present in a number of sites of less than one metre in the Thames Region. Dace, chub, gudgeon and roach all show patchy distributions across stream widths of 2-4 metres in lowland England and are absent from western areas. Eels are only recorded patchily in lowland areas and hardly at all in Wales - it is not certain whether this a true reflection of their distribution or a confusion between recorded absence and missing values. Sticklebacks, minnows and lampreys all show a sparse distribution across sites in lowland England and are absent from sites in western areas (this may also be an artefact of recording). Bullheads and stoneloaches show a higher utilisation in lowland sites but again are absent from sites in upland areas (again possibly an artefact).

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

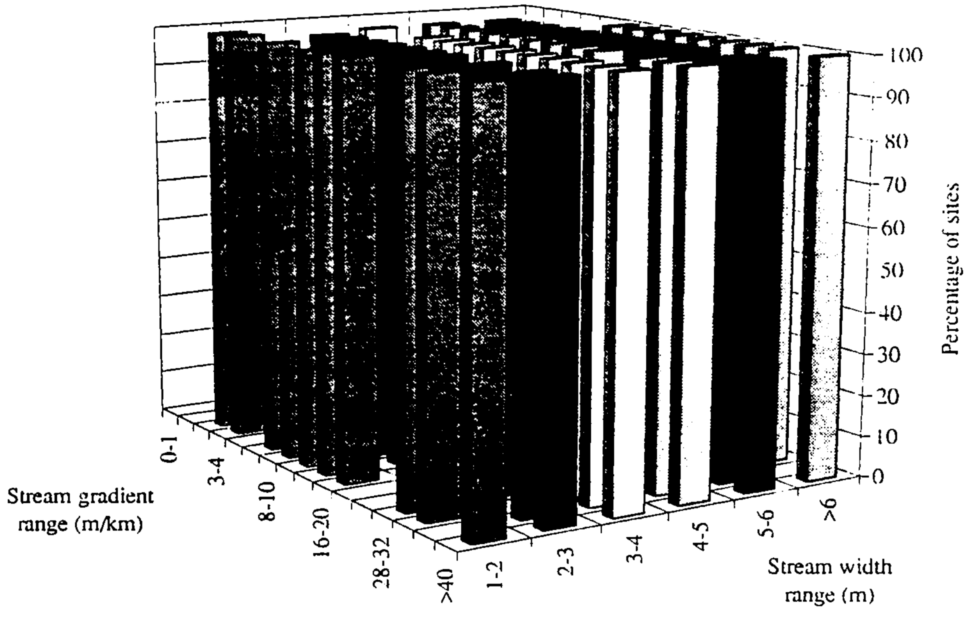
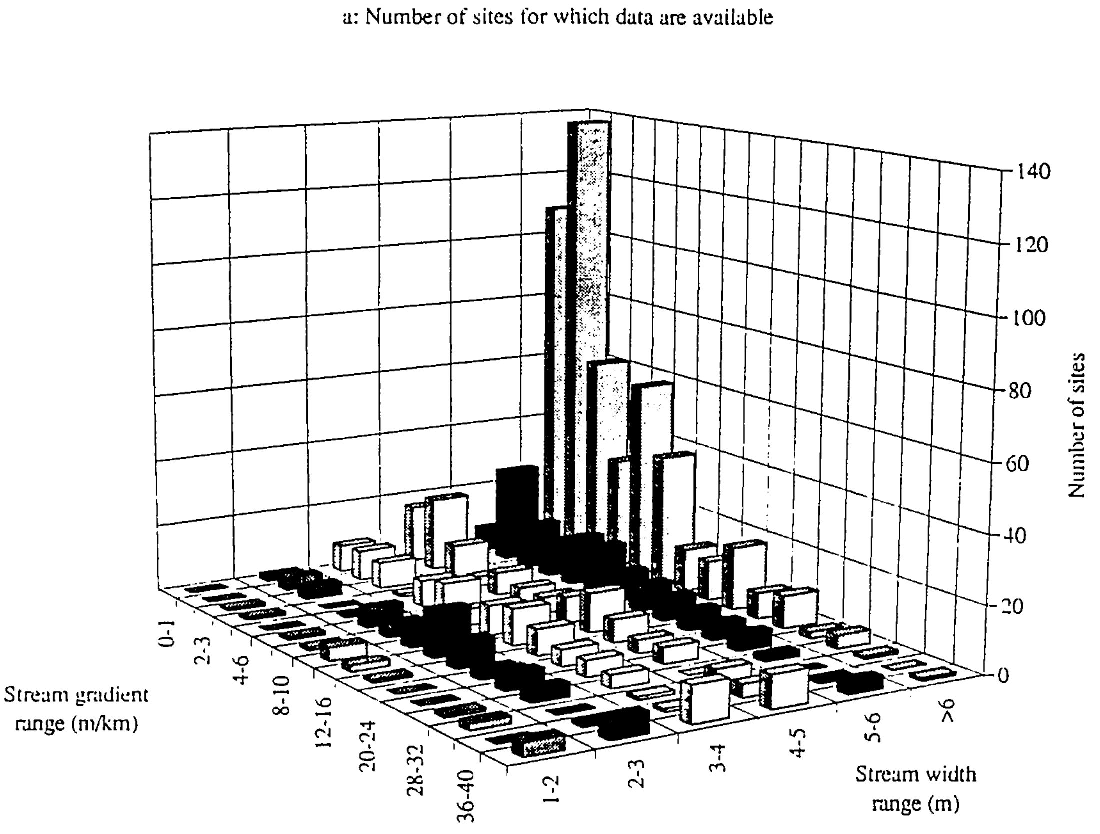


Figure 3.1 The frequency of occurrence of brown trout in England and Wales on the basis of stream width and gradient



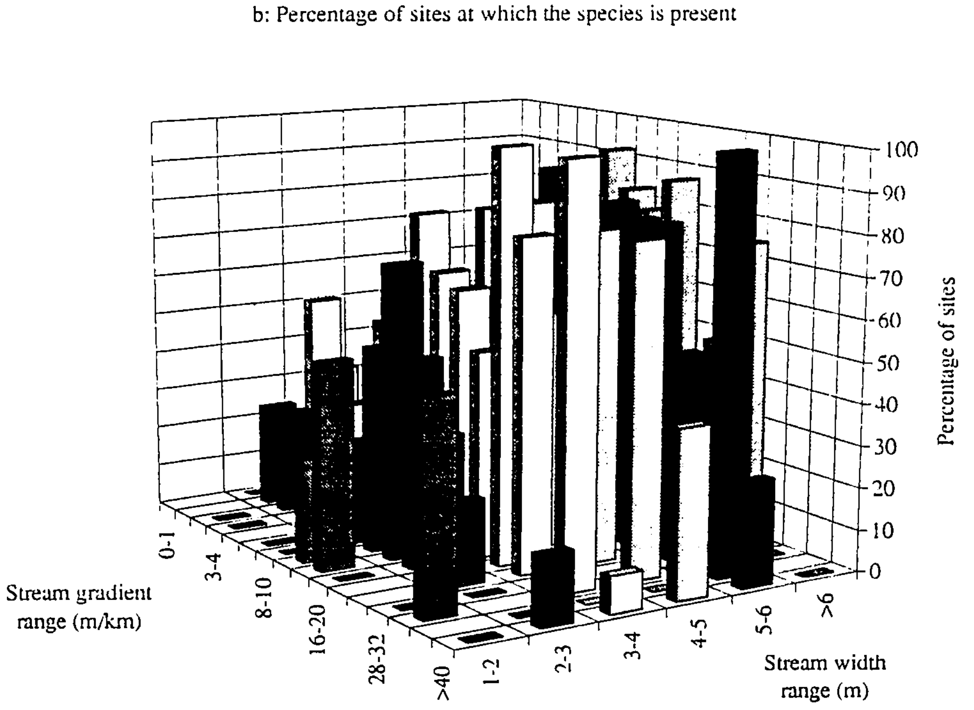
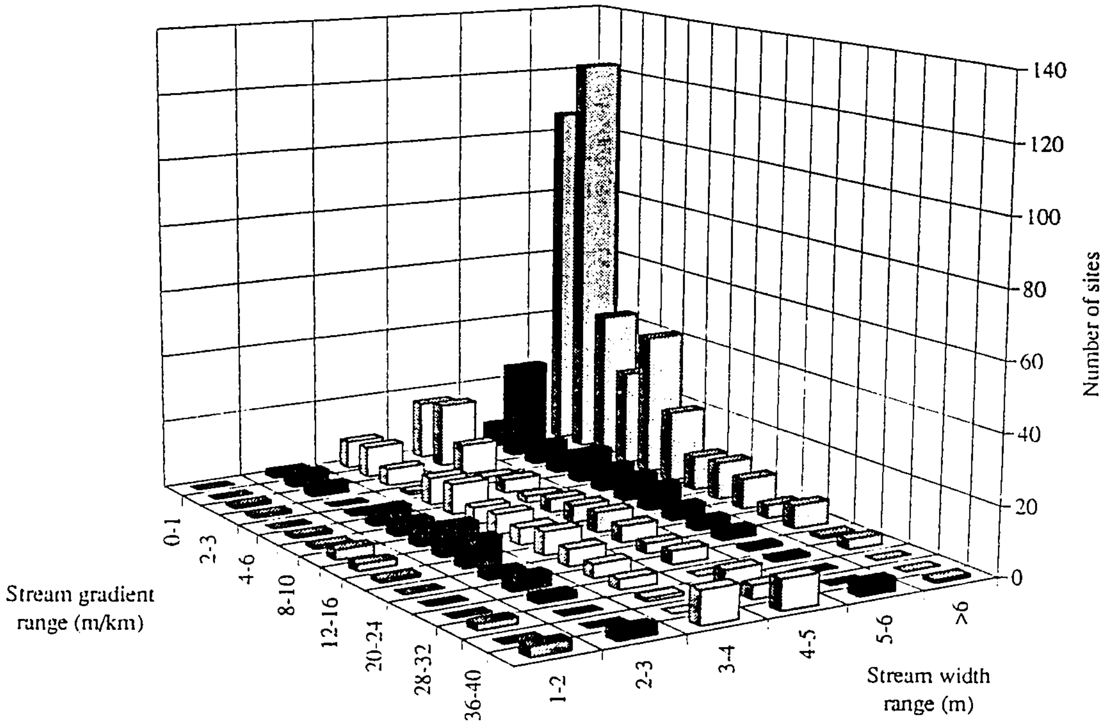


Figure 3.2 The frequency of occurrence of salmon in England and Wales on the basis of stream width and gradient

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

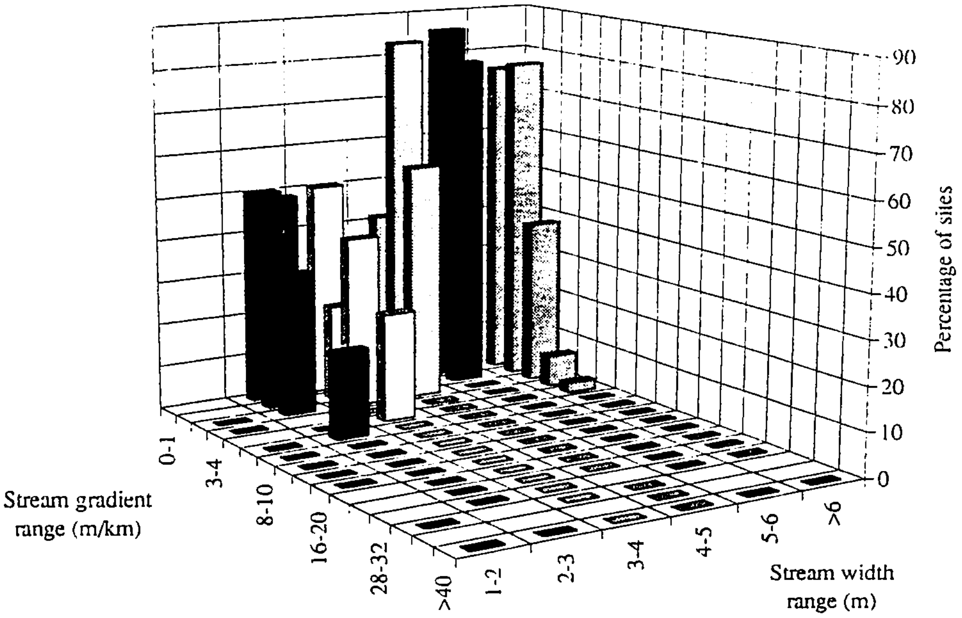
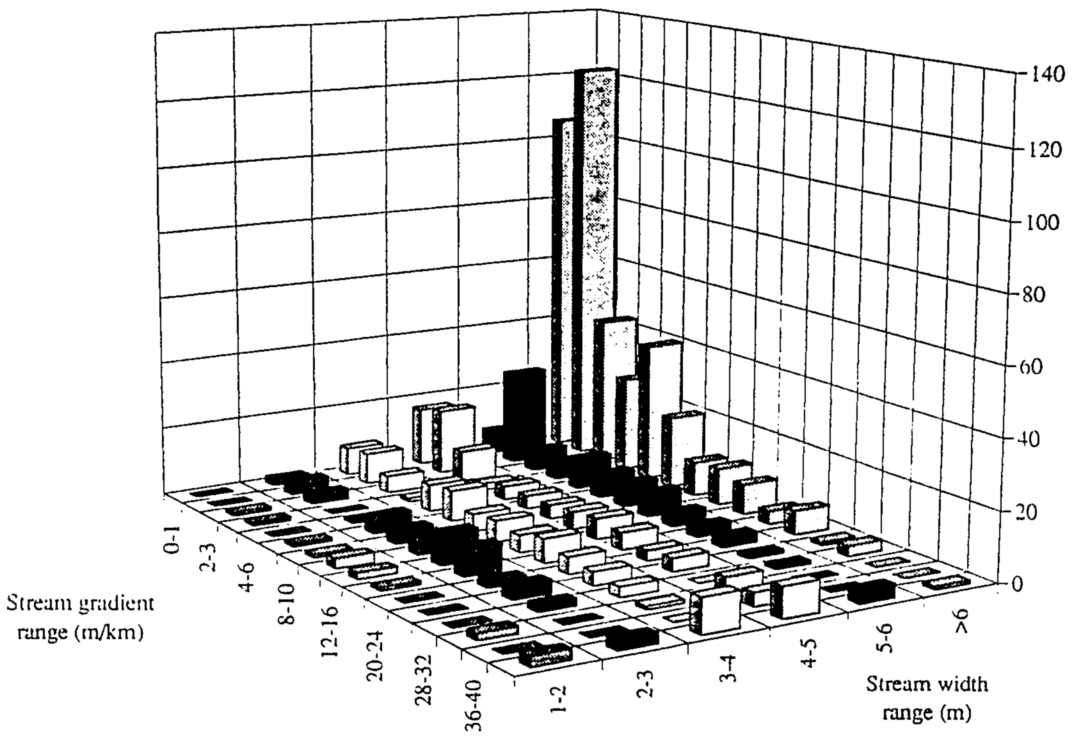


Figure 3.3 The frequency of occurrence of dace in England and Wales on the basis of stream width and gradient

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

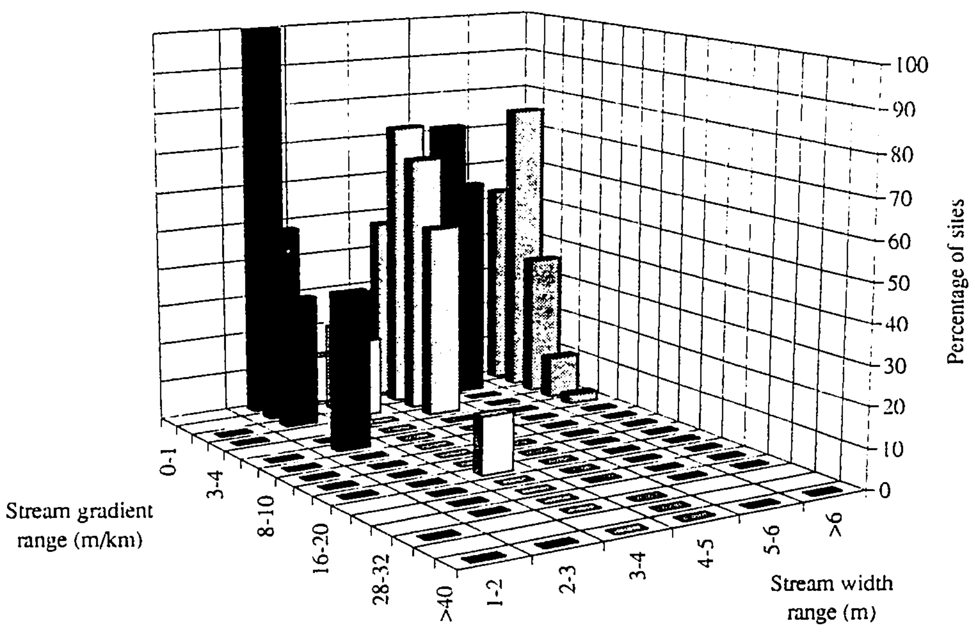
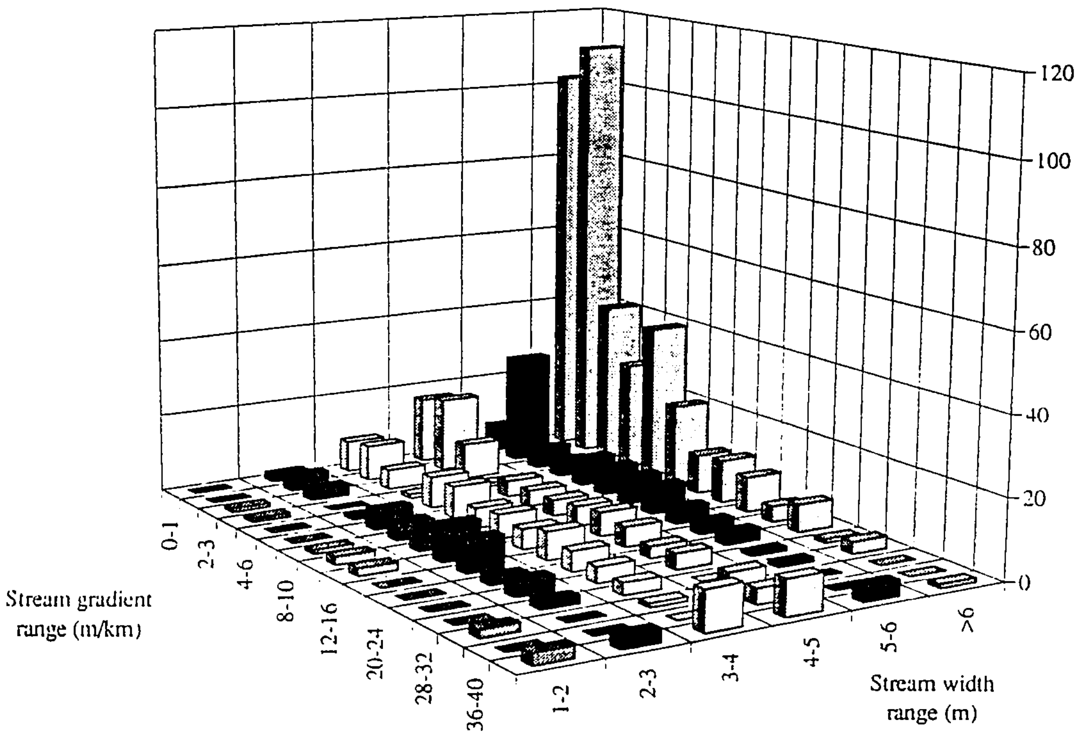


Figure 3.4 **The frequency of occurrence of chub in England and Wales on the basis of stream width and gradient**

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

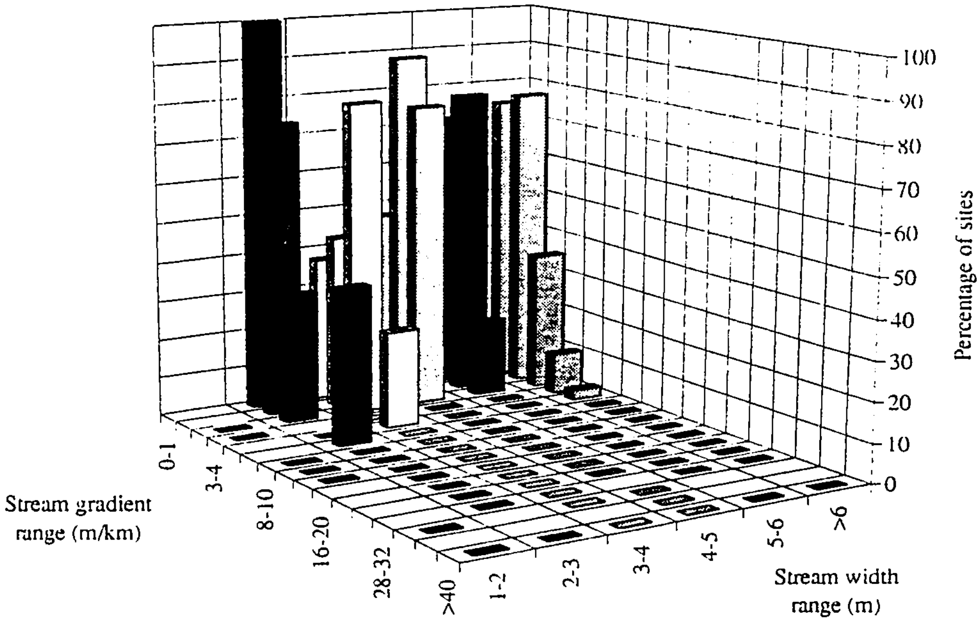
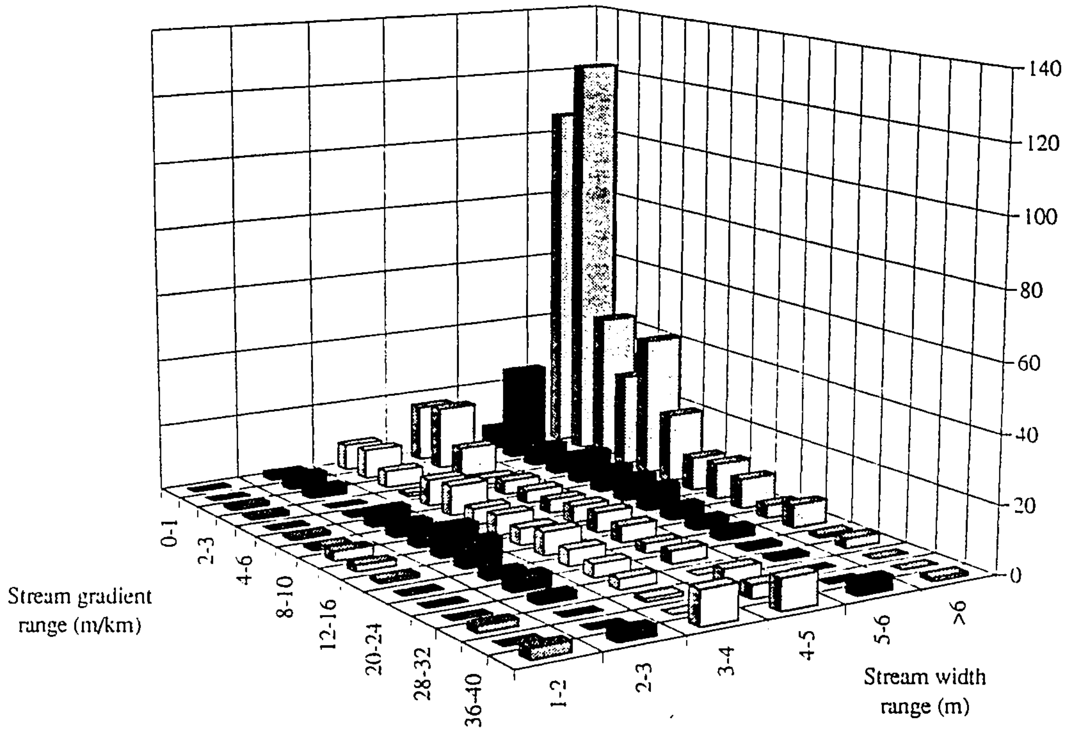


Figure 3.5 The frequency of occurrence of gudgeon in England and Wales on the basis of stream width and gradient

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

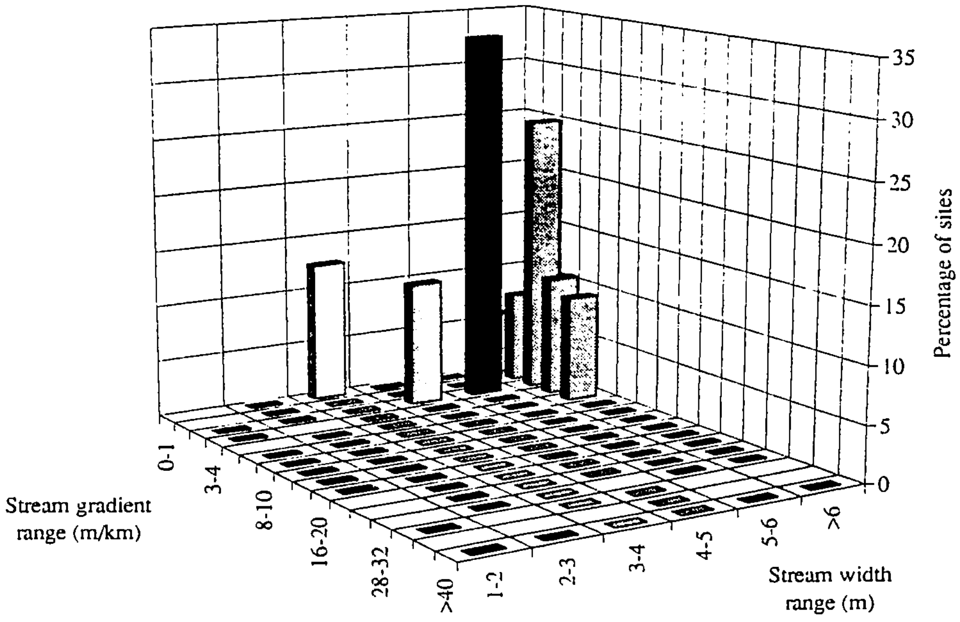
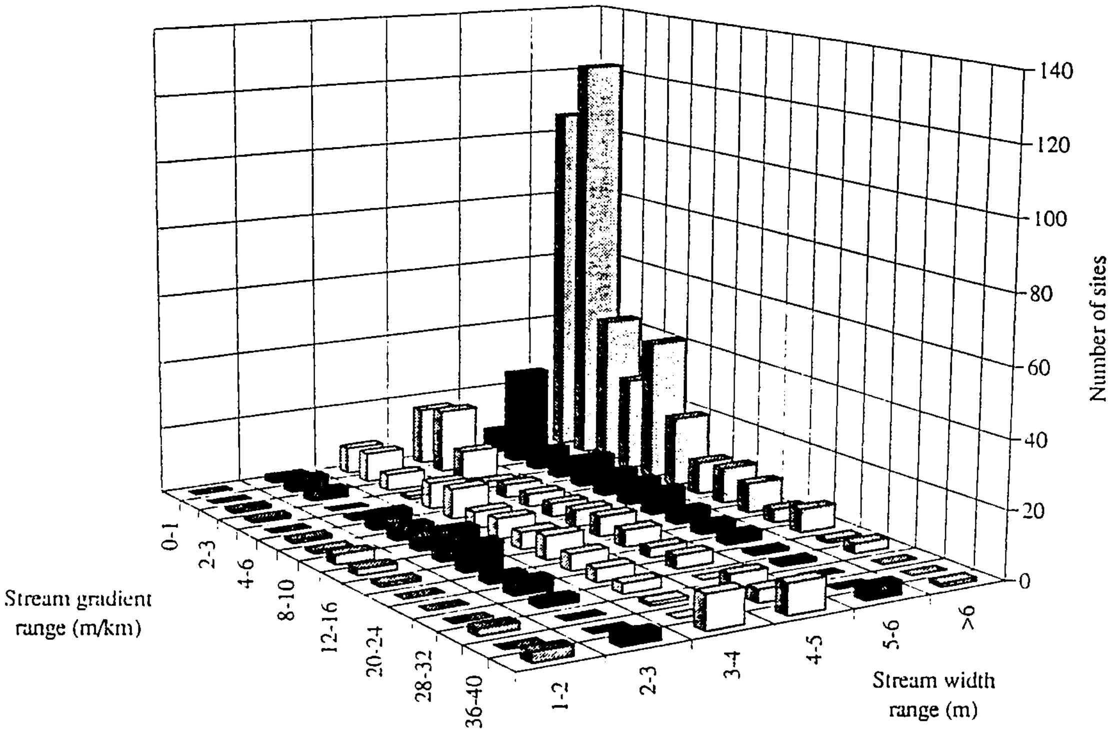


Figure 3.6 The frequency of occurrence of grayling in England and Wales on the basis of stream width and gradient

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

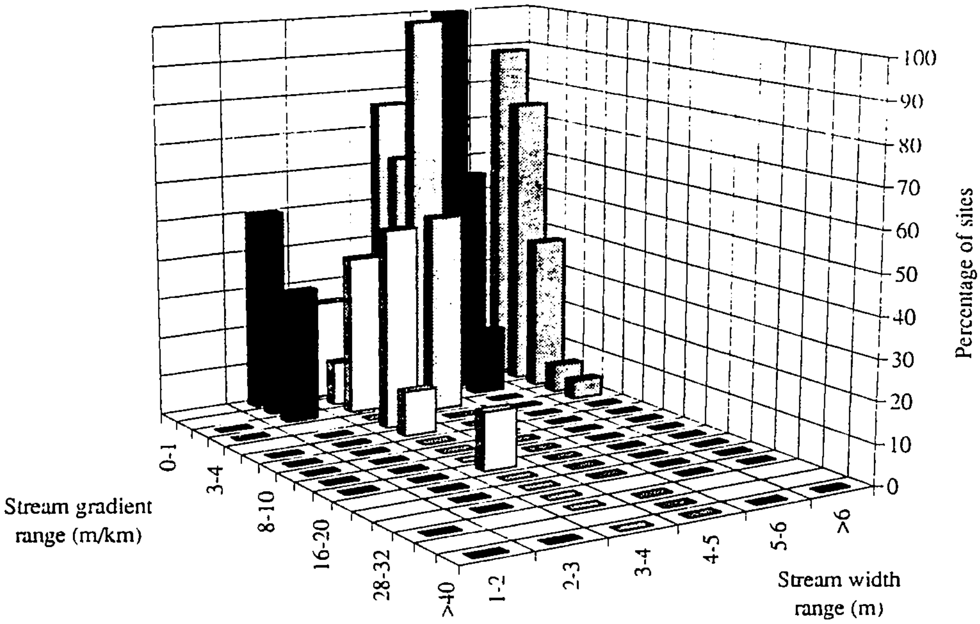
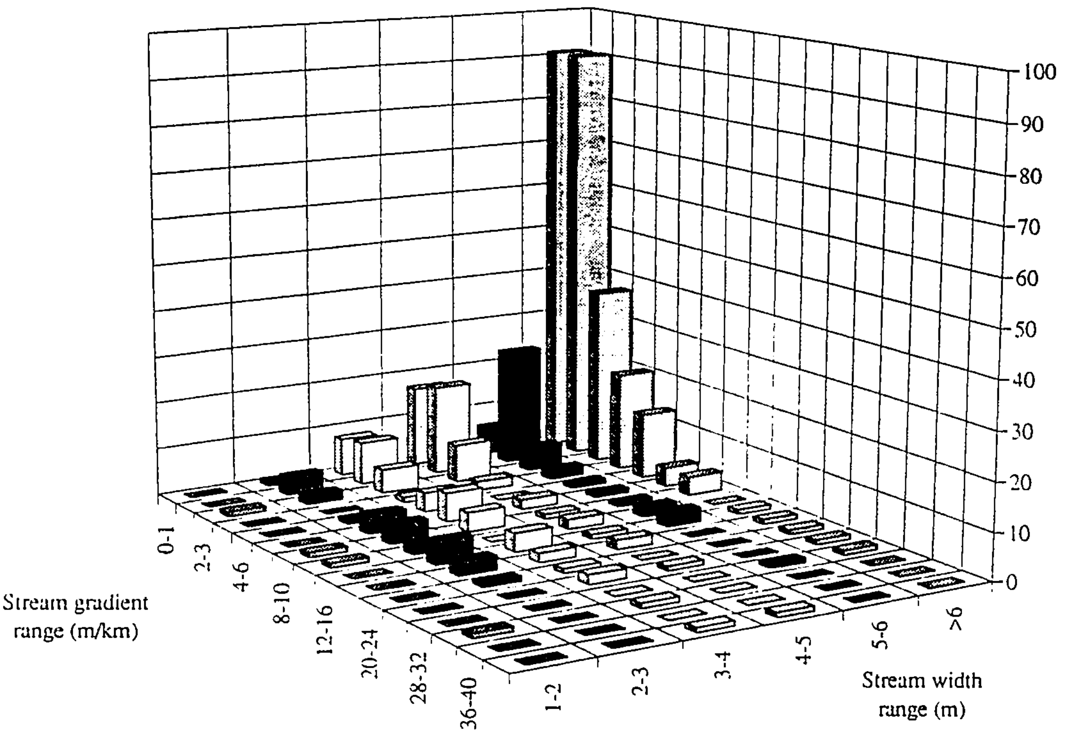


