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IMPACTS OF ANTHROPOGENIC ACTIVITIES ON THE FISHERIES OF THE DON, ROTHER AND DEARNE CATCHMENTS

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SUMMARY

Human uses and abuses of rivers have grown and diversified over the last few centuries with increasing urban development. With increasing population growth, there has been increasing demand for the use of rivers to satisfy a diverse range of human needs including solid waste disposal and the discharge of industrial, sewage and mining effluents. Rivers have been abstracted for agricultural and potable water supply and river channels have been modified for navigation, flood defences and hydro-electric power generation. These modifications to the river system disrupt the fabric of the aquatic ecosystem and diminish its integrity, affecting equally the capacity of fish and other organisms to survive. Fish depend on undamaged interactive pathways to enhance their survival, growth and recruitment.

The Don, Rother and Dearne catchment in South Yorkshire and North East Derbyshire has suffered from a legacy of pollution and land contamination that dates back to the Industrial Revolution. These rivers have been grossly polluted from industrial, sewage, and mining effluents and from the disposal of solid wastes in the catchment. Much of the lengths of these rivers were fishless into the mid 1980s.

Fish populations in the catchment remain low and species diversity is poor at most locations in the Don sub-catchment. Brown trout and coarse fish species are present in the Don catchment, with the salmonid populations confined to the upper reaches. Most tributaries of the River Don provide brown trout recruits to the main rivers but poor water quality and degraded habitats have prevented the successful colonisation of the waters by the species. Coarse fish, where present, were found at the middle and lower reaches of the river.

Fish populations and species diversity in the River Dearne are generally poor due to serious water quality problems. Limited numbers of brown trout and coarse fish were found at few locations in the catchment, reflecting the widespread nature of poor water and habitat quality. The sub-catchment receives diverse discharges from sewage, industry and abandoned mines. This is exacerbated by various pollution incidents, the causes of some of which remain unidentified.

The River Rother has low fish population densities, and many stretches of the river are fishless due mainly to poor water quality and lack of suitable habitats. Some tributaries of the River Rother, particularly the River Hipper, Redleadmill Brook and Brookside Beck hold considerable numbers of brown trout. The Rother sub-catchment also receives sewage, industrial and mine effluents which impact on the water quality.

The benthic macroinvertebrate fauna of the sites studied were mainly pollution-tolerant taxa with low species diversity reflecting poor water quality. Heavy metal levels were generally low and declining which, possibly, relate to the decline in steel and coal industry in the catchment.

A concerted programme to improve effluent discharges from major sewage treatment works and industries serving the catchment area coupled with a decline in the coal, steel and manufacturing industries has resulted in marked improvements in water quality of the rivers. Reductions in ammonia and BOD levels have been achieved since 1991 due mainly to improvements to sewage treatment works. As a consequence the fisheries of the rivers have shown some evidence of recovery. Unfortunately these improvements are localised and the fish populations suffer periodic setbacks because of isolated pollution incidents.

Despite considerable efforts by the Environment Agency and its predecessors (the National Rivers Authority and Yorkshire Water), to improve the fish populations through stocking and some habitat improvement measures, the general status of the fisheries remains poor particularly in the Rivers Dearne and Rother. A strategic Aquatic Resources Management Plan (ARMP) targeting the bottlenecks to recovery and improvement in the water quality and fisheries habitat is proposed for the long-term sustainable improvement of the fisheries. Project Concept Notes and Logical Project Frameworks have been developed to address the water quality, habitat and fisheries rehabilitation problem. These constitute draft proposals for which additional information would be needed before projects can be progressed.

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CHAPTER ONE

INTRODUCTION

1.1 Rivers

A river may be viewed as a series of reaches or sectors each receiving and discharging water, sediments, organic matter and nutrients (Calow & Petts, 1994). Traditional views consider a river as a longitudinal gradient or sequence of inter-linked zones (Illies & Botosaneanu, 1963; Huet 1949, 1959). The classic high gradient upland stream with a small channel, cold temperatures and highly oxygenated water, dominated by fast water habitats, contrasts with low gradient sectors of large floodplain rivers with a diversity of channel forms and floodplain water bodies. Rivers have also been described as arteries of the catchment ecosystem (Calow & Petts, 1994) providing drainage to the catchment area.

From a hydrological and geomorphological point of view, a river may be viewed as the artery of the drainage basin, and large drainage basins can be viewed as a nested hierarchy of basins of different size. The simplified model of a river defined by Schumm (1977) recognises three zones: the headwater catchment, a transfer zone, and a downstream depositional or storage zone. This division fits well with the river continuum concept (Vannote *et al.*, 1980) which describes the change in the relative abundance of invertebrate functional groups along a river from headwaters to mouth. Individual sectors of a river may be defined by tributary confluences, by changes of valley and channel morphology, or by changes of riparian vegetation; variables reflecting changes of hydrological water quality and disturbance regimes. Habitats include pools and riffles, backwaters, marginal and mainflow sites.

In their synthesis of recent research, Calow and Petts (1994) described the functional characteristics of rivers as: "three-dimensional systems driven by hydrology and fluvial geomorphology; structured by food webs; characterised by spiralling processes and dependent upon fluctuating flows, shifting sediments and channels".

For many decades societies have abused rivers using them primarily as mechanisms for disposal of wastes, and for transport, power generation, agriculture and industry. In these processes, the water courses, which previously formed the focus of the landscape providing diversity of habitat for terrestrial, wetland, and aquatic plant and animal communities, have lost their original form to become simple, often featureless, channels (Cowx & Welcomme, 1998).

Throughout the world, river systems have been significantly altered by human action. These changes have been induced directly by dams and reservoirs (Petts, 1984) and channelization (Brookes, 1987), and indirectly by landuse developments throughout the drainage basin (Lauga *et al.*, 1986). Some species of both fauna and flora have disappeared (Petts, 1984); exotic species have invaded (Cowx & Welcomme, 1998); the functional characteristics of the river systems have been disrupted (Zalewski *et al.*, 1994) and there has been a reduction in landscape quality and loss of wilderness areas (Calow and Petts, 1994).

In several countries of the world, political concern for river systems has arisen mainly in response to pollution problems, but increasingly there is also a broader concern for ecosystem sustainability in the face of both socio-economic and climatic changes (Roberts, 1993). In rivers and streams, anthropogenic perturbations play a considerable role in influencing the structure of biotic communities and ecosystems (Townsend, 1989; Reice *et al.,* 1990), through pollution of the watercourses and degradation of the aquatic habitat. This has important management implications, especially with regard to the long-term effects of human impacts (Petts, 1980, 1988). The long term effects of pollution can affect the fish and macroinvertebrate composition and abundance and also other aquatic biota.

1.2. The rivers of the United Kingdom

The United Kingdom (UK) occupies an area of some 241 000 km^2 (Petts, 1988) and spans ten degrees of latitude north of 50° N. The limited areal extent of the UK means that rivers and their catchments are small by international standards. No river has a gauged catchment area > 10000 km^2 (Petts, 1988), and only one, the River Tay, has a mean annual discharge of more than 100 $m^3\ s^{-1}$. The River Severn is the longest river with a mainstream length of 354 km (Petts, 1988). Many UK rivers have a legacy of direct and indirect modification.

Through changes of catchment hydrology, Man has had a marked impact on the rivers of the UK influencing both the timing and distribution of flows and the water quality. The early development of flow regulation of rivers began in the 18th Century (Petts, 1988) in upland areas where small streams were impounded to create reservoirs to store part of the high flows in winter to supplement the flows in summer. The highly industrialised areas of Lancashire and Yorkshire within the southern Pennines was the centre for much early river development. Each town developed its own local water resources, often in the valleys in which the towns were situated e.g. Sheffield and Barnsley developed their resources from the Don catchment.

The need to develop rivers and their water resources, particularly fisheries, continues to intensify, due to their socio-economic, conservation and recreational values. Over the past two decades, increasing efforts have been directed to the application of scientific principles to the development of environmentally-sensitive approaches for managing rivers (Gore and Petts, 1989; Boon, 1992) and their fisheries (Harper *et al.*, 1995).

The rivers of the UK are shown to have an underlying character that reflects the marked climatic, geological and topographical differences between the upland north and west, and the lowland south and east; differences in part that relate to their histories during the Pleistocene (Petts, 1988). However, many rivers show the effects of human impacts that began about 5000 years ago (Petts, 1988) and pollution has had the most dramatic effects. In addition, virtually all major rivers in the UK are impacted directly or indirectly by mainstream impoundments, inter-basin transfers, pumped storage reservoirs, groundwater abstractions or pollution.

Rivers in the UK constitute a very valuable natural resource in the socio-economic and recreational lives of the people (Steel *et al.,* 1998). In the UK, riverine fisheries remain an important source of recreational activity yielding enormous income to the angling industry. In addition to providing a vast facility for anglers and other water-based recreational activities, the rivers of the UK are also invaluable for the country's industrial development (Atkinson, 1994). The rivers also provide a drainage and irrigation facility for agricultural and urban development and a medium for the treatment and disposal of sewage.

Angling has been reported as one of the fastest-growing leisure activities in the UK, generating huge amounts of money from licences and revenues taken from over three million anglers in the country (NRA, 1994a). With an estimated 2.3 million coarse anglers in England and Wales, the total national expenditure on coarse angling is around £2.4 billion per year (NRA, 1994a). It is therefore important that the rivers and the fish stocks on which the industry depends are managed on a sustainable basis, and exploited rationally. A number of fluvial and diadromous fish species in the UK are widely exploited for sport. These are Atlantic salmon (*Salmo salar* L.) brown trout (*Salmo trutta* L.) rainbow trout (*Oncorhynchus mykiss* (Walbaum)), char (*Salvelinus alpinus* L.) barbel, *Barbus barbus* (L.); bream, *Abramis brama* (L.); carp, *Cyprinus carpio* L.; chub, *Leusciscus cephalus* (L.); dace, *Leusciscus leusciscus* (L.); gudgeon, *Gobio gobio* (L.); roach, *Rutilus rutilus* (L.); perch, *Perca fluviatilis* L.; pike, *Esox lucius* L.; and grayling, *Thymallus thymallus* (L.) (NRA, 1994a).

The bulk of inland sport fishing in England and Wales, however, is devoted to coarse fishes, primarily cyprinids: barbel, *Barbus barbus* (L.); bream, *Abramis brama* (L.); carp, *Cyprinus carpio* L.; chub, *Leusciscus cephalus* (L.); dace, *Leusciscus leusciscus* (L.); gudgeon, *Gobio gobio* (L.); roach, *Rutilus rutilus* (L.); perch, *Perca fluviatilis* L.; pike, *Esox lucius* L.; and grayling, *Thymallus thymallus* (L.) (NRA, 1994a).

1.3. Anthropogenic impacts and riverine fisheries

Human use of river systems has intensified considerably in the last century due to increasing population size and the associated higher demand for water through industrial and agricultural technologies. This intensification process has impacted rivers and resident organisms, especially fish. Most uses of rivers require modifications to the system to become fully efficient. These modifications disrupt the fabric of the aquatic system and diminish its integrity, affecting equally the capacity of the fish and other organisms to survive. The living components of aquatic ecosystems have been used for food at least since the Palaeolithic, and fisheries were one of the key components of the earliest civilisations in Mesopotamia (Kreutzer, 1984). For most of human existence, fisheries remained the prime use of the aquatic ecosystem apart from drinking water, but in the last few centuries, they have been displaced in much of the world in favour of other societal goals (Welcomme, 1985, 1995).

Many of the principal factors affecting the status of inland fisheries are directly related to the degradation and loss of suitable habitat conditions through the effects of activities associated with land and water resource developments (Hellawell, 1988; Cowx & Welcomme, 1998). Such activities have included land drainage schemes (Cowx *et al.*, 1986), river channel engineering works, urban development and sewage disposal, agricultural development, afforestation, and water-based recreation (Cowx, 1994; Cowx & Welcomme, 1998). Conflicting interests and interactions in river uses by various communities have often arisen and there has been loss of natural habitat and reduction in water quality. Concomitantly, the fisheries have come under sustained intense pressure. Unfortunately, these activities have resulted from man's attempt to restructure the environment and the aquatic ecosystem to suit his requirements.

In many areas of the UK, there is growing concern over the apparent decline in coarse fish populations within major river systems. This decline is not a new phenomenon but has persisted for more than twenty years (Cowx & Welcomme, 1998). Anglers have reported lower catches in many of the major rivers, but much of the evidence is anecdotal or circumstantial (Cowx, 1990). Fisheries scientists and managers have also observed changes in fish community and population structures of many rivers. Some fisheries survey data collected by the Environment Agency (EA), and the erstwhile Regional Water Authorities lend support to these allegations (Cowx & Welcomme, 1998). Many reasons have been advanced for the decline in the density and diversity of riverine or inland fisheries. Notable among these are the effects of pollution resulting from the manipulation of the river environment through the various anthropogenic activities mentioned earlier.

Increase in organic matter or nutrient input may improve a fishery by increasing growth rates without causing community changes. However, the necessary balance is rarely achieved (Davies, 1977; Moss *et al.*, 1979). Excessive nutrient input, particularly of phosphorus, could result in eutrophication or hyper-eutrophication (Harper *et al.*, 1995). Algal blooms would result, and fish deaths may possibly occur.

Disposal of industrial and domestic effluents into fresh waters is, or has been, one of the primary factors responsible for large scale changes in water quality, which in turn have resulted in deterioration of fish stocks and fisheries (Axford, 1994). The pollution can act directly on fish; for instance toxic chemicals may have acute or chronic effects depending on their concentrations. Pollution may also act indirectly by changing water quality parameters and consequently the suitability of the habitat for fish.

Many other anthropogenic factors also impinge on water quality and these have an effect on the fish and fisheries. Diffuse inputs from both the air and surface run-off can cause considerable change. "Acid rain" is known to lower the pH of watercourses, particularly in upland regions where the buffering capacity of the system is often weak (Evans *et al.*, 1994; Haines, 1981). This tends to lead to an impoverished, or in extreme cases, a denuded fish fauna, primarily through loss of recruitment success. Similarly, nutrient run-off from agricultural activities has resulted in eutrophication of inland waters and marked changes in the fish community structure (Walker, 1994; Persson, 1994; Axford, 1994). Shifts in fish communities in response to pollution have been well documented Persson, 1994; Welcomme, 1995). Salmonids are sensitive to various forms of organic pollution and would generally avoid such habitats. The most demonstrated effect of pollution on biotic populations has been the loss of migratory salmonid fisheries (Banks, 1990). Studies carried out in the River Thames lend credence to this observation (Banks, 1979; 1990). Some coarse fish (cyprinids) e.g. gudgeon (*Gobio gobio*), chub (*Leuciscus cephalus*), roach (*Rutilus rutilus*), however, are relatively resilient to pollution (Cowx *et al.* 1993; Cowx, 1998a). The headwaters of the River Don once held salmon stocks (Firth, 1997; Environment Action, 1998) but these disappeared due to pollution problems. A recent catch of salmon after 150 years (Environment Action, 1998) in the Don by an angler in the Doncaster area might suggest some improvement in water quality but this needs to be investigated further.

1.4. Objectives

One region of the UK which has suffered heavily through industrial developments and population growth is in South Yorkshire and North East Derbyshire. This region is drained by three major rivers: the Rivers Don, Rother and Dearne.

The Don, Rother and Dearne catchment is impounded by 19 reservoirs at its uppermost reaches, supplying drinking water to the towns and cities in the region. The catchment has a long history of poor water quality and pollution (NRA, 1994b) and receives major discharges of industrial, agricultural, sewage and mining effluents which may contain heavy metals and complex organic chemicals (NRA, 1994b). This has caused considerable damage to the fish populations of the catchment over the years. However, the rivers are now the subject of considerable attention to improve and develop the status of the fisheries.

Flood defence schemes are important in the Don, Rother and Dearne catchment, and these are aimed at protecting people and property from floods. Flood defence schemes often involve considerable dredging of the river bed and the construction of levees or embankments (Cowx & Welcommme, 1998). Dredging of channels results in downstream clogging of gravel interstices reducing invertebrate production and the availability of spawning substrate for lithophilous species (Morris *et al.*, 1968). Bankside trees or vegetation may be removed during flood defence works. These activities result in considerable alterations to the habitat and affect its suitability as feeding, spawning or nursery areas for fish (Copp, 1990a, 1990b; Gaudin *et. al.*, 1995), and for cover or protection (Cowx & Welcomme, 1998).

Against the background of the Don, Rother and Dearne catchment, this study has the overall objectives of assessing the status of fish populations in the rivers and examining mechanisms for improving and enhancing them through aquatic resource management techniques (Cowx, & Welcomme, 1998).

The specific objectives of the study are to:

- ❒ provide baseline information against which the issues related to fisheries can be related. This will be based primarily on catchment management plan and the Local Environment Agency Plan.
- ❒ evaluate the spatial and degree of degradation of the water quality of the catchment;
- ❒ conduct in-depth studies to evaluate the fish community structure for future management utilising primary and secondary data;

- assess the impact of river management practices on the river system and the fisheries;
- formulate mitigation and rehabilitation methods that are fisheries-orientated and promote development of the fish communities especially of angling species.

The preliminary approach was to examine historical data on the fisheries and water quality of the catchment over the past 14 years to elucidate changes in fish status and water quality of the rivers. Field surveys were undertaken to evaluate the current status of fish populations and macrobenthic invertebrate communities to assess the main issues affecting the aquatic biota and how they have responded to management activities to date. In the light of this information, a strategic management plan for the enhancement of the fisheries is formulated. It is anticipated that this will form the basis of future development activities.

CHAPTER TWO

REVIEW OF THE DON, ROTHER AND DEARNE CATCHMENT

2.1. Catchment boundaries

The Don, Rother and Dearne catchments are bounded to the west by the Pennines, to the north by the Calder and Lower Aire, and to the east and south by the River Trent (Fig. 2.1). The main River Don rises from the Pennine highlands and then flows east to its confluence with the River Ouse around the lowlands of Goole. These combined waters of the two rivers then flow into the Humber Estuary.

The Don catchment encompasses all land from which surface water drains to the River Don and its main tributaries, the Rivers Rother and Dearne plus tributaries (NRA, 1994b). It also includes those parts of the Sheffield and South Yorkshire Navigation. The catchment covers an area of about 1849 km^2 with a human population of about 1.4 million (EA, 1997). Population densities are highest in the major towns and cities namely, Sheffield, Rotherham, Chesterfield, Barnsley, and Doncaster.

The River Rother and its main tributary, the River Hipper, rise from the Peak District National Park. The main River Rother flows through urban and industrial areas in the Chesterfield and Rotherham area before reaching its confluence with the Don east of Sheffield.

Rising from Denby Dale, the main River Dearne drains the high ground to the south and east of Huddersfield and west of Barnsley. The Dearne valley which has steep sides opens out at Bretton Hall Country Park, flows through Barnsley, Wath and Mexborough, and reaches its confluence with the main river Don at Conisborough.

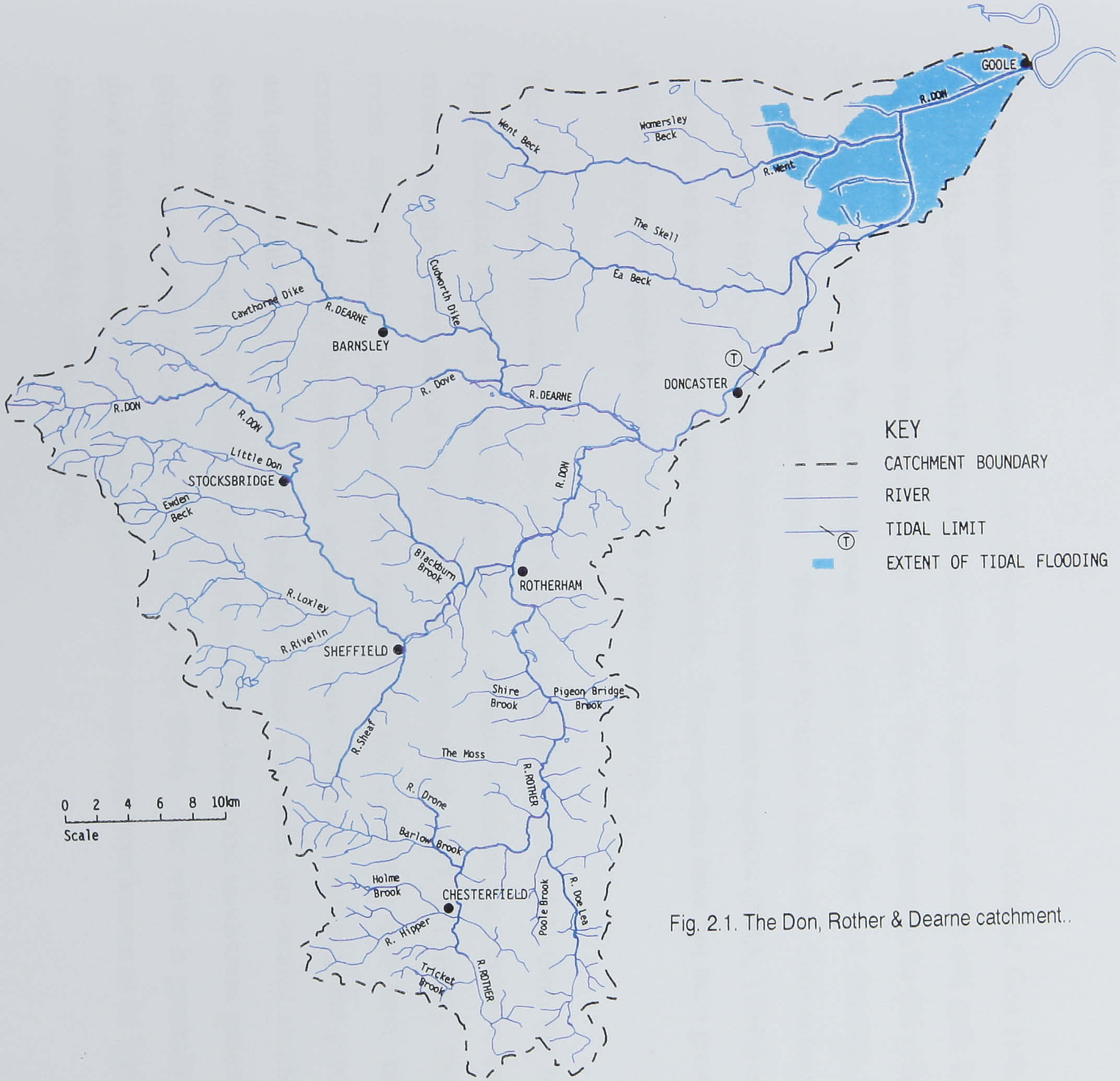


Fig. 2.1. The Don, Rother & Dearne catchment..

2.2. Catchment geology and hydrogeology

The geology of the catchment is produced by Carboniferous rocks consisting largely of coal measures (Fig. 2.2). The coal measures consists of shales, grits and seams, and some of the grits form higher ground such as the Wooley Edge Rock. Coal has been extensively mined, particularly in the thick Barnsley seam (Firth, 1997). The River Dearne lies wholly within the Coal Measures and was therefore a prime target for pollution from this source.

The headwaters of the catchment are, however, formed in the Millstone Grit (NRA, 1994b; Firth, 1997). The Millstone Grit represents a sequence of shales and grits that produce the characteristic moorlands of the Pennines. They are known to be the oldest rocks and date back to the Carboniferous age (EA, 1997). They are overlain by successively younger groups of rocks. The grit horizons within the Carboniferous Millstone Grit and Coal Measures form some complex minor aquifers (NRA, 1994b) and out-crop on the valley sides to give rise to springs. These aquifers have not been greatly utilised for water supply because borehole yields are often low.

The Magnesian Limestone and the soft Sherwood Sandstone (Fig. 2.2) form the low lying floodplain between Doncaster and Goole. At these locations are extensive areas covered by glacial and alluvial material up to 20 m thick (Firth, 1997; EA, 1997). These rocks are particularly important major aquifers in the catchment and have been extensively abstracted for industrial, agricultural spray irrigation, bottling, and private and public water supply. The main Yorkshire Water well fields are located south of Selby and Doncaster. The yields of the boreholes in the Sherwood sandstones generally produce up to 6000 m^3 per day (NRA, 1994b; EA, 1997). The water is generally of good quality, although iron, manganese and nitrate levels have been known to be high in certain areas (NRA, 1994b; EA, 1997).

The Coal Measures lie beneath the Magnesian Limestone. The Magnesian Limestone form the eastern edge of the Rother catchment and determines the drainage patterns of the Don, Rother, and Dearne catchment (EA, 1997) as their waters flow through the limestone valley between Rotherham and Doncaster.