Figure 3.7 The frequency of occurrence of roach in England and Wales on the basis of stream width and gradient

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

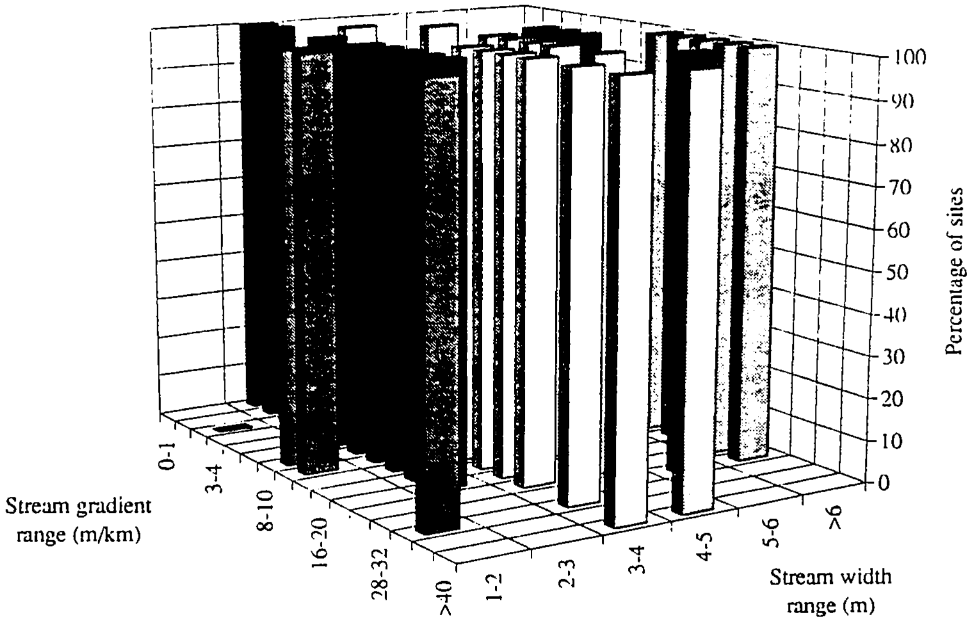
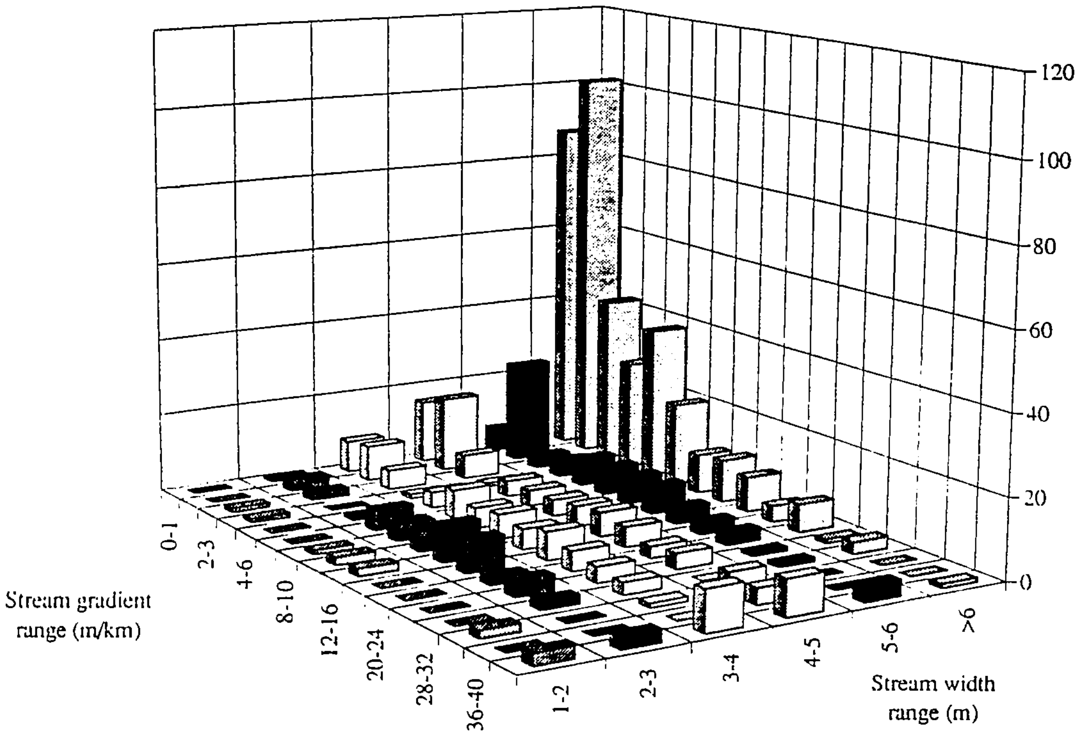


Figure 3.8 The frequency of occurrence of eels in England and Wales on the basis of stream width and gradient

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

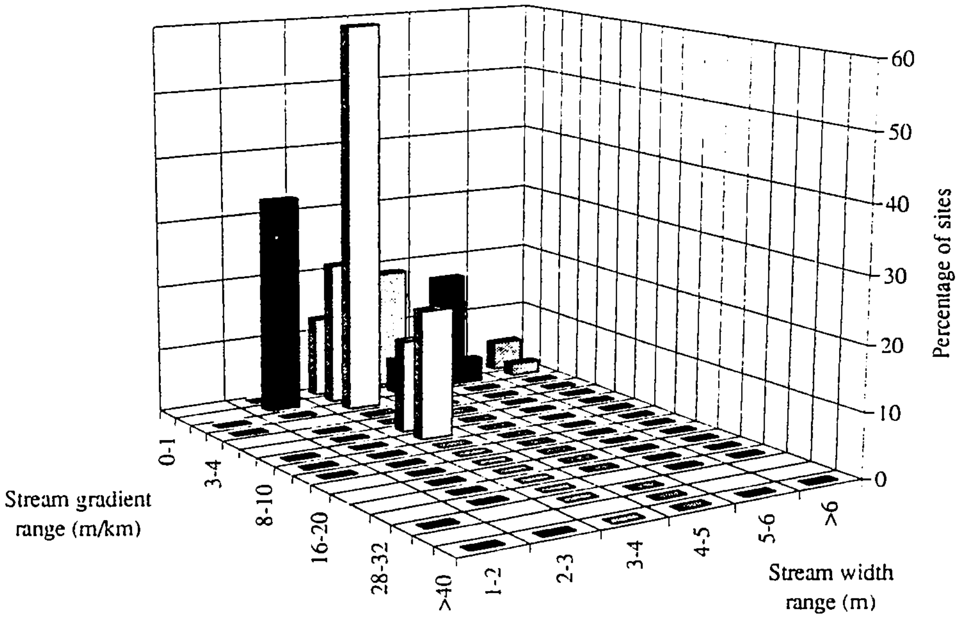
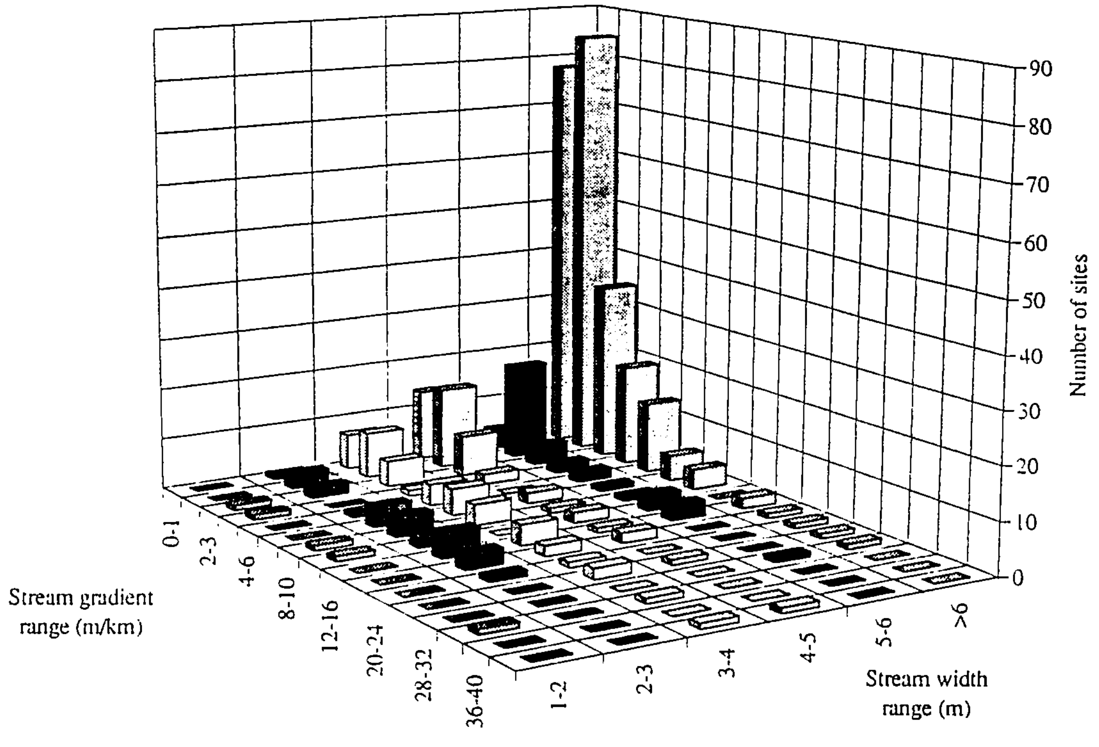


Figure 3.9 **The frequency of occurrence of three-spined stickleback in England and Wales on the basis of stream width and gradient**

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

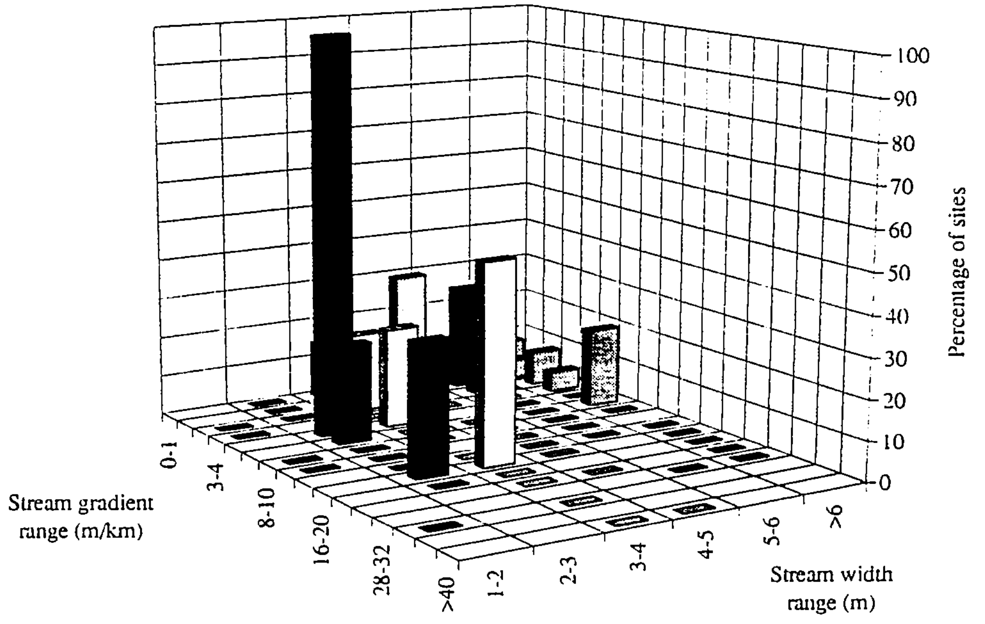
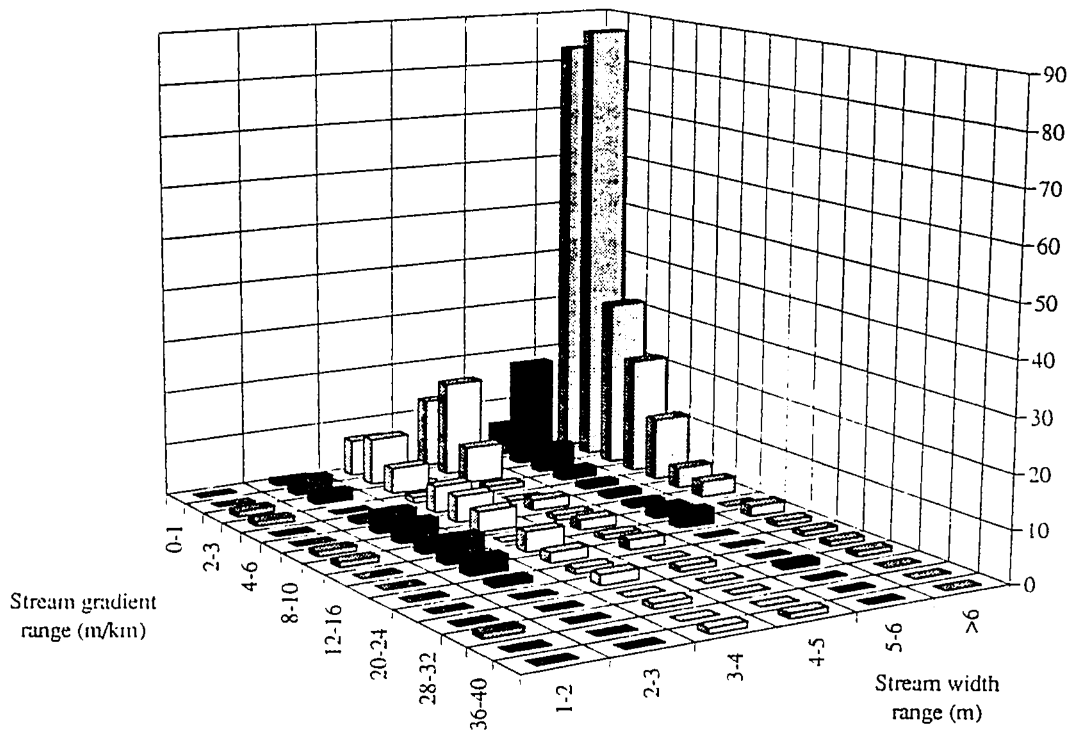


Figure 3.10 The frequency of occurrence of minnow in England and Wales on the basis of stream width and gradient

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

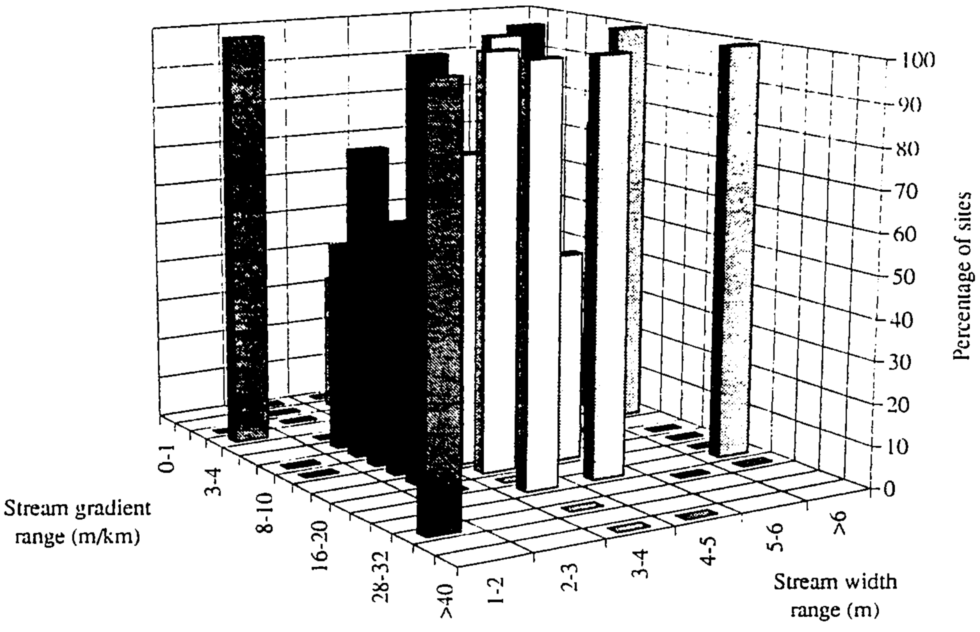
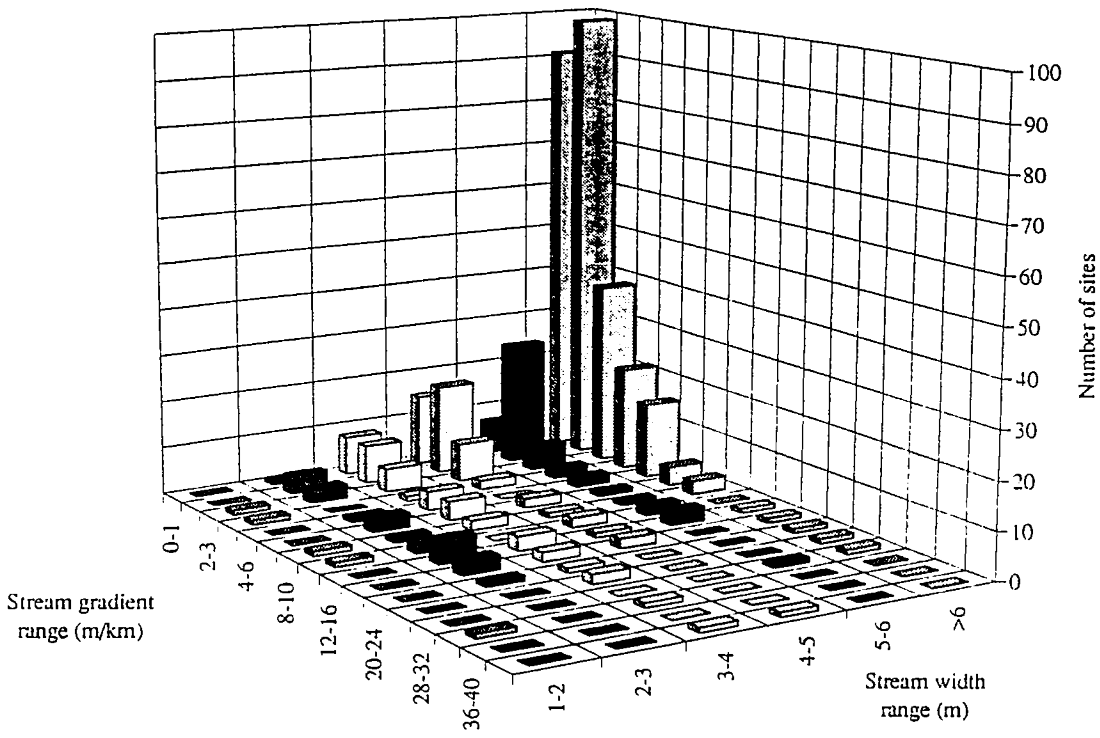


Figure 3.11 **The frequency of occurrence of bullhead in England and Wales on the basis of stream width and gradient**

a: Number of sites for which data are available



b: Percentage of sites at which the species is present

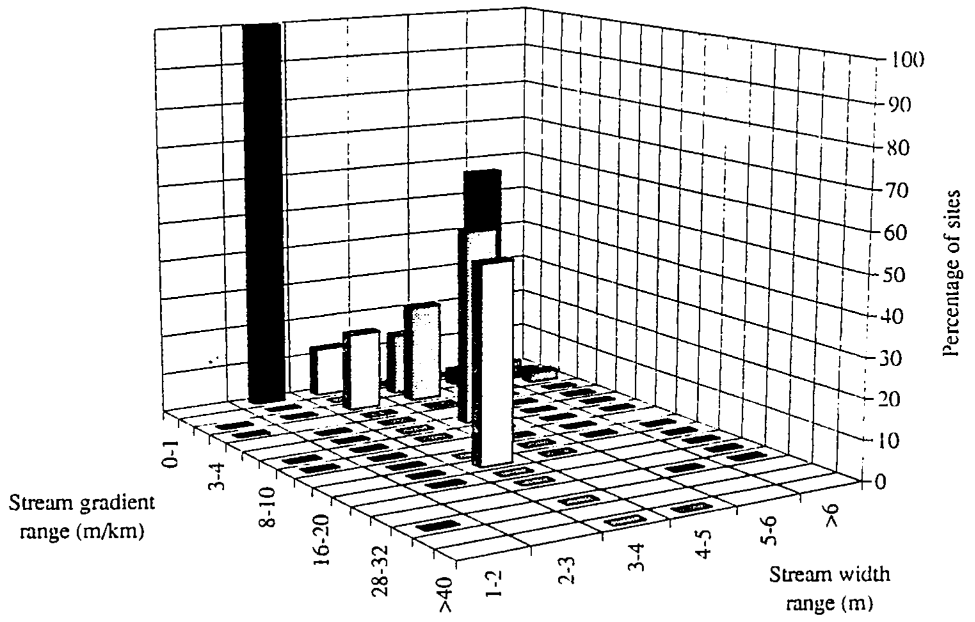


Figure 3.12 The frequency of occurrence of lamprey in England and Wales on the basis of stream width and gradient

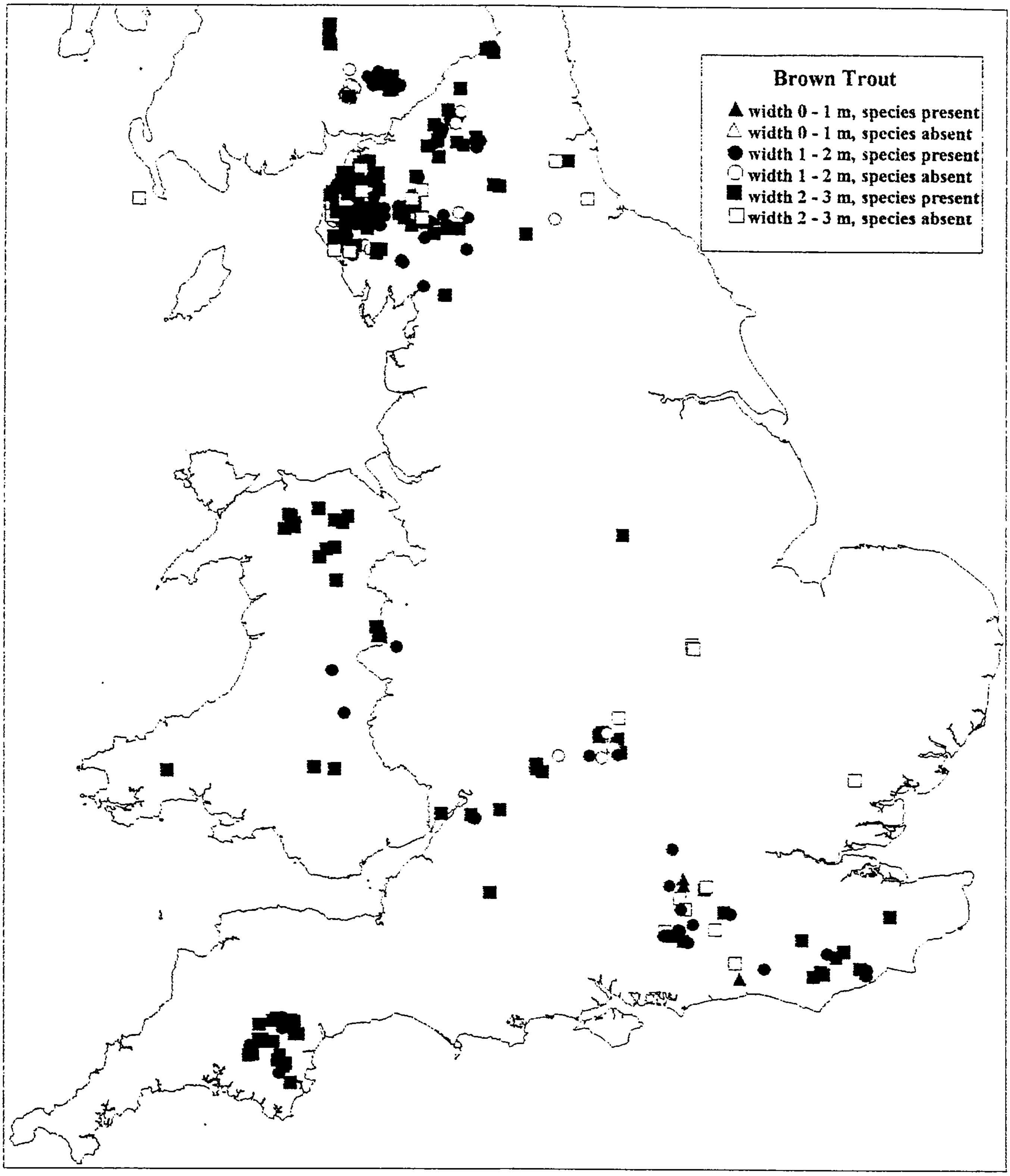


Figure 3.13 The geographical distribution of brown trout in England and Wales in streams less than 3 metres in width

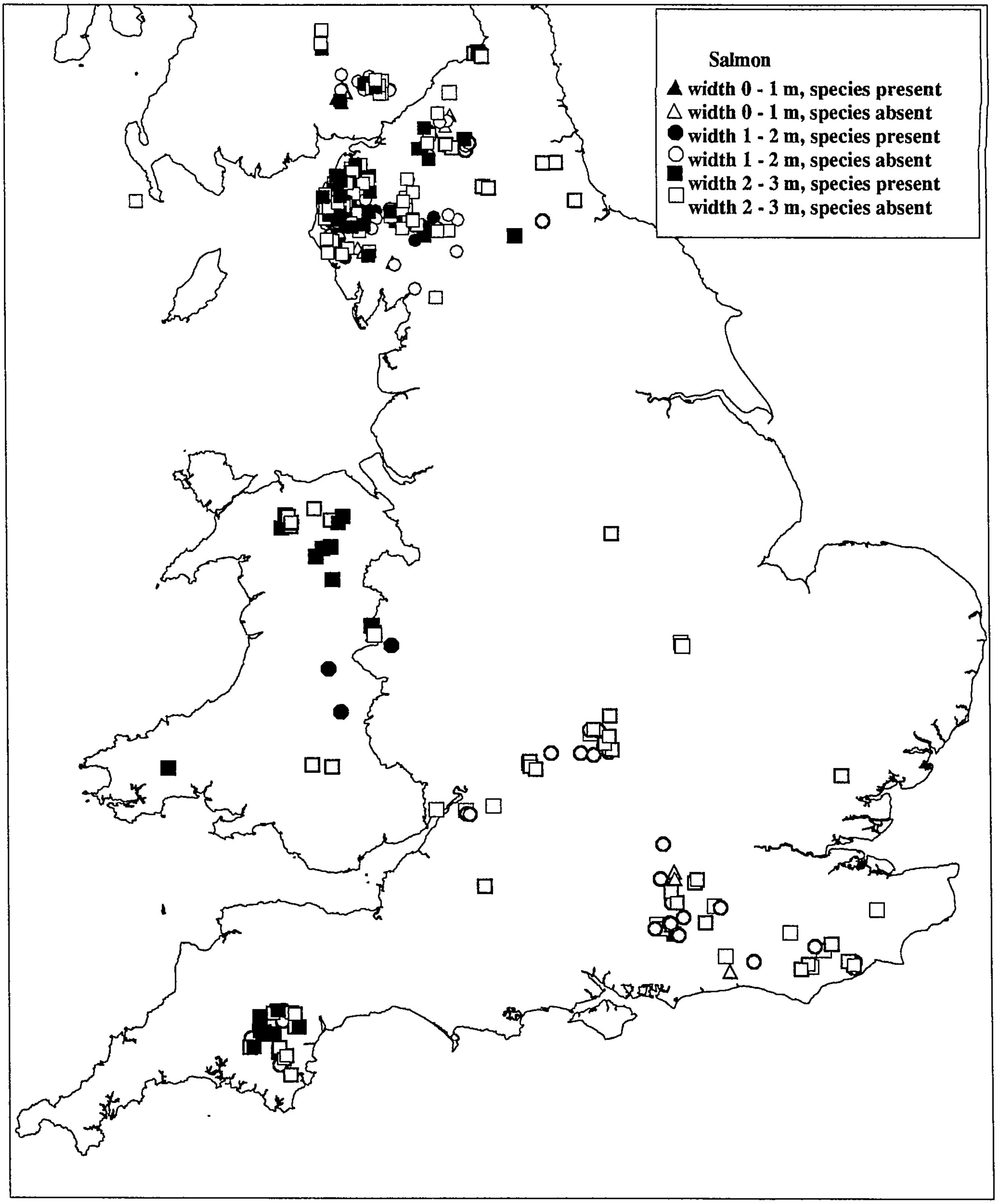


Figure 3.14 **The geographical distribution of salmon in England and Wales in streams less than 3 metres in width.**

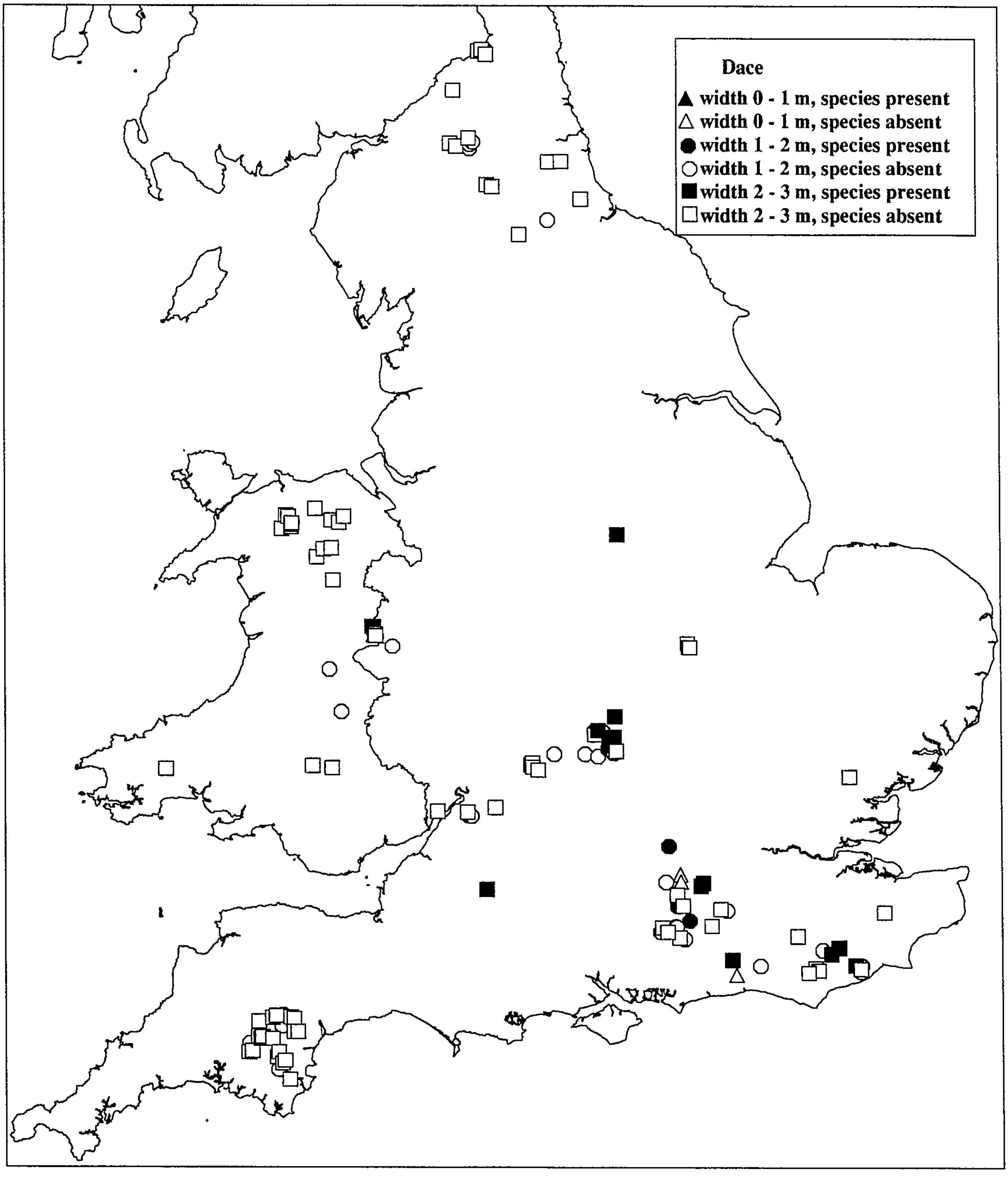


Figure 3.15 The geographical distribution of dace in England and Wales in streams less than 3 metres in width.