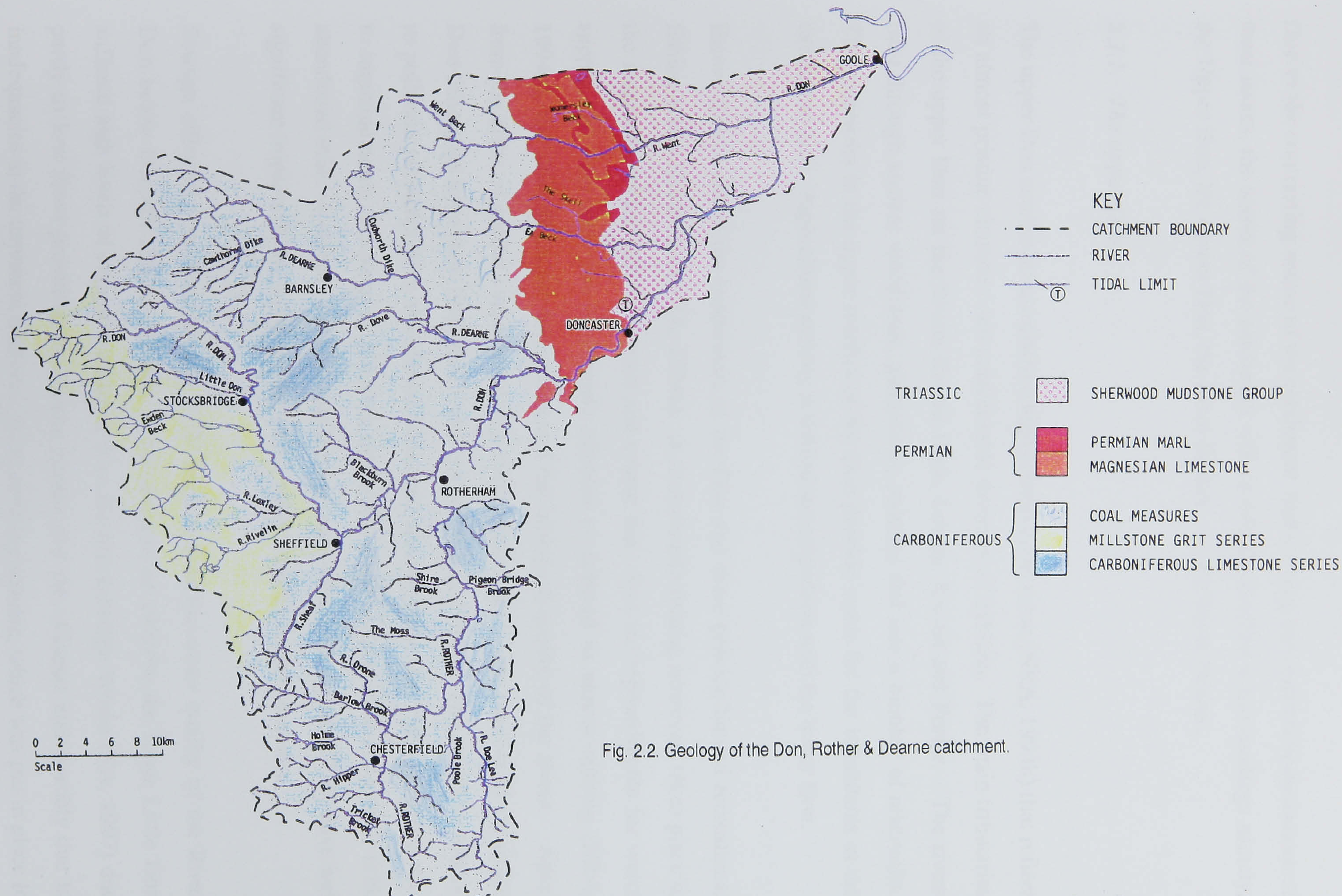


Fig. 2.2. Geology of the Don, Rother & Dearne catchment.

Source: Environment Agency North East Region

2.3 Status of the Don, Rother and Dearne catchment

Due to the contrasting nature of the catchment, and to carry out detailed examinations of local issues, the status of the catchment will be described under 4 sub-headings namely, the Upper Don, the Lower Don, the River Rother, and the River Dearne.

2.3.1. The upper Don

The upper Don catchment maintains a high conservation value (NRA, 1994b) that reflect an almost pristine character and considerable diversity of habitats. The main tributaries of the upper Don are the Rivers Ewden Beck, Loxley, Rivelin and Porter. The rivers flow through ancient woodlands, plantations, pastures and into a number of reservoirs. The reservoirs in the upper reaches of the Don provide water for the inhabitants in the catchment area. Agricultural activity is limited in comparison with the lower Don.

Brown trout exist in the headwaters of the Don and these provide limited recreational fishing below Hazlehead (NRA, 1994b). A considerable fishing, however, takes place in the reservoirs which hold both trout and coarse fish. Due to impoundments for water supply, the river flow can be severely affected or reduced to almost nothing (NRA, 1994b), and this affects the fish stocks and the biological quality of the rivers. Apart from the areas of special conservation interests, most of the lower reaches of the upper Don tributaries have poor biological water quality (NRA, 1994b). This might be related to pollution problems from abandoned mines and sewage effluents. Flow reduction due to impoundments, discharge of effluents, especially ochreous (rust-coloured) water from abandoned mine workings, and effluents from sewage treatment works (STW) have had significant impacts on the water quality of the upper Don for several decades.

Sewage effluents from Stocksbridge STW impoverishes the water quality of the River Don below Deepcar (NRA, 1994b). In the drought of 1995/96 the River Little Don suffered high levels of copper discharges from the Stocksbridge Works (EA, 1997) due partly to low flows providing inadequate dilution for the effluents and possibly due to inadequacies in the treatment facilities. A refurbishing scheme, which was put in place to address the problem, was completed in 1997 (EA, 1997).

Between Stocksbridge and Sheffield the River Don supports a poor cyprinid fishery (NRA, 1994b) due to poor water quality. Coarse fish populations are improving at the confluence of Blackburn Brook and the River Don (NRA, 1994b) but this is also constrained by poor water quality and severe degradation of fish habitats due to urban development and industrialisation.

Below Sheffield water quality shortfalls are due to discharges of sewage effluent from Blackburn Meadows STW (NRA, 1994b). Major refurbishments to the sewage works and to the Don Valley interception sewer have been undertaken resulting in considerable improvements to the water quality (EA, 1997; Firth, 1997).

Combined Sewer Overflows (CSOs) are operated in the catchment. CSOs are overflow structures that allow discharges from a sewerage system during extreme wet weather conditions. These mechanisms were originally intended to operate only in periods of heavy rainfall. However, due to inadequacies in the sewerage systems, the CSOs often operate in dry weather conditions causing some systems to become severely overloaded. This is a major cause of water quality shortfalls in the catchment. In 1980, the Don Valley interception sewer was constructed to eliminate many unsatisfactory overflows (NRA, 1994b). Aldwarke STW which serves Rotherham fails to meet its ammonia discharge limits which impact on the main River Don between Blackwater Dyke and Roundwood (EA, 1997). Further improvements to the works are expected to be completed in April 1998 (EA, 1997). Most of the Don tributaries, particularly the River Sheaf, Porter Brook, Cubley Brook, Graves Park Beck and the River Little Don also do not meet the water quality targets due to intermittent discharges from CSOs. Yorkshire Water has put in place a programme of refurbishing the CSOs over the next 10 years (EA, 1997).

Evidence of cyprinids has been found below Rawmarsh where the combined waters of the Don and Rother flow to Thryberg weir (NRA, 1994b). Recreational fishing becomes increasingly important below this point. The input from the polluted waters of the Rother and the degradation of habitats are the main factors limiting the establishment of fish populations in this stretch of the river, particularly, in and around Rotherham.

Considerable flooding occurs downstream of Sheffield and the protection of life and property remains an important function of the EA (Environment Agency).

2.3.2 *The lower Don*

The lower Don catchment has some important sites of conservation interest. These include Sprotborough Gorge SSI, the Nearcliffe Woods, Hexthorpe Flats and the River Don Navigation (NRA, 1994b). These provide diverse aquatic and terrestrial habitats, woodland, marshland, limestone and grassland for the plants and animals associated with the river corridor (NRA, 1994b). This diversity and conservation values rather deteriorate as the river flows through Doncaster where the impacts of industrialisation and urban development have resulted in a loss or deterioration of habitats.

The River Don down to Doncaster has diverse cyprinid fish populations and this stretch is progressively becoming a focus for recreational fishing (NRA, 1994b, Environment Action, 1998). This might be attributed to localised improvements in water quality due to improved quality of discharges from industry in the area (Firth, 1997). Recreational fishing in canal waters associated with the main river is well established in this area, and national angling matches have also been held (NRA, 1994b). Recent years have seen the installation of extensive treatment facilities by industry to improve the quality of effluents discharged to the river. This has been achieved due to pressure from the NRA (now EA) and co-operation from the industries involved (NRA, 1994b). The water quality improvements have, possibly, facilitated the recreational coarse fishing in the area. On the other hand, the River Don through Doncaster and downstream continues to be impacted by contaminated surface waters from industrial estates (NRA, 1994b).

About 70 sewage pumping stations are located in the lower Don sub-catchment, each equipped with an emergency overflow (NRA, 1994b). Periodic discharges from these sources have occurred due to incidents such as power failure (NRA, 1994b). In addition to major sewage treatment works, there are significant industrial effluents discharged to the main river in the lower Don, by various companies around Goole and Doncaster. Large scale re-sewerage work and new sewage treatment works have been planned for the Goole area (EA, 1997) and this should further improve the fishery in the lower Don. For the purpose of flood defence, the lower Don is embanked between Doncaster and

Goole with embankments reaching up to 3 or 4 metres high (NRA, 1994b). Information on the effect of the scheme on the fisheries was not available for this study. However, the impacts of flood defence activities on fish stocks are well documented (Section 1.4) and have been described earlier in this study.

The River Went, the main tributary of the lower Don, continues to be a focus for development and part of the river has been designated as an EC fishery (EA, 1997), a designated site at Went Bridge where water quality and fisheries monitoring take place C. Firth, pers. comm.). The river does not meet the EC water quality limits due to impacts of Ackworth and Carleton STWs (EA, 1997). Sewage effluents and low flows affect many of the Lower Don tributaries including the Ea Beck and Little Went. A scheme to improve South Elmsall STW has been put in place (EA, 1997) and will improve considerable lengths of the Ea Beck. Other tributaries in the low-lying catchment are impacted by run-off from colliery spoil heaps and contaminated land.

2.3.3 The River Rother

A legacy of mineral extraction and land contamination, channel modification, land drainage for agricultural improvements and general industrial development has constrained the habitat diversity and conservation value of the River Rother. Modifications and enlargements to the Rother channel, flood defences, and the construction of a complex system of washlands between Chesterfield and the confluence with the Don at Rotherham have been undertaken in the Rother catchment.

The River Moss is a tributary of the River Rother and has considerable conservation value. It is characterised by an almost pristine character in its channel, an adjacent semi-natural habitat and extensive areas of woodland (EA, 1997).

Water quality problems in the Rother and the degradation or loss of habitats are the main bottlenecks to the development of fisheries in the catchment. Most of the tributaries of the Rother are polluted where they flow into the main river (NRA, 1994b) but stretches of the upper reaches are cleaner and hold some fish. The main River Rother, however, remains polluted for most of its length.

There are 30 sewage treatment works (STWs) in the Rother catchment (NRA, 1994b; EA, 1997). Water quality shortfalls are caused mainly by effluents from sewage works at Danesmoor (Clay Cross), Old Whittington (Chesterfield), Staveley, Woodhouse Mill and Dronfield. Major capital investment schemes to allow water quality targets to be met by these STWs by the year 2000 are planned (EA, 1997). Danesmoor STW causes poor water quality in the upper reaches of the Rother, and from the headwaters of the Rother to Wingerworth there are sparse populations of coarse fish (NRA, 1994b). Some trout exist in the uppermost reaches and in several tributaries. No fish is present below Wingerworth and this is attributed to poor water quality and contaminated sediments (NRA, 1994b).

Many habitats in the catchment are severely degraded and need restoration. Improvements in the water quality were achieved through capital investment at Old Whittington STW (NRA, 1994b) which has been substantially upgraded and now discharges lower levels of ammonia.

Apart from some ingress of fish stocks from the Don into the lower reaches of the Rother (NRA, 1994b), there is no evidence of fish populations between Chesterfield and the confluence with the Don. Recolonisation of this stretch of the river by fish has been constrained by chronic water quality problems and lack of suitable habitats. As part of the measures of rehabilitating the fishery, a fish refuge was created in the river below the regulator at Rother Valley Country Park, and fish were introduced into this stretch in the spring of 1994 (NRA, 1994b).

As in the case of the Don, the operation of CSOs under dry weather conditions occurs throughout the catchment and this affects water quality. Industrial effluents also contribute to poor water quality in the Rother. Industry, whilst providing the economic base for the area, has left a legacy of environmental damage and potential for further damage. The Chesterfield and Bolsover area has a history of coal mining, coking and associated chemical industries which were implicated for causing major pollution of the Rivers Rother and Doe Lea. The Doe Lea at Bolsover has a very poor water quality reflecting a long history of pollution in the area.

High levels of dioxins and furans have been found in the sediments of the River Doe Lea (NRA, 1994b). The Water Research Centre was funded by the NRA (now EA) to investigate the effects of dioxins on fish in the catchment. Polychlorinated dibenzo-para-dioxins and furans are two complex groups of organic compounds that are ubiquitous in the environment at ultratrace levels (Alawi *et al.*, 1996; Jones & Stewart, 1997). They have attracted attention in recent years due to their toxicity problems, environmental persistence and tendency to bioaccumulate through the food chain. They are known to be produced by various combustion processes and often occur as unwanted by products in various chlorinated chemical formulations, e.g. pentachlorophenol (Jones & Stewart, 1997).

2.3.4 The River Dearne

The River Dearne rises from the high ground west of Denby Dale. It drains the high ground south and east of Huddersfield and west of Barnsley. The river corridor provides important wildlife habitats (NRA, 1994b). The catchment has SSIs such as Wilthorpe Marsh, Gunthwaite Hall Woods and Wath Ings (NRA, 1994b) and these provide diverse habitats for wildlife.

Brown trout populations between Haigh and the headwaters of the Dearne are maintained by regular introductions of hatchery-reared fish (NRA, 1994b). Water quality problems are responsible for fish mortalities, poor recruitment and reproduction in the Dearne. No trout fishing takes place in the river above Bretton but club angling for coarse fish takes place in the lakes at Bretton Park (NRA, 1994b). The Worsborough Reservoir and the Fleets Dam also offer recreational fishing opportunities.

The main STWs which impact on the water quality in the Dearne catchment are Clayton West, Lundwood, Wath (Barnsley), Cudworth, Dodworth, and Worsborough. Worsborough Reservoir receives diverse effluents, the most remarkable of which is effluents from Dodworth STW. Worsborough reservoir is liable to pollution due to the reduction in dilution with the cessation of mine water pumping (NRA, 1994b). This represents a typical example of how the closure of a colliery with cessation of mine water pumping can affect water quality. Abandoned mine waters can affect the aquatic biota with the deposition of ochre.

The River Dove, a tributary of the Dearne, fails to meet its water quality target below Worsborough (EA, 1997), mainly as a result of ammonia levels in the effluent from Dodworth STW. The works have now been abandoned with flows being pumped to an extended works at Worsborough.

The upper reaches of the Dearne downstream of Clayton West STW and the tributaries below Cudworth, Wath and Worsborough STWs continue to have pollution problems from these sources. A scheme was put in place to resolve the problem in 1997 (EA, 1997). Although water quality problems compounded by heavy deposits of ochre from mines continue to impact on the Dearne, the catchment as a whole retains a river corridor of reasonable conservation quality (NRA, 1994b). Many stretches of the river maintain their original sinuosity, pools and riffles. The vertical banks of the river at most locations are vegetated.

Discharges from coking works also impoverish the water quality of the Dearne. With the closure of Coalite's plant at Grimethorpe and improvements at Moncton (Royston) coking plant, it is expected that pollution from this source would be reduced.

A small mixed fish population occurs between Haigh to Stairfoot but only cyprinids are found below Darton NRA, 1994b). Fish populations and diversity are limited by poor water quality and severe degradation of the physical habitat. Fish populations between Stairfoot and the confluence of the Don with the Dearne are limited by poor water quality but there is an important recreational fishery developing below Harlington (NRA, 1994b). Work to improve the physical habitat of the engineered sections at these locations has been suggested (NRA, 1994b). Some limited fishing occurs downstream in the Barnsley area, and formal arrangements for club use of EA-owned fishing stretch of the river have been put in place. The stretch commences at Little Houghton and extends almost to the confluence with the Don (NRA, 1994b). Parts of this fishery are available to anglers for use without charge.

The Dearne sub-catchment provides a focus for flood alleviation schemes. Such schemes include channel enlargements, flood defences and the construction of a complex system of washlands between Barnsley and the confluence with the Don at Cadelby. Other activities have taken place to counteract the effects of coal mining subsidence. However, with the decline of the coal mining industry and the closure of several pits, the problem is likely to improve (NRA, 1994b). Similar schemes are also being pursued to address the problem of pollution from sewage effluents in the Dearne catchment. In January 1997, contracts were awarded by Yorkshire Water for major capital works to begin at Lundwood as agreed with the EA. This involved the installation of high rate filters and sand filters at Lundwood STW. It is envisaged that the completion of these works would allow the River Dearne to achieve its water quality objectives to facilitate the re-development of the fishery below the discharge from the works. The improvement scheme is scheduled for completion by the end of 1998 (Firth, 1997).

2.4. Uses and potential uses of the Don, Rother and Dearne catchment

The Don, Dearne and Rother catchment has a diverse array of uses. The uses and potential uses of the catchment have determined the environmental objectives (NRA, 1994b) that have been set to ensure sustainability and for the resolution of conflicts and interactions the usage might generate. The uses of the catchment may be categorised as follows.

2.4.1. Abstraction for drinking water supply

The upper reaches of the catchment are impounded by 19 reservoirs (NRA, 1994b) to supply drinking water to the towns and cities within it. In addition, there are 4 compensation reservoirs which supplement flows in the catchment. There is potential for further abstraction of water following improvements to the water quality in the lower reaches of the catchment.

2.4.2. Effluent disposal

Generally, rivers provide a medium for the disposal of industrial and sewage effluents. The catchment area is highly industrialised with discharge of considerable quantities of sewage and industrial effluents at many locations (Fig. 2.3). Effluent discharges are controlled by consents and authorisations of the EA which regulates the quantity and quality of the discharge to facilitate the achievement of the desired water quality objective.

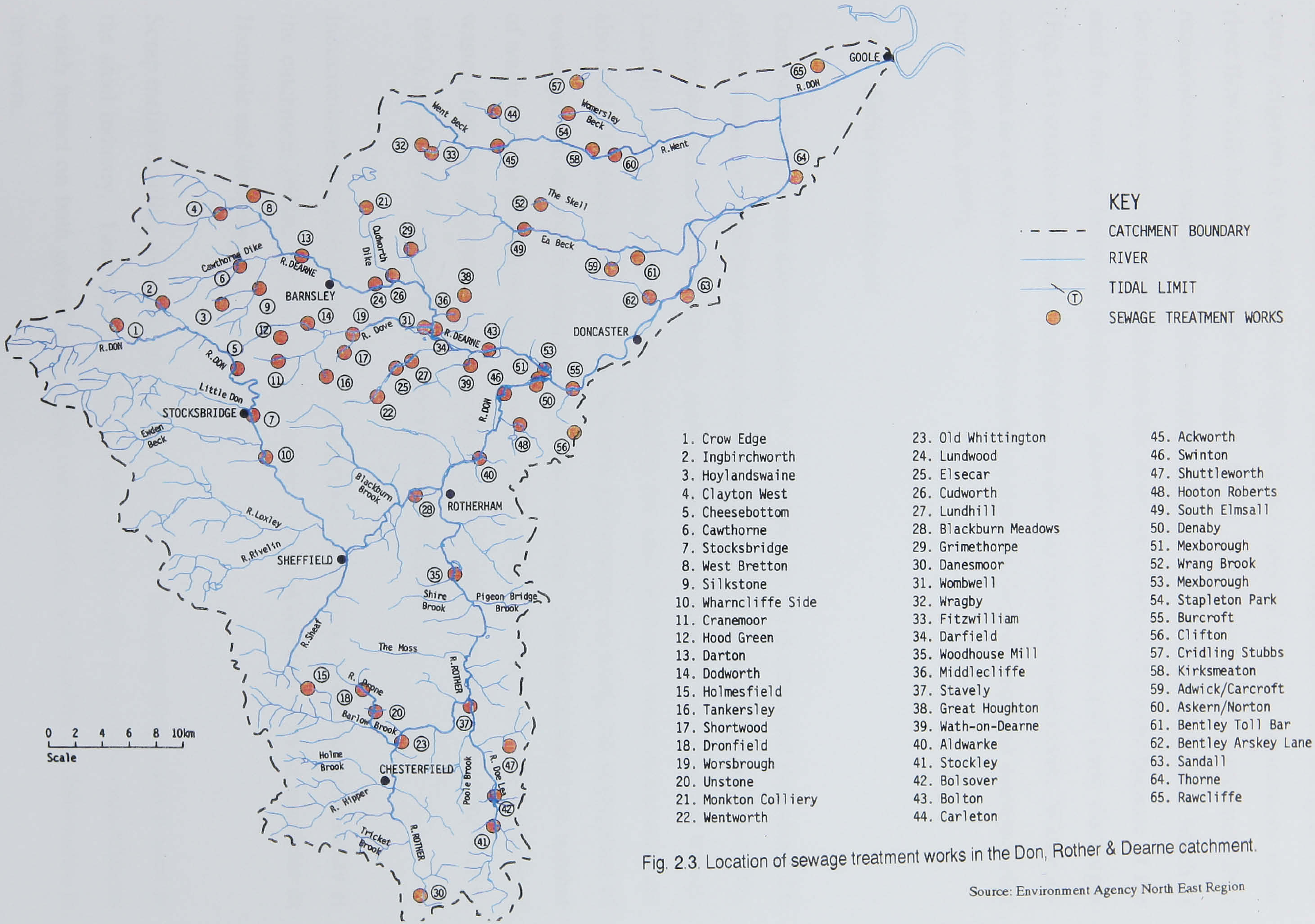


Fig. 2.3. Location of sewage treatment works in the Don, Rother & Dearne catchment.

Source: Environment Agency North East Region

2.4.3. *Industrial and agricultural abstraction*

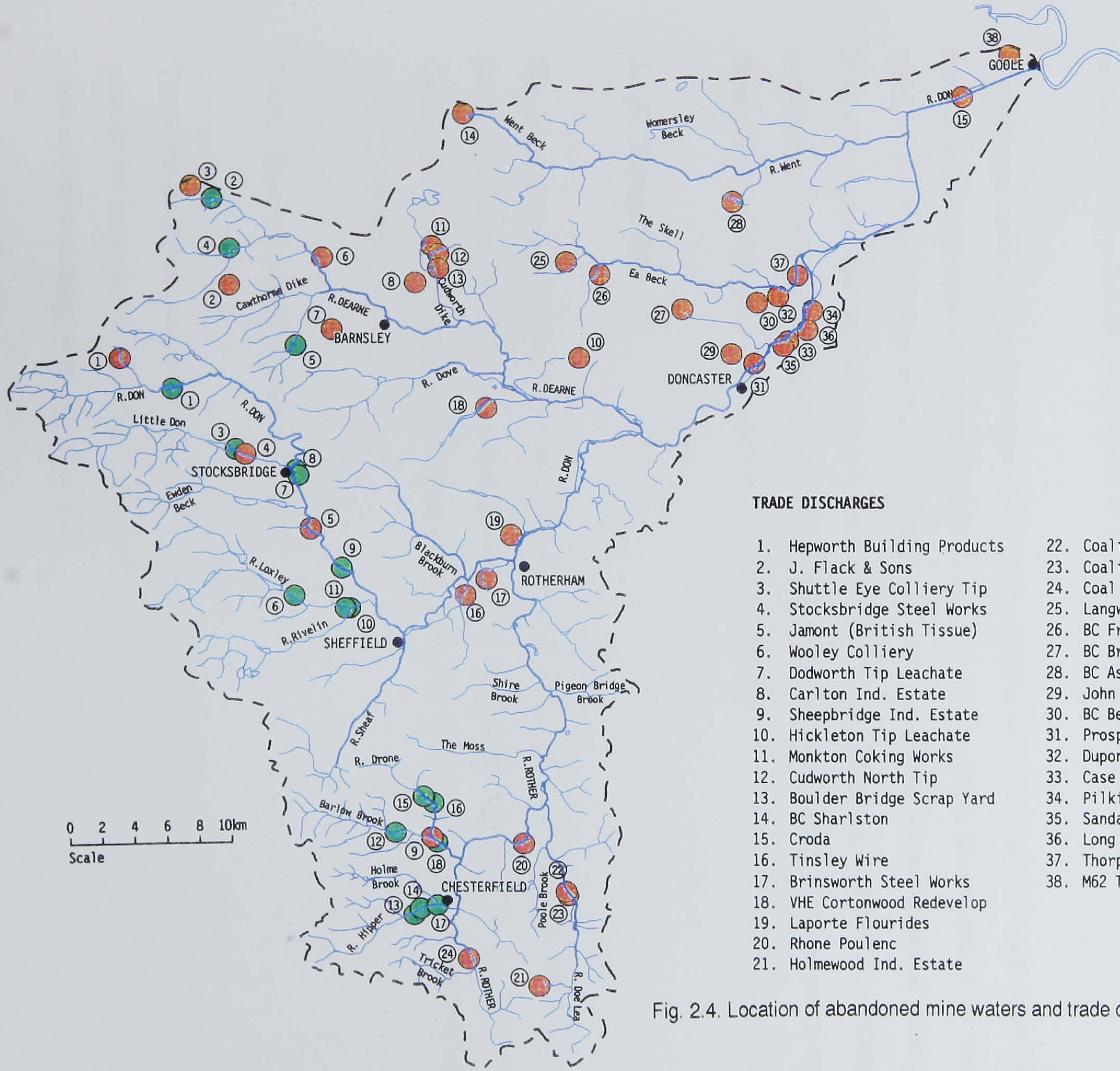
The catchment represents a source of water for various agricultural activities such as crop irrigation and livestock watering. There are 60 licensed abstractions for agricultural spray irrigation in the catchment of which 15 are required to cease abstractions when river flow falls below a specified limit (EA, 1997). This ensures that the minimum flow requirements are met and the environmental needs of the rivers are protected. Much of the industry within the catchment area has developed close to the river because of the need for water in industrial processes. Abandoned mine waters and trade discharges (Fig. 2.4) continue to impact on the water quality and fisheries in the rivers. Within the catchment as a whole there are 125 licensed abstractions for industrial and manufacturing purposes (EA, 1997).