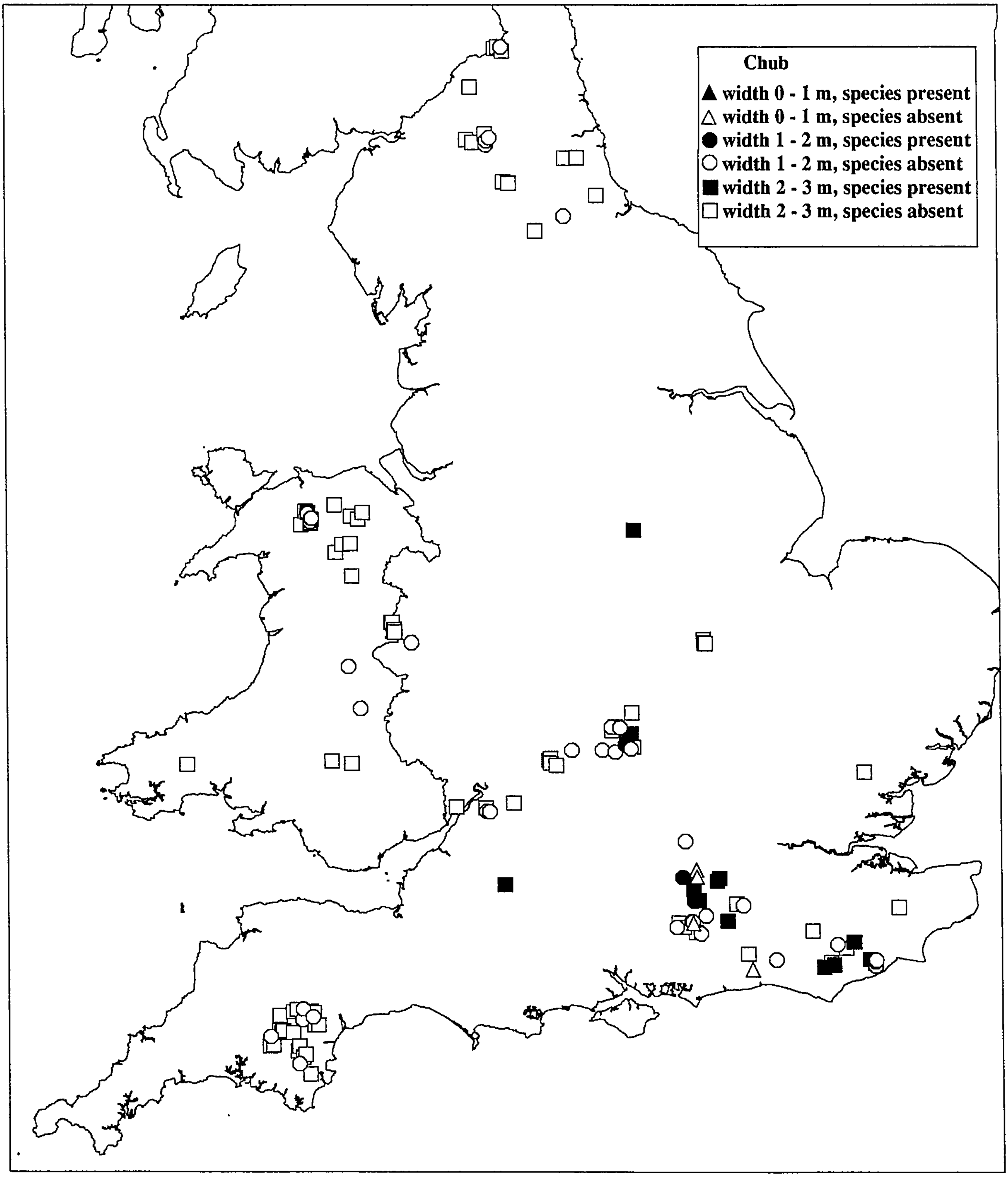


Figure 3.16 The geographical distribution of chub in England and Wales in streams less than 3 metres in width.

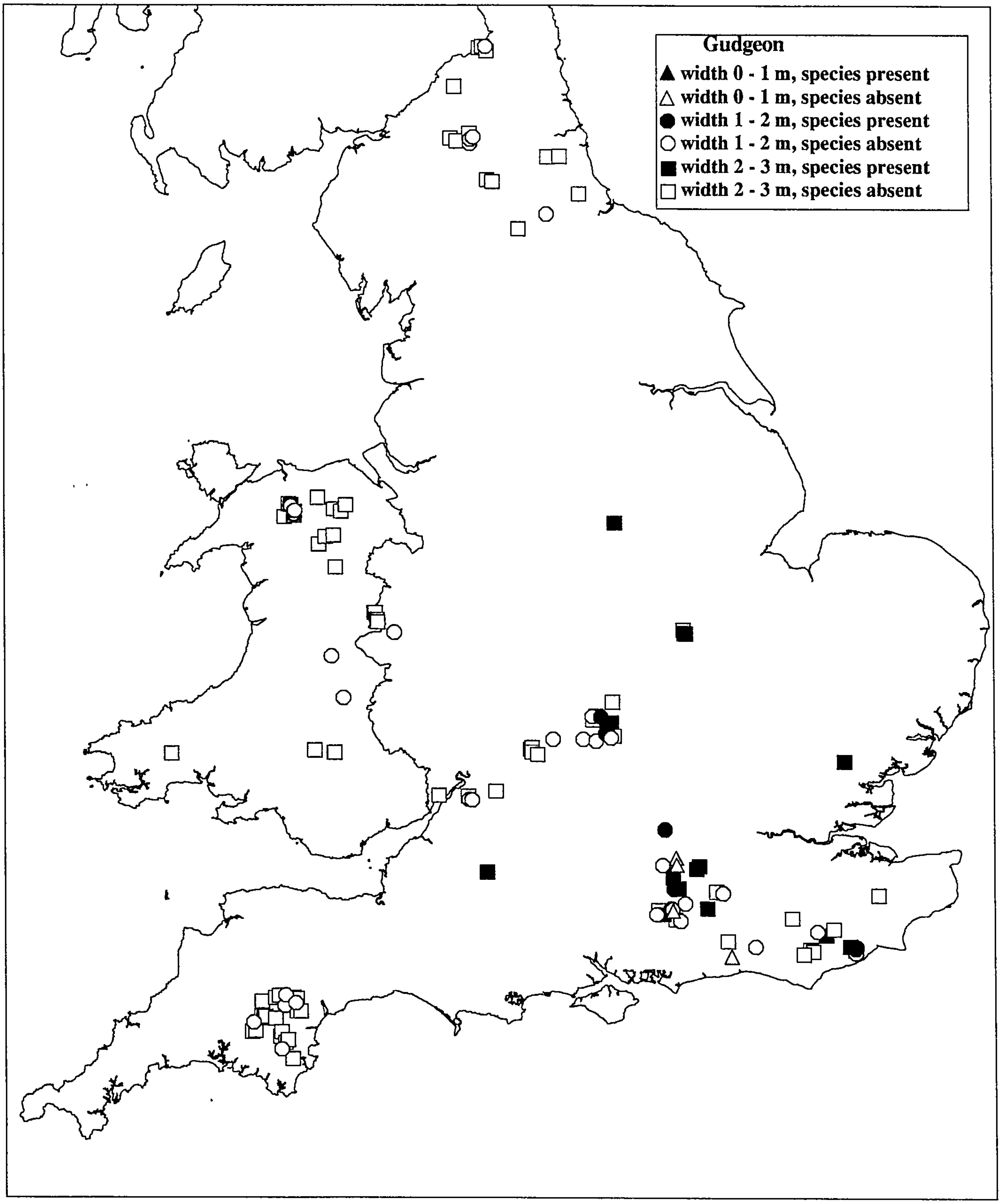


Figure 3.17 The geographical distribution of gudgeon in England and Wales in streams less than 3 metres in width.

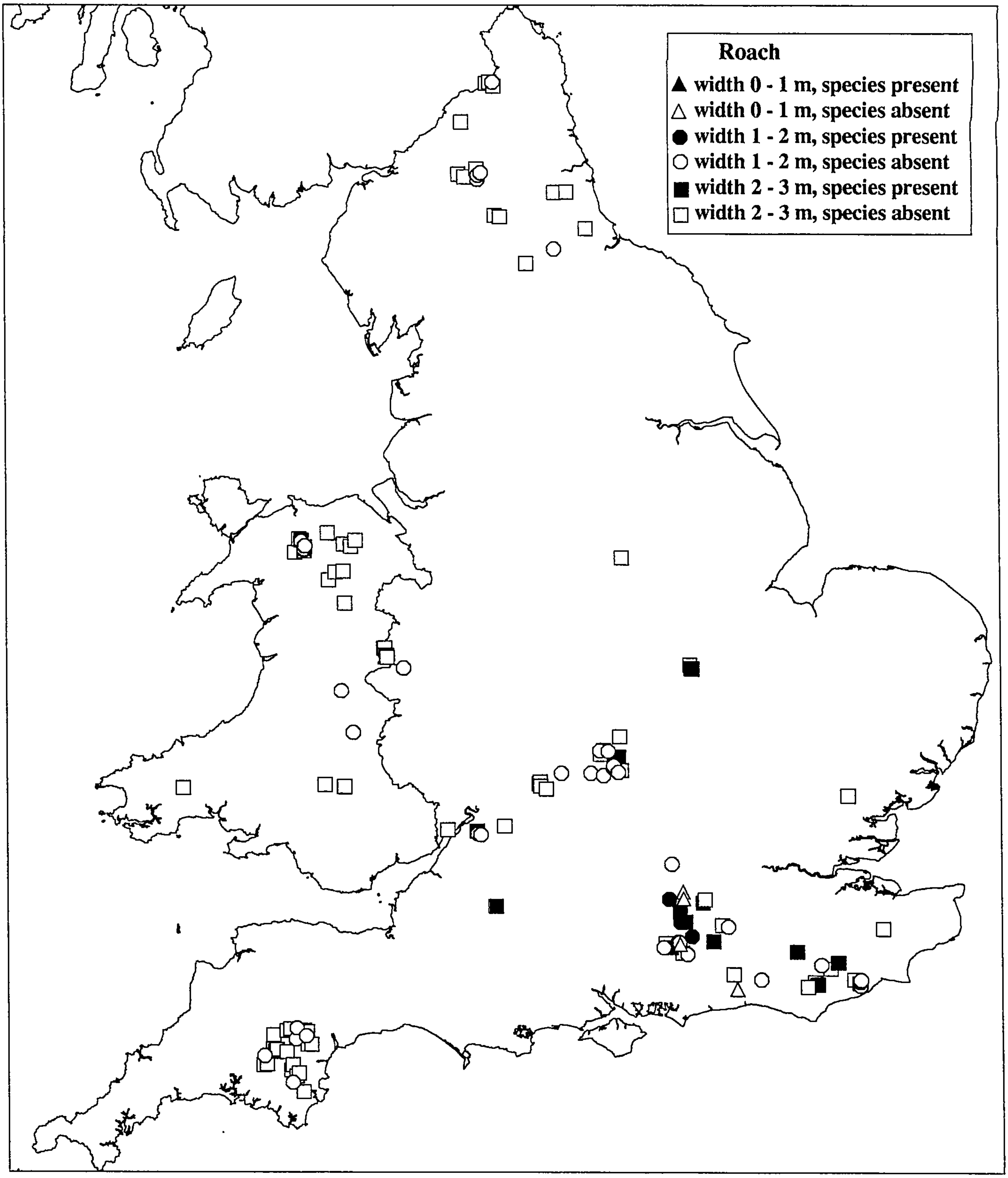


Figure 3.18 The geographical distribution of roach in England and Wales in streams less than 3 metres in width.

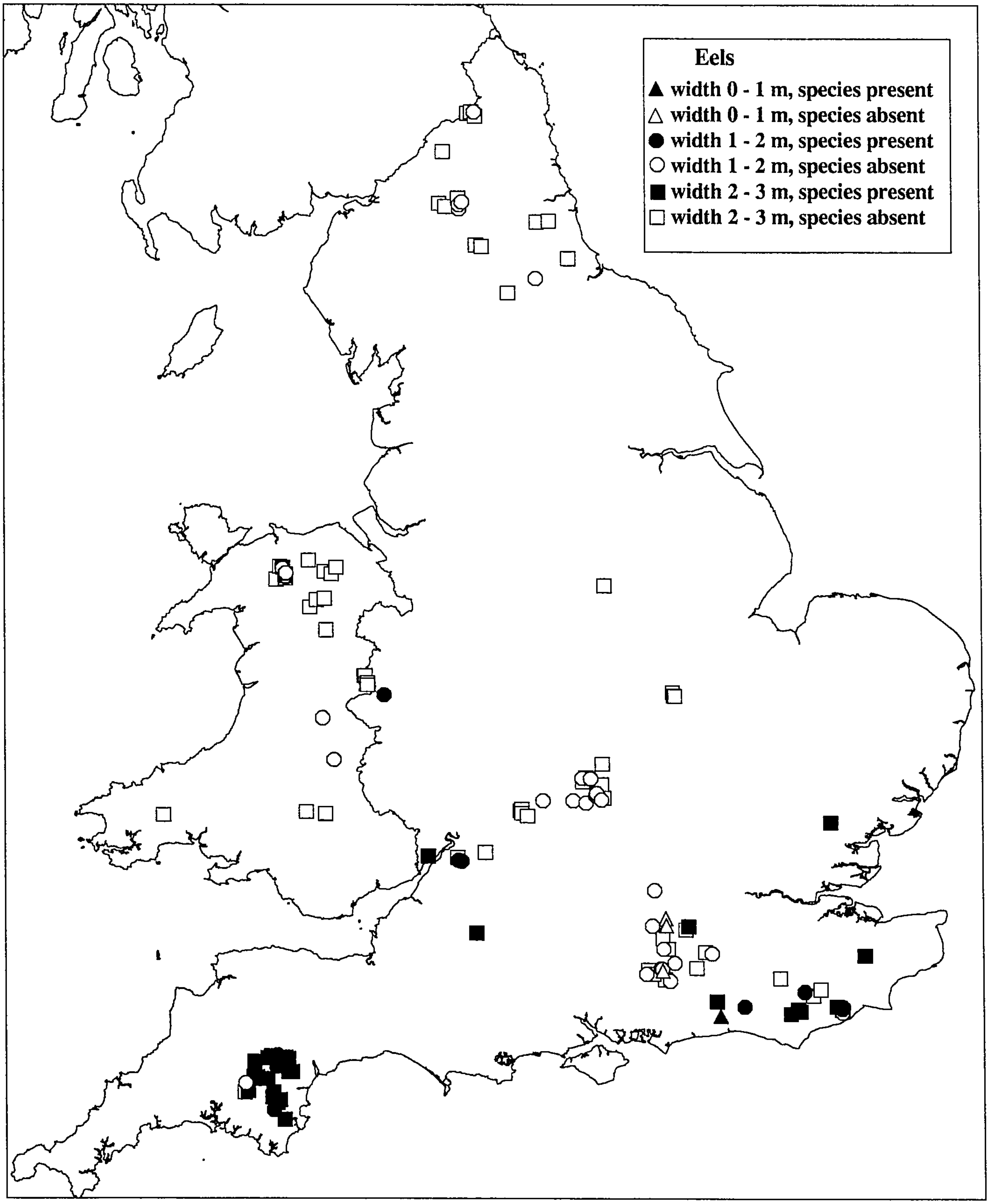


Figure 3.19 The geographical distribution of eels in England and Wales in streams less than 3 metres in width.

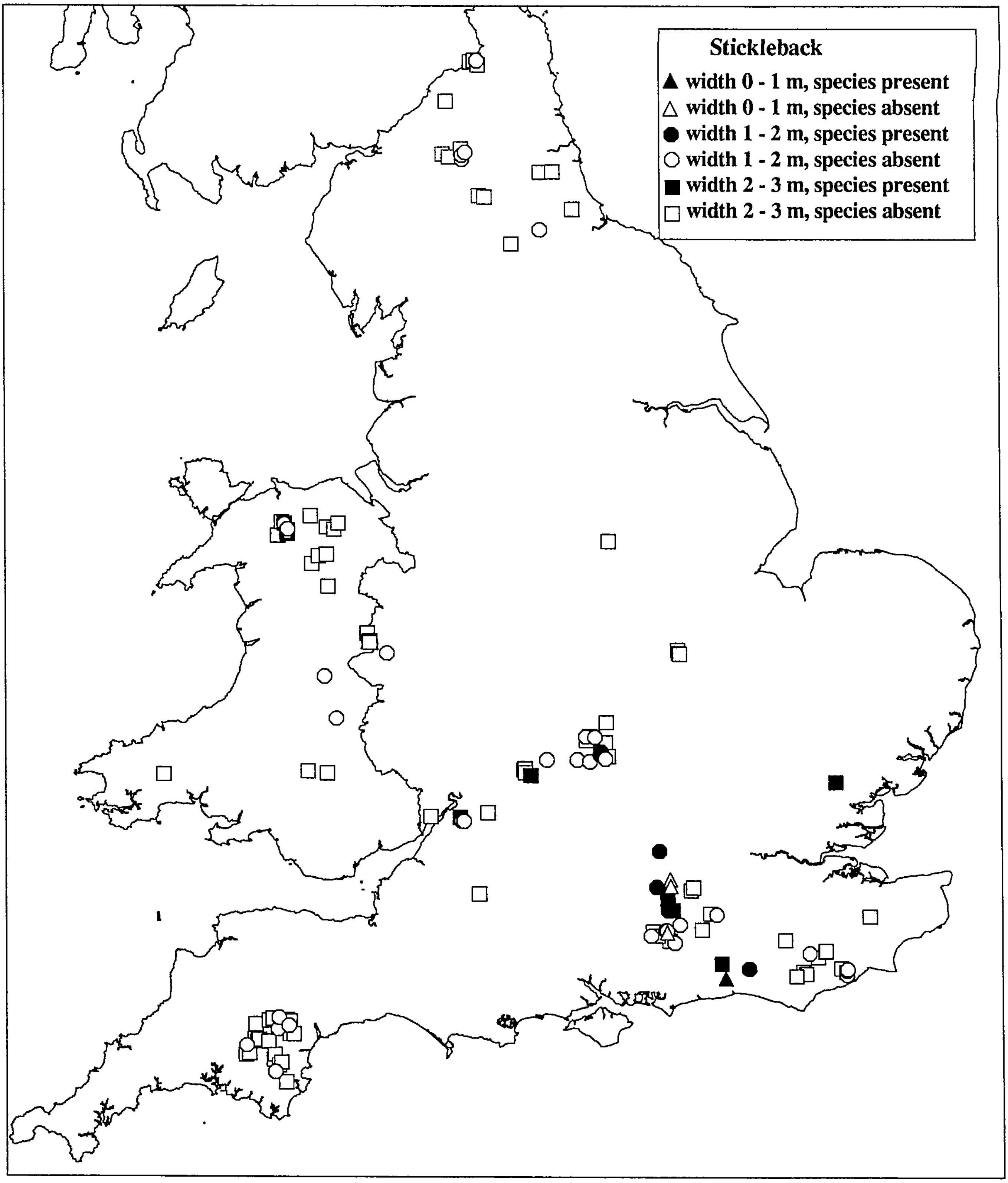


Figure 3.20 The geographical distribution of three-spined stickleback in England and Wales in streams less than 3 metres in width.

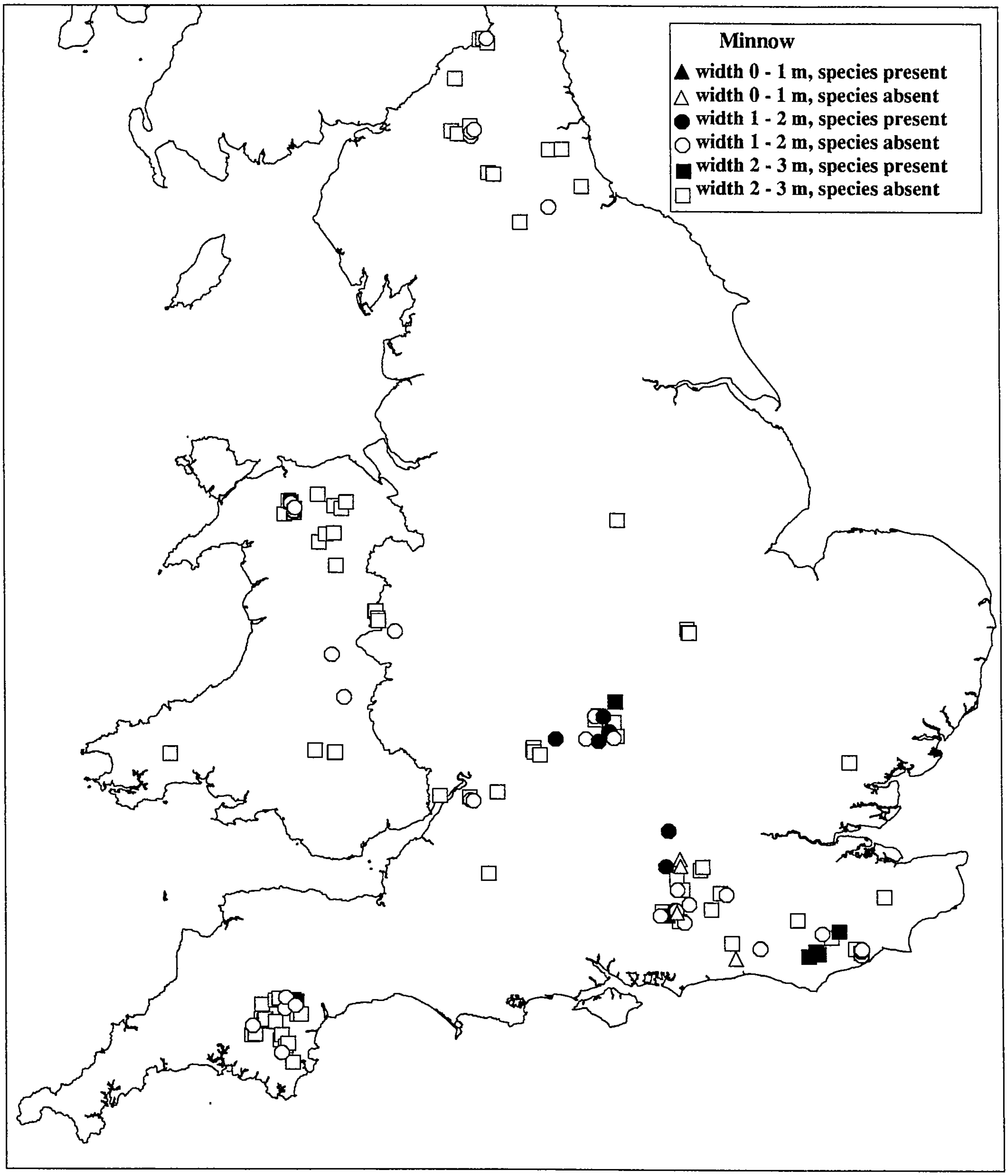


Figure 3.21 The geographical distribution of minnow in England and Wales in streams less than 3 metres in width.

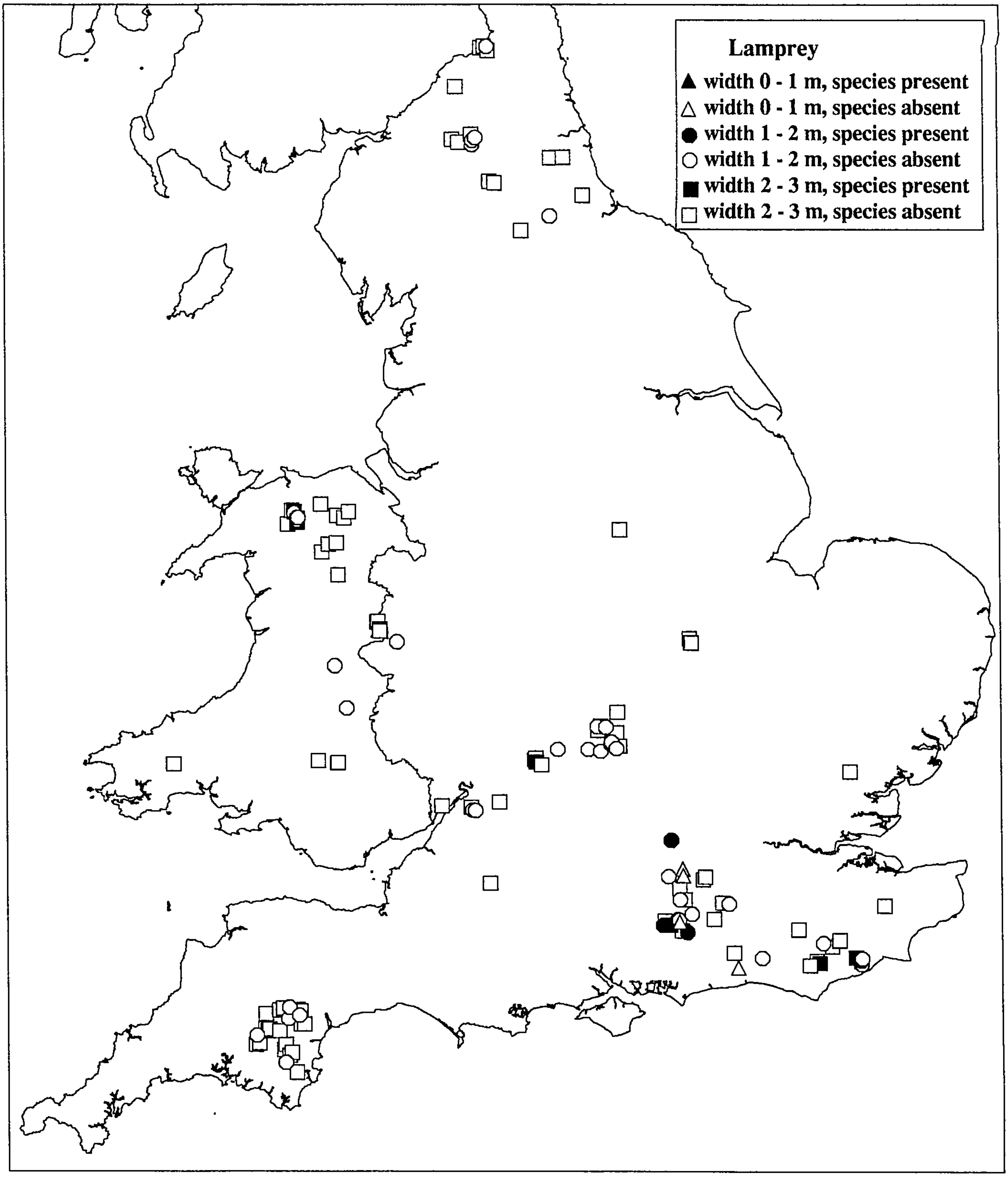


Figure 3.22 The geographical distribution of lamprey (all species) in England and Wales in streams less than 3 metres in width.

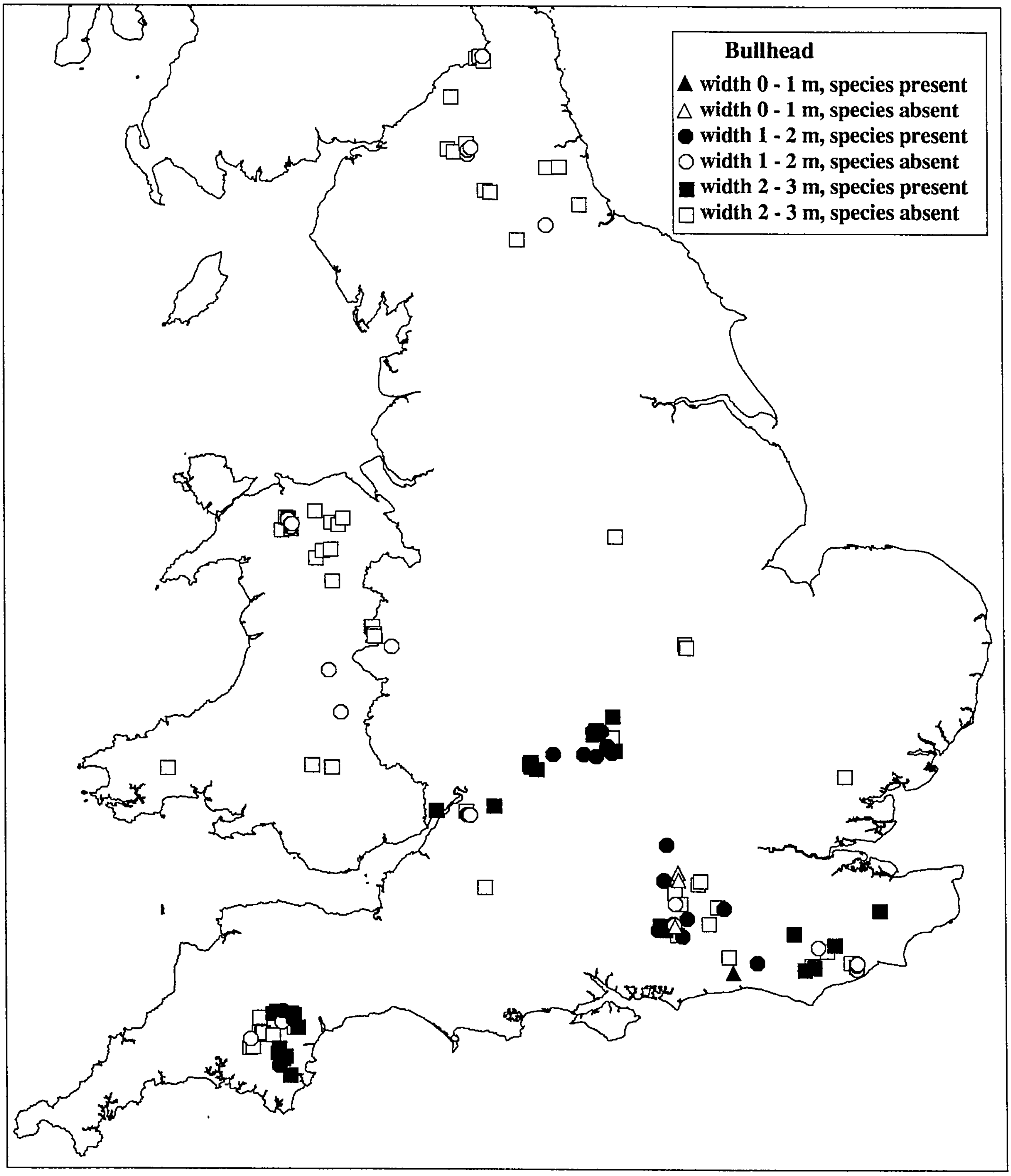


Figure 3.23 The geographical distribution of bullhead in England and Wales in streams less than 3 metres in width.

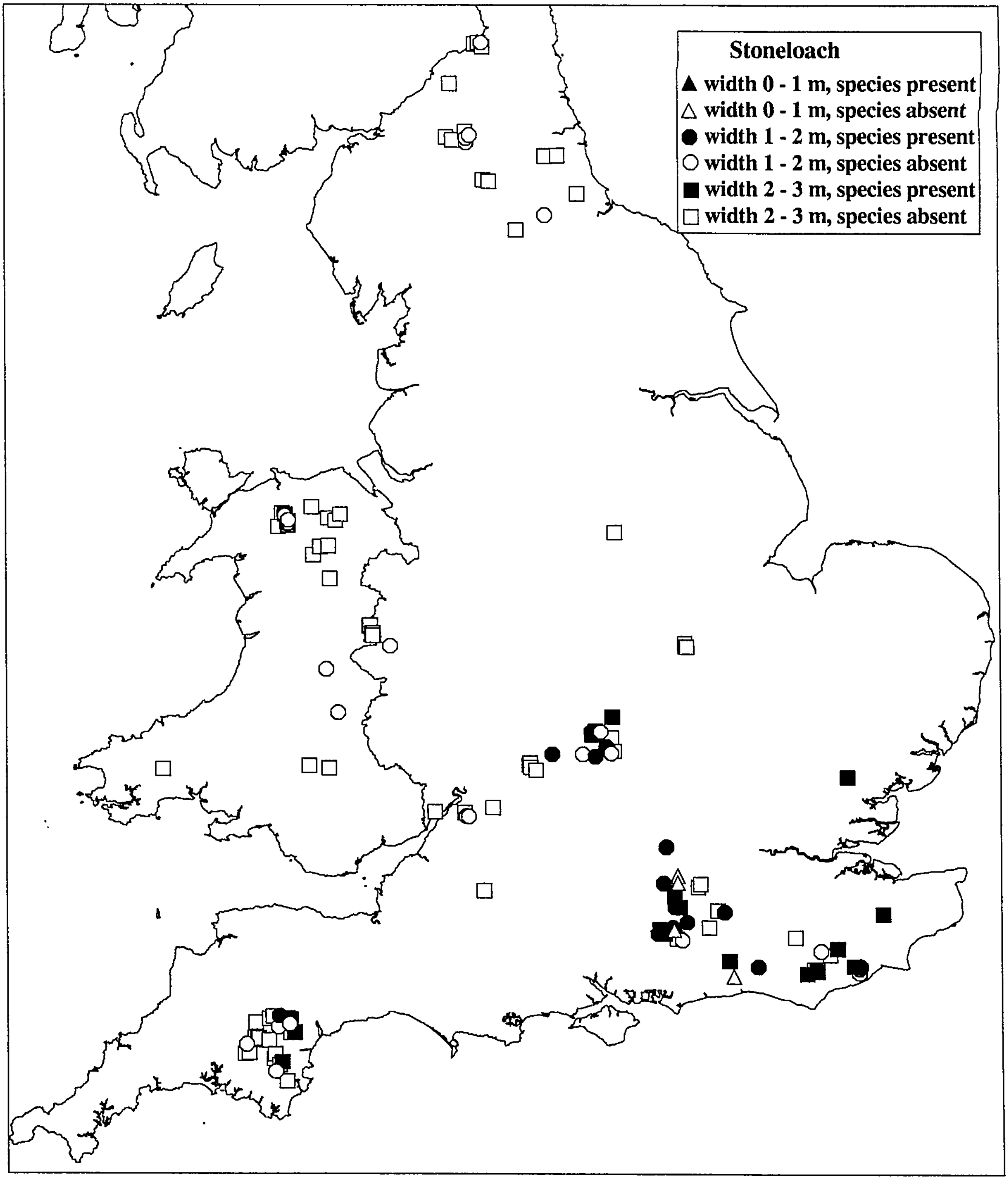


Figure 3.24 The geographical distribution of stoneloach in England and Wales in streams less than 3 metres in width.

A good deal more sites on small streams have been identified during the course of this scoping study, but available resources have not allowed the collation and presentation of these data. If available information were collated, the maps shown could be transformed into very useful illustrations of the distribution of fish species in small streams. If ancillary data could be collected on these sites (such as on stream gradient and distance from source), such data could also be subjected to cluster analysis in order to explore broad community associations and underlying environmental influences.

4. THE IMPORTANCE OF HEADWATER FISH POPULATIONS

4.1 Introduction

The importance of headwaters as a habitat for specialist macroinvertebrate species has already been identified (Furse *et al.* 1993). In order to secure adequate protection for headwater fish populations, their significance in relation to populations in the wider catchment has to be determined. This can be achieved in three ways:

1. by estimating the proportion of the total standing stock in a catchment that such streams support;
2. by quantifying the contribution that juvenile populations in headwaters make to recruitment into main river populations;
3. by assessing the provision of habitat to threatened or declining species.

Each of these issues is considered in turn in subsequent sections.

4.2 Standing stocks in headwaters

4.2.1 Existing assessments of standing stocks

Only one study, that of Cooper (1991) in the Conwy catchment, has been located in which the standing stock of fish in a catchment has been apportioned into different sizes of watercourse. Other studies have been undertaken along similar lines, but have not produced the same kind of spatial resolution. For instance, Cruddas and McCubbing (1994) surveyed salmonid stocks in the Esk catchment in Cumbria, concluding that 80% of trout production is contained within the tributaries, whilst 20% is held in the main river itself. Other examples are where dams have been planned that cut off part of the upper catchment, or where there are plans to bypass impassable falls and open up new areas to migratory salmonids (for example the Conwy fish pass, NRA Welsh Region 1992).

Cooper (1991) undertook a detailed study of salmonid populations in first order streams of the River Conwy and related his observations to salmonid production in the rest of the catchment. The upstream extent of salmonid presence in selected streams was determined by electrofishing, whilst field observations were also made of ephemeral sections and variations in wetted widths. It was found that, on average, only the last 30% of stream length (i.e. from the confluence upstream) in first order streams was inhabited by salmonids, due to the occurrence of impassable natural obstacles and the drying out of upstream reaches. This has important implications for the extrapolation of fishery data to unsurveyed parts of the river network, although it is not known how transferable these results are to other catchments. Whilst it may be reasonable to assume that a similar situation may exist in other similar upland catchments, there is certainly no justification in applying this result to lowland rivers where environmental conditions are very different. It is also important to point out that electrofishing in this study was carried out in the late summer period of low flow, and that there may be greater winter usage of first order streams for spawning, with juveniles subsequently migrating downstream. The work was also conducted over only one year, preceded by a number of dry years causing drought conditions in many tributaries. The result may therefore represent a worst-case estimate of utilisation.

Following this initial analysis, Cooper compared the densities of trout fry and parr in the selected first order streams with densities in the main river of each sub-catchment. Parr densities were higher in first order streams, whilst fry densities were also higher where they occurred; however, fry were completely absent at most first order sites (again, this may not be typical due to adverse conditions). Comparing densities with fishery results from different stream orders across the Conwy catchment, trout parr densities in first order streams were found to be second only to second order streams (Table 4.1). The fry result is difficult to interpret given the possibility of confounding factors. It is also interesting to note the lack of salmon in first order streams, and their preference for third and fourth order streams as opposed to the trout preference for first, second and third order. Based on these densities, calculations of inhabited stream lengths and observations of wetted widths, it was estimated that first order streams contributed less than 10% of the fish production (based on numbers of fish) within the sub-catchments studied, and less than 3% of the total production within the Conwy catchment as a whole.

Table 4.1 Mean densities of salmonids in different stream orders in the Conwy catchment (after Cooper 1991)

Stream order	Trout fry		Trout parr		Salmon fry		Salmon parr	
	No 100 m^{-2}	SD	No 100m^{-2}	SD	No 100 m^{-2}	SD	No 100 m^{-2}	SD
First	2.18	2.39	12.7	6.00	0.00	0.00	0.00	0.00
Second	40.2	51.6	19.0	19.2	7.09	6.29	2.63	3.99
Third	38.3	44.1	5.08	6.29	42.5	33.1	6.86	6.59
Fourth	5.01	4.09	1.69	2.32	32.7	46.0	4.75	5.54
Fifth	0.75	0.20	0.07	0.11	7.91	1.90	0.69	0.76

These are perhaps surprisingly small numbers, and should be tempered by the possibility that these results may be atypical. It should also be noted that, depending upon the definition of headwater adopted, all second order and even a proportion of third order streams may be brought into the headwater category for this catchment, thereby greatly changing the complexion of the analysis. A further complication is the tendency for fishing efficiency to decline from small to large watercourses, meaning that population estimates in larger rivers generally have lower reliability.

Using the stream attributes available, the best model to describe trout fry abundance used stream order, altitude and pollution status, accounting for 58.2% of the variance. Table 4.4 gives the predicted density in each combination of stream order and altitude for which fishery data exist, **assuming high water quality.** Bracketed values indicate where tentative extrapolations have been made into areas for which no fishery data exist, assuming that densities are no worse than the nearest combination of stream order and altitude for which there is a predicted density. These results suggest that fry densities decline dramatically from first to third order streams, presumably being a reflection of the more favourable fry conditions in very small streams. The best model for describing parr densities used only stream order and pollution status, accounting for only 20.4% of the variance. Table 4.5 shows predicted densities for stream order/altitude combinations assuming clean water conditions, indicating the lack of significance of altitude as a descriptor. The model suggests that parr densities peak in second order streams, which would be consistent with first order streams being too restrictive and the larger third order streams being occupied by fewer but older individuals. However, the lack of success of the best model in explaining variability in parr densities should be borne in mind, suggesting that local habitat factors are playing a highly important role.

Table 4.4 Predicted fry (0+) densities (No. 100 m^{-2}) in the Western Cleddau catchment by stream order and altitude

Altitude class	Stream order			
(metres)	1	2	3	4
0-50	6.2	3.0	1.4	(1.4)
50-100	30.1	14.4	6.9	(6.9)
100-150	16.7	8.0	3.8	
150-200	(16.7)			
200-250	(16.7)	(8.0)		

Total numbers of fish (that would be present under conditions free of organic pollution) are estimated by multiplying the predicted fry and parr densities in each reach (summarised in Tables 4.4 and 4.5) with the wetted area of each reach (summarised in Table 4.3) and summing the numbers in individual reaches. Tables 4.6 and 4.7 apportion (in percentage terms) the estimated total number of trout fry and parr that would be present in the river network according to stream order and altitude. These results suggest that nearly three quarters of fry would reside in first order streams, with a further 16.5% of parr also residing in them. Second order streams seem to be the most important for parr, with nearly 40% of the total number residing in them in clean water conditions. It would be interesting to see how this apportionment of parr would change if the calculations were performed in terms of biomass, or numbers in separate year-classes (such data are not available).

Table 4.5 Predicted parr (>0+) densities (No. 100 m^{-2}) in the Western Cleddau catchment by stream order and altitude.

Altitude class	Stream order			
(metres)	1	2	3	4
0-50	1.8	6.9	3.8	(3.8)
50-100	1.8	6.9	3.8	(3.8)
100-150	1.8	6.9	3.8	
150-200	(1.8)			
200-250	(1.8)	(6.9)		

Table 4.6 The predicted percentage distribution of fry numbers (assuming no organic pollution) in the Western Cleddau catchment by stream order and altitude

Altitude class	Stream order				
(metres)	1	2	3	4	**Total**
0-50	1.4	3.4	1.0	3.3	**9.1**
50-100	60.5	11.2	5.1	1.4	**78.3**
100-150	7.6	2.3	0.3	-	**10.2**
150-200	0.3	-	-	-	**0.3**
200-250	1.7	0.5	-	-	**2.1**
Total	**71.5**	**17.4**	**6.4**	**4.7**	**100.0**

Tables 4.8 and 4.9 present the same information but in terms of combinations of stream order and distance from source. Table 4.8 suggests that around two-thirds of trout fry would reside within 2.5 km from source, a distance highly coincident with the downstream limit of first order streams in the Western Cleddau (evident from the table). Table 4.9 suggests that a quarter of trout parr would reside within 2.5 km of source, with around half residing within 5 km. As with Table 4.7, it would be interesting to see the data expressed in terms of biomass or divided into separate year-classes.

Table 4.7 **The predicted percentage distribution of parr numbers (assuming no organic pollution) in the Western Cleddau catchment by stream order and altitude**

Altitude class (metres)	Stream order 1	2	3	4	**Total**
0-50	1.2	16.3	7.7	26.1	**51.3**
50-100	10.8	16.0	8.5	2.3	**37.6**
100-150	2.4	5.9	0.9	-	**9.2**
150-200	0.1	-	-	-	**0.1**
200-250	0.5	1.2	-	-	**1.7**
Total	**15.0**	**39.4**	**17.1**	**28.4**	**100.0**

Table 4.8 **The predicted percentage distribution of fry numbers in the Western Cleddau catchment by distance from source and stream order**

Stream order	Distance from source (km) <2.5	2.5-5	5-10	>10	**Total**
1	61.5	10.0	0.0	0.0	**71.5**
2	5.0	7.6	4.9	0.0	**17.4**
3	0.1	1.0	4.0	1.3	**6.4**
4	0.0	0.0	0.8	3.9	**4.7**
Total	**66.5**	**18.6**	**9.7**	**5.2**	**100.0**

Table 4.9 The predicted percentage distribution of parr numbers in the Western Cleddau catchment by distance from source *and stream* order

Stream order	Distance from source (km) <2.5	2.5-5	5-10	>10	**Total**
1	13.0	2.0	0.0	0.0	**15.0**
2	10.1	17.6	11.7	0.0	**39.4**
3	0.3	2.6	10.8	3.5	**17.1**
4	0.0	0.0	1.7	26.7	**28.4**
Total	**23.4**	**22.2**	**24.1**	**30.3**	**100.0**

The distribution of estimated trout numbers between classified and unclassified river reaches is given below, demonstrating the enormous importance of unclassified watercourses to trout populations in catchments of this type.

	Trout fry	**Trout parr**
Unclassified	86%	73%
Classified	14%	27%

The Colne catchment

Fishery data were available for the Colne from a range of survey reports on both tributaries and the main river. Although surveys were undertaken in different parts of the catchment in different years, the data provide a reasonable overview of fish populations in much of the river network. This said, data were only available for tributaries draining the western, chalk-dominated part of the catchment, with no sites in eastern, clay-dominated areas (Figure 4.3). This was unfortunate, as it meant that only the western half of the catchment could be considered in the analysis, since the eastern half is so different in terms of the fish habitat provided. It also meant that Base Flow Index, which would have been a valuable discriminator between fish habitats in the two halves of the catchment, would not now be useful in the modelling process.

An initial analysis of the data revealed that, although numerous fishery sites were located on first order streams, these streams are so long (being chalkstreams) that little information was available within 5 km from source. Any model produced that used distance from source as a parameter would therefore be extrapolating into the very habitat where good estimates of fish abundance are required. This uncertainty was felt to be too great for fish species that make good use of headwaters, such that models were produced that were based on other parameters.

Table 4.13 The division (in %) of predicted fish numbers between classified and unclassified reaches in the western half of the Colne catchment

	Dace	Chub	Perch
Unclassified	0.2	2.0	7.9
Classified	99.8	98.0	92.1
Total	**100.0**	**100.0**	**100.0**

4.3 The contribution to recruitment in main river populations

The above analysis of standing stocks gives a very static picture of fish populations and does not recognise that fish make both upstream migrations into headwaters (associated with spawning) and downstream migrations out of headwaters (associated with growth and maturation). The importance of headwaters to main river populations depends upon the extent to which these movements occur, which in turn depends upon the species in question, accessibility, the distances involved, and the suitability of headwater habitat for spawning and juvenile development (in terms of current velocities, spawning substrates etc). Utilisation of a headwater stream by main river fish becomes less likely as the distance between the stream and the main river increases. It follows that headwater streams entering the main river directly will be of highest importance to fish populations in the main river, and this has been found to be the case by various workers. Development of the HABSCORE model has demonstrated that such tributaries of main rivers are highly important (Wyatt *et al.* 1995), and Osborne and Wiley (1992) have found that streams that are lower in the catchment and connected to the main river have higher species richness values than small streams in the upper catchment.

Although both upstream and downstream movements are known to occur, little work has been undertaken in terms of quantifying their importance. In terms of adult movements upstream, the extent of penetration of migratory salmonids into headwaters is relatively well known, although movements of non-migratory brown trout are less clear. Very little seems to be known about the geographical extent of coarse fish spawning migrations into small streams. What detailed published work has been undertaken on coarse fish ecology has generally not extended into smaller watercourses (e.g. Stott 1967) or has not considered spawning movements at all (e.g. Mann 1973, 1974, Mann *et al.* 1984).

In relation to the downstream movement of juveniles, most research has been undertaken on salmonids. Even so, the extent to which downstream-moving salmonid juveniles contribute to populations further downstream is unclear. A high proportion of salmonid fry are likely to die once they lose the fight for space in the near vicinity of their emergence site and start to move downstream. Elliott (1984) reported that the majority of trout fry moving out of a study section in a Lake District stream were either dead or moribund, suggesting that mortality rather than emigration is the most likely fate of individuals involved in downstream movements at this age. He has further concluded that the majority of losses of 1+ individuals are also due to mortality rather than emigration downstream (Elliott 1994). At 2+, emigration becomes the dominant cause of losses from the brook as smolts begin their downstream passage. Some parallel studies were undertaken by Elliott in a stream dominated by resident trout (Wilfin Beck) and a similar pattern of mortality was found up to the 2+ age class, with very few individuals being taken in a trap located downstream of the study area (Elliott 1994).

This question of mortality/emigration is crucial to the assessment of the importance of juvenile headwater populations to adult populations in larger watercourses downstream. The answer is likely to differ widely depending upon site-specific considerations (such as the quality of downstream habitat and the level of competition found there) and the species in question. It would seem sensible to assume that juveniles closer to maturity generally make more successful and more wide-ranging movements, and that main rivers with poor spawning habitat and good adult habitat will give rise to less competition to downstream-moving individuals.

4.4 Conservation importance of headwaters

An assessment of conservation status has been conducted by Maitland and Lyle (1991) for all fish species inhabiting the British Isles, based upon frequency of occurrence, trends in abundance and vulnerability. Species were divided into six classes as shown in Table 4.14. Although the highest priority species (in Classes I, A, B and C) are not associated with headwaters (or even rivers in many cases), Class D contains seven species that either do, or may have, strong associations with headwater streams (i.e. all Class D species except the sea bass).

Table 4.15 shows species that utilise headwaters (or are likely to) that also occur in various national and international priority lists for wildlife conservation. As can be seen, the EC 'Habitats' Directive (92/43/EEC) and the UK Biodiversity Steering Group report (instigated by the Rio Convention on Biodiversity) are the only documents in which such species are listed. Annex IIa of the Habitats Directive relates to animal species whose conservation requires the designation of Special Areas of Conservation. The 'L' designation under the Biodiversity Action Programme refers to the 'Long list' of globally threatened/nationally declining species, for which the UK Biodiversity Steering Group recommend that populations of all species should be monitored if possible. No species likely to utilise headwaters occurs in the 'Short' and 'Middle' lists of priority species, for which more direct conservation action is recommended.

Table 4.14 Prioritisation of conservation action for British freshwater fish (Maitland and Lyle 1991)

	Conservation class					
Species	I	A	B	C	D	E
Sturgeon	*					
Allis Shad		*				
Twaite Shad		*				
Vendace		*				
Powan			*			
Smelt			*			
Arctic Charr				*		
Sea Lamprey					*	
River Lamprey					*	
Brook Lamprey					*	
Atlantic Salmon					*	
Brown Trout					*	
Spined Loach					*	
Ten sp. Stickleback					*	
Sea bass					*	
Other species						*

I	International action urgently required
A	Urgent conservation action needed now
B	A conservation action plan should be implemented soon
C	A conservation management plan should be prepared
D	A conservation management plan should be prepared
E	No immediate action needed

Table 4.15 Scheduled species that significantly utilise (or are likely to utilise) headwater streams

Species	Hab Dir	Bern	Bonn	W&CA	BAP
Sea Lamprey	IIa	-	-	-	L
River Lamprey	IIa	-	-	-	L
Brook Lamprey	IIa	-	-	-	L
Atlantic Salmon	IIa	-	-	-	L
Bullhead	IIa	-	-	-	L
Spined Loach	IIa	-	-	-	L

Hab Dir	EC Directive on the conservation of natural habitats and wild flora and fauna
Bern	Bern Convention on
Bonn	Bonn Convention
W&CA	1981 Wildlife and Countryside Act and amendments

Biodiversity Action Programme (UK Biodiversity Steering Group 1995)

As was evident from Section 3, it is not possible to adequately quantify the importance of headwater habitats to each species at present, with data being particularly poor for 'minor' species. Targeted surveying for the three lamprey species has recently been commissioned by English Nature, who are working in association with the Agency to develop protection measures and management guidelines (as part of R&D Project 640, concerning species management in aquatic habitats). This work has highlighted the importance of headwater habitats to lamprey species. As part of the same Agency project, targeted surveying and ecological studies have recently been commissioned on the spined loach, again in association with English Nature. Within the operational activities of the Agency, opportunities are increasing for the recording of such fish species in headwaters, with the increasing use of backpack electrofishing equipment and the advent of the national Fisheries Classification Scheme (FCS) software. The FCS software has entry fields on threatened species, which include all three lamprey species and the spined loach. The need for better recording of minor fish species in routine fishery surveys is being stressed as part of R&D Project 640, and the FCS requires that all minor species are recorded as part of the assessment process.

At a genetic level, headwaters can play host to distinct populations that have conservation value in their own right, irrespective of the extent of dependence of the species as a whole on the habitat. This has been most frequently observed in brown trout (Ryman 1981, Ferguson 1989) and salmon (Cross 1989) in the UK due to their commercial importance, and the need to protect and manage genetically distinct populations has been stressed by such authors. Distinct populations will presumably also occur in other species in headwaters where access problems exist and no stocking of the species has been undertaken.

5. THREATS TO HEADWATER FISH POPULATIONS

5.1 Introduction

The very nature of headwaters makes them intrinsically vulnerable to impacts, and it is important to understand the reasons for this prior to analysing specific threats. For this reason, a brief account of the factors influencing their vulnerability is given below, followed by a discussion of the nature of each major threat and any information on the likely extent and magnitude of impacts on a national scale. Headwater fish populations are vulnerable to a wide variety of threats, any one of which could warrant (and often has warranted) a review in its own right. In a brief study such as this, only a brief description of the major threats is possible, with specific illustrations where available. In general, information specific to headwaters is greatly lacking, such that although some impacts will inevitably occur in headwaters, information to characterise and quantify the impact may only be available from non-headwaters. In relation to water quality, a new project is due to commence concerning investigations into the causes of poor quality in headwater streams (New Start Project P2C(96)2); this should address a number of the issues raised in subsequent sub-sections.

Human activities interact in a complex way in rivers such that one type of impact may be caused by a variety of activities, and one activity can contribute to a variety of impacts. Figure 5.1 attempts to illustrate these complex interactions, but should not be taken as a comprehensive inventory of the linkages that exist. The current section has been structured in relation to key mechanisms of impact, with discussion of the human activities contributing to these impacts. This is perhaps the most unequivocal way to provide an illustrated account of threats to headwaters, since whilst impacts are often described in the literature or in survey reports, it is often not clear what activity (or activities) has caused the impact.

5.2 Intrinsic vulnerability of headwater populations

Fish populations in headwater streams are particularly vulnerable to environmental stress for a wide variety of reasons, all connected with their position in the river network. The low dilution capacity makes them particularly vulnerable to polluting inputs (even relatively small inputs), whilst human activities that reduce flow can cause the headwater source to migrate downstream with the complete loss of fish habitat or reductions in depth that make conditions impossible for sizeable fish. From a regulatory viewpoint, the small and disperse nature of headwaters means that it is difficult to adequately monitor activities that impact upon fish populations, particularly considering the relatively small polluting inputs or physical changes required to affect habitat suitability. With little or no stream channel above them, there is often little potential for recolonisation of impacted areas with downstream-moving juveniles, such that recovery often depends upon the movement of older fish upstream. If access is physically restricted, as it often is (either naturally or artificially), natural recovery becomes even more difficult.

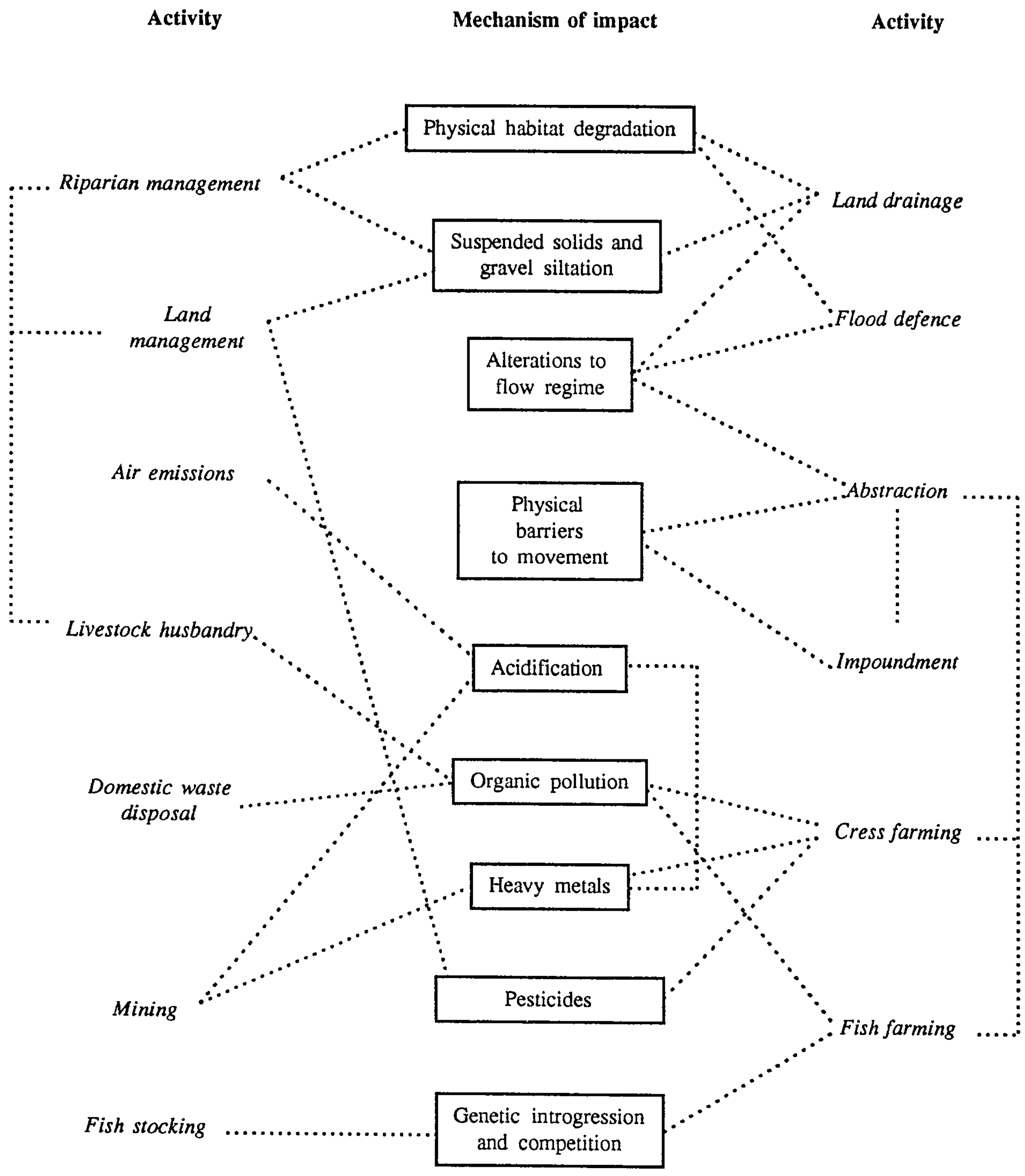


Figure 5.1 Links between human activities and mechanisms of impact upon headwater fish populations.

Headwaters have little thermal inertia, which results in fish populations being subjected to extremes in temperature from winter to summer (Hynes 1970), particularly those in upland locations. In the winter, low temperatures are compounded with high flows to produce a highly stressful environment, particularly for juvenile fish. Whilst fish inhabiting headwaters are likely to be more resistant to such environmental extremes (Matthews and Styron 1979), their ability to cope with additional stress (such as from intermittently poor water quality) is likely to be impaired. Moreover, fish populations in headwaters are highly dependent upon over-wintering refugia, typically deeper water with reduced flows and lower rates of water exchange (and therefore temperature change), and are therefore particularly vulnerable to the loss of such habitat.

In terms of population recovery following transient impacts, Wightman (1989) concluded that recovery of salmonid populations begins the following year as long as a good source of colonists has access to the affected reach. He felt that the impacts observed on short stretches of river may be masked by rapid redistribution of juveniles from unaffected reaches. The corollary is that, as the extent of impacts increases, the number of individuals available for redistribution declines and the potential for short-term recovery is impaired. The Ebbw catchment in South Wales (which has had a history of pollution from domestic and industrial discharges) has demonstrated this situation, where Harcup *et al.* (1984) concluded that recruitment from the few remaining small tributaries supporting trout would be insufficient to repopulate the system within reasonable timescales.

It is important to note that different types of headwater differ in their vulnerability to impacts, both in terms of the immediate response and their ability to recover. It follows from the discussions on migrations in Section 4.3 that headwaters that are remote from the main river are unlikely to have significant interaction with it. Such streams need to satisfy the full life cycle of a fish species for a population to survive, including habitat for spawning, juvenile rearing and growth to sexual maturity. Moreover, these habitat conditions need to be sufficiently close to each other to allow movement of one life stage to the next in numbers that will ensure an adequate spawning to maintain the population. Observations of genetic differences in brown trout along the length of individual small streams suggest that fish movements can be negligible in such habitats (Ryman 1981). It can be seen that habitat features, particularly the riffle-pool sequence, are critically important in such streams, becoming more and more important as accessibility declines. In contrast, small streams that permit easy access to fish in the main river may only provide spawning and nursery habitat but still play a vital role in sustaining fish populations.

Drainage density can critically influence the vulnerability of headwaters to certain impacts. In areas of low drainage density, such as in chalk stream areas, few tributaries exist to act as: a) refugia during pollution incidents; and b) sources of colonists following incidents. In this sense, their vulnerability to impacts can be seen as higher than in catchments with a high drainage density (essentially those in upland areas and in lowland areas dominated by impermeable soils). However, catchments with high drainage densities may be more susceptible to spatially diffuse impacts, such as acidification, low flows and polluted agricultural run-off, since a higher proportion of the river network is close to the source of impact.

The principal food source of a headwater fish population may influence its vulnerability to indirect effects from impacts acting upon prey species. Some headwaters, particularly those of low productivity, will rely largely on allochthonous sources of food, largely terrestrial invertebrates that alight on the water surface or get washed into the stream. Such populations may be less vulnerable to indirect water quality impacts than those relying more heavily on autochthonous sources. However, some fish populations (particularly salmonids) have been found to switch food sources rapidly in response to anthropogenically induced changes in prey availability (see Section 5.10), which would tend to buffer any problem.

5.3 Physical habitat degradation

Many observations have been made of habitat segregation by different fish species and age classes in streams (e.g. Schlosser 1982, Johnson *et al.* 1992 , Zweimuller 1995), highlighting the importance of structural diversity to the maintenance of diverse communities. Whilst headwater streams may provide excellent spawning and juvenile-rearing habitat in many instances, it has been concluded that the close proximity of the two habitats is essential to good juvenile recruitment (Scheimer *et al.* 1991) and a self-sustaining population. Similarly, the presence of deep pool habitat adjacent to juvenile-rearing habitat is a key factor in determining the long-term persistence of juvenile fish in a stream (Schlosser 1987), since without such adult habitat the population has to rely on good accessibility of the stream to migrating adults. Small-scale habitat diversity is therefore crucial to the survival of headwater fish populations, and it follows that the replacement of the typical riffle-pool sequence by channels of a more uniform nature will lead to considerable disruption of fish communities and an increased dependence on adjacent watercourses to sustain any kind of fish population.

The causes of reduced physical diversity in headwaters are numerous, but the major factors are:

- flood defence works - channel reprofiling, over-deepening, over-widening, straightening, bank reinforcing, for the purposes of protecting both urban and agricultural land;

- land drainage operations -for the purpose of urbanisation, agricultural improvement or forestry, often involving similar activities to flood defence activities;

- poor riparian management.

A major investigation of the impact of land drainage operations (whose impact can be assumed to be similar to many flood defence operations) was made by Cowx *et al.* (1986), who studied the response of coarse fish populations on the upper Soar (a river of some 6 metres in width at this point) to channel modifications made as part of a land drainage scheme. The fish population of the modified reach was devoid of major species (i.e. those of angling interest, such as roach, chub and dace) when surveyed after engineering works, whereas the population in the control section improved. The standing crop of major species increased in the control section by ten-fold over the ensuing six years, whilst major species remained absent from the modified reach for five years (whereupon small numbers began to recolonise). The 8-year period of observation illustrates that the differences in fish populations in the modified and unmodified reaches are not a short-term result of disturbance, but rather a long-term consequence of permanent changes to the physical environment. The main factors implicated in the poor performance of the modified reach were loss of instream cover and removal of the riffle-pool sequence. Although the Soar would not be considered a headwater at this point by most people, these observations graphically illustrate the effect of such physical modifications on major fish species.

Whilst little quantitative evidence of habitat degradation in headwater streams has been gathered from data collated from Regional fishery staff, qualitative descriptions are provided in some fishery survey reports. Such descriptions have been collated for streams of less than 3 metres in width in the Thames Region and have been resolved into a crude three-class scale that provides an indication of the level of physical impact (Table 5.1). Alterations to the streams surveyed are evidently quite extensive, largely relating to channel straightening, loss of riffle-pool sequence, over-widening, over-deepening and bank alterations. The data are inadequate to assess the effect of this type of habitat degradation on resident fish populations, although survey reports often note markedly low abundances of major fish species at heavily degraded sites.

Table 5.1 Extent and degree of physical alterations to stream channels less than 3 metres in width (from qualitative observations during NRA fishery surveys in the Thames Region).

		Degree of physical impact		
Catchment	No. sites =<3metres	Low/none	Moderate	Severe
South Wey	7	3	3	1
Blackwater	6	1	1	4
Cherwell	13	9	3	1
Windrush	4	1	2	1
Colne	11	4	7	0

Extensive information on the link between habitat quality and fishery status is given by HABSCORE, which produces an estimate of salmonid abundance for a site (the Habitat Quality Score, or HQS) based upon a range of parameters related to physical quality. Figure 5.2 plots observed trout parr numbers against the HQS for sites in the extended HABSCORE database, covering a wide range of salmonid-dominated rivers in England and Wales (Wyatt *et al.* 1995). Although there is a large amount of scatter, largely associated with unexplainable stochastic variation, a clear trend of declining trout numbers with declining HQS is apparent. Whilst many of the sites used in this figure would not be termed headwaters, the same mechanisms of impact will apply.