2.4.4. *Solid waste disposal*

Controlled solid waste disposal occurs in the catchment. It is estimated that about 2.6 million tonnes of controlled waste is disposed of in the catchment each year (EA, 1997). The wastes include excavated spoils, rubble, domestic, commercial and industrial wastes. Landfill is the main disposal method used in the area, although waste incinerators are also used. In recent years attention has been given to the recycling and segregation of wastes prior to disposal to reduce environmental damage. This has increased the number of waste transfer stations in the catchment (NRA, 1994b). About 1.28 million tonnes of wastes from the construction and demolition industry were disposed of in 1996/97 (EA, 1997), of which 25% was from contaminated site clearance.

Indiscriminate dumping of tyres has been identified as a threat to environmental safety in the catchment (NRA, 1994b), and this occurs on a considerable scale at locations in Hampole and Deepcar.

Scrap metal recycling also takes place in the catchment. Recycled scrap metal is used in the steel industry. Leachates from scrap metal disposal sites may carry contaminants which impact on both ground and surface water quality, and possibly on fish stocks in the rivers.



TRADE DISCHARGES

1. Hepworth Building Products
2. J. Flack & Sons
3. Shuttle Eye Colliery Tip
4. Stocksbridge Steel Works
5. Jamont (British Tissue)
6. Wooley Colliery
7. Dodworth Tip Leachate
8. Carlton Ind. Estate
9. Sheepbridge Ind. Estate
10. Hickleton Tip Leachate
11. Monkton Coking Works
12. Cudworth North Tip
13. Boulder Bridge Scrap Yard
14. BC Sharlston
15. Croda
16. Tinsley Wire
17. Brinsworth Steel Works
18. VHE Cortonwood Redevelop
19. Laporte Flourides
20. Rhone Poulenc
21. Holmewood Ind. Estate
22. Coalite Chemicals
23. Coalite Fuels
24. Coal Products, Wingerworth
25. Langwaithe Grange Ind Estate
26. BC Frickley
27. BC Brodsworth
28. BC Askern
29. John Carr
30. BC Bentley
31. Prosper de Mulder
32. Dupont
33. Case International
34. Pilkingtons
35. Sandall Ind Estate
36. Long Sandall Ind Estate
37. Thorpe Marsh Power Station
38. M62 Trading Estate

ABANDONED MINEWATER DISCHARGES

1. Bull House Minewater
2. Alexandra Drift Minewater
3. Sheephouse Wood
4. Benny Lane Adit
5. Silkstone
6. Marshall
7. Deepcar
8. Wharncliffe Side
9. Claywheels Lane
10. Loxley Bottom
11. Myers Grove
12. Fender Shaft
13. Robinsons Borehole
14. Forge Dam Adit
15. Summerley No 1
16. Unstone Minewater
17. Dock Walk
18. Mary Anne Shaft

Fig. 2.4. Location of abandoned mine waters and trade discharges in the Don, Rother & Dearne catchment.

Source: Environment Agency North East Region

2.4.5. *Habitat conservation*

The catchment has areas of significant conservation interest including 22 Sites of Special Scientific Interests (SSSIs), and 44 Sites of Scientific Interest (SSI). Notable among these is the Peak District National Park. The flora and fauna in these sites remain an important feature of the catchment for both their scientific value and benefits to the community.

2.4.6. *Water-based recreation*

Water-based recreation as boating and sailing, wind surfing and canoeing, takes place in the Rother Valley Country Park and a number of Pennine reservoirs.

Recreational fishing is an important sport in the catchment. For example, some sites on the River Don are used by anglers for both trout and coarse fishing (Environment Action, 1998). The River Dearne at Pastures Bridge has also been used for recreational fishing. It is anticipated that as water quality and the fish stocks improve, recreational fishing activities will become enhanced. Physical obstructions to fish passage, such as weirs and flow control structures are also present in the catchment.

2.4.7. *Navigation*

The natural course of the River Don and its canalised stretches provide the basis of the Sheffield and South Yorkshire Navigation. This eventually connects to the Aire and Calder and Trent Navigation. The main part of the river is used for both commercial and leisure purposes.

2.4.8. *Riverside amenity and recreation*

The river corridors and the lands adjacent to the reservoirs within the catchment area provide an important locations for the local community to exercise their leisure pursuits such as bird-watching, walking or picnics.

2.4.9. Flood alleviation and storage

The catchment is located within a highly urbanised area, and this requires the protection of people and property from floods. The catchment provide routes through which floodwaters can be controlled to protect people and property. They also provides areas to store floodwaters to reduce flood levels and risks for the community.

2.5 Main Issues affecting the Don, Rother and Dearne catchments

A number of issues relating to the uses and abuses of the catchment impact on the fisheries and water quality. The main issues are summarised below for the catchment.

2.5.1. The Upper Don catchment

- Abandoned mine waters represent a significant threat to water quality and the fisheries, e.g. the River Don at Penistone.
- Effluents from STWs and CSOs impact on the water quality and the fisheries, particularly around Sheffield.
- Industrial discharges constitute an important factor.
- Impoundments or reservoirs affect water quantity and reduce dilution for pollutants.
- Solid wastes, landfills, scrap metal and rubble degrade both water quality and the fish habitats e.g. at Deepcar and Hampole.
- The physical habitat of the river at some stretches has been degraded due to culverting and channel modification, e.g. the River Don through Rotherham and Sheffield.
- Fish movements are restricted by weirs or flow control structures, e.g. Beeley Woods, Sprotborough and Aldwarke weirs.

2.5.2. The Lower Don catchment

- Sewage effluents from sewage works and CSOs.
- Trade and industrial discharges occur around Doncaster and Goole area.
- Water abstractions for livestock, spray irrigation, and industrial uses affect water quantity and degrade the riverine habitats.

- Flooding and flood risks. The river is embanked from Doncaster to Goole with embankments 3-4 m above adjacent ground level.
- Poor physical habitat due to channel modification for flood defences and culverting, e.g. the tidal reaches of the River Don.
- Restricted fish movements due to flow control structures, e.g. the Crimpsall Sluice at Doncaster.

2.5.3. The River Dearne

- Sewage effluents from STWs and CSOs are found at many locations in the catchment.
- Trade and industrial discharges occur at many locations.
- Abandoned mine discharges occur particularly in the south and east of Barnsley (viz. Benny Lane Adit, Alexandria Drift Mine Water & Silkstone) and impact on the river.
- Pollution incidents resulting from agricultural run-offs, silage liquors, animal slurries, and deliberate or inappropriate disposal of industrial oils or chemicals.
- River engineering works at certain stretches of the main river, e.g. the River Dearne at Pastures Bridge.
- Culverting of the river degrades the physical habitat and restricts colonisation by aquatic biota, e.g. the River Dearne through Barnsley.

2.5.4. The Rother catchment

- Sewage effluents from STWs occur at many locations in the catchment.
- Abandoned mine waters occur in the Chesterfield and Bolsover areas.
- Contaminated land due to leachates escaping from landfill and waste disposal sites, (e.g. at Beighton landfill site where leachate has entered the Shire Brook) and former colliery tips.
- Trade and industrial discharges occur at several locations in and around Chesterfield.
- Flooding risks on the main river and tributaries (e.g. at the confluence of the River Rother and the River Hipper).
- Flow regulators (e.g. Rother Valley Country Park) and impoundments affect fish migrations.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Background

The Don, Rother and Dearne catchments have long histories of pollution resulting from mine and industrial discharges, and also from agricultural and sewage effluents (Section 1.4). Some water courses in the catchment have also become dumping grounds for domestic waste and other refuse. Consequently the water quality and the fisheries have come under sustained pressure resulting in poor status of fish populations.

This study investigates the impacts of anthropogenic activities on the fisheries of the catchment by examining data from fisheries and water quality surveys, and for the last 14 years. In addition some selected sites were sampled for further more detailed study of the fisheries and water quality to show recent trends in relation to environmental and habitat improvement measures made over the past 5 years.

3.2. Historical surveys

Fisheries and water quality data on the Rivers Don, Rother and Dearne were obtained from the Environment Agency (EA) and its predecessor, NRA, to study the impacts of pollution on the fisheries of the above named catchment. These consisted of data collected from 3-yearly rolling programmes and *ad hoc* surveys by Yorkshire Water Authority (YWA), the NRA and the EA (Table 3.1).

The Environment Agency and its predecessors used electric fishing equipment and techniques for their routine and *ad hoc* surveys of the catchment. At each site electric fishing was carried out using a generator producing 2 kVA DC with a single anode or a 2.9 kVA generator ("Electracatch" DC fishing box) operating two anodes and wading in an upstream direction. A single run was made at each site. In deeper waters, exceeding two metres in depth, electric fishing was carried out from a boat moving in an upstream direction. The gear had twin electrodes.

The site details and locations of the historical surveys by the EA and its predecessors are described in Tables 3.2a, 3.3, 3.4, and 3.5. The sites sampled on a regular basis (Tables 3.2b & 3.4b) are indicated.

Tributaries have the potential to influence fish populations in the main river as there is generally migration and dispersion of fish between them. The tributaries of the River Don were therefore sampled by electric fishing by the NRA (EA) in January 1986 to assess the status of fish populations of the Don catchment. The site details of the tributaries that were surveyed are described in Table 3.3.

Table 3.1 Summary of the programme of surveys by YWA, NRA and EA.

Organisation	River Don		River Dearne		River Rother	
	Year of survey	No. of sites surveyed	Year of survey	No. of sites surveyed	Year of survey	No of sites surveyed
Yorkshire Water Authority	1981	25	1985	5	1984	30
	1984	6	1988	18		
	1986	24				
	1987	11				
National Rivers Authority	1990	12	1991	19	1988	12
	1993	25	1994	16	1992	3
					1994	40
Environment Agency					1995	5

Table 3.2a. Details of sampling sites in the River Don

Site No..	Location	Grid reference	Width (m)	Depth (m)	Site description
1	Dunford Bridge	SE 159 024	2	0.20	Riffles and shallow pools.
2	Soughley Farm	SE 189 028	5	0.30	Mainly riffles, cobbles with some boulders and gravel
3	Above Millstone Bridge	SE 212 029	5	< 1.20	Mainly pools with one shallow riffle. Boulders and silt.
4	Thurlstone	SE 237 035	8	< 1.50	Deep riffles and pools. Bedrock with boulders; ochreous deposits.
5	Penistone	SE 254 034	6	0.40	Riffles and shallow pools. Mainly gravel and boulders.
6	Cheesebottom STW	SE 279 015	8	0.50	Riffles and runs. Mainly boulders and pebbles
7	Wortley	SK 298 991	12	< 0.80	Deep riffles and runs. Silted gravel and pebbles.
8	Stocksbridge STW	SK 299 977	10	< 1.00	Deep riffles and pools. Bedrock with boulders. Water brown and turbid.
9	Wharncliffe Side	SK 299 977	12	< 1.20	Riffles and pools. Silted bedrock and boulders.
10	Above British Tissues	SK 302 942	12	< 0.60	Riffles and small pools. Bedrock with cobbles and boulders.
11	Below Beeley Wood	SK 319 920	15	< 1.50	Riffles except for weir pool. Cobbles and boulders. Rising sludge in weir pool.
12	Hillsborough	SK 332 905	10	< 0.60	Riffles and pools. Silted cobbles and pebbles.
13	Borough Bridge	SK 354 882	20	< 0.60	Riffles and small pools, cobbles gravel and pebbles
14	Smithfield House	SK 359 877	20	< 1.00	Runs, riffles and small pools. Cobbles, pebbles, silted gravel.
15	Below Meadowhall Weir	SK 385 904	20	0.80	Riffles and runs. Silted gravel.
16	Below Blackburn Meadows Weir	SK 403 921	30	0.50	Riffles and runs. Heavily silted pebbles and gravel
17	Marsh Street	SK 424 923	25	< 1.00	Fast runs. Silted boulders and cobbles. Water very turbid.
18	Below Aldwarke Weir	SK 451 945	20	> 1.00	Fast runs below weir, otherwise slow runs. Silty.
19	Below Kilnhurst Bridge	SK 466 973	25	< 1.00	Fast runs with few pools. Silted boulders, cobbles and pebbles.
20	Nr. Denaby	SK 491 998	30	> 1.00	Fast runs. Boulders and cobbles
21	Below Sprotborough	SE 538 014	25	> 1.00	Runs and pools; silted cobbles.
22	Nr. Doncaster Power station	SE 568 039	20	> 1.50	Fast runs and pools. Silt and clay with cobbles
23	Thorpe Marsh Power station	SE 609 091	25	> 1.50	Tidal, silt and clay.
24	Stainforth	SE 639 120	25	> 2.00	Tidal, silt and clay
25	Went Confluence	SE 668 187	30	> 2.00	Tidal, silt and clay.