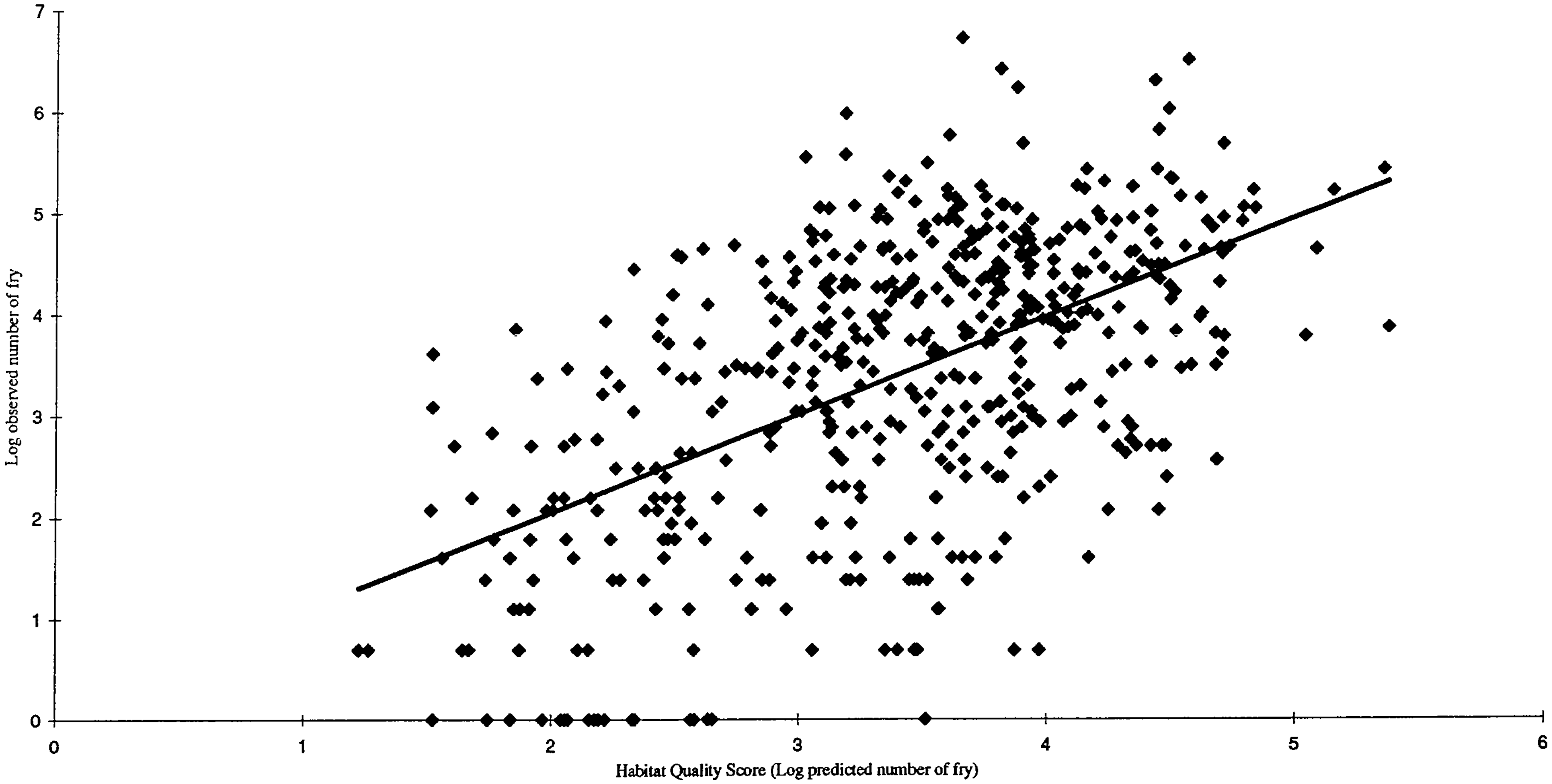


Figure 5.2 The relationship between brown trout fry abundance and the Habitat Quality Score (generated by the HABSCORE model) at sites across England and Wales.

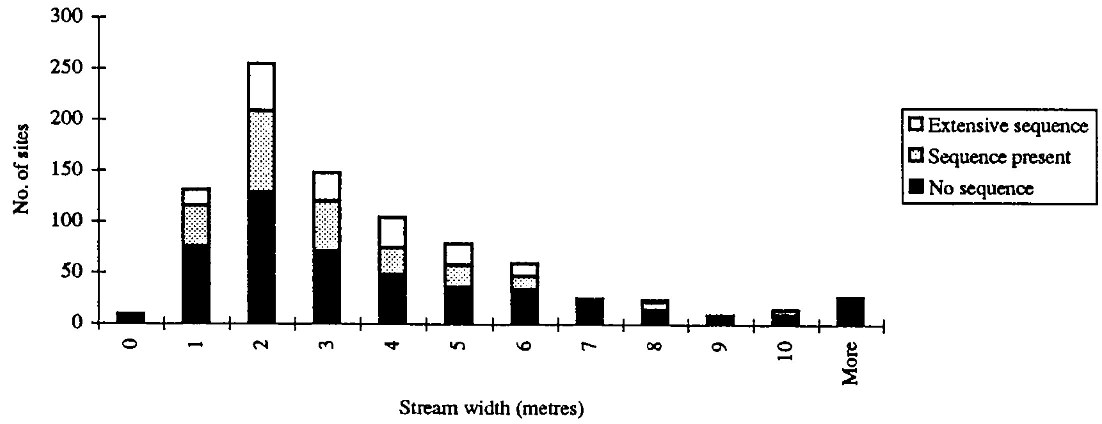
The River Habitat Survey database includes a range of information related to the physical diversity of the river channel and modifications made to it. In the future, such information will be incorporated into a Habitat Modification Score, but this was not available during this study. Data on RHS parameters relevant to this study have been kindly provided by Marc Naura (North West Region) in electronic format. Figure 5.3 shows the occurrence of riffle-pool sequence at sites surveyed in 1995 within 10 km from source, grouped by stream width. Only a small proportion of sites in the database have an extensive riffle-pool sequence, becoming smaller as stream width increases. To a certain extent this decline with increasing width can be expected, since the wavelength of the riffle-pool sequence naturally increases with stream width (being empirically estimated at 5-7 stream widths - Hynes 1970). The proportion of sites with no apparent sequence is very high, at around 50% for sites less than 3 metres in width. Parts (b) and (c) of Figure 5.3 give an indication of the regional variability in this proportion within the database, being somewhat higher for North East Region and lower than average for Anglian Region.

In order to gain an indication of the scale of river engineering works in headwaters, Figure 5.4 shows the extent of channel resectioning at RHS sites less than 10 km from source (this time for both 1994 and 1995 data). The data are presented in terms of the percentage of spot checks in which obvious resectioning was observed, 10 spot checks being made over a distance of 500 metres. At a national scale, extensive resectioning (taken as >60% of spot samples) has been observed at 15-20% of sites less than 3 metres. Since the RHS methodology specified that resectioning should be 'obvious', this may well be a significant underestimate of the true scale of modification. Again, parts (b) and (c) suggest a certain amount of regional variability, although the statistical significance of these differences is not known.

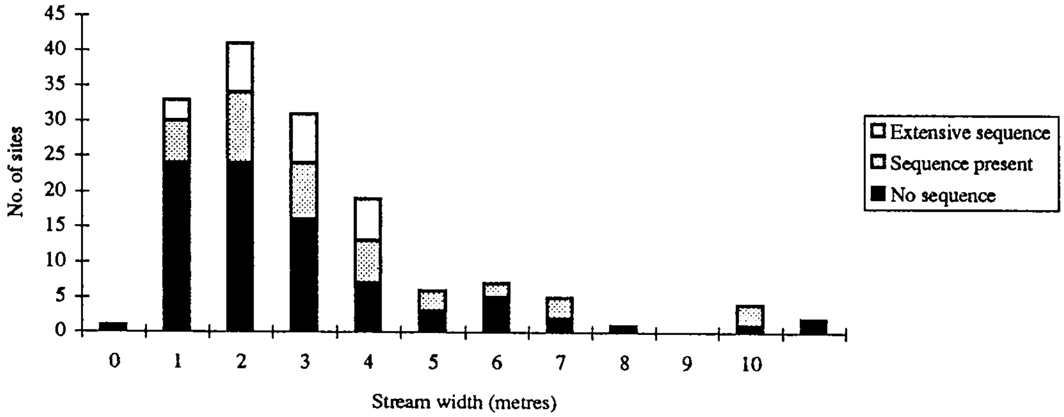
The extent of impact on riffle-pool sequences is unclear from Figure 5.3, since the natural state of the sites in question is unknown. Nevertheless, it can be guessed that most sites on small streams would have once had an observable sequence, such that the number of sites allocated to the category of 'no sequence' would be small in the natural state. Table 5.2 considers the interaction between the occurrence of riffle-pool sequences and evidence of resectioning, suggesting that, irrespective of the natural state of sites, resectioning operations have caused a general shift away from extensive sequences towards an absence of any sequence.

It is not clear how far these results from the RHS database can be taken as representative of small streams across the country, since the RHS methodology specifies that GQA-classified reaches should be surveyed in preference to unclassified reaches. This has resulted in the majority of RHS sites with flows that are lower than the guideline value (0.31 $m^3 s^{-1}$) being part of the GQA network (Table 5.3). It is unknown what differences in the physical management of a small stream might be expected if it is GQA classified, but it is possible that there may be more uncontrolled physical disturbance in unclassified reaches owing to the reduced regulatory attention. The bias in the RHS database towards classified reaches may therefore conceivably introduce an unrepresentative picture of physical impact. It is, however, the most comprehensive picture that can be obtained at present.

a) All Regions



b) North East Region



c) Anglian Region

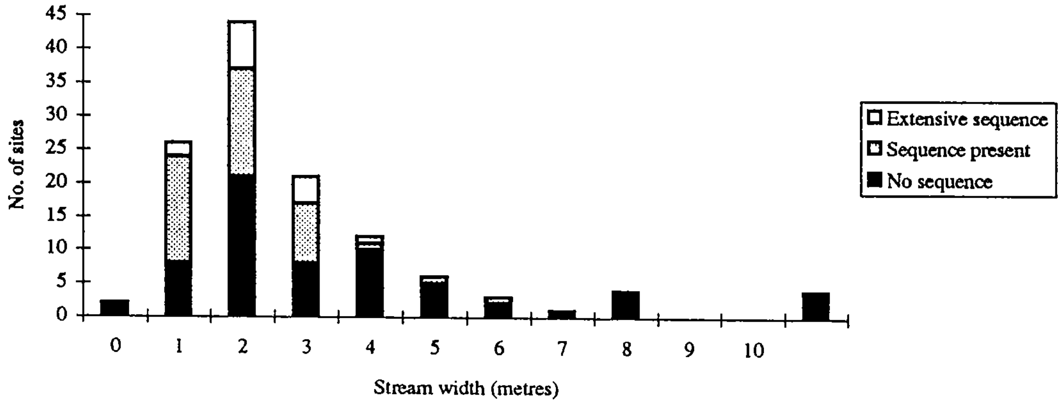
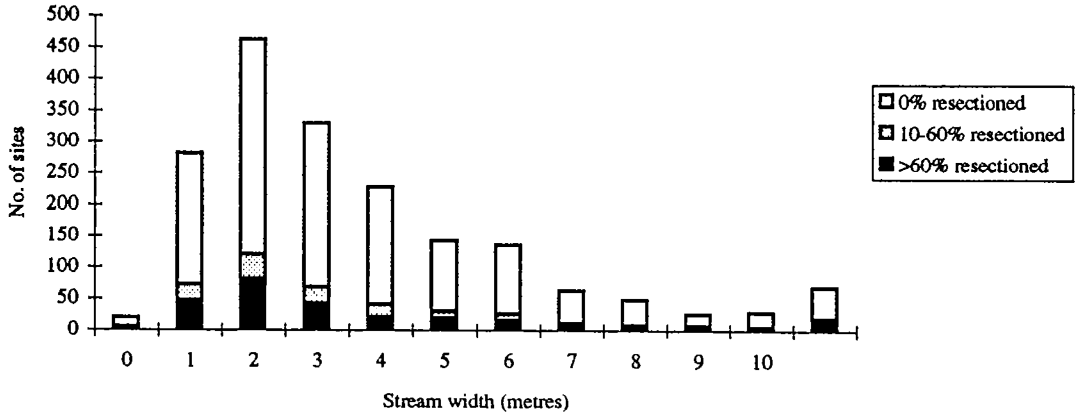
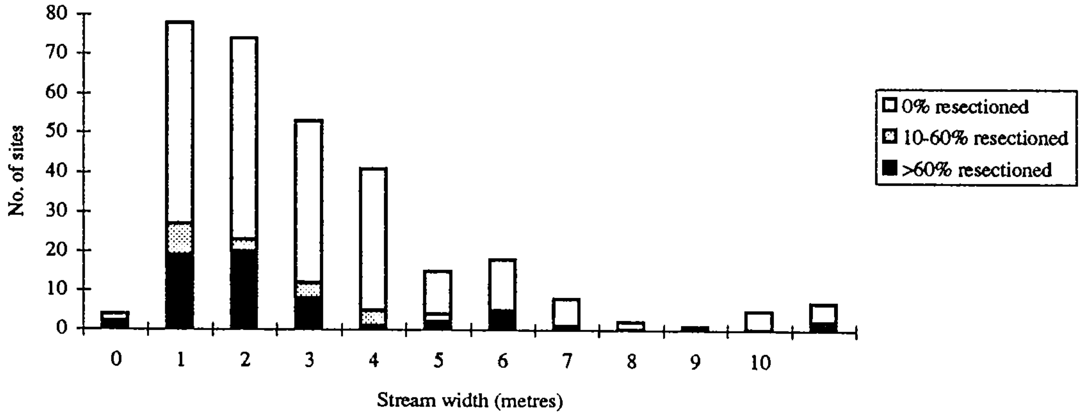


Figure 5.3 Extent of riffle-pool sequence at sites less than 10 km from source in the River Habitat Survey database (1995 data only).

a) All Regions



b) North East Region



c) Anglian Region

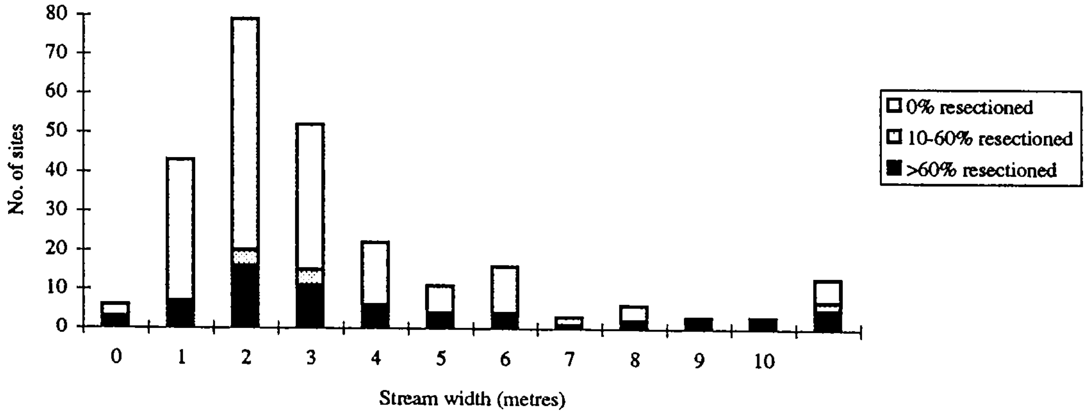


Figure 5.4 Extent of channel resectioning (as the percentage of spot checks made) at sites less than 10 km from source in the River Habitat Survey database (1994 and 1995 data).

Table 5.2 **The percentage distribution of sites in the River Habitat Survey database less than 10 km from source (1995 data only), according to the occurrence of riffle-pool sequence and resectioning operations**

	Percentage of spot checks where obvious resectioning was recorded		
Riffle-pool sequence	0%	10-60%	>60%
No sequence	47	51	86
Sequence present	31	40	9
Extensive sequence	21	9	7
Total	**100%**	**100%**	**100%**

Table 5.3 **The distribution of sites in the RHS database by flow category and GQA designation.**

Flow category	Flow range ($m^3 s^{-1}$)	Not GQA classified	GQA Classified
1	=< 0.31	135	568
2	0.31-0.62	3	146
3	0.62-1.25	1	69
4	1.25-2.5	0	16
5	2.5-5	0	9
6	5-10	0	1
7	10-20	0	2
8	20-40	0	2
9	40-80	0	0
10	>80	0	0

5.4 Acidification

Acid stress operates directly on fish through interference with ion regulation (Potts and McWilliams 1989), but pH also has an important secondary effect in controlling the toxicity of aluminium. In addition, acidified run-off also tends to increase the mobility of other metals in soils and thereby increases their concentrations in receiving waters, leading to further stress on fish populations. Afforestation can increase the acidity and aluminium levels of run-off through enhanced acid deposition onto the forest canopy (Hornung *et al.* 1987) and is known to have a detrimental impact on salmonid populations (Stonor and Gee 1985); however, the mechanisms of forestry impact on fish populations are varied and include effects on physical habitat and food supply. Upland headwaters are particularly vulnerable to acidification, as buffering capacity is generally at a minimum in such watercourses and the availability of heavy metals in soils tends to be high. Acidity is ameliorated further down the catchment as the river network runs onto mineral soils with higher acid neutralising capacities.

Aluminium is thought to be most toxic to fish at pH values ranging from 5.0 to 5.5 (Fivelstad and Leivestad 1984), such that in acid conditions hydrogen ions and aluminium act together to produce serious effects on fish populations. At pH values lower than 5, aluminium toxicity is reduced but the direct effects of acidity are inevitably increased. The effects of acidity are most pronounced on the younger life stages (eggs and fry - Brown and Sadler 1989), particularly immediately pre- and post-hatching (Rosseland 1986). The effects of acid episodes triggered by rainfall can be particularly important in terms of adult mortalities, with both episodic and chronic acidity producing recruitment problems due to effects on younger life stages. Fiss and Carline (1993) found that short-term acid episodes in three second-order US streams reduced the survival of brook trout embryos in natural redds (survival rates of between 16 and 68% were recorded) to an extent which appeared to be dependent on the concentration of inorganic monomeric aluminium (95 percentile values ranged from 0.049 to 0.322 mg l^{-1} from the least to most impacted streams). Older brook trout have been observed to make net downstream movements of hundreds of metres in response to acid episodes involving pH values of less than 5 and total dissolved aluminium concentrations of more than 0.2 mg l^{-1} (Gagen *et al.* 1994). Over the twenty day period in which these episodes occurred, a third of the fish studied died. In terms of chronic exposure to aluminium, effects on fish growth have been observed experimentally at concentrations down to 0.027 mg l^{-1} (Sadler and Lynam 1987).

Turnpenny (1989) examined fishery data from a range of UK rivers and concluded that salmonid abundances were much lower in streams with a pH of less than 5.5, being an average of 16.1% of abundances in streams with pH values greater than 6.5. Salmon were found to be absent from streams with a pH of less than 5.5. With respect to brown trout, Turnpenny *et al.* (1987) found that populations with densities greater than 5 g m^{-2} only occurred at sites with labile aluminium concentrations of less than 0.04 mg l^{-1} and concentrations of zinc, lead and copper at less than 40% of their combined lethal threshold concentrations. A survey of 83 stream sites in Wales by the Welsh Water Authority revealed that trout populations were poor or absent at concentrations of dissolved aluminium greater than 0.1 mg l^{-1}, when coinciding with pH values of less than 5.4 (Milner and Varallo 1990). This equates to a higher limiting value of aluminium than suggested by Turnpenny *et al.*, although this may be explained by the WWA's inclusion of afforested catchments, which could have produced higher concentrations.

Assessment of the geographical extent of acidification impacts on headwater fish populations is hampered by major confounding variables associated with habitat quality and the buffering capacity of soils (Milner and Varallo 1990). An acid vulnerability classification has been developed for Wales on the basis of rainfall and soil characteristics, with 20% of the principality falling into the two most vulnerable categories. These areas are shown in Figure 5.5, together with the main rivers draining them. From the geographical scale of the area involved, it can be seen that the potential for impact in Welsh headwaters is great. Monitoring of headwater streams for indications of acidification impact on fish populations is on-going in the Welsh Region of the Agency, through their acid waters monitoring programme.

No large scale assessments of acidification impact have been identified in other Agency Regions, although there are likely to be significant impacts in headwaters across upland England associated with high rainfall, low acid neutralising capacities and high metal availability in soils. Some fishery information is available from North West Region, where analysis of survey data from the southern Lake District has shown strong tendencies towards lower trout parr abundances in base-poor streams (pers comm Don McCubbing, North West Region) which may be at least partly attributable to acidification problems. A trend towards lower abundances of both trout fry and parr has also been suggested with increasing altitude in base-poor streams, although the effect of acid stress will be heavily confounded by factors relating to stream productivity (such as temperature and nutrient availability) and accessibility.

The sensitivity of surface waters to acidification has been mapped for the whole of Great Britain by the Institute of Terrestrial Ecology (Figure 5.6, Hornung *et al.* 1994), on the basis of the buffering capacity afforded by soils and underlying geology (as modified by established liming practices). This picture confirms the high risk associated with northern and western catchments in England and Wales.

5.5 Organic pollution

Organic pollution problems arise from two principle sources, these being animal husbandry and domestic sewage. Organic inputs from livestock farms have long been associated with problems in headwater streams, particularly in western areas of England and in West Wales. Problems are generally associated with inadequate storage facilities for slurry, silage and farmyard run-off, lack of clean water separation, and poor waste disposal practices (Mainstone *et al.* 1994c). Polluting potential is increased by high rainfall, sloping land and impermeable soils, all associated with areas of intensive livestock (particularly cattle) husbandry. Inputs are often transient and related to rainfall, producing oxygen sags and high levels of ammonia that can give rise to extensive fish kills (NRA 1992). Chronic inputs can lead to the proliferation of 'sewage fungus', bacterial communities that can smother the benthos and create unsuitable conditions for both fish and their macroinvertebrate food source (Mainstone *et al.* 1994c). Much less studied but of potential significance to headwater streams (owing to their low dilution capacity) are inputs from septic tanks, the loads from which are difficult to monitor and control due to their large number and small size. Such inputs are likely to be of greatest importance in headwaters running through semi-rural lowland areas of low soil permeability where population densities are significant but too inconsequential for connection to sewer. The likely extent of problems is difficult to determine and certainly not possible with currently available information.

An example of the scale of fishery impact that is possible from animal husbandry is given by surveys of fish populations in headwater streams in the Teifi, Taf and Tywi catchments, undertaken by the Welsh Water Authority in 1988 (Wightman 1989). These were focused on areas deemed to be at high risk of organic pollution from livestock farming, identified by an analysis of recent pollution incidents. Semi-quantitative surveying at 63 sites in 24 high risk areas revealed reduced trout densities in 25% of areas (as indicated by a drop of two categories in the Welsh Regional Fisheries Monitoring Programme (RFMP) classification compared to upstream control sites), amounting to an affected stream length of 5.5 km out of 40 km surveyed (14%). On the basis of upper and lower estimates of typical parr densities (2 and 20 100 m^{-2}) and an average stream width of 3 metres, it was estimated that this level of pollution resulted in the loss of between 330 and 3300 trout parr per annum over the affected area. It was concluded that direct effects on fish populations are confined to first order streams, with salmon being less affected than trout due to their preference for larger watercourses.

In the adjacent Western Cleddau catchment, HABSCORE assessments made by Wightman and Jones (1992) on low order streams indicated good habitat quality at the limited number of sites where habitat was evaluated, but very poor habitat utilisation by trout (see Table 5.4). Salmon were not a focus for the investigation due to their patchy distribution in such small streams. Trout abundances were poor at most of the 78 sites fished (around half of which were on first order streams), with 41% and 33% being categorised as Class D (poor) and E (absent) respectively according to the Welsh RFMP classification. Biological monitoring using a bankside indicator key (Rutt and Mainstone 1995) revealed that 94% of sites exhibited some degree of organic pollution in the spring (13% being grossly polluted), with 65% showing signs in the summer (16% grossly polluted). It was concluded that organic loadings were likely to be a principal cause of the depressed trout abundances in the catchment, along with siltation of spawning gravels associated with changes in agricultural practice.

West Wales is an important area for intensive dairy farming and as such cannot be taken as representative of the rest of England and Wales in terms of fishery impact. Figure 5.7 is the result of a national assessment of pollution risk from livestock farming (Rutt and Mainstone 1995), based on livestock densities, the loadings of livestock excreta in relation to the available agricultural land area, and certain factors affecting the frequency and extent of surface run-off (rainfall, soil permeability and land slope). This analysis highlights West Wales as being of particularly high risk, along with the Cheshire Plain livestock area, catchments in the south west and north west of England, and clusters of catchments in easterly areas. Pollution incidents arising in 1988 as a result of livestock farming activity are also included in the assessment for validation purposes; however, data were only available for certain Regions, as is evident from the map coverage (see Rutt and Mainstone for more details).

Considering the number of high risk catchments highlighted, organic pollution caused by livestock farming is likely to have a considerable impact on a national scale. However, the extent of impacts at a local level is driven by the adequacy of farm waste management, such that water quality problems can be effectively contained even in high risk areas if arrangements are satisfactory. This is confirmed by the success of remedial measures implemented on problem farms in West Wales, identified through the use of a bankside appraisal method using the benthic macroinvertebrate community (Rutt and Mainstone 1995).

Table 5.4 Habitat utilisation by trout at five headwater sites in the Western Cleddau catchment (after Wightman and Jones 1992).

Watercourse	NGR	0+ Trout (No. m^{-2})			>0+ Trout (No. m^{-2})		
		Obs	Pred	Sig	Obs	Pred	Sig
Nant-y-Coy	921242	64.7	24	NS	0	23	***
Nant-y-Coy	957253	2.5	37	**	0	39	***
Knock Brook	939189	1.7	36	***	2.5	27	***
W. Cleddau	945332	0	27	***	8	24	*
W. Cleddau	921308	1.0	16	**	3.6	26	**

Obs - Observed abundance
Pred - Abundance predicted by HABSCORE
Sig - Significance of difference: * - $p<0.1$; ** - $p<0.05$; *** - $p<0.01$

5.6 Suspended solids and siltation of spawning gravels

High concentrations of suspended solids can cause direct physical stress on fish through the clogging of gills and other sensitive surfaces (Rabeni and Smale 1995), with Alabaster and Lloyd (1982) recommending a threshold value of 25 mg l^{-1} (as an annual mean) for the protection of fish life. However, even in situations where levels of suspended solids appear relatively low, important indirect effects can be induced through excessive silt deposition in riverine gravels, leading to the in-filling of gravel interstices and consequent reductions in the flow-through of water and oxygen. This has serious consequences for fish species that use gravels for spawning, most notably salmonid species. Increased salmonid egg mortalities have been observed as a result of enhanced siltation (Naismith *et al.* 1996), which can lead to a recruitment bottleneck and subsequent fishery decline.

Another potentially important effect of siltation is stress on the invertebrate community inhabiting riverine gravels, which is a vital food source for fish populations, particularly those with a benthic feeding habit but also those feeding off invertebrate drift. Rabeni and Smale (1995) undertook intensive monitoring of three second- and third-order streams in Missouri that were environmentally similar except for differing rates of siltation. They were able to correlate increasing levels of siltation with reductions in the absolute abundance of benthic insectivores (Spearman's rank correlation coefficient, $r_s = -0.07$, $p=< 0.05$), as well as the abundance of lithophilous spawners (such as salmonids, $r_s = -0.08$, $p=<0.01$). The abundance of herbivorous fish species was also negatively correlated with siltation, presumably due to a decline in plant biomass resulting from increased turbidity, the smothering of lower plants and the shoots of rooted plants, as well as changes in rooting depth (known to cause stress to rooted plants, Mainstone *et al.* 1993).

Based largely on work in the US (referenced in Beaumont *et al.* 1995), reduced survival of salmon to the emergence stage can be expected in gravels with a composition of greater than 20% 'fines' (i.e. sediment particles less than 2 mm in diameter). This figure has been used as a broad guide to sediment quality in relation to salmonid spawning in England and Wales (Beaumont *et al.* 1995), with the caveat that the relationship between spawning success and sediment composition is likely to be continuous in reality, with no distinct threshold composition at which success suddenly declines. Studies by IFE have revealed that many streams in southern England are close to this guideline value, indicating potential recruitment problems on a widespread basis; however, the prevalence of upwelling flows in many southern rivers, from underlying aquifers, may allow better survival than might be expected from an assessment of sediment composition alone (Beaumont *et al.* 1995).

Excessive siltation can result from excessive sediment loads or a lack of flushing events of sufficient current velocity to properly scour the riverbed; in many instances problems are probably a combination of both factors. A further consideration of potential consequence is the scouring effect created by spawning salmonids when cutting redds, which releases significant amounts of silt and helps to prevent compaction. If spawning activity declines for any reason, the potential of a population for cleaning its own spawning habitat is reduced, which could lead to a spiral of decline without intervention.

It should be noted that even in locations where gravels appear to be clean, heavy siltation may exist below the surface that would create poor conditions for egg incubation. In a study of gravels on the River Test, Carling (In Draft) found one of the three sites studied to contain extensive deposits of organic silts below a superficial layer of clean gravel. These deposits extended down to a depth of at least 50 cm, below the depth to which salmonids generally cut redds (which is 20-30 cm, Crisp and Carling 1989). Importantly, Carling considered that natural freshets on chalk streams will only scour the top few centimetres clean of silt, with the implication that artificial scouring will be required if excessive siltation has occurred below this but above the maximum depth at which salmonid eggs are incubated. This means that, even if sediment loads are reduced to the river, raking or pressure hosing will be required in affected gravels in order to 'kick-start' successful spawning.

In terms of sediment loading to the river, the relative contributions from point sources, streambed and bankside erosion (particularly livestock-induced erosion), run-off from land immediately adjacent to the stream channel and transport from areas further afield is unclear and likely to vary greatly from river to river. Research into the contributions made by different non-point sources has been proposed by Naismith *et al.* (1996). Intensification of livestock grazing regimes has been cited as a possible cause of increased problems in recent decades (Naismith *et al.* 1996). Excessive grazing pressure can result in soil compaction and the breakdown of the grass sward, leading to enhanced erosion risk (Hudson 1981). This situation would be particularly problematical in areas of sloping land and high rainfall such as those to the west of the UK where livestock grazing (and salmonid populations) are concentrated. In an investigation of factors affecting salmonid populations in six headwater streams in the US, including an analysis of grazing history of riparian land and artificial over-grazing experiments, Rinne and Medina (1988) found suggestions that livestock grazing was a significant contributor to the fines loading in spawning gravels. Rabeni and Smale (1995) have estimated that over 2000 kg of sediment per year is eroded from the streambed and banks of their Missouri study streams, implying that the control of internal and riparian sources, rather than general catchment sources, is critical.

Forestry practices can contribute considerable loads of solids to streams, particularly if management precautions are not taken. Activities such as ploughing, draining, harvesting and road construction destabilise the soil and can increase the energy of run-off, thereby increasing its capacity to carry suspended particulates (e.g. Mills 1986). On the River Wharfe, afforestation of the upper reaches has led to high solids loadings to headwaters (Hey and Winterbottom 1990), although the effects of these loadings on spawning gravels are most likely to be felt further downstream where water energy declines sufficiently for significant deposition to occur. Scouring of headwater gravels would be also enhanced by the higher peak flows typical of drained forestry plantations.

In southern England, watercress farming can add considerable loads of suspended solids to the headwaters of chalk streams. During bed cleaning, which generally occurs every 6-8 weeks on a rotation (meaning that one or two beds would be cleaned out every week on a sizeable farm), Casey and Smith (1994) observed suspended solids concentrations of over 17 000 mg l^{-1} downstream of a farm. They concluded that a large farm could contribute over 100 tonnes of solids to the receiving stream, representing a considerable load to both the water column and the stream bed. They also report that many watercress farmers are in the process of installing sediment traps to reduce the load, although the efficacy of such measures cannot be taken for granted and needs to be monitored.

Fish farms are also capable of introducing large loads of suspended material into high quality headwaters (Mainstone *et al.* 1989). Settlement ponds have now been installed on many farms in order to reduce loadings, although adequate maintenance of these ponds is often lacking. For instance, fish have been observed in settlement ponds, which greatly reduces the efficacy of the settlement process due to the turbulence created. The cleaning out process can also introduce large transient loads of suspended matter to the adjacent river if precautions are not taken.

Observations of impoverished trout populations in the upper reaches of the River Piddle, (Table 5.5, NRA South Western Region 1993), have been linked to low flows exacerbated by abstraction, in addition to excessive rates of siltation brought on by the reduced current velocities and high rates of sediment delivery to the stream. Figure 5.8 shows the extent of siltation along the main river in an earlier survey (Wessex Water Authority 1988). The implied mechanisms of impact are reduced availability of spawning habitat and reduced fry territory and pool habitat under low flows. Stock damage to riverbanks is cited as a likely cause of high sediment inputs, together with the conversion of riparian land from pasture to arable. Figure 5.9 illustrates the widespread bank damage inflicted by livestock in the upper reaches where riparian areas are unfenced (Wessex Water Authority 1988). Table 5.6 provides a comparison of trout parr abundance in the upper Piddle and two major tributaries with lower levels of bank damage and siltation, indicating a strong coincidence of poor trout survival, high siltation rates and extensive bank damage (Wessex Water Authority 1988). Possible obstructions to the upstream migration of adult trout into the upper Piddle were investigated and it was concluded that they were probably not a major constraining factor.

Excessive siltation has been observed in the headwaters of the Great Stour in Kent, at least partly as a result of low flows following motorway construction, drought and over-abstraction from the North Downs (NRA Southern Region, undated a). A similar situation has been observed in spawning gravels in streams of the upper Medway, which is being rectified by high pressure hosing and channel rehabilitation to encourage natural scouring (NRA Southern Region, undated b).

Nationally, concern over the effects of gravel siltation on the sustainability of fish (particularly salmonid) populations is widespread, although it is difficult to gauge the extent of impact. In upland headwaters, scouring forces will generally be high owing to their flashy characteristics, and this may result in relatively clean gravels even where the suspended solids loading is high. In such situations, gravels further downstream are likely to bear a greater impact, in larger rivers where water energy declines sufficiently for significant sedimentation to occur. In lowland catchments with less flashy characteristics, there will be a greater likelihood of siltation effects in headwaters owing to the lower scouring capacity.

5.7 Alterations to flow regime

Flow and current velocity are critically important factors for any riverine fish populations, and variations in both parameters are at their greatest in headwaters. Changes to the natural flow regime can affect fish populations in a number of ways, which can be summarised as follows:

- reduction in habitat size (length, width and depth) and consequent increase in competition/predation;
- loss/replacement of habitat niches;
- reduced dissolved oxygen levels in the water column and within substrate interstices;
- increased siltation of the riverbed (dealt with in Section 5.6);
- increased water temperatures;
- reduced food supply for juveniles;
- reduced access for migrating adults;
- reduced dilution of pollutant inputs.

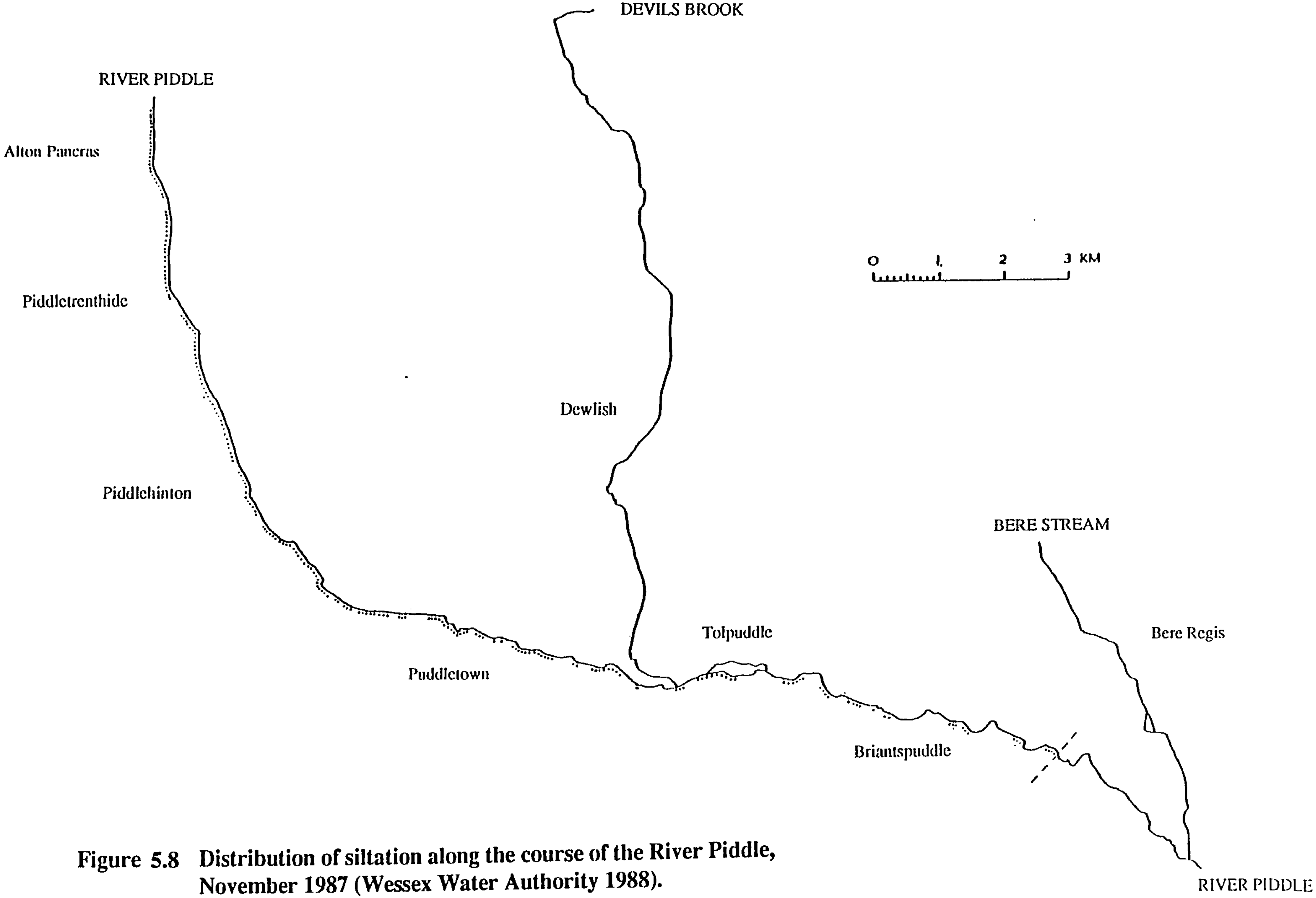


Figure 5.8 Distribution of siltation along the course of the River Piddle, November 1987 (Wessex Water Authority 1988).

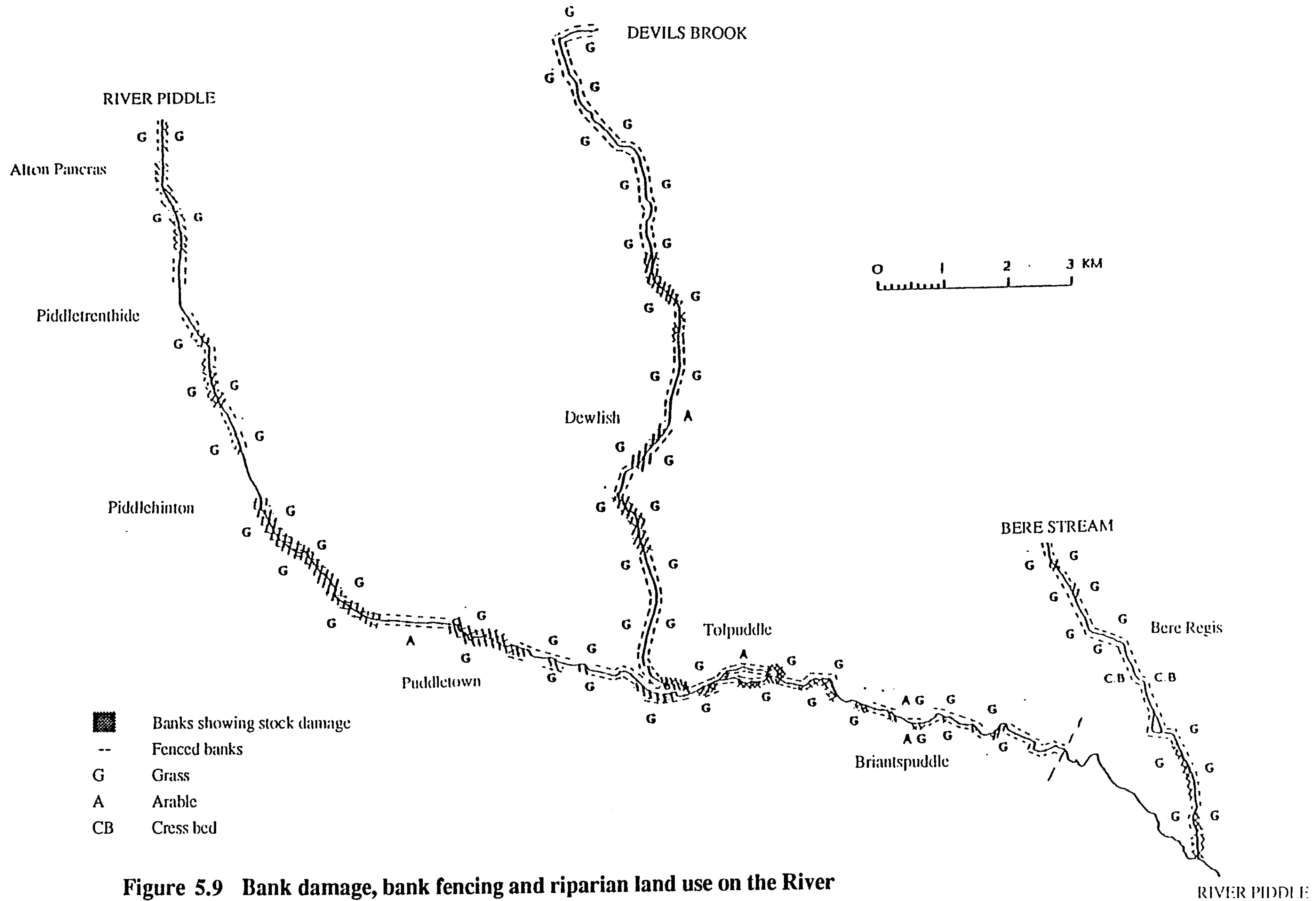


Figure 5.9 **Bank damage, bank fencing and riparian land use on the River Piddle, October 1987 (Wessex Water Authority 1988).**

Table 5.5 Trout abundances on the River Piddle (NRA South-western Region 1993)

Distance from source (km)	Mean wetted width	0+ trout	>0+ trout
4.9	2.7	0	0
5.0	2.4	6	0
5.2	2.4	0	0
5.4	3.1	0	0
5.6	2.2	0	0
5.8	2.0	0	0
5.9	2.4	0	0
6.0	1.7	0	0
7.6	3.0	0	0
7.8	2.2	0	0
8.0	2.9	0	0
8.2	3.2	0	0
8.4	2.3	0	0
8.6	2.7	0	0
8.8	2.8	0	0
9.0	2.5	0	0
11.6	2.9	28	5
12.4	4.5	25	7
12.6	5.4	11	3
13.0	5.7	84	1
13.2	5.4	52	30
13.5	4.7	31	9

Values are numbers per 300 metres caught with fixed effort fishing

Aprahamian (1986) reviewed the principal mechanisms of effect that can act on different life stages in salmonid populations. In terms of the survival of eggs and very young fry, reduced flows in winter can lead to the dewatering of redds (Becker and Neitzel 1985) or at least to reduced oxygen supplies to developing eggs and emerging fry (Wickett 1958). Reduced spring flows, during alevin emergence, have been found to be related to low population densities of subsequent life stages (Frenette *et al.* 1984, Solomon and Paterson 1984). Reductions in current velocity (to less than 0.3 m s^{-1}) have been found to result in the movement of fry off their typical riffle habitat and into pools (Campbell and Scott 1984), where predation pressure from adult fish and bird and mammalian predators is increased. High river flows during downstream smolt migration (April to June) have been suggested as being favourable to migration success (Frazer 1975), increasing habitat availability and reducing competition and predation pressures. The implication is that reduced flows during this period may affect the size of the returning adult population. Adult movement upstream appears to be triggered at a range of flows within any one river, relating to the occurrence of 'freshets' following rainfall. The flow rate at such times has to be sufficient to allow passage past obstacles (such as waterfalls and weirs) that may be impassable under low flows.

Table 5.6 Trout parr densities in the Upper Piddle and two tributaries with lower levels of siltation, 1987 (Wessex Water Authority 1988)

Watercourse	Trout parr density (No. $100m^{-1}$)	River length surveyed (m)	% area of bed silt-covered*	% bank length stock damaged
Upper Piddle (3 sites)	0	1200	65/18	65
Bere Stream (1 site)	3.53	200	10/0.5	17
Devil's Brook (2 sites)	3.45	600	13/11	13

* First value was recorded in October 1987, the second in March 1988

Alterations to flow regime take many forms and can be caused by a range of activities. The principal causes of detrimental effects are abstraction, impoundment (these two often in association with each other), flood defence and land drainage. Abstractions can be made either directly from the stream or from groundwater sources feeding the stream. Abstractions for potable supply, industrial supply, and for spray irrigation are large consumers of water, but smaller abstractions that are more specific to headwaters are made by fish farms and watercress farms. Abstractions can be continuous or intermittent and can result in extreme low flow conditions. Where they are associated with impoundment, current velocities immediately upstream are greatly reduced (and water depth increased), whilst velocities downstream can lose their flashiness and consequently their bed-scouring potential. Flood defence and land drainage activities are associated with an increase in the range of current velocities encountered, in addition to reductions in the spatial diversity of flow conditions within the channel.

The typical low flow period of late summer and early autumn can be a particularly stressful time for headwater fish populations, where individuals vacate their territories and crowd into available pools or migrate downstream (if possible). Additional reductions in flow over and above natural conditions will exacerbate the already stressful conditions. Observations on the River Piddle suggest that abstraction rates in the upper reaches during this period are sufficiently high to constrain trout populations (Wessex Water Authority 1988). Taking as an indicator the average daily flow during the low flow period as a percentage of the average daily flow over the whole year, sites in the upper reaches have been found to decline from 25.5-27.3% to 10.6-12.8% as a result of abstractions. This takes such sites from flow conditions at which reasonable trout populations can be supported to conditions indicative of high stress (Wessex Water Authority 1988). Later application of the Instream Flow Incremental Methodology (IFIM) highlighted significant reductions in summer habitat availability for adult and juvenile trout at sites on the upper Piddle and one of its tributaries (Devil's Brook), as a result of abstractions (Johnson and Elliot 1995). Effects were most notable for juveniles, where reductions in Weighted Usable Area of over 20% were evident for over 80 and 60% of the time on the upper Piddle and Devil's Brook respectively. Reductions of over 50% were operating for 70 and 30% of the time respectively. A survey of the river in 1994 (NRA South Western Region 1994) highlights a distinctive trough in 0+ trout numbers located about 4 km from the source (Figure 5.10), coinciding with the cone of depression produced by an abstraction at Briantspuddle (this effect was also noted in previous surveys).

Operational investigations have been undertaken into the effects of groundwater abstraction on resident fish populations in the River Allen, a small chalkstream (NRA South Western Region 1992). Application of the IFIM at two sites demonstrated significant reductions in available habitat for adult and juvenile trout and juvenile salmon, which were attributed to an adjacent abstraction. In a later survey, the discontinuous nature of the distribution of trout fry along the river was related to the occurrence of deep glide habitat created by impoundments for abstraction (NRA South Western Region 1994), such habitat being unsuitable for juvenile trout and replacing the natural riffle-pool sequence. Figure 5.11 shows these discontinuities in relation to the locations of abstraction points for mills.

Land drainage for agricultural or forestry purposes has a considerable impact on the pattern of river flow throughout the year, leading to higher peak flows during rainfall and lower summer flows due to a reduction in the water retention capacity of the soil. Increased peak flows can disrupt headwater fish populations by physically displacing individuals downstream, from where it may be difficult to regain station due to access difficulties. This impact is particularly severe if refugia from high current velocities have been removed during land drainage or for other purposes (see Section 5.3). Lower summer flows can lead to reductions in water depth and consequently habitat availability, to the point where the stream head might migrate downstream for considerable distances.

Fish farm abstractions can have a considerable effect on river flows over the length of river between the inflow and outflow, which can be up to several kilometres in length on streams of low gradient (Mainstone *et al.* 1989). The situation can be particularly pronounced if the farm is located on headwater streams with little, if any, spare capacity to accommodate abstraction. A fishery survey by NRA Southern Region (internal survey report) on the Wiston Brook, a headwater stream of around 1 metre in width, revealed substantially reduced flows (though not measured) as a result of a fish farm abstraction. This was coincident with a complete absence of brown trout in the affected reach, with numerous trout occurring below the discharge where the full flow was restored. Other than the difference in flow, the habitat in the affected and unaffected reaches was comparable, leading to the conclusion that the abstraction was making the affected reach unsuitable for trout.

Lowland headwaters are equally vulnerable to abstractions made by watercress farms, which are typically located in the upper reaches of chalk streams. This is largely a regional problem, since 90% of England's water cress production is concentrated in Dorset, Hampshire and Wiltshire (Casey and Smith 1994). However, pressure on headwaters in this area can be intense; for instance, the Test supports seven farms in its upper reaches and the Itchen supports ten (Thorpe, undated). Indeed, cress farming accounts for 90% of licensed water abstraction on the Itchen (NRA 1992), although no information is available on the effects on flows in headwater streams. It is important to note that, whilst cress farms abstract water from both streams and groundwater and therefore create the potential for reduced stream flows, some also maintain or enhance flows in chalk streams through borehole pumping of water over the cress beds and into the receiving stream. Their net impact on flows is therefore not easy to assess and needs to be considered on a case-by-case basis.

At the extreme, river sections can dry up as a result of natural or artificially induced reductions in flow, and inevitably headwaters are most susceptible by virtue of their position in the catchment. This can result in adult and juvenile fish being stranded in isolated pools, which slowly dry out (Solomon and Templeton 1976). It has been shown that salmonids can make use of naturally ephemeral headwater streams for spawning during the winter period when access is made possible during high flows (Mann 1989, NRA South Western Region 1992); in such situations, juvenile fish have been observed to migrate downstream as flows decline and the channel dries out in late summer (e.g. Mann 1989). In winterbournes, it has been suggested that juvenile salmonid production may be important in wet years but less successful in dry years (Berrie and Wright 1984), with the implication that any artificial reductions in flow that extend the dry phase are likely to hamper the winterbourne's contribution to recruitment within the catchment.

It is currently not possible to provide a reasonable assessment of the scale of low-flow impacts on headwater fish populations nationally, or to separate the effects on flow of natural drought and artificial abstractions at the national scale. However, rapid assessment techniques that could provide a relevant overview of flow conditions are apparently being developed (pers. comm. D Bird, South West Region). To date, the most comprehensive assessment of artificially impacted flows in rivers has been provided by the NRA (as was) as part of their low flow alleviation programme (NRA 1993) This provides details of the 40 rivers of most concern across England and Wales at that time (Figure 5.12), these being distributed widely and largely relating to groundwater abstractions. The flow problems on these priority rivers are briefly summarised in the report, with many having reduced flows in the headwaters. Table 5.7 attempts to identify those rivers with headwater problems, based on the summary descriptions provided in the report. The decision as to whether headwaters are affected in each case was based on the distance from source (the only relevant parameter with information available in the report), interpreting distances of less than around 5 km as headwater streams.

The NRA report inevitably concentrates on the most obvious examples of low flows, particularly those giving rise to public complaints and with relatively simple causes. There will be many more catchments with flow problems of a significant and complex nature, particularly in small headwater streams that are not publicly accessible and therefore attract less attention. For instance, the effects of land drainage on summer flows in headwater streams are easily overlooked, since they are widespread, they are not associated with physical abstraction (which can be gauged) and they are difficult to separate from normal seasonal downstream migrations of stream heads. A reasonable national assessment of this particular problem might be made using a risk assessment procedure based on the prevalence of land drainage activities in relation to catchment characteristics (such as soil type and drainage density), linked to detailed before/after investigations of specific schemes.

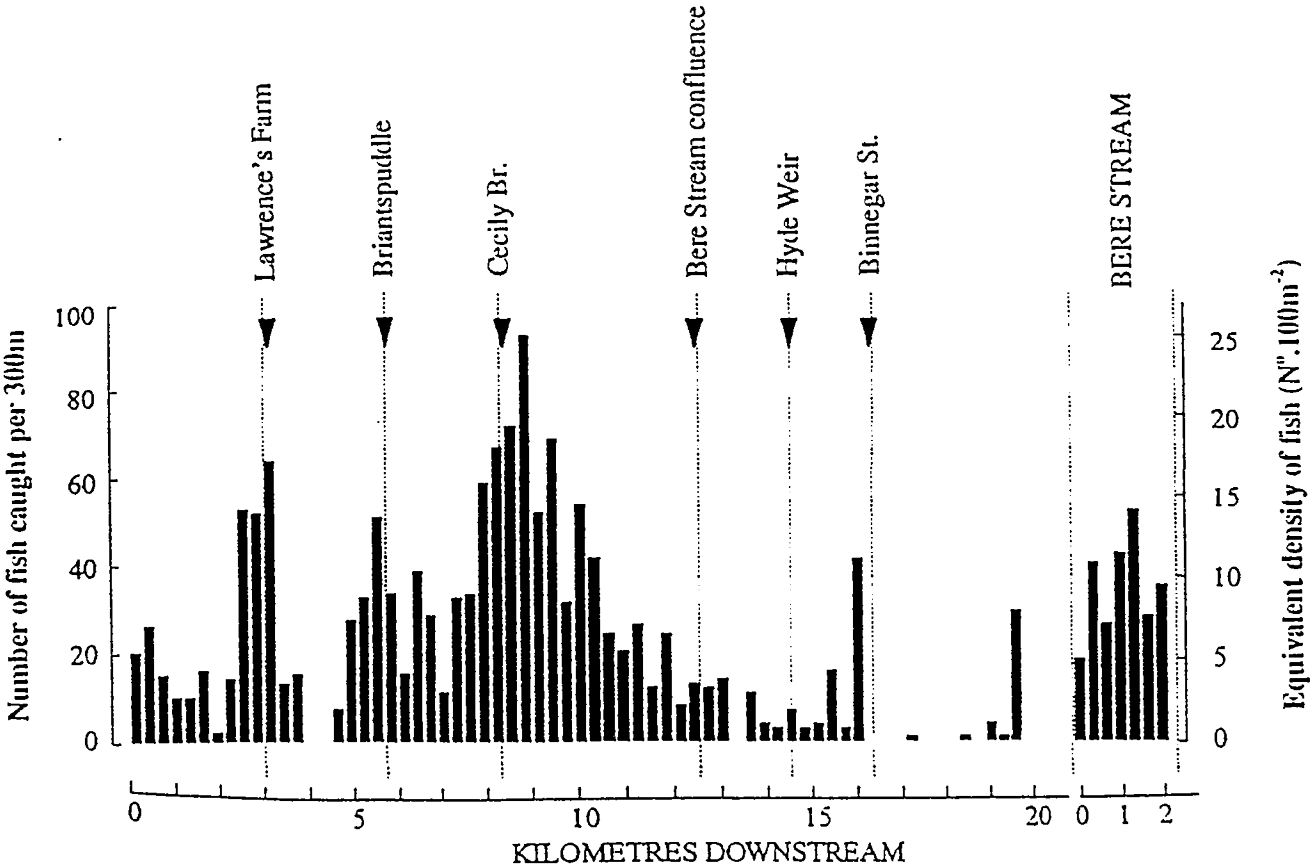


Figure 5.10 Brown trout fry caught in the River Piddle in 1994 (NRA South Western Region 1994).

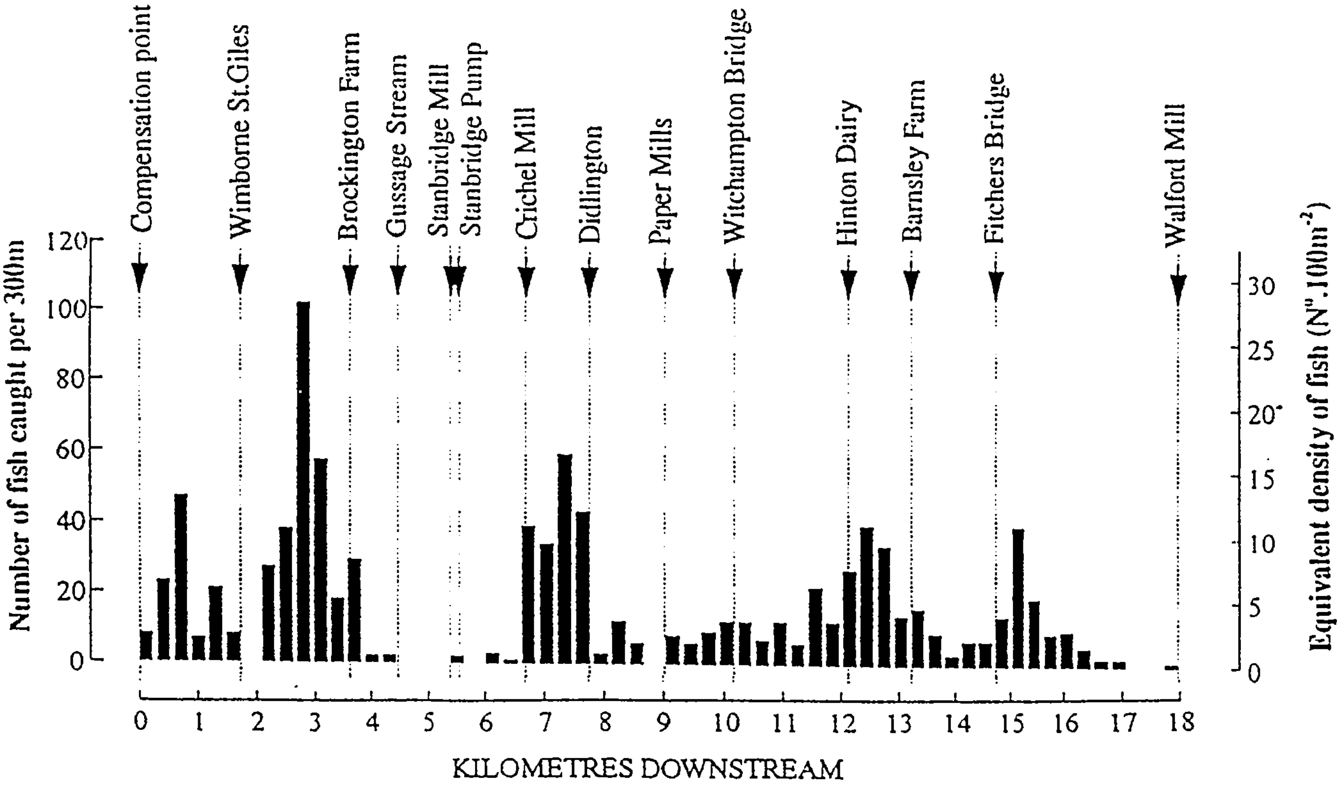


Figure 5.11 Brown trout fry caught in the River Allen in 1994 (NRA South Western Region 1994).

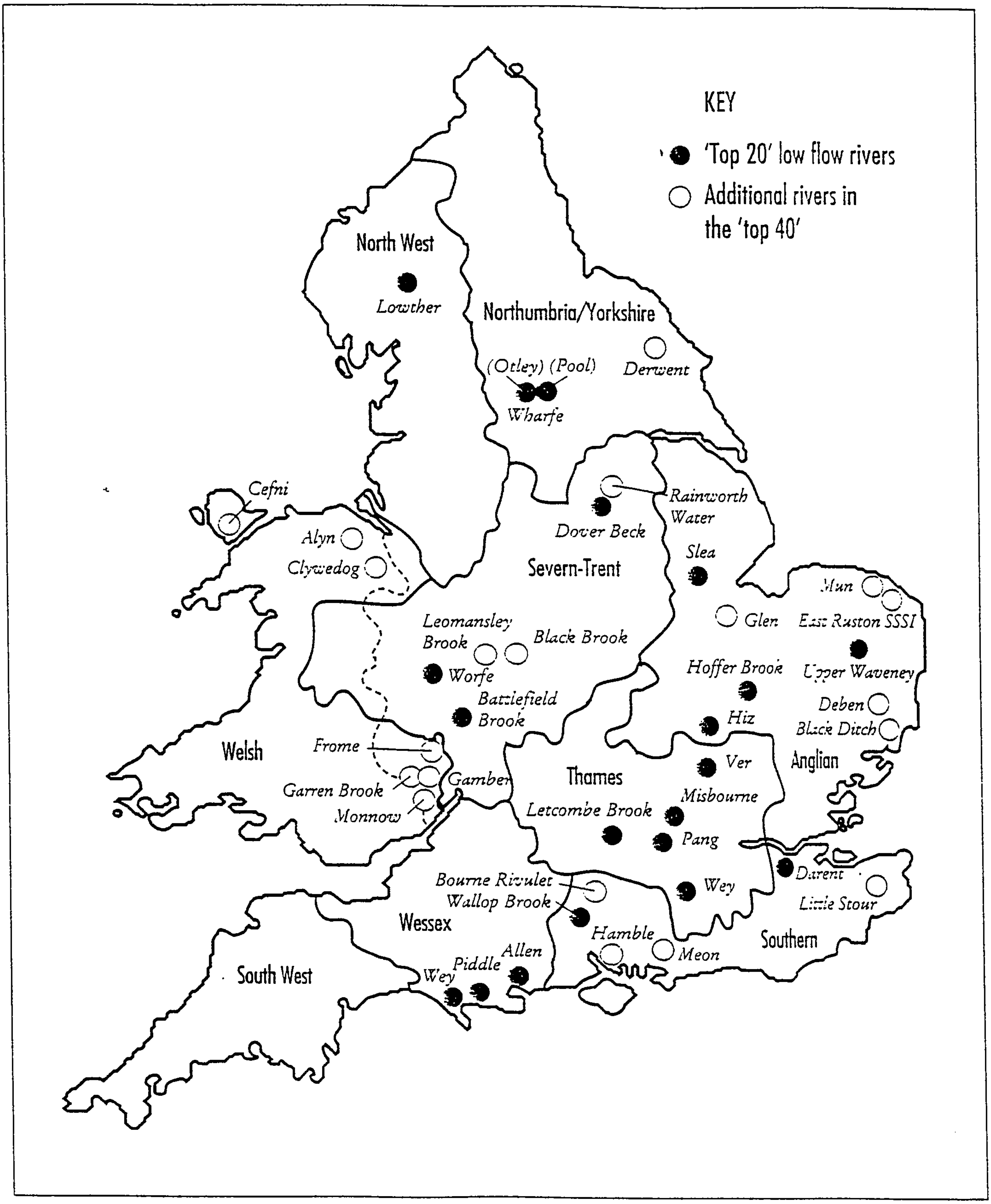


Figure 5.12 Locations of the 'top forty' low-flow rivers in England and Wales (NRA 1993).

Table 5.7 The involvement of headwaters in low flow problems on priority rivers in England and Wales (based on information in NRA 1993)

Region	River	Headwaters involved?	Principal problem
Anglian	Black Ditch	No	
	Glen	Yes	Gr. abstraction
	Slea	No	
	Hiz	Yes	Gr. abstraction
	Mun	No	
	East Ruston SSSI	Yes	Gr. abstraction
	Deben	No	
	Upper Waveney	No	
	Hoffer Brook	Yes	Abstraction
Northumbria and Yorkshire	Wharfe at Pool	No	
	Wharfe at Otley	No	
	Derwent	No	
North West	Lowther	Yes	Abstraction
Severn-Trent	Battlefield Brook	Yes	Abstraction
	Leomansley Brook	Yes	Gr. abstraction
	Dover Beck	Yes	Gr. abstraction
	Worfe	Yes	Gr. abstraction
	Rainworth Water	Yes	Gr. abstraction
	Black Brook	No	
Southern	Darent	No	
	Bourne Rivulet	Yes	Gr. abstraction
	Wallop Brook	No	
	Hamble	Yes	Gr. abstraction
	Little Stour	Yes	Gr. abstraction
	Meon	No	
Thames	Letcombe Brook	Yes	Gr. abstraction
	Pang	Yes	Gr. abstraction
	Ver	Ver	Gr. abstraction
	Misbourne	Yes	Gr. abstraction
	Wey	Yes	Gr. abstraction
Welsh	Cefni	No	
	Clywedog	?	
	Garren Brook	?	
	Gamber	Yes	Spray irrigation
	Alyn	No	
	Frome	Yes	?
	Monnow	?	
Wessex	Allen	Yes	Gr. abstraction
	Piddle	Yes	Gr. abstraction
	Wey	Yes	Gr. abstraction

5.8 Barriers to movement

Physical or chemical barriers that interfere with fish movements between headwaters and the rest of the river network can inevitably have considerable consequences for both headwater and main river fish populations. The well-being of main river populations are at risk when small weirs are constructed on minor tributaries that are used as spawning areas. Where such tributaries cannot satisfy the complete life cycle of a species without connection to the main river, impoundment can eradicate the species from the tributary. Larger impoundments on main rivers can prevent migratory salmonids reaching headwater areas (for example the Kielder scheme, Brady *et al.* 1985), resulting in the loss of large areas of spawning habitat to the species. However, it is interesting to note that Crisp (1985) found that brown trout densities increased in the headwaters of the Upper Tees after construction of the Cow Green Reservoir, thought to be due to spawning by larger reservoir trout. Impoundments may be constructed for abstraction, the maintenance of water depth, flow compensation, hydro-electric power, navigation or a combination of these purposes. It is not possible to assess the scale of impact nationally with available information.

Chemical barriers to movement are likely to play an important role in lowland areas, although no studies are known to have been undertaken on this issue. Fish movement between adjacent small streams that connect directly to a main lowland river may be greatly impaired if the main river has inadequate water quality for the species concerned. This is most likely to be a problem for trout, which are present in many lowland catchments only in minor streams. Such chemical barriers would greatly increase the vulnerability of lowland trout populations, since the potential for recolonisation from other streams following impact would be restricted.