Table 3.2 b. Details of sampling periods for the River Don

Site No	August 1981	October 1984	Sept. 1987	October 1990	Nov. 1993
1	✓				✓
2	✓	✓	✓	✓	✓
3	✓				✓
4	✓				✓
5	✓				✓
6	✓				✓
7	✓	✓	✓	✓	✓
8	✓				✓
9	✓				✓
10	✓				✓
11	✓		✓	✓	✓
12	✓		✓	✓	✓
13	✓	✓	✓	✓	✓
14	✓		✓	✓	✓
15	✓		✓	✓	✓
16	✓	✓	✓	✓	✓
17	✓		✓	✓	✓
18	✓				✓
19	✓				✓
20	✓				✓
21	✓	✓	✓	✓	✓
22	✓			✓	✓
23	✓				✓
24	✓	✓	✓	✓	✓
25	✓				✓

The sites surveyed are indicated by a tick (✓).

Table 3.3. Site details of some upper Don Tributaries, January 1986

Site No.	Stream	Location	Grid Ref.	Length (m)	Width (m)	Av. Depth (m)	Substrate
T1	Crow Edge Beck	Sledbrook north of B6106	SE 196036	50	1.5	0.15	Gravel, cobbles, pebbles, sand and silt
T2	Scout Dyke	Below Ingbirchworth	SE 226057	60	1.5	0.15	Gravel cobbles, pebbles, sand and silt
T3	Scout Dyke	Above Penistone	SE 240045	50	4.0	0.20	Gravel, pebbles, silt
T4	Cubley Brook	Below B6462	SE 259028	50	1.5	0.10	Boulders, gravel, cobbles pebbles
T5	Little Don	Below Langsett Reservoir	SE 219004	50	6.0	0.15	Boulders, gravel, cobbles pebbles
T6	Little Don	Above Underbank Reservoir	SK 232999	50	5.0	0.15	Boulders, gravel, cobbles pebbles
T7	Little Don	Below Underbank Reservoir	SK 254992	50	8.0	0.15	Boulders, gravel, cobbles pebbles
T8	Little Don	Below Stocksbridge	SK 290980	50	8.0	0.30	Gravel, cobbles, pebbles, sand
T9	Ewden Beck	Above Broomhead	SK 242968	50	5.0	0.20	Boulders, gravel, cobbles, pebbles, sand
T10	Ewden Beck	Below A616	SK 298995	50	5.0	0.20	Boulders, gravel, cobbles, pebbles and sand
T11	Hobson Moss Dyke	Agden Bridge	SK 243940	50	3.0	0.15	Boulders, gravel, cobbles, pebbles.

Table 3.3. continued

T12	River Loxley	S.W. of Loxley	SK 299894	50	6.0	0.15	Boulders, gravel, cobbles, pebbles and sand
T13	River Loxley	Above A61	SK 336897	50	8.0	1.00	Cobbles, pebbles, sand and silt
T14	Strines Dyke	Strines	SK 221909	50	4.0	0.15	Boulders, gravel, cobbles, and pebbles
T15	Strines Dyke	Below Dale Dyke Reservoir	SK 255918	50	4.0	0.10	Bedrock, boulders, gravel, cobbles, and pebbles
T16	Ughill Brook	Below waterfall	SK 260902	50	2.5	0.10	Bedrock, boulders, gravel, cobbles, and pebbles
T17	Ughill Brook	Above waterfall	SK 259902	50	2.0	0.15	Bedrock, boulders, gravel, cobbles, pebbles and sand
T18	River Rivelin	Above Rivelin Dams	SK 263874	50	6.0	0.20	Bedrock, boulders, gravel, cobbles, and pebbles
T19	River Rivelin	Rivelin Mill	SK 292873	50	5.0	0.20	Bedrock, boulders, gravel, cobbles, and pebbles
T20	River Rivelin	Nr. Havelock Dam	SK 323887	50	6.0	0.15	Boulders, gravel, cobbles, pebbles
T21	River Sheaf	Abbeydale Park	SK 330824	50	5.0	0.20	Boulders, gravel, cobbles, pebbles
T22	River Sheaf	Heeley	SK 351851	50	6.0	0.30	Boulders, gravel, cobbles, pebbles
T23	River Porter	Near A625	SK 333858	50	4.0	0.15	Boulders, gravel, pebbles, cobbles
T24	Blackburn Brook	Ecclesfield	SK 366940	50	4.0	0.30	Boulders, gravel, pebbles, cobbles.

Table 3.4a. Details of sampling sites in the River Dearne (1985-1994).

Site No.	Location	Grid Reference	Length Fished (m)	Width (m)	Depth (m)	Comments
1	Park Gate Dyke, u/s footbridge	SE 234 114	50	1.0	0.2	
2	u/s Denby Dale	SE 219 084	90	3.0	0.3	Little cover
3	d/s Denby Dale,u/s road bridge	SE 250 085	100	3.0	0.4	
4	Scissert, u/s Dairy from bridge	SE 250 103	100	4.0	0.4	
5	Scissert, d/s Dairy	SE 253 108	50	3.0	0.4	
6	Park Mill from bridge	SE 255 115	100	3.5	0.5	
7 (RP)	u/s Bretton Lakes	SE 272 123	100	6.0	0.5	Silted gravel.
8	d/s Haigh Roundabout d/s bridge	SE 300 120	100	4.0	0.4	
9	R. Dearne, Darton from footbridge	SE 313 101	100	7.0	0.8	
10	Cawthorne Beck	SE 316 090	1.5	0.4	50	
11	Cawthorne Dyke	SE 318 091	70	5.0	0.6	

Table 3.4a continued

12	R. Dearne, Low Barugh	SE 320 091	100	8.0	0.6	Deep pool difficult to fish
13	R. Dearne d/s Star Paper Mill Weir,	SE 350 072	100	8.0	0.7	Deep pool, Foam.
14	R. Dearne, Hoyle Mill	SE 362 067	100	8	0.3	Pebbles and cobbles
15 (RP)	Stairfoot, u/s A633 road bridge	SE 372 063	100	8.0	0.8	
16	Cudworth Common, u/s road bridge	SE 403 070	100	10.0	0.7	
17	Darfield, u/s road bridge	SE 420 045	100	15.0	1.0	
18 (RP)	Broomhill above road bridge	SE 420 031	200	10.0	>1.2	Angular cobbles and silted sand.
19	R. Dearne, Bolton on Dearne	SE 457 020	12.0	> 1.0	1300	
20	R. Dearne, Adwick on Dearne	SE 474 023	10	> 1.0	300	
21 (RP)	Pastures Bridge above bridge	SE 495 009	200	12.0	>1.2	Silt and clay, marginal weeds
22	R. Dearne, Above Don confluence	SE 504 003	200	10	> 1.5	
23	River Dove-d/s Worsborough reservoir 50m d/s dam	SE 353 034	100	4.0	0.6	
24	R. Dove-Worsboro Dale d/s bridge	SE 368 035	50	3.5	0.5	Oily exudation in substrate
25	R. Dove-A633 Bridge	SE 387 045	100	3.5	0.4	
26	R. Dove-Low Valley, d/s bridge	SE 406 038	50	8.0	0.5	

(RP) = rolling programme site; d/s = downstream; u/s = upstream

Table 3.4b. Sampling frequencies at sites in the River Dearne and tributaries (1985-1994).

Site No.	Location	1985	1988	1991	1994
1	Park Gate Dyke, u/s footbridge		✓	✓	
2	u/s Denby Dale		✓	✓	✓
3	d/s Denby Dale, u/s road bridge		✓	✓	✓
4	Scissett u/s Dairy from bridge			✓	✓
5	Scissert, d/s Dairy				✓
6	Park Mill from bridge		✓	✓	✓
7 (RP)	u/s Bretton Lakes	✓	✓	✓	✓
8	d/s Haigh Roundabout, d/s bridge		✓	✓	✓
9	R. Dearne Darton from footbridge		✓	✓	
10	Cawthorne Beck, Low Barugh		✓		

Table 3.4b. continued

11	Cawthorne Dyke				✓
12	R. Dearne, Low Barugh		✓	✓	✓
13	R. Dearne, Hoyle Mill	✓			
14	R. Dearne d/s Star Paper Mill Weir		✓	✓	✓
15 (RP)	Stairfoot, u/s A633 road bridge	✓	✓	✓	✓
16	Cudworth Common, u/s road bridge		✓	✓	✓
17	R. Dearne Darfield, u/s road bridge		✓	✓	✓
18 (RP)	R. Dearne, Broomhill above road bridge	✓	✓	✓	✓
19	R. Dearne, Bolton on Dearne		✓		
20	R. Dearne, Adwick on Dearne		✓		
21 (RP)	Pastures Bridge above bridge	✓	✓	✓	✓
22	R. Dearne, Above Don confluence				✓
23	River Dove-d/s Worsborough reservoir below dam			✓	
24	R. Dove-Worsboro Dale, d/s bridge			✓	
25	R. Dove-A633 Bridge			✓	
26	Dove-Low Valley, d/s bridge		✓	✓	

(RP) = rolling programme site; d/s = downstream; u/s = upstream

Table 3.5 Details of sampling sites in the Rother catchment (1984-1995)

Site No.	Location	Grid Reference	Width (m)	Depth (m)	Comments
1	River Rother, North. Wingfield track Bridge	SK 402652	3.5	0.3	
2	River Rother, Birdholme u/s road bridge	SK 387695	6.0	0.4	Little cover
3	River Rother, Chesterfield d/s culvert	SK 391736	6.5	0.9	
4	River Rother, Brimington d/s bridge	SK 412752	7.7	1.5	Difficult to fish safely
5	River Rother, Hall Lane u/s bridge	SK 432752	6.0	0.9	
6	River Rother, Slittingmill d/s viaduct	SK 437767	10.0	0.5	

Table 3.5. continued.

7	River Rother, Holbrook u/s bridge	SK 448813	12.0	0.6	Difficult to fish
8	River Rother, Rother Valley Country, d/s bridge	SK 455827	12.0	0.6	
9	River Rother, Beighton, d/s weir	SK 445841	14.0	0.9	Deep pool below weir
10	River Rother, Woodhouse Mill d/s A57 road bridge	SK 431858	12.0	0.7	
11	River Rother, Catcliffe u/s bridge	SK 424882	12.0	0.7	Little Cover
12	River Rother, u/s Don confluence,	SK 424922	15.0	1.5	
13	Doe Lea, Stainsby; Track Bridge	SK 456653	3.0	0.3	
14	Doe Lea , Doe Lea Bridge; Weir.	SK 460691	3.0	0.25	
15	Doe Lea , Netherthorpe, d/s bridge	SK 445750	7.0	0.60	
16	Doe Lea, Renishaw; d/s bridge	SK 443770	4.5	0.40	
17	Locko Brook, Road Bridge	SK 412641	3.0	0.25	
18	Redleadmill Brook, Tupton d/s road bridge	SK 391666	2.5	0.35	
19	Calow Brook, d/s road bridge	SK 402699	3.5	0.30	
20	Barlow Brook, Commonside u/s trout farm	SK 336757	7.5	0.3	Clear, good cover, trees.
21	Barlow Brook, d/s trout farm	SK 344755	7.5	0.3	Clear, good cover
22	River Drone Unstone Green	SK 375761	3.7	0.4	Ochreous, silt overlay
23	Muster Brook; u/s road bridge	SK 417685	2.5	0.30	
24	River Hipper, Somersall Lane road Bridge	SK 354700	5.0	0.4	
25	River Hipper, Holymoorside d/s footbridge	SK 339693	4.5	0.4	
26	Brookside Beck, Somersall Lane u/s bridge	SK 354702	2.0	0.3	
27	Brookside Beck, Westwick Farm u/s farm track bridge	SK 343726	2.0	0.3	
28	Holme Brook d/s Linacre reservoir, d/s track	SK 343726	2.0	0.3	
29	Holme Brook, Chesterfield d/s footbridge	SK 372714	3.0	0.3	
30	River Whitting, Chesterfield	SK 381745	4.0	0.3	Poor cover
31	Chesterfield Canal Brimington	SK 415746	3.0	1.0	*Lemna* and *Sparganium* on margins.
32	Trough Brook, Brimington	SK 415 743	2.5	0.1	Little flow Poor cover, clear.
33	Barlborough Brook, Woodthorpe	SK 452738	2	0.2	Turbid waters
34	Smithy Brook, Renishaw	SK 447782	2.5	0.2	Sewage fungus below effluents, large, deep pool

Table 3.5 continued.

35	Birdholme Brook, Birdholme Road Bridge	SK 374687	3.0	0.3	
36	The Moss, Povey Farm. End of track	SK 385805	3.5	0.3	
37	The Moss, Ford. d/s bridge	SK 401804	4.0	0.5	
38	The Moss, Eckington. u/s weir	SK 429779	4.0	0.6	
39	Pigeon Bridge Brook, Aston u/s road bridge	SK 464843	4.0	0.3	
40	Ochre Dyke, Crystal peaks. d/s footbridge	SK 433828	1.0	0.2	Little Flows
41	Smithy Brook, d/s STW, corner of field	SK 447782	3.0	0.3	
42	Smithy Brook, u/s STW, d/s footbridge	SK 433843	3.5	0.3	
43	Shire Brook, Beighton. u/s footbridge	SK 433843	3.0	0.3	
44	Shire Brook, Normanton Spring d/s footbridge	SK 408845	3.0	0.3	
45	Ulley Brook, Guilthwaite d/s road bridge	SK 443891	4.0	0.4	
46	Whiston Brook, stables Track Bridge	SK 435898	4.0	0.5	Storm sewage on substrate
47	Whiston Brook, Whiston u/s footbridge	SK 448908	3.0	0.3	
48	Rother, Moss Confluence	SE 440800	10	1.3	Deep runs
49	Rother Valley CP, u/s weir	SE 452836	12	1.2	
50	Rother Valley CP d/s weir	SE 452837	12	1.0	
51	RotherWoodhouse washlands, d/s riffle	SE 437852	15	1.0	
52	Rother, Woodhouse washlands dev't. site	SE 438851	15	1.0	

*u/s denotes upstream; d/s denotes downstream

3.3. Fisheries survey techniques

Electric fishing, like other fish sampling techniques, are affected by gear selectivity and changes in efficiency between sites and sampling occasions (Cowx & Lamarque, 1990). This places limitations on the interpretations of survey data collected by these means. The method was, however, used extensively to capture fish for stock assessment exercises and is the main source of historical information. Throughout the historical data collection exercises, fish species numbers proved to be too small and thus only relative estimates of abundance (Cowx, 1996) are available to show trends in fish population structure and distribution.

3.4. Current study programme

3.4.1. Study area

Between November 1995 and September 1997 five sites on the Rivers Don, Rother and Dearne were surveyed by electric fishing for further investigation of their fisheries.

Reconnaissance visits to the NRA and Yorkshire Water Authority sites and to other alternative sites in the catchment were undertaken to facilitate the selection of sites for further surveys and studies. Ideally, the sites within the catchment should be selected to be representative of the diversity of habitats in the river to give a broad representation of the systems and its diversity of characterisation. However, practical considerations such as habitat variability and access difficulties (Ward *et al.*, 1993, Harvey & Cowx, 1996), also influenced site selection for this study.

The River Don was surveyed at two sites, Penistone and Beeley Woods (Table 3.6). The River Dearne was sampled at Cudworth Common and Pastures Bridge whilst the River Rother was surveyed at Birdholme Bridge (Table 3.6).

The surveys were carried out, at 3-monthly intervals, when river conditions permitted. Locations of selected sites are shown in Figure 3.1 whilst details of the sites are also described in Table 3.6.

Fig. 3.1. Locations of study sites in the Don, Rother and Dearne catchment.

Source: Environment Agency North East Region

Table 3.6 Details of the sampling sites in the Don, Rother and Dearne catchment

River	Location	Grid Reference	Approx. Length fished (m)	Mean width (m)	Mean depth (m)	Comments
Don	Penistone	SE 254034	100	6.0	0.40	Substratum mainly large boulders, gravel, and stones. Lots of riffles, bankside vegetation mainly of deciduous trees, ferns and grasses.
Don	Beeley Wood, d/s weir	SK 319920	100	15.0	0.60	Substratum of boulders, gravel and stones. Mud and allocthonous inputs in places. Rust coloured input on one bank of river. River well shaded by trees.
Dearne	Cudworth Common, u/s road bridge	SE 403070	100	8.0	0.70	Substratum of stones, fine gravel and mud. Submerged aquatic macrophytes mainly *Ranunculus* species.
Dearne	Pastures Bridge, u/s road bridge	SE 495007	200	10	1.50	Bottom sediments of black, peaty mud. Vegetation on banks of river
Rother	Birdholme Bridge, d/s road bridge	SK 387695	80	6.0	0.40	Muddy substrate of black, oily and peaty material. Domestic wastes on banks; concrete washings in water.

The sampling sites for the River Don at Penistone and Beeley Woods described in Table 3.6 above are pictorially shown in Plates 1 and 2 respectively. Plate 3 represents the River Dearne at Cudworth Common whilst Plate 4 shows the River Rother at Birdholme Bridge.

The River Dearne at Pastures Bridge before and after channel modification works is shown in Plates 5 and 6 respectively.

Plate 1. The River Don at Penistone with riffles and bankside tree cover.

Plate 2. The River Don at Beeley Woods with ochre discharge and a dumped scrapped vehicle.

Plate 3. The River Dearne at Cudworth Common with ageing flood defence walls and eutrophicating waters.

Plate 4. The River Rother at Birdholme receiving concrete washings from a building construction site.

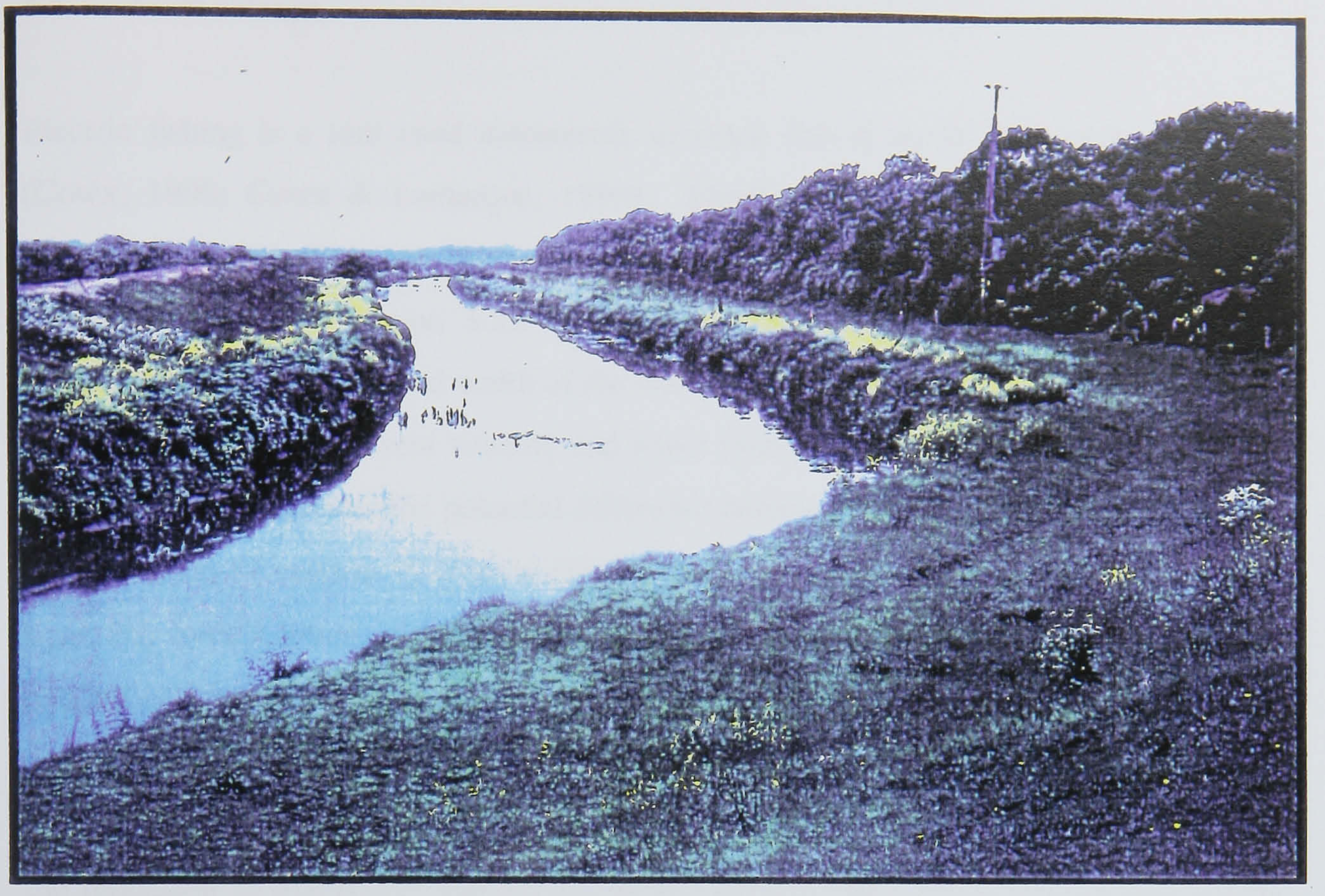


Plate 5. The River Dearne at Pastures Bridge before re-engineering of channel.

Plate 6. The River Dearne at Pastures Bridge after re-engineering of channel.

Courtesy of the EA (North East Region).

3.4.2. *Field surveys*

Electric fishing is a tool used extensively to catch fish in stock assessment exercises (Cowx, 1990; Cowx & Lamarque, 1990). Electric fishing, like other fish sampling techniques, suffers from the problem of selectivity and changes in efficiency between sites and samples (Section 3.3). The method also suffers from many limitations primarily related to depth and width of the water body being surveyed, as well as factors such as conductivity, current velocity and water clarity (Zalewski & Cowx, 1990). The larger the fish the greater the potential difference between the head and the tail and hence the likelihood of capture by electric fishing. It has been shown that juvenile and small-sized fish have a lower probability of capture than larger individuals under comparable conditions (Zalewski and Penczak, 1981; Keast, 1985; Zalewski & Cowx, 1990).

A major advantage of using electric fishing gears as an alternative to netting techniques is the reduction in manpower and survey times (Cowx *et al.*, 1989; Harvey and Cowx, 1996). The electric fishing method used in this study is considered acceptable since precise estimates were not feasible due to low numbers of fish present. Also standard operating and reporting procedures were used at each site during the surveys to give relative estimates of abundance.

Except for Pastures Bridge on the River Dearne, the fish populations were sampled using electric fishing with a 2 kVA DC generator (Briggs & Stratton) with a pulsed DC control box and a single anode. The electric fishing was conducted whilst wading in an upstream direction. At Pastures Bridge, the survey was carried out using a boat-mounted, electric fishing boom ring array with a 7.5 kVA generator and a sequential firing control box (Harvey and Cowx, 1996). In all cases, only a single run was made at each site due to the small catch. A second run to calibrate the gear was therefore not warranted.

Fish stunned or immobilised by the electric current were rapidly collected with the aid of hand nets and transferred into, and held in, large open plastic containers of water. The length of all the fish was measured to the nearest millimetre, and a subsample of fish were weighed to the nearest g. Scale samples were removed from the fish and these were kept in scale packets for later examination in the laboratory. Scale samples were generally removed from above the lateral line below the anterior insertion of the dorsal fin. After scale samples had been taken, the fish were returned to the river after a brief recovery period. Scale packets were labelled to show the fish species, length, date and site of capture. A standard procedure was adopted to reduce handling time of the fish, and hopefully, to reduce stress effects on the fish. Only a subjective estimate of abundance was made for small or minor species.

3.5. Data analysis

3.5.1. Age and growth determination by back-calculation

In the laboratory, fish scales were read with the aid of a microfiche projector with a magnification of x34. All scales were clean and needed no further processing to remove debris. Measurements of scale annuli and of total scale radii were made with the aid of a ruler. With the aid of a computer, the relationship between fish length *(l)* and total scale radius *(S)* was determined by regression for each age category according to the formula (Bagenal & Tesch, 1978):

$$l = a + b * S$$

where *a* is the intercept on the length (y) axis and *b* is the regression coefficient (slope of the line).

Growth rates were determined by back-calculation from scale readings (Bagenal & Tesch, 1978). The output generated from the regression analysis for each species was used to back-calculate the length of fish at age to provide a growth history of the species. Graphs were constructed to show the growth of fish at various locations in relation to standard growth rates for the species. Owing to the rather small numbers of some fish species captured during the surveys, the mean lengths-at-age for the species were simply tabulated.

Due to the lack of scales from many historical surveys, there were many gaps in the age and growth data. These omissions made it impossible to carry out back-calculations to study the growth history of the fishes for the historical data. Some survey sites were also either fishless or had too few fish to warrant back-calculation of age and growth of the fish.

3.5.2. Fish density

Fish densities at various surveys were calculated as number of fish per 100 m^2 of river. These values, considered to be the minimum density, were tabulated to show fish densities at various sites of the river. Graphical illustrations were presented to show the variations in fish densities at the sites.

3.5.3. Length-frequency distribution

The data from both historical and recent surveys consisted largely of fish population numbers, fish lengths and ages. The length data were used to study the recruitment and length-frequency distributions of the fishes. Fish numbers were often too low to warrant length-frequency histograms to be constructed for most sites.

3.6. Measures of Diversity

Diversity indices are mathematical expressions which use three components of community structure, namely richness (number of species present), evenness (uniformity in the distribution of individuals among the species) and abundance (total number of organisms present) to describe the response of a community to the quality of its environment (Metcalfe-Smith, 1994). Undisturbed environments are characterised by high diversity indices or richness, an even distribution of individuals among the species, and moderate to high counts of individuals (Ghetti and Bonazzi, 1977; Kolavak, 1981; Mason *et al.*, 1985)

The most widely used diversity index is the Shannon-Weiner index (H') because it is stable in any spatial distribution and insensitive to rare species (Cairns and Pratt, 1986). It is expressed as: (after Wilhm and Dorris, 1968):

$$H' = - \sum (Ni / N) \ln (Ni / N)$$

where H' = index value, N = total number of individuals of all species collected, and Ni = number of individuals belonging to the ith species. The higher the value of H' the greater the diversity and, supposedly the cleaner the environment. It is evident that species diversity is dependent on the number of species (richness) and the distribution of individuals among the species (evenness).

Diversity for fish and macrobenthic fauna were determined for the various sites during the study. Diversity has remained a central theme in ecology and measures of diversity are frequently seen as indicators of the well-being of ecological systems, hence its application in this study. The purpose of measuring a community's diversity is usually to judge its relationship to other community properties such as productivity and stability (Pielou, 1970, 1975) or to the environmental conditions to which the community is exposed.

3.6.1. Fish diversity

Fish diversity indices based on the Shannon-Weiner index, H', was determined as:

$$H' = (Ni / N) \ln (Ni / N) \quad \text{(Wilhm \& Doris, 1968)},$$

where N is the total number of individuals of all species collected and Ni is the number of individuals in the ith species. The Shannon-Weiner index was used in this study to measure changes in species numbers and evenness.

3.6.2. Species richness

Species richness measures provide an instantly comprehensible expression of diversity. Species richness as a measure of diversity has been used successfully in many studies (Connor & Simberloff, 1978; Kempton, 1979; Magurran, 1988; Brownlow and Bolen, 1994). However, the great range of diversity indices and models which go beyond species richness is evidence of the importance that many ecologists place on information about the relative abundance of species. Kempton (1979), however, observes that the distribution of species abundance is often a more sensitive measure of environmental disturbance than species richness alone.

The Shannon-Weiner function increases as both the number of species and the equitability of species abundance increase. It is desirable to consider indices that treat these aspects separately since the two components of diversity may react differently to certain types of stress (Dahlberg & Odum, 1970).

In this study the species richness index was determined using Margalef's index (D_{Mg}) described as:

$$D_{Mg} = (S\text{-}1) / \ln N$$

where S is the number of species and N is the total number of individuals of all species summed together.

Margalef's index was used in this study because it has been demonstrated to show substantial discriminant ability and a reasonably high sensitivity to sample size (Magurran, 1988; Brownlow and Bolen, 1994). It is also easy to calculate.

3.6.3. Evenness index

The diversity of a community depends on the number of species and the evenness with which individuals are apportioned among them. To describe a community diversity merely in terms of its diversity is to confound these two factors. A community with a few, evenly represented species can have the same diversity as one with many unevenly represented species. It is obviously desirable to calculate these two aspects separately.

Although the Shannon-Weiner index takes into account the evenness and abundance of species (Peet, 1974), it is also possible to calculate a separate additional measure of evenness. Evenness index (J) was measured using Pielou's (1975) index , described as:

$$J = H' / \ln S$$

where H' is the Shannon-Weiner value, and S is the number of species sampled. Evenness is constrained between 0 and 1.0 representing a situation in which all species are equally abundant. As with H' evenness measure assumes that all species in the community are accounted for in the sample.

Evenness was measured in this study to provide an indication of species abundance and the equitability of their distribution among other species. The calculations of diversity indices were repeated for the historical data where applicable, and graphical illustrations of the indices at the various sites were made to show variations in diversity at each site.

3.7. Water quality data for historical surveys

3.7.1. Chemical water quality

A large number of different properties and parameters are available to describe the chemical characteristics of rivers. These range from general descriptors such as measures of salinity and acidity, to composition in terms of major cation and anion content, to the concentrations of organic and inorganic micro-pollutants.

In recent years, the EA has applied the General Quality Assessment (GQA) scheme to describe the chemical quality of rivers and canals in England and Wales (Firth, 1997). The basic chemical grade of the GQA Scheme is defined by standards for the concentrations of BOD, ammonia, and dissolved oxygen. These have been selected because they are indicators of the extent to which waters are affected by waste-water discharges and rural land use run-off containing organic, degradable material. The quality of many rivers in England and Wales is affected by such discharges and include effluents from sewage treatment works and industries, and drainage from farms. These three determinands are therefore the best overall basic chemical measure of river water quality for the purpose of GQA which will apply to all rivers and canals within the classified network.

The use of these three determinands provides some continuity with the National Water Council (NWC) system (NRA, 1994e). In the GQA assessment, however, data from three years sampling are used to make the assessment of class. For the 1993 assessment, data from 1991, 1992, and 1993 were used. The boundaries of each class are summarised in Appendix 1.1. The National Water Council (NWC) classification scheme has also been used to characterise rivers and canals in England and Wales. Details of the NWC classification scheme are described in Appendix 1.2.

Historical data on the chemical water quality of the Don, Rother and Dearne catchment for the past decade were obtained from the databases of the EA to elucidate the trends in water quality over time.

3.7.2. Biological water quality

There has been growing interest in the use of biological methods to assess the biotic integrity of streams. The advantage of biological methods is that aquatic communities integrate the totality of environmental factors within a stream and, therefore represent a powerful tool for quickly, economically and comprehensively assessing stream health.

Biotic integrity can be summarised briefly as the ability to support a biological community and processes typical of undisturbed, natural conditions (Angermeir and Karr, 1994). Biotic integrity can be evaluated from fish, macroinvertebrates or diatom data (Patrick, 1973; Plafkin *et al.*, 1989).

Biological studies can serve an early warning function by detecting intermittent pollution and subtle disruptions which would likely be missed by conventional chemical surveys (Howmiller and Scott, 1977; Reynoldson, 1984). In addition it must also be recognised that not all impacts are chemical in nature; biological assessments may also be able to detect the impact of flow alterations, habitat destruction, and over-harvesting of biological resources (Karr, 1991).

Direct assessment of the health of biotic communities in receiving waters offers several important advantages over chemical-based approaches. For example, organisms integrate environmental conditions over time, whereas chemical data are instantaneous in nature and require large numbers of measurements for an accurate assessment (De Pauw and Vanhooren, 1983). Biological communities also integrate the effects of multiple stresses and demonstrate cumulative impact (Plafkin *et al.,* 1989).

Historical information on Water Quality Classes or Biological Classes for designated sites in the Don, Rother and Dearne catchment were obtained from the databases of the EA (NRA). These classifications were based on the NWC classification (Appendix 1.2).

3.7.3. Benthic macroinvertebrates and biological water quality

The use of benthic macroinvertebrates to assess the health of aquatic environments has been widely adopted (Hellawell, 1977; Reynoldson, 1984; Pinder & Farr, 1987). The distribution of benthic macroinvertebrates is generally considered to be indicative of the chemical quality of surface waters (Sloff, 1983), and often serve as indicators of organic pollution.

Hellawell (1977) and Reynoldson (1984) have shown various benefits for using benthic macroinvertebrates in biological quality assessment. Macroinvertebrate communities are differentially sensitive to pollutants of various types and react to them quickly (Cook, 1976; Pratt and Coler, 1976). Macroinvertebrates are present in most aquatic habitats especially flowing water systems (Reynoldson, 1984), and are abundant and relatively inexpensive to collect (Plafkin *et al.*, 1989). Furthermore their taxonomy is well established, although admittedly difficult at the species level for some groups (Reynoldson, 1984). Benthic macroinvertebrates are relatively sedentary, and are therefore representative of local conditions (Cook, 1976; France 1990). They also have life spans long enough to provide a record of environmental quality (Pratt and Coler, 1976).

3.7.4. Benthic macroinvertebrate surveys

Macrobenthic invertebrates were sampled during fishing surveys according to the standard method described by Mackey *et al.*, (1984) to assess possible impacts of pollution on the fisheries. A standard pond net of mesh size 900 µm and approximately 275 mm deep fitted to a 230 mm x 225 mm frame on a 1.5 m handle was used in macroinvertebrate sampling at the various sites. The net was placed on the stream bottom, facing upstream and the substratum directly in front of the net was kicked and agitated so that the dislodged benthic organisms were swept into the net by the water current. A standard 3-minute kick sample was taken this way for all the sites, and river bed stones and rocks were washed into a polythene bag for a minute to dislodge the macroinvertebrates present on them. However, in the River Dearne at Pastures Bridge, a Van Deen grab was used to collect samples from the river bed. This technique was necessary because the water was too deep to permit kick samples to be taken.. At the end of the collection the samples were washed into polythene bags, stored in a cool place and returned to the laboratory for examination and species identification. With the aid of reference materials and literature, Freshwater Biological Association keys (Windermere), Macan, (1975) and Fitter and Manuel, (1986), identification of the macroinvertebrates to their taxonomic families and species was undertaken in the laboratory. Abundance of all the benthic macroinvertebrate taxa (identified to the family level) were determined for the various sites.

3.7.5. The Biological Monitoring Working Party (BMWP) scores and Average Score Per Taxon (ASPT)

The need for a reliable method of assessing the biological quality of rivers and streams in Britain and the subsequent development of the Biological Monitoring Working Party (BMWP) score system has been well documented (e.g. Chesters, 1980; Armitage *et al.,* 1983). The BMWP score is now used by Water Authorities and the Environment Agency for routinely reporting water quality.

The BMWP score and its derivative, the Average Score Per Taxon (ASPT) for the benthic macroinvertebrates of the study area (Table 3.6), were used to evaluate water quality. The higher the BMWP or ASPT score, the cleaner the water is supposed to be. Conversely, poor water quality is indicated by a low BMWP or ASPT score.

BMWP scores for the study sites were determined by listing all the macroinvertebrate families present at each site. With the aid of the BMWP score system (Armitage *et al.*, 1983), the appropriate score was ascribed to each family for the site. The scores were then summed to give the total BMWP score for the site. The ASPT computation was determined by dividing the BMWP score by the number of scoring taxa. Historical data of the EA (NRA) for BMWP scores and water quality classifications were also studied.

3.7.6. Macroinvertebrate abundance and diversity

Benthic macroinvertebrate diversities were determined for the various sites using the indices of Shannon-Weiner, Margalef and Pielou described earlier.

3.8. The application of the project cycle approach to fisheries management in the Don, Rother and Dearne catchment

The project cycle approach was used in this study to formulate projects. Project concept notes were developed for each project to describe the key issues of the projects for the rehabilitation of fisheries in degraded riverine habitats. Logical Project Frameworks (LPF) were also developed for each project to facilitate the logical progression of the projects.

There is no universally accepted definition of what constitutes a project. Projects have been referred to as "the cutting edge of development" (Gittinger, 1982); and the same author defined projects as "an investment activity in which financial resources are expended to create capital assets that produce benefits over an extended period of time". The author further defined a project as " an activity for which money will be spent in expectation of returns and which logically seems to lend itself to planning, financing and implementing as a unit". A project provides a disciplined and systematic approach by which the allocation of resources can be determined, analysed and evaluated. Therefore the management of issues and the implementation of options can be viewed in the project format.

The project approach provides a framework for the collection and analysis of both quantitative and qualitative information for comparing project alternatives, addressing social, institutional and policy issues and addressing the year by year benefits and costs of a project. The approach also enables planners to assess the effects of the project on national income and its impact with regard to national and sector objectives.

The project approach is designed to encourage reasoning beyond the technical and financial merits, since it also involves social, environmental and technical aspects. It also ensures that projects are acceptable to all the catchment's user groups and that valuable resources are not wasted on projects that are inappropriate to the time and location within the catchment.

Despite considerable investment, many inland fisheries projects have performed below expectation. Whilst the reasons for this are complex, a root cause has probably been the lack of adequate planning and appraisal (Crean, 1994). The project approach provides a methodology that can be used for development in many sectors. It sets out in an orderly way the aims, objectives, inputs, outputs, indicators and risks associated with the project.

The project approach to development is characterised by a number of phases which are linked together and relate overall to national policies and sector plans. Essentially the phases encompass project identification, preparation, appraisal, implementation and evaluation. The first stage of the project cycle is concerned with identifying those projects of high priority and suitability. In the project identification phase, various tools are used to consider the concept and viability of the projects presented. These include the Project Concept Note (PCN) and the Logical Project