5.9 Mine drainage

Mining of coal and metal ore has a long history in England and Wales, resulting in extensive mine workings and spoil heaps in the north and west, often in headwater areas. Contaminated waters can originate from run-off draining spoil heaps or from water finding its way into mines and either being pumped or draining into surface waters. Mine drainage waters can vary considerably in terms of quality, depending upon the geological characteristics of the area, such that it is difficult to generalise. However, they are generally low in pH (although they can be alkaline) with varying amounts of a range of heavy metals, such as cadmium, copper, zinc and aluminium. They often contain high concentrations of iron in the form of oxides, creating a bright orange floc (ochre) that can carpet the stream bed. They may be also saline, caused by the leaching of chloride and sulphate salts.

Abandoned mine workings are often the most problematical in terms of impact on surface waters, since their drainage waters are essentially uncontrolled by current water pollution legislation. Such mines fill up with water through seepage, allowing long contact times between water and rock. Leaching rates are therefore high, and the low pH, metal-laden water eventually finds its way into the river network through adits, fissures or via seepage. Active mine workings have consented discharges and drainages water are generally treated by settlement and neutralisation prior to reaching surface waters.

In addition to the direct toxic effects of acidity and heavy metals (previously discussed in Section 5.4), ochreous floc can carpet the streambed, physically clogging gravel interstices and both reducing salmonid spawning success (see Section 5.6) and impoverishing the benthic macroinvertebrate community (a vital food source for fish populations). Examples of reported impacts on headwaters include the Nant Melyn (a tributary of the River Aman in Wales), where trout abundances are around 25% of those predicted by HABSCORE (NRA 1994).

Regarding the extent of impact on headwater fisheries, the only known national assessment of the effects of mine drainage has been produced by the NRA (as was, 1994). However, the figures given relate to general water quality impact and only relate to classified river reaches, thereby excluding headwaters in almost all cases. Tables 5.8 and 5.9 outline the extent of water quality impact from coal and metal mine operations on classified rivers, and it is logical to assume that for every kilometre in these tables many kilometres of headwater streams will be affected. The scale of effect of these water quality impacts on fish populations is unclear, although it is likely to be considerable despite the fact that fish are known to acclimate to elevated metal concentrations (Alabaster and Lloyd 1982). In terms of geographical extent, impacts from coal mines (largely abandoned) are confined to Welsh, North East, North West and Midlands Regions, with impacts from metal ore mines additionally affecting South West Region. Indeed, this latter Region is the worst affected by drainage from metal ore mines.

Table 5.8 Lengths of classified river affected by discharges from coal mines (NRA 1994)

Region	No. of discharges	Length affected (km)	No. of working mines	No. of abandoned mines
North East	51	68	4	47
North West	24	57	0	24
Midlands	4	19	0	4
Welsh	21	54	0	21

Table 5.9 Lengths of classified river affected by discharges from metal ore mines (NRA 1994)

Region	No. of discharges	Length affected (km)	No. of working mines	No. of abandoned mines
North East	20	43	2	17
North West	5	36	1	4
Midlands	2	5	0	2
South West	Unknown	212	1	~1700
Welsh	21	54	0	21

5.10 Pesticides

Pesticides can gain entry to headwater streams from a number of sources, the most important being sheepdipping operations and pesticide applications on arable crops, soft fruits, forestry plantations and grassland. In chalk streams, the application of pesticides directly to commercial cress beds represent an obvious threat to headwaters. Whilst most modern chemicals used are formulated for specific invertebrate or plant groups, non-target invertebrate species can be affected by pulses of contamination, with possible indirect effects on fish populations due to interruptions in food supply. In addition, high exposure levels caused by spillages or gross misuse (such as the emptying of sheep dippers directly into watercourses) can cause direct effects and have been implicated in a number of reported pollution incidents (NRA 1992). The accumulation of modern agrochemicals in fish tissue, to levels at which toxic effects may be observed, is far less likely than with the highly bioaccumulable organochlorines that have now been replaced in virtually all applications. However, residual levels of prohibited pesticides remain in river systems and may exert a low-level effect on food webs.

Sheepdipping represents a significant threat to headwater fish populations in the north and west of England and in Wales, where a large number of dippers are operated in remote locations, often by third parties using mobile facilities (Mainstone *et al.* 1994c). Old dippers are often sited close to watercourses where seepage, overflow (during rainfall) and spillage into the receiving water is likely (Blackmore and Clark 1994). Recent trends towards the use of pour-on treatments (Coddington 1992) are reducing the risk from this source, together with the withdrawal of the Sheep Scab Order that required sheep in England and Wales to be treated twice yearly. However, a careful watch needs to be kept on the impact of this activity.

Review work by Ashby-Crane *et al.* (1994) revealed little information on the effects of pesticides on fish populations in environmentally realistic situations. Work in the US on the effects on invertebrate drift following pesticide applications to forest plantations has shown the potential effects on the food supply to headwater fish populations (e.g. Kreutzweiser and Kingsbury 1987), although no similar studies are known to have been undertaken in the UK. The indirect effects of reductions in invertebrate food supply following such applications have been rarely studied. Kreutzweiser (1990) concluded that there were no effects on the density, age structure, movement or condition of brook trout following the treatment of a Canadian stream with permethrin, which induced massive invertebrate drift and significant reductions in benthic macroinvertebrate densities. The likelihood of indirect effects will depend upon a variety of factors, including:

1. the fish species involved and their dependence upon the affected non-target species;

2. the magnitude of downstream drift from unaffected reaches upstream (to act as an immediate food source);

3. the rate of recovery of the benthic macroinvertebrate population (which largely depends upon downstream drift);

4. the ability of the fish population to utilise alternative (including allochthonous) sources of food if necessary.

The second and third factors can become extremely important in headwaters, where unaffected reaches upstream are short or non-existent and the rate of recolonisation can be impaired by the lack of potential colonists. Regarding the fourth factor, Kreutzweiser and Kingsbury (1987) found that brook trout in a stream subjected to a high dose of insecticide survived almost exclusively on terrestrial arthropods and non-insect aquatic invertebrates.

New research is due to commence within the Environment Agency's R&D Programme on the impact of pesticides on river ecology (New Start Project P2C(96)5). This is likely to focus on headwater streams, where impacts from agrochemicals are most likely (owing to the lack of dilution capacity and potential recolonisation difficulties).

5.11 Genetic introgression and competition

Although the genetic integrity of coarse fish populations has been greatly modified by stocking in England and Wales, a high degree of genetic heterozygosity is known to exist in salmonid populations. Extensive small-scale genetic differences have been found in brown trout populations only a few kilometres apart (Ryman 1981), in small streams where access is limited. Whilst the adaptive significance of such differences is unclear, there is potential for impacts on the ecological 'fitness' of such populations if their genetic composition is modified by breeding contact with other genotypes. Impacts may also occur purely as a result of competition from non-resident fish.

Situations in which contact with non-resident fish may occur can be divided into three main areas:

1. stocking;
2. provision of access for migratory salmonids to previously inaccessible headwaters (such as the opening of the Conwy Falls fishpass, NRA Welsh Region 1992);
3. accidental escapes from fish farms.

The need for sensitive management of genetically distinct salmonid populations has been stressed in a number of previous reports (Mainstone *et al.* 1989, Mainstone *et al.* 1992), and this need is perhaps nowhere more acute than in headwater streams, where isolated populations are most likely to be encountered.

6. CONCLUSIONS

6.1 Defining headwaters

1. The term headwater stream has historically been used very loosely without any clear definition that can be related to stream size or position in the river network. Perceptions of a headwater therefore vary widely, particularly in relation to the scale of observation. Any definition in the fishery context requires a reasonable consensus of opinion among the users of the term.

2. Within any general definition of headwaters, there is a wide range of river habitat conditions, ranging from mountainous brooks to chalk streams. The most sensible approach is deemed to be a broad definition encompassing everybody's view of headwaters, with a classification of headwater types based upon ecological considerations.

3. The definition used in Environment Agency Project 242, that is all watercourses within 2.5 km from source, omits many unclassified reaches that require greater attention in the regulatory context. In the fishery context, reaches between the Project 242 definition of headwaters and the classified network are likely to be more important than reaches within 2.5 km from source, as they represent more substantial fish habitats and are likely to have more interaction with the main river network.

6.2 The importance of headwaters

1. Of the fish species that make significant use of headwaters in England and Wales, brown trout and Atlantic salmon are the most economically important, with salmon appearing to make less use than trout of streams less than 3 metres in width. Other species of angling and/or commercial interest that can exploit headwater habitats significantly include dace, chub and eel. Typically, younger age classes increasingly dominate the community as stream size declines.

2. Headwaters are highly important habitats for smaller fish species, comprising bullhead, three-spined stickleback, lamprey species, stoneloach and minnow, with fish communities generally becoming more and more dominated by such species as stream size (particularly depth) declines.

3. There is little information in the published literature that relates the presence of different species and age classes to objective descriptors of stream size and location in the river network. The original fishery classification database has been used in this study as the best collated source of information available. However, a good deal more information exists within Agency archives that could be used to provide an overview of the occurrence of different species in small streams.

4. Very little work has been identified that relates to the detailed quantification of the spatial distribution of fish standing stock across the catchment, considering different species, age classes, and watercourses of different size and location in the catchment. Such work is essential to a proper understanding of the significance of headwaters in a catchment context. The analysis undertaken in the present study, using historical data for two contrasting catchments, has illustrated the type of assessment required. It has also highlighted the need for a customised survey programme that collects data specifically for the assessment.

5. Modelling of historical fishery data from the Western Cleddau (a catchment in West Wales of high drainage density) has suggested that, in the absence of organic pollution problems, around two-thirds of brown trout fry and a quarter of trout parr would reside within first order streams, which generally lie within 2.5 km from source. Around half the trout parr in the catchment would reside within 5 km from source. This suggests a highly significant contribution from small streams in such catchments, and confirms their importance to the catchment fishery resource. However, it is unclear to what extent the abundance of smaller fish in these headwaters are incorporated into adult populations further downstream.

6. The Western Cleddau analysis suggests a much greater significance of small streams in western catchments than the work of Cooper, who estimated their contribution in the Conwy catchment. However, the Conwy is a very different catchment, being much larger and rising at higher altitude. In addition, some of the headwaters suffer from acidification, and Cooper's analysis was undertaken during a period of low rainfall in which many first order streams dried out.

7. Results from the Colne (Thames Region), focusing on the western half of the catchment, suggest that first order streams contribute very little (less than 4%) to the standing stock of chub and dace in chalkstream-dominated areas, with around 70 and 80% respectively of the stock residing in the main river channel. The contribution of first order streams to perch numbers is somewhat higher but still modest (at just over 10%). Brown trout were not considered owing to the absence of any good relationship between densities and the parameters available for modelling.

8. The spatial resolution of the Colne analysis was too crude to assess the importance of reaches on first order streams that are adjacent to the main river. No previous analyses are known to have been undertaken on similar lowland catchments.

9. In terms of the distribution of standing stock between the classified and unclassified parts of the river network, modelling results suggest that trout fry and parr numbers in unclassified reaches account for 86 and 73% respectively of the total standing stock in the Western Cleddau catchment. Small streams therefore represent an extremely important habitat for this species in such catchments. In the western half of the Colne catchment, dace and chub numbers in unclassified reaches account for less than 2% of the total standing stock, with perch numbers accounting for just under 8%. This reflects the fact that, in chalkstream-dominated catchments, there are fewer and larger watercourses that tend to be classified very close to their source.

10. Such assessments of the distribution of standing stock are constrained in salmonid-dominated regions by a lack of knowledge of main river populations, and in cyprinid-dominated regions by a lack of knowledge of headwater populations (and main river populations where main rivers are very large). Constraints in cyprinid-dominated regions are more easily overcome, since headwaters are not difficult to fish and methods exist for fishing main river sections in lowland areas (which is not the case in salmonid-dominated areas).

11. Very little information exists on the extent and importance of fish movements in and out of streams of different size, either in terms of adult movements upstream or juvenile movements downstream. Such information is crucial if a proper understanding is to be gained of the extent of interaction between fish populations in small streams and the main river.

12. It is generally regarded that small tributaries running directly into main rivers can be highly important in terms of the provision of spawning and juvenile-rearing habitat for main river populations. However, no research has been identified that quantifies the extent to which fish populations resident in larger rivers depend upon juvenile recruitment from any type of minor tributaries. The importance of headwaters in this respect is likely to vary greatly on a site-specific basis.

6.3 Intrinsic vulnerability

1. Fish populations in small streams are vulnerable to a wide range of threats by virtue of their size and location in the river network. Key factors are their numerous but individually insignificant nature, the low dilution capacity afforded to polluting inputs, their small gathering grounds, their remoteness from the main river network in many instances, and the frequent lack of accessibility to fish from other areas.

2. Small streams that are remote from the main river network are highly vulnerable to physical habitat degradation, as they have to satisfy the habitat requirements of the whole life cycle, often within restricted lengths of river, in order to maintain viable fish populations.

3. The rate of fish population recovery is a key factor in the assessment of vulnerability. Little is known about rates of population recovery following transient impacts (such as pollution incidents), and how the rate varies with local conditions and the species concerned. A better understanding of the influence of local conditions on population recovery is required if vulnerability is to be assessed in a meaningful way.

6.4 Impacts on headwaters

1. Headwaters are subjected to a range of impacts that can have important consequences for resident fish populations, problems being exacerbated by their intrinsic vulnerability. Whilst the nature of most impacts is relatively well known, the extent of effects nationally is generally poorly understood. The quantification of impacts and the linkage of cause and effect is frequently impaired by a lack of knowledge of baseline conditions,

natural variability in fish populations, and the occurrence of different mechanisms of impact acting (and interacting) simultaneously.

2. The River Habitat Survey database provides clear evidence of extensive physical degradation of headwater habitats across England and Wales, associated with channel resectioning. Of the RHS sites within 10 km from source, around 15-20% show extensive resectioning of an obvious nature, even at stream widths of 2 or 3 metres. Increasing amounts of resectioning at sites appears to be associated with a decline in the occurrence of riffle-pool sequences.

3. Fish populations are known to suffer from the loss of physical habitat diversity typically produced by resectioning, but quantitative evidence of effects on fish populations is sparse in both headwaters and larger rivers. There is a clear need for an evaluation tool that quantifies physical habitat quality in a way that can be related to physical impacts and fishery status. HABSCORE could form the basis of this tool in upland areas (at present it cannot identify physical impacts as such but can compare relative habitat quality between sites), but no existing system parallels this in cyprinid-dominated areas. This issue is being addressed under Agency Project EA001, concerning the development of a river fisheries habitat inventory.

4. Siltation of spawning gravels seems to be an important mechanism of impact in salmonid rivers, with trials of gravel-cleaning methods on-going in numerous catchments. However, the extent to which headwaters are affected by gravel siltation is unclear.

5. Headwaters in a range of catchments are known to be affected by low flows as a result of human activity, particularly groundwater abstraction. However, no true national assessment is possible with available data and there would appear to be little detailed quantitative data on the individual effects of different activities, particularly land drainage schemes, on flows and fish populations in headwaters.

6. Extensive work has been, and is being, undertaken on the effects of acidification on headwater fish populations in Wales. Less work seems to have been undertaken in acid-vulnerable areas in England. Quantification of the extent of impact is hampered by confounding environmental variables and the lack of suitable control sites.

7. Organic pollution from livestock farming is a serious problem in headwater areas with intensive livestock production, particularly the salmonid-dominated streams of the western half of England and West Wales. Inputs from septic tanks may be a significant insidious source of organic pollution in some areas, although this issue does not seem to have been studied.

8. Drainage from metal and coal mining activity, both present and historical, affects the water quality of headwaters in a number of Agency Regions, although the extent of effects on fish populations is not well documented.

9. Pesticides arising from a range of activities represent an insidious threat to headwater fish populations, largely through the potential to interrupt macroinvertebrate food availability. However, the known effects of modern chemicals on fish populations are restricted to episodic acute exposure due to occasional spillages or mis-use.

10. Fish stocking and escapees from fish farms have been responsible for the intermingling of genotypes in both salmonid- and cyprinid-dominated areas, presumably extending into many headwaters (particularly with respect to salmonids). In salmonid-dominated headwaters, genetically isolated populations remain vulnerable to such threats, whilst the extent of genetically distinct cyprinid populations in headwaters is unstudied.

7. RECOMMENDATIONS

7.1 Defining headwaters

1. Since an Agency definition of headwaters already exists that is relatively well-established but relates to a very restricted group of the smallest watercourses, it is recommended that the term 'minor stream' is used to describe the watercourses of interest in the fishery context.

2. The main driving force for the current study is the lack of protection afforded to fish populations that fall outside of the classified river network, and it is therefore logical to link the definition of minor streams to unclassified river reaches. However, since there are inconsistencies introduced into the classified/unclassified river networks by subjective considerations of 'local importance', *it is proposed that minor streams are defined as all streams allocated to Environment Agency Flow Category 1* (i.e. all streams with a mean annual flow less than the guideline value for classified reaches, $0.31\ m^3\ s^{-1}$), even though some will be part of the classified network. This provides an objective physical basis to the term, even though the reliability of the flow categorisation is likely to be poor owing to the lack of hard information on river flows.

3. These minor streams should be sub-divided into meaningful categories in the fishery context, using parameters considered in Section 2 of this report. This exercise should be undertaken using information on fish communities produced in Phase 2 of this project, and should attempt to incorporate the Project 242 definition of headwaters in some way.

7.2 Assessing the importance of headwaters

1. Existing raw data on fish populations in minor streams that are available from the Regions should be collated in order to improve the preliminary picture of minor stream utilisation produced in this Phase 1 analysis. Such a collation exercise would allow an exploratory analysis of species associations in relation to stream characteristics, and permit the results of detailed investigations of case study catchments (the basis of Phase 2) to be placed in a national context.

2. The Phase 2 survey design should aim to compartmentalise the standing stock of different species and year classes between reaches of different size and position in the river network, collecting data from a sampling programme designed for the purpose and building on the methodology used in this scoping study. It should also incorporate ways of assessing the scale and extent of fish movements in relation to minor streams so that their importance in supporting main river populations can be evaluated.

7.3 Specific studies of headwater vulnerability

1. The capacity for natural fishery recovery in minor streams should be investigated in relation to local conditions, considering factors such as drainage density, the proximity of sources of colonists and access difficulties (due to both physical and chemical barriers).

Whilst separate and detailed investigations are desirable, a broad classification of vulnerability can be produced as part of Phase 2 of this study.

7.4 Studies of specific impacts

1. It is recommended that studies of specific impacts (such as acidification, mine drainage, organic pollution from livestock farming, land drainage etc.) are not included in the Phase 2 design, since this would make the project too large and unmanageable and create possible overlap with on-going or new impact-orientated studies (see below).

2. The Agency needs to ensure that fish populations are considered in the New Start project on the impact of pesticides on river ecology (Project P2C(96)5), which is to focus on headwater streams. Consideration needs to be given to the possibility of both direct toxicological effects and indirect effects on invertebrate food supply.

3. The Agency also needs to ensure that the implications for fish populations are considered in the New Start project on the causes of poor water quality in headwater streams (Project P2C(96)2).

4. The effects of land drainage operations on flow regimes and fish populations in minor streams should be studied through a separate before/after analysis of planned drainage activity in contrasting catchments.

5. Greater emphasis should be placed on providing an overview assessment of the extent of fishery impact caused by headwater acidification in England, in addition to an assessment of the impact of mine drainage in minor streams in both England and Wales.

6. A brief desk-study should be undertaken into the potential of septic tank systems to affect water quality in small streams, with a view to assessing the likelihood of significant fishery impact (this may be covered in (3)).

8. DESIGN OF PHASE 2

8.1 Suggested Phase 2 aims

There are a number of issues that require investigation, but the aims of Phase 2 must be restricted to what is achievable with the funds likely to be available. Based on the recommendations made in the previous section, suggested specific objectives are given below.

(i) To characterise fish communities in the different types of minor stream occurring in England and Wales, by reference to historical data and new fieldwork in a number of case study catchments.

(ii) To describe and quantify the spatial distribution of fish species across the river network in case study catchments, to include consideration of the age structure of populations, in order to determine the importance of minor streams in relation to standing stocks.

(iii) To examine the nature and magnitude of interactions between observed standing stocks in minor streams and the main river network, in order to determine the extent of interdependence in different types of catchment.

(iv) To use information from (ii) and (iii) to build a model which would allow the secondary effects of impacts occurring in different parts of the catchment to be assessed in relation to minor stream populations and whole river communities.

(v) To use the model in (iv) to provide a classification of the vulnerability of fish populations in the minor streams of different catchment types to different types of impact.

The first two objectives are the easiest to achieve and largely build on and refine what has been done in Phase 1. Objective (iii) relates to fish movement at different stages of the life cycle, which is an extremely important aspect of the importance of minor streams but is equally difficult to address in a meaningful way with limited funds. Objectives (iv) and (v) depend to a large extent on fulfilling Objective (iii). Objectives (ii) to (iv) would all need to be addressed through field investigations of representative case study catchments. Methods of fulfilling each objective are outlined in the following section.

8.2 Discussion of strategy

8.2.1 Objective (i)

A large amount of raw data on minor streams was identified in Phase 1 that could be put to good use. It would seem sensible for all available raw data on the presence/absence of fish species in minor streams to be collected from the Regions and collated into a single database of information in order to place the detailed results from Phase 2 into a national context. Any ancillary information useful in characterising the stream type (such as stream width, gradient, altitude and geology) would also be requested, and gaps in data availability filled in where possible through the use of OS and geological maps. Fishery data could be augmented by data collected in the case study catchments used to address Objectives (ii) to (iv).

Multivariate techniques (such as cluster analysis) could then be employed on this national dataset to group sites on the basis of their fish communities. The site groupings would then be related to available environmental descriptors of stream type to produce a coarse classification of minor streams based on fish species associations. This exercise would have strong links with Agency Project EA001 (see Section 8.3), which aims to develop a habitat inventory for river fisheries and will be producing a methodology for characterising fish populations nationally using key environmental variables.

8.2.2 Objective (ii)

This would be achieved at a more detailed level of resolution than objective (i), by the surveying of case study catchments using sites representative of the range of stream types encountered. The river network would need to be stratified into a number of reach categories using basic habitat parameters, and sites chosen randomly within each category. R&D Note 292 could be used to identify an appropriate optimisation between the number of sites surveyed and the reliability of the standing stock apportionment between different reach types.

Surveying would include the recording of all species present, quantitative determination of fish densities, division into age classes for all major species, and possibly biomass determination for selected (coarse fish) species using length-weight relationships. Fully quantitative fishing is deemed important for such assessments, since it is necessary to have results with high associated confidence after data have been extrapolated to the wider catchment. It is also important to have fully quantitative data in order to address Objective (iii) below, where subtle differences in age structure need to be detected through time and between sites. Fish populations would be modelled using a mixture of GIS and field-derived environmental parameters (as in Phase 1) and the models applied to unfished streams in order to produce a picture of the distribution of species and age classes across each catchment. The contribution of minor streams, and other categories of watercourse, to the standing stock in each catchment could then be assessed.

General characterisation of physical habitat conditions (and possibly chemical conditions if deemed necessary) will need to be undertaken in order to understand the constraints acting on the populations studied and to refine the extrapolation procedures used. For this characterisation work, it would be desirable to link with Agency Project EA001 (see Section 8.3). It should be possible, as a result of the characterisation work undertaken, to assess the potential effect of physical habitat degradation by using the resultant models to test scenarios.

Regarding the logistics of survey work, it may be possible to link with on-going regional fishery monitoring programmes of larger watercourses in order to reduce R&D costs. However, it is often difficult to arrange such coordination owing to the way in which regional programmes are planned. In addition, it may produce inconsistencies in the data collation process that are best avoided.

8.2.3 Objective (iii)

This objective presents the greatest challenge, which is borne out by the lack of information on the subject in the published literature. The two basic types of movement that need to be understood are:

1. adult migrations from the main river into minor streams for spawning purposes;

2. juvenile migrations from minor streams and recruitment into main river populations.

There are four principal ways in which an indication of movement between minor streams and the main river network can be gained.

1. indirectly, through interpretation of population age structure;

2. directly, through marking/recapture;

3. directly, through trapping;

4. directly, through radio-tagging.

a) Age structure

Much can be achieved by analysing age distributions to identify whether a population is a net importer or exporter of individuals at different life stages. The only problem with this approach is that it is difficult to distinguish between emigration and mortality, unless apparent export from one reach can be matched by apparent import to adjacent reaches (which needs spatially intensive sampling). Seasonal sampling improves the data greatly, and it is often possible to detect seasonal immigration or emigration of different life stages. Simple models of emigration, mortality and recruitment can be built to try to explain the age structures observed at different sites.

b) Mark/recapture

This provides direct evidence of movement but requires spatially intensive sampling for recapture to occur at sufficient frequencies. It would probably be best to undertake such sampling in one or two tributaries and adjacent main river, with less intensive sampling elsewhere. The marking of young fish is, however, a time-consuming process and may result in unacceptable levels of stress.

c) Trapping/radio-tagging

Both of these approaches are resource-intensive and therefore difficult to accommodate in Phase 2, given that fish movement is only one component of the project. Temporary traps (such as fyke nets) require daily attention over long periods and the effort required would detract from the amount of survey effort that could be directed to stock assessment. However, it may be possible to identify/arrange regional initiatives or identify suitable cheap labour local to each study catchment that would make the approach financially feasible. Permanent traps exist, but these are few and far between and are unlikely to coincide with locations in the catchment that are compatible with

Phase 2 objectives. An Agency 'new start' project is currently being set up that will review all work undertaken to date on radio-tracking. This may provide some useful information in relation to headwater utilisation.

Data from (b) and (c) can be looked upon as a means of refining and enhancing the models developed using considerations of age structure.

One further approach that should be mentioned is a highly interventionist method involving the blocking of access between selected minor streams and adjacent main river, with associated before-and-after monitoring of fish populations to identify any changes. Blockage could be to upstream movements only, through the use of a weir, or to movements both ways, through the use of nets.

8.2.4 Objective (iv)

With the models used to explain fish movements outlined above, it will be possible to assess the likely knock-on effects of changes in minor stream and main river populations to be assessed. For instance, if values can be assigned to the contribution of minor streams to recruitment in main river populations, the effect of a reduction in minor stream populations on the main river fishery can be estimated. This type of exercise would graphically illustrate the importance of minor streams to fish populations in larger rivers, in addition to the importance they have in their own right. It would be a useful planning tool when considering the possible consequences of various impacts, such as land drainage, flood defence works and water quality deterioration. However, it should be noted that it will not indicate the sensitivity of fish populations to various impacts, but rather the implications of an impact should one of a specified size occur.

8.2.5 Objective (v)

Following from Objective (iv), it should be possible to identify types of minor stream where movements are minimal, making them naturally slow to recover from transient impacts and particularly vulnerable to the removal of physical habitats necessary to fulfil the full life cycle of resident fish species. Others with greater interaction with larger rivers are likely to recover rapidly and still support fish populations even if certain types of habitat are removed. However, fish communities in this latter type of stream may be reliant on main river populations and would therefore be more at risk from impacts occurring further downstream. This provides the basis for producing a classification of minor streams based upon their ability to cope with certain environmental changes, such as the blocking of access, the removal of habitat features, transient impacts acting on the minor streams itself, and transient impacts acting on populations further downstream. Such a classification could be used to guide headwater management and steer possibly damaging activities away from streams that are more likely to be impacted.

8.3 Linkage of Phase 2 with other Agency projects

There are potential advantages to linking Phase 2 with the second phase of the Agency project to develop a Stream Habitat Inventory, if they can be timed appropriately:

1. the Inventory study could provide a provisional means of dividing up the river network into appropriate reaches for the headwater study;
2. the Inventory study could provide a procedure for habitat assessment, which could be incorporated into the modelling procedures required to address Objective (ii);
3. the Headwaters study could provide useful fishery information on populations in minor streams for the Inventory study.

The benefits of linkage would be maximised if both projects were conducted in the same case study catchments. However, it should be noted that, as is evident from the assessments made in this Phase I report, linkage is not necessary to fulfil the proposed aims of the Headwaters study. Considering the parallel timescales of the two projects, the Inventory project may not be able to supply outputs to the Headwaters study in time for use.

With respect to the proposed project on the comparison of river classification procedures discussed at a recent Agency workshop (pers. comm. D Bird, South West Region) this initiative is not felt to be sufficiently linked to an ecological study of headwater fish populations to warrant constraints on the catchment selection process and project implementation. Agency Project 242 (on macroinvertebrate communities in headwaters) has a closer affinity to Phase 2, but a closer look at unclassified watercourses in the case study catchments being used would be necessary before they could be properly assessed for suitability. The type of GIS data sets being collected under Project 242 appear to relate largely to land use and are not particularly relevant to the fishery issues to be addressed in Phase 2 of this project.

Regarding fish movements (Objective (iii)), another Agency R&D Project is looking specifically at coarse fish movements and it may be possible for the two projects to either link together physically (i.e. in the same catchments) or for this other project to incorporate consideration of movement into and out of minor streams. However, the timescales and focus of the coarse fish project are not known and may well be unsuitable for linkage.

Regarding the assessment of vulnerability (Objective (iv), the suggested work has strong links with Agency Project 675 aimed at developing a salmon life cycle model for the Dee catchment, North Wales which can subsequently be applied more widely. The Dee catchment provides extensive information on adult salmonids, such as marine survival and exploitation rates, that would allow vulnerability to be assessed in the context of the whole life cycle. It may therefore be useful for the Dee to be used as a case study catchment in order to maximise these linkages. In any case, the modelling procedures used for the salmon life cycle model can be modified for use in the Headwaters study.

8.4 Discussion of candidate study catchments

Catchments need to be selected to provide a representative picture of headwater habitats in England and Wales, including consideration of climate, topography and geology, all of which are inter-related to a greater or less extent. Ideally, the catchments studied would have simple dendritic drainage patterns that are not complicated by major artificial access difficulties, canal or drainage networks, or heavily braided channels. This simple pattern of watercourses is more likely to produce interpretable results on natural headwater function. An additional populations, or locations where answers may be obtained about fish species of particular conservation interest that are likely to depend on minor streams (such as the spined loach or lamprey species).

Ideally, the catchments selected should not be too large, as the resources that can be committed to such a project will be spread too thinly to gain a reasonable understanding of the fish populations present. However, additional data may be available from contemporaneous regional monitoring that would reduce the importance of this issue. A further problem with large catchments is that the main river will be difficult to survey with any reliability. Water quality and physical habitat quality should not be major constraints in the catchments selected, since poor conditions would only serve to confound the issues being studied.

In very crude terms, the range of environmental conditions available in minor streams might be divided into:

1. upland, steep streams on hard geology;
2. mid-altitude streams of intermediate gradient, typically on impermeable substrates;
3. low altitude streams of low gradient on impermeable substrates;
4. low altitude streams of low gradient on permeable non-calcareous substrates;
5. low altitude streams of low gradient on permeable calcareous substrates.

Conditions 1-3 give rise to dendritic networks of high drainage density, with a large proportion of total stream length concentrated in minor streams. Conditions 4 and 5 typically produce low drainage densities with a relatively low proportion of stream length residing in minor streams.

Some catchments contain streams ranging across a number of these broad categories and might therefore be more attractive in terms of Phase 2 work, since they could reduce the number of catchments required. Inevitably, a case can be made for many catchments, and it is fair to say that a large number of catchments would make suitable case studies. Table 8.1 provides information on a number of possible catchments, indicating the broad headwater conditions available (in relation to the types listed above) and the relevance of each catchment in relation to known existing data and research. List A comprises catchments that were identified through a knowledge of relevant on-going work, whilst List B was produced from examination of superficially suitable drainage patterns shown on 1:250 000 scale River Quality Survey maps.

List A catchments

The **Dee** is a heavily studied upland catchment which is a case study for the development of a salmon life-cycle model (Agency Project 675). Whilst the aim of the modelling is to evaluate the effects of various management options on fishery performance, the exercise also provides a basis for assessing the importance (and vulnerability) of fish populations in different stream types, including minor streams. The catchment is large, but it is likely that the survey work needed to understand the fish populations present would be reduced by linking with on-going work. Water quality is variable, with acidification problems and polluting inputs from livestock farming being evident in a number of tributaries (NRA Welsh Region 1994b). The drainage pattern is complicated by a number of lakes in the catchment. In terms of physical habitat, a range of instream conditions exist from degraded to good quality.

Table 8.1 Candidate catchments for Phase 2

Catchment	Geographical location	Approx size (km^2)	Water quality	Physical habitat quality	Headwater conditions available	Good historical fishery data	On-going/recent relevant fishery research	On-going research on headwaters
List A								
Dee (W)	Westerly	2200	Generally high	Variable	1, 2	Yes	Salmon life cyc. model	No
Yorkshire Derwent (NE)	Easterly	2000	High	Prob. good	1, 2	Yes	None known	R&D Project 242
Conwy (W)	Westerly	600	Generally high	Variable	1, 2	Yes	ROI	ROI
Nidd (Y)	Northerly	600	High	?	1, 2,	?	RHS/fishery study	
Colne (Th)	Southerly	800	Good	?	3, 5	Yes	No	Effects of low flows
Dorset Stour (SW)	Southerly	1000	Good	?	2, 3, 5	?	?	R&D Project 242
Lugg (W)	Westerly	1000	Good	Prob. good	1, 2, 4	?	?	R&D Project 242
Cam (A)	Easterly	1100	Fair	Fair in hw	3,5	?	?	R&D Project 242
Hampshire Avon (SW)	Southerly	1700	High	Mainly good	3,5	Yes	Yes	No
List B								
Avon Stour (M)	Midlands	300	High	?	2	?	?	?
Rea (Teme) (M)	Westerly	200	High	?	2	?	?	?
W Sussex Rother (S)	Southerly	300	High	?	5	?	?	?
Ouse (S)	Southerly	500	High	?	3,5	?	?	?
Adur (S)	Southerly	400	High	?	3,5	?	?	?
Upper Great Ouse (A)	Easterly	800	High	?	3,5	?	?	?
Thame (Th)	Southerly	700	High	?	3	?	?	?

The **Yorkshire Derwent** is another catchment with extensive upland headwaters and is one of four study catchments being used under Agency Project 242. Water quality in the catchment is good, although acidification is being investigated as a possible constraint on aquatic communities (NRA Northumbria and Yorkshire Region 1994). The physical condition of the catchment is generally good, although the quality of headwaters in particular is not clear. Access problems for fish are evident in some locations, although it is not known to what extent these affect the interaction between minor streams and the main river.

The smaller **Conwy** is predominantly upland but provides contrasting conditions in its western and eastern halves, with the former being underlain by hard, base-poor geology and the latter underlain by softer geology giving rise to a less rugged and more productive landscape (NRA Welsh Region 1993). Water quality is generally high although acidification affects a number of upland headwaters. The physical condition of minor streams in the catchment is not known. Fish populations have been extensively studied, but above the Conwy Falls they are likely to be in a state of flux owing to the recent construction of a fishpass for migrating salmonids.

The **Nidd** has been included since a complete assessment has recently been undertaken of the catchment using the RHS methodology, which has been linked to fishery survey data. This habitat database would provide a good basis for extrapolating new fishery data from headwaters and larger river reaches to the whole river network.

The **Colne** is a lowland catchment providing good contrasting conditions between chalk streams and small watercourses running over clay. Inevitably, the length of unclassified river is small in the chalk-dominated half of the catchment, permitting only a minor role for fish populations in minor streams. It has the advantage of being a case study catchment in Phase 1, meaning that relevant GIS data sets are available and validated. The main river is heavily braided, making the river network more complicated than desirable; however, it has already been characterised using GIS. Water quality is generally good, at least in the classified river network.

The **Dorset Stour** is another Project 242 catchment, having a mixed geology and providing a range of lowland conditions in its minor streams. Water quality is generally good.

The **Lugg** is a mid-altitude catchment with high water quality, supporting diverse, mixed fisheries It has numerous unclassified streams feeding into the main river at points all along its length, creating good opportunities to observe fish populations in a wide variety of conditions. These minor streams appear to have been little studied in the fishery context. The Lugg is one of the catchments being used in Project 242 and is a strong candidate for Phase 2 of this study.

The **Cam** is the last Project 242 catchment, being small and lowland in nature, having a good abundance of unclassified streams, and providing contrasting geologies giving rise to chalkstreams and small watercourses running over clay-dominated landscapes. Water quality ranges from very good to bad, but is predominantly reasonable. Headwaters are prone to drying out, which will significantly reduce their utilisation potential for fish. However, the upper reaches of the Cam and various tributaries are known to hold brown trout populations (NRA Anglian Region 1992).

The **Hampshire Avon** is a large lowland catchment dominated by chalk geology; however, the minor streams entering lower down the catchment run off acidic clays and sands ((NRA

Southern Region 1992) and have a very different character. The river network supports diverse fish communities, but owing to its chalk character there are few minor streams other than in the lower reaches. Water quality is high across the catchment.

List B catchments

All of these catchments have a relatively high proportion of unclassified stream length in the river network. Water quality is good, at least in their classified reaches, and they are all of a size that is very amenable to study. All are worthy of further investigation at the beginning of Phase 2, involving discussion with local fishery staff on the likely status of fish populations in minor streams, communication between tributaries and main river, and physical habitat quality.

8.5 Conclusions concerning the aims and strategy for Phase 2

1. Objective (i) is seen as high priority and can be achieved at little expense. It should therefore be included in Phase 2.

2. Objective (ii) is seen as essential to Phase 2 and must be included.

3. Objective (iii) should be addressed through intensive mark/recapture surveys on selected tributaries as a minimum. If it can be arranged cheaply, temporary trapping should also be undertaken in order to produce hard evidence of movement and to distinguish this from mortality. The blocking of access to/from selected tributaries may be a useful approach for work following on from Phase 2.

4. Objective (iv) is high priority and can be achieved at little expense through analysis of the data collected for the purposes of other objectives. It should therefore be included.

5. Based on the aims to be addressed, investigations should be restricted to three catchments and one 12-month period of surveying in order to contain the project budget within reasonable limits. Repeat surveying should be undertaken within the year in order to investigate seasonal movements. The final selection of catchments cannot be made without detailed discussions with local fishery staff and field appraisals of conditions where necessary. A shortlist of catchments is therefore the best that can be achieved within Phase 1.

6. The single year of study makes Phase 2 vulnerable to the possibility of unusual conditions, and in addition only provides one opportunity to recapture marked fish. However, there is always an option of further surveys in subsequent years if they are felt to be necessary. The end of Phase 2 should therefore be seen as a review point at which further work can be considered.

On the basis of these conclusions, an outline specification for Phase 2 is provided in Appendix B.

8.6 Catchments to be considered in more detail at the start of Phase 2

Out of the catchments in List A, the best combination of catchments is probably:

1. Dee, Yorkshire Derwent or Nidd;
2. Lugg;
3. Cam or Colne.

However, closer inspection of List B catchments may reveal that some are ideal choices that should be used in preference. Quite apart from ecological issues, there may also be good logistical reasons why one catchment might be favoured over another. Such considerations can only really be made at the outset of Phase 2. The Dee, Yorkshire Derwent, Lugg, Cam, Colne, Dorset Stour and all List B catchments should therefore be investigated further at the start of Phase 2, with attention being paid to:

- the physical and chemical condition of minor streams;
- the perceived fishery status of minor streams;
- the presence of artificial barriers to fish movement between minor streams and the main river network;
- the fishability of the main river;
- the general accessibility of rivers for survey

Once this process is complete, a final selection may be made and detailed investigations of site locations undertaken.

9. ACKNOWLEDGEMENTS

We are indebted to all those Agency fishery staff who have found time to provide information for this review. A list of staff who are known to have contributed is given in Appendix A. Thanks are also due to Agency staff who provided relevant catchment management plans or parts thereof. Lastly, thanks go to the Project Leader for his technical involvement.

REFERENCES

Alabaster, J.S. and Lloyd, R. (1982) *Water quality criteria for freshwater fish* (2nd Ed.). FAO. Butterworth Scientific.

Aprahamian, M. (1986) The effect of abstraction on fisheries. Welsh Water Authority internal report, No. SE/10/86. Fisheries Technical Unit, South Eastern District, WWA.

Ashby-Crane, R.E., Clarke, S. and Mainstone, C.P. (1994) Impact of pesticides on river ecology. NRA R&D Note 269. NRA, Bristol.

Beaumont, W.R.C., Welton, J.S., Masters, J.E.G. and Ladle, M. (1995) An investigation of spawning gravels in the Sutton Brook. IFE Report to NRA. NRA, Southern Region.

Becker, C.D. and Neitzel, D.A. (1985) Assessment of inter-gravel conditions influencing egg and alevin survival during salmonid redd dewatering. *Environmental Biology of Fishes*, **12**, 33-46.

Berrie, A.D. and Wright, J.F. (1984) The winterbourne stream. In: Ecology of European Rivers. Ed. B.A. Whitton. Blackwell, Oxford. 179-206.

Blackmore, J. and Clark, L. (1994) The disposal of sheep dip waste, effects on water quality. SNIFFER/NRA R&D Report 11. HMSO, London.

Brady, J.A., Douglas, F.W. and Walker, W.J. (1985) Chemical and biological characteristics of Kielder Reservoir and the upper River North Tyne. *The Public Health Engineer*, **13**, 1, 11-20.

Brown, D.J.A. and Sadler, K. (1989) Fish survival in acid waters. In: *Acid toxicity and aquatic animals*. Eds. R. Morris, E.W. Taylor, D.J.A. Brown and J.A. Brown. Society for Experimental Biology, Seminar Series 34. Cambridge University Press.

Campbell, R.N.B. and Scott, D. (1984) The determination of minimum discharge for 0+ brown trout (*Salmo trutta*) using a velocity response. *New Zealand Journal of Marine and Freshwater Research*, **18**, 1-11.

Carling, P.A. (In Draft) Quality of salmonid spawning gravels in the River Test. IFE Report to NRA Southern Region.

Carpenter, K.E. (1928) *Life in inland waters*. Sidgwick and Jackson, London. 267pp.

Casey, H. and Smith, S.M. (1994) The effects of watercress growing on chalk headwater streams in Dorset and Hampshire. *Environmental Pollution*, **85**, 217-228.

Clarke, D.R.K., Varallo, P.V., Noott, M.T. and Mawle, G.W. (1987) Tywi juvenile survey. Welsh Water Authority internal report, No. SW/87/38. Fisheries Technical Unit, South Western District, WWA, Llanelli.

Coddington, J.A. (1992) Problems arising from sheepdipping in England and Wales: an NRA view. In: Sheep dip seminar, 11 November, 1992, Perth. SNIFFER.

Cooper, G.R. (1991) Habitat usage in relation to stream order in salmonids. NRA Welsh Region.

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

Crisp, D.T. (1985) Effects of impoundment and regulation of the River Tees at Cow Green (Northern Pennines, UK) upon fish populations in afferent tributaries and in the river immediately downstream of the dam. In: *Habitat modification and freshwater fisheries*. Ed. J.S. Alabaster. Butterworths.

Crisp, D.T. and Carling, P.A. (1989) Observations on the siting, dimensions and structure of salmonid redds. *Journal of Fish Biology*, **34**, 119-134.

Cross, T.F. (1989) *Genetics and the management of the Atlantic Salmon.* Atlantic Salmon Trust, Pitlochry. 74pp.

Cruddas, A. and McCubbing, D.J.F. (1994) A report on the strategic stock assessment survey of the River Esk catchment 1994, with particular reference to salmonids. NRA North West Region internal report, No. NRA/NW/FTR/94/14.

Elliott, J.M. (1994) *Quantitative ecology and the brown trout.* Oxford University Press.

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.

Ferguson, A. (1989) Genetic differences among brown trout, *Salmo trutta*, stocks and their importance for the conservation and management of the species. *Freshwater Biology*, **21**, 1, 35-46.

Fiss, F.C. and Carline, R.F. (1993) Survival of brook trout embryos in three episodically acidified streams. *Transactions of the American Fisheries Society*, 122, 2, 268-278.

Fivelstad, S. and Leivestad, H. (1984) Aluminium toxicity to Atlantic salmon (*Salmo salar* L.) and brown trout (*Salmo trutta* L.): mortality and physiological response. *Institute of Freshwater Research Drottningholm*, **61**, 69-77.

Frenette, M., Caron, M., Julien, P. and Gibson, R.J. (1984) Interaction entre le debit et les populations de tacons (*Salmo salar*) de la riverier Matamec, Quebec. *Canadian Journal of Fisheries and Aquatic Science*, **91**, 954-963.

Gagen, C.J., Sharpe, W.E. and Carline, R.F. (1994) Downstream movement and mortality of brook trout (Salvelinus fontinalis) exposed to acid episodes in streams. *Canadian Journal of Fisheries and Aquatic Sciences*, **51**, 1620-1628.

Harcup, M.F., Williams, R. and Ellis, D.M. (1984) Movements of brown trout, *Salmo trutta*, in the River Gwyddon, South Wales. *Journal of Fish Biology*, **24**, 415-426.

Hey, R.D. and Winterbottom, A.N. (1990) River engineering in national parks: the case of the River Wharfe, UK. *Regulated Rivers: Research and management*, **5**, 35-44.

Hornung, M., Bull, K.R., Cresser, M., Ullyet, J., Hall, J.R., Langan, S. and Loveland, P.J. (1995) The sensitivity of surface waters of Great Britain to acidification predicted from catchment characteristics. *Environmental Pollution*, **87**, 207-214.

Hornung, M., Reynolds, B., Stevens, P.A. and Neal, C. (1987) Increased acidity and aluminium concentrations in streams following afforestation. In: Proceedings of an international symposium on acidification and water pathways. Norwegian National Committee for Hydrology, Bolkesjo, Norway. 259-268.

Hudson, N. (1981) *Soil Conservation*. Batsford Academic and Educational, London.

Huet, M. (1959) Profiles and biology of western European streams as related to fish management. *Transactions of the American Fish Society*, **88**, 155-163.

Johnson, I.W. and Elliot, C.R.N. (1995) Habitat modelling and flow requirements: River Piddle. Draft Project Report to NRA. Institute of Hydrology, Wallingford.

Johnson, J.H., Dropkin, D.S. and Shaffer, P.G. (1992) Habitat use by a headwater stream fish community in North-central Pennsylvania. *Rivers*, **3**, 2, 69-79.

Karr, J.R., Toth, L.A. and Dudley, D.R. (1985) Fish communities of mid-western rivers: a history of degradation. *BioScience*, **35**, 2, 91-95.

Kreutzweiser, D.P. (1990) Response of a brook trout population to a reduction in stream benthos following an insecticide treatment. *Canadian Journal of Fisheries and Aquatic Science*, 47, 1387-1401.

Kreutzweiser, D.P. and Kingsbury, P.D. (1987) Permethrin treatments in Canadian forests. Part 2: impact on aquatic invertebrates. *Pesticide Science*, **19**, 49-60.

Mainstone, C.P., Barnard, S. and Wyatt, R. (1994a) The NRA National Fisheries Classification Scheme: a guide for users. NRA R&D Note 206. NRA, Bristol.

Mainstone, C.P., Barnard, S. and Wyatt, R. (1994b) Development of a fisheries classification scheme. NRA Project Record 244/7/Y. NRA, Bristol.

Mainstone, C.P., Rutt, G., Pickering, T., Woodrow, D, Bascombe, A.D. and Turner, C. (1994c) Sources of farm pollution and impact on river quality. NRA Project Record 001/13/W. NRA, Bristol.

Mainstone, C.P., Gulson, J. and Parr, W. (1993) Phosphates in freshwater - standards for nature conservation. English Nature Research Reports No. 73. English Nature, Peterborough.

Mainstone, C.P., Wyatt, R. and Clarke, S.J. (1992) A review of optimum fish stocking strategies. Report to NRA Fish Culture Review Group. WRc, Medmenham.

Mainstone, C.P., Lambton, S., Gulson, J. and Seager, J. (1989) The environmental impact of fish farming - a review. WRc Report No. PRS 2243-M. WRc, Medmenham.

Maitland, P.S. and Campbell, R.N. (1992) *Freshwater fishes of the British Isles*. Harper Collins.

Maitland, P.S. and Lyle, A.A. (1991) Conservation of freshwater fish in the British Isles: the current status and biology of threatened species. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **1**, (1), 25-54.

Mann, R.H.K. (1974) Observations on the age, growth, reproduction and food of the dace *Leuciscus leuciscus* in two rivers in southern England. *Journal of Fish Biology*, 6, 237-253.

Mann, R.H.K. (1973) Observations on the age, growth, reproduction and food of the roach *Rutilus rutilus* in two rivers in southern England. *Journal of Fish Biology*, 5, 707-736.

Mann, R.H.K. (1967) The production of coarse fish in some southern chalk streams. Proceedings of the third British coarse fish conference, University of Liverpool.

Mann, R.H.K., Mills, C.A. and Crisp, D.T. (1984) Geographical variation in the life history tactics of some species of freshwater fish. In: *Fish reproduction: strategies and tactics*. Ed. R.J. Wooton. Academic Press, London. 170-186.

Mann, R.H.K. (1995) Species Action Plan - Spined Loach (*Cobitis taenia*). Report to English Nature. English Nature, Peterborough.

Mann, R.H.K., Blackburn, J.H. and Beaumont, W.R.C. (1989) The ecology of brown trout *Salmo trutta* in English chalk streams. *Freshwater Biology*, **21**, 57-70.

Matthews, W.J. and Styron, J.T. (1979) Tolerances of headwater vs. mainstream fishes for abrupt physicochemical changes. *The American Midland Naturalist*, 105, 1, 149-158.

Mills, D.H. (1986) The effects of afforestation on salmon and trout rivers and suggestions for the control. In: *Effects of land use on freshwaters*. Ed. J.F. de L.G. Solbe. Ellis Horwood, Chichester.

Milner, N.J. and Varallo, P.V. (1990) Effects of acidification on fish and fisheries in Wales. In: *Acid waters in Wales*. Eds. R.W. Edwards, A.S. Gee, and J.H. Stoner. Monographiae Biologicae, Vol. 66. Kluwer Academic.

Milner, N.J., Scott, M.D. and Walne, A. (1991) The contribution of small streams to potential fish production in the Conwy catchment. Internal technical memorandum, EAN/91/TM06. NRA Welsh Region, Caernarfon.

Naismith, I.A. and Knights, B. (1993) The distribution, density and growth of the European eel, Anguilla anguilla, in the freshwater catchment of the River Thames. *Journal of Fish Biology*, **42**, 217-226.

Naismith, I., Wyatt, R., Gulson, J. and Mainstone, C.P. (1996) The impact of land use on salmonids - a study of the River Torridge catchment. NRA R&D Report 30. NRA, Bristol.

NRA (1996) Rivers Habitat Survey newsletter. Issue Number 1, February 1996. NRA Head Office, Bristol.

NRA (1994) Abandoned mines and the water environment. Water Quality Series Report No. 14. HMSO, London.

NRA (1993) Low flows and water resources. Facts on the top 40 low flow rivers in England and Wales. NRA, Bristol.

NRA (1992) The influence of agriculture on the quality of natural waters in England and Wales. Water Quality Series No. 6. NRA, Bristol.

NRA Anglian Region (1992) The River Cam: a catchment management plan consultation report.

NRA Northumbria and Yorkshire Region (1994) River Derwent catchment management plan - final plan.

NRA Southern Region (1992) Hampshire Avon catchment management consultation report.

NRA Southern Region (undated a) River Great Stour fishery - strategic management plan. Kent Fisheries Department.

NRA Southern Region (undated b) River Medway fisheries strategy. Kent Area Fisheries Department.

NRA South Western Region (1994) Juvenile salmonid monitoring: survey report for 1994. South Wessex Fisheries Department.

NRA South Western Region (1993) Fish population survey of the upper Piddle, 1993. South Wessex Fisheries Department.

NRA South Western Region (1992) The impact of groundwater abstraction on the fisheries of the River Allen. Avon and Dorset Area Fisheries Department.

NRA Welsh Region (1994a) Cleddau catchment management plan - consultation report.

NRA Welsh Region (1994b) The River Dee catchment management plan consultation report.

NRA Welsh Region (1993) The River Conwy catchment management plan report.

NRA Welsh Region (1992) Reappraisal of salmonid recruitment potential above Conwy Falls. Technical Memorandum EAN/92/TM13. NRA, Caernarfon.

Osborne, L.L. and Wiley, M.J. (1992) Influence of tributary spatial position on the structure of warm water fish communities. *Canadian Journal of Fisheries and Aquatic Science*, **49**, 671-681.

Perrow, M. and Jowitt, J.D. (1997) The habitat and management requirements of spined loach (*Cobitis taenia*). Draft Report to English Nature. University of East Anglia, Norwich.

Rabeni, C.F. and Smale, M.A. (1995) Effects of siltation on stream fishes and the potential mitigating role of the buffering riparian zone. *Hydrobiologia*, **303**, 211-219.

Rinne, J.R. and Medina, A.L. (1988) Factors influencing salmonid populations in six headwater streams, Central Arizona, USA. *Polskie Archiwum Hydrobiologii*, **35**, 3-4, 515-532.

Rosseland, B.O. (1986) Ecological effects of acidification on tertiary consumers: fish population responses. *Water, Air and Soil Pollution*, 30, 451-460.

Rutt, G.P. and Mainstone, C.P. (1995) Investigations of farm pollution impact and development of a control strategy. NRA R&D Note 373. NRA, Bristol.

Ryman, N. (1981) Conservation of genetic resources: experiences from the brown trout, *Salmo trutta*. In: *Fish gene pools*. Ed. N. Ryman. *Ecological Bulletin* (Stockholm), **34**, 61-74.

Sadler, K. and Lynam, S. (1987) Some effects on the growth of brown trout from exposure to aluminium at different pH levels. *Journal of Fish Biology*, **37**, 171-179.

Scheimer, F., Spindler, T., Wintersberger, H., Schneider, A and Chovanec, A. (1991) Fish fry associations: important indicators for the ecological status of large rivers. *Verhandlungen der Internationalen Vereinigung fur Theoretisch und Angewandte Limnologie*, **24**, 2497-2500.

Schlosser, I.J. (1987) A conceptual framework for fish communities in small warmwater streams. In: The ecology and evolution of North American stream fishes. Eds. W.J. Matthews and D.C. Heins. University of Oklahoma Press.

Schlosser, I.J. (1982) Fish community structure and function along two habitat gradients in a headwater stream. *Ecological Monographs*, **52**, 4, 395-414.

Solomon, D.J. and Paterson, D. (1980) Influence of natural and regulated streamflow on the survival of brown trout (*Salmo trutta* L.) in a chalk stream. *Environmental Biology of Fishes*, **5**, 4, 379-382.

Solomon, D.J. and Templeton, R.G. (1976) Movements of brown trout, *Salmo trutta*, in a chalk stream. *Journal of Fish Biology*, **9**, 411-423.

Stonor, J.H. and Gee, A.S. (1985) Effects of forestry on water quality and fish in Welsh rivers and lakes. *Journal of the Institute of Water Engineers and Scientists*, **39**, 27-45.

Stott, B. (1967) The movements and population densities of roach *Rutilus rutilus* and gudgeon *Gobio gobio* in the River Mole. *Journal of Animal Ecology*, 36, 407-423.

Strahler, A.N. (1957) Quantitative analysis of watershed geomorphology. *Transactions of the American Geophysical Union*, **38**, 913-920.

Thorpe, T. (undated) A study of factors influencing the success of the salmon populations of the Rivers Test and Itchen, Hampshire: recommendations for action. NRA Southern Region.

Turnpenny, A.W.H. (1989) Field studies on fisheries in acid waters in the United Kingdom. In: *Acid toxicity and aquatic animals*. Eds. R. Morris, E.W. Taylor, D.J.A. Brown and J.A. Brown. Society for Experimental Biology, Seminar Series 34. Cambridge University Press.

Turnpenny, A.W.H., Sadler, K., Ashton, R.J., Milner, A.G.P. and Lynam, S. (1987) The fish populations of some streams in Wales and Northern England in relation to acidity and associated factors. *Journal of Fish Biology*, **31**, 415-434.

Wessex Water Authority (1988) Fishery investigations of the River Piddle, 1986-88. Internal Report, Avon and Dorset Division.

Wickett, W.P. (1958) Review of certain environmental factors affecting the production of pink and chum salmon. *Journal of the Fisheries Research Board of Canada*, **15**, 1103-1126.

Wightman, R. (1989) The effects of agricultural pollution on headwater fisheries in West Wales Welsh Water Authority internal report, No. PL/EAW/89/1. Environmental Appraisal Unit, South Western District, WWA, Llanelli.

Wightman, R. (1988) The results of fisheries and biological surveys to assess the impact of agricultural pollution in five catchments in West Wales. Welsh Water Authority internal report, No. SW/88/22. Fisheries Technical Unit, South Western District, WWA, Llanelli.

Wightman, R. and Jones, R. (1992) An investigation into the impact of agricultural pollution on the salmonid fish populations of the Western Cleddau. NRA internal report, No. PL/EAW/92/2. NRA Welsh Region, Llanelli.

Woodrow, D., Parr, W. Norton, R.L. and Johnson, D. (1994) River eutrophication risk modelling: a GIS approach. WRc Report to SNIFFER No. NR 3698. WRc, Medmenham.

Wyatt, R., Barnard, S. and Lacey, R.F. (1995) Salmonid modelling literature review and subsequent development of HABSCORE models. NRA Project Record 338/20/W. NRA, Bristol.

Zweimuller, I. (1995) Microhabitat use by two small benthic stream fish in a second order stream. *Hydrobiologia*, **303**, 125-137.

APPENDIX A AGENCY STAFF WHO HAVE ASSISTED IN THE PROVISION OF INFORMATION FOR THE STUDY

Region	Name
Anglian	Irven Forbes
Midlands	Phil Hickley Paul Lidgett Rick North
North East	Steve Axford Ian Dolben
North West	Miran Aprahamian Don McCubbing Marc Naura
Southern	Ian Johnson
South West	Dave Bird
Thames	Dave Willis Richard Tyner
Welsh	Alan Winstone Helen Wright

APPENDIX B - PROPOSED SPECIFICATION FOR PHASE 2

B1 OBJECTIVES

1. To characterise fish communities in the different types of minor stream occurring in England and Wales, by reference to historical data and new fieldwork in a number of case study catchments.

2. To describe and quantify the spatial distribution of fish species across the river network in case study catchments, to include consideration of the age structure of populations, in order to determine the importance of minor streams in relation to standing stocks.

3. To examine the nature and magnitude of interactions between observed standing stocks in minor streams and the main river network, in order to determine the extent of interdependence in different types of catchment.

4. To use information from 2 and 3 to build a model which would allow the secondary effects of impacts occurring in different parts of the catchment to be assessed in relation to minor stream populations and whole river communities.

5. To use the model in 4 to provide a classification of the vulnerability of fish populations in the minor streams of different catchment types to different types of impact.

B2 STRATEGY

B2.1 Historical data collation

All raw data available in electronic format on the presence/absence of fish species in minor streams should be collected from the Regions and collated into a single database of information. Any ancillary information useful in characterising the stream type (such as stream width, gradient, depth and altitude) should also be requested, and gaps in data availability filled in where possible through the use of OS maps.

B2.2 Case study catchment selection

The catchments shown in Table B1 should be screened for suitability as case studies, considering the following criteria:

- their representativeness of headwater conditions in England and Wales;
- the physical and chemical condition of minor streams;
- the perceived fishery status of minor streams;
- the presence of artificial barriers to fish movement between minor streams and the main river network;
- the fishability of the main river;

- the general accessibility of rivers for survey;
- possible linkage with regional monitoring activity;
- historical fishery data;
- links to related Agency and other projects.

This exercise should be undertaken in collaboration with local fishery staff in the Agency. Other catchments may be considered, but it should be noted that the main purpose of the case studies is to assess natural (near-natural) catchment function. This means that physico-chemical quality must generally be high across the catchments chosen.

A total of **three** catchments should be selected for study.

Table B1 Candidate case study catchments

Catchment	Region
Cam	Anglian
Upper Great Ouse	Anglian
Yorkshire Derwent	North East
Nidd	North East
Dorset Stour	South West
Avon Stour	Midlands
Rea (Teme)	Midlands
W Sussex Rother	Southern
Ouse	Southern
Adur	Southern
Colne	Thames
Thame	Thames
Dee	Welsh
Lugg	Welsh

B2.3 Acquisition of GIS data

Digital data should be obtained/generated at 1:50 000 scale that will assist in the characterisation of stream habitat types. As a minimum, this should include distance from source, stream order, altitude, channel gradient and a descriptor of underlying geology.

B2.4 Reach definition

The river network of each catchment should be divided into reaches, with reach boundaries at:

1. all confluences;

2. other discernible changes in physical or chemical conditions (anthropogenic or otherwise).

Arbitrary reach boundaries should be put in place where reach lengths would otherwise exceed 5 km.

B2.5 Site selection for standing stock assessments

Fishery sites should be chosen that are representative of the broad habitat types found in the catchment, including both minor streams and the classified river network. As far as possible, sites should be chosen so as to reflect unimpacted physical and chemical conditions, so that the full potential of the system can be assessed. In order to do this, the river network should be stratified into a number of reach categories using basic habitat parameters, unimpacted areas of the catchment should be identified, and then sites chosen randomly within unimpacted areas and within each reach category. R&D Note 292 should then be used to identify an appropriate optimisation between the number of sites surveyed and the reliability of the standing stock apportionment between different reach types.

B2.6 Stream and site selection for mark/recapture experiments

One stream in each catchment should be selected for more detailed investigations, which should be connected directly to the main river and therefore have potential for extensive interaction with it. Sites should be chosen at equal intervals along the stream to represent at least 50% coverage of the total stream length (or more depending upon stream length). Extra sites should also be located on the adjacent main river.

B2.7 Survey procedures

Surveying should involve catch-depletion between stop nets, including the recording of all species present, fully quantitative determination of fish densities (relative abundances for minor species), division into age classes for all major species, and biomass determination for selected key species using length-weight relationships. At sites selected for mark/recapture studies, individuals of key species should be marked to allow subsequent movements to be identified. Two surveys should be undertaken in each study catchment at two different times of year, timed so as to maximise the chances of observing seasonal movements in fish populations (this may vary between catchments) but with due consideration to the possibility of damage to spawning fish.

At each site, data should be collected on factors relating to habitat dimensions and physical habitat quality. As a minimum, this should include wetted width, water depth, and a coarse classification of physical habitat diversity (possibly based on the percentage coverage of riffle, pool and glide habitat within the surveyed area). It may be possible to receive guidance on habitat assessment from Project EA001, concerning the development of a habitat inventory for river fisheries.

B2.8 Data analysis

a) Community characterisation at a national scale

Using presence/absence data from historical sources and the case study catchments, multivariate techniques (such as cluster analysis) should be employed to group sites on the basis of their fish communities. The site groupings should then be related to available environmental descriptors of stream type to produce a national-scale classification of species associations in minor streams together with an indication of broad habitat requirements. This should be used to help place the finding of case study investigations into a national context.

b) Standing stock assessment

Within each case study catchment, fish density (and biomass where applicable) should be modelled for individual species using a mixture of GIS and field-derived environmental parameters, and the best-fit models applied to all reaches in the catchment in order to produce a quantitative picture of the distribution of species and age classes across each catchment. The contribution of minor streams, and other categories of watercourse, to the standing stock in each catchment should then be assessed and reported with an indication of the level of uncertainty associated with the results.

c) Assessment of fish movements

For each case study catchment, differences in population age structure between the two seasonal surveys should be analysed at all sites in order to assess the likely extent of fish movements, particularly in relation to movements between minor streams and adjacent main river. Recaptures of individuals marked at selected sites should be analysed in order to build a picture of the frequency of occurrence, distance and direction of known movements.

d) Modelling of fishery status and function

Using information from (b) and (c), a model of standing stocks, immigration/emigration, recruitment and mortality should be constructed for key species that provides the best explanation of the survey data. This should be used to simulate the interactions between minor streams and the main river network, mimicking spawning movements of adults into minor streams, and the extent of recruitment of juveniles from minor streams to the main river network.

e) Modelling of 'what-if' scenarios

Once such models are produced, scenarios should be tested to assess the consequences of disruptions to both minor stream and main river populations. It will be possible to simulate issues such as restrictions to the communication between minor streams and the main river, (i.e. barriers to access), the loss of adult habitat in minor streams, and impacts upon main river populations.

f) Classification of vulnerability

The scenario modelling in (e) should be built into a classification of minor stream vulnerability based upon the ability of the population to cope with certain environmental changes, such as the blocking of access, the removal of habitat features, transient impacts acting on the minor streams itself, and permanent and transient impacts acting on populations further downstream. Such a classification would be used to guide headwater management and steer possibly damaging activities away from streams that are more likely to be impacted.

B3 TIMESCALES

The envisaged timescales for each work item are given in the Gantt chart below.

Work item	1997		1998												1999						
	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
1. Collation of historical data	-	-	-	-	-																
2. Catchment selection	-	-																			
3. Assembly of GIS data			-																		
4. Reach/site selection				-	-																
5. Surveying						-						-									
6. Data analysis																					
a. Analysis of national dataset							-	-	-	-	-										
b. Standing stock assessment						-	-	-	-	-			-								
c. Assessment of fish movements																-					
d. Modelling of populations																	-				
e. Scenario-testing																		-			
f. Classification of vulnerability																				-	
6. Report production												+									*

+ Interim report * Draft final report

B4 OUTLINE COSTS

It is recommended that a budget of £130 000 is set aside for the work, split evenly between 1997/98 and 1998/99. This does not include the cost of downstream trapping on the streams selected for mark-recapture experiments, which realistically can only be undertaken if a suitable source of cheap labour can be located close to each study catchment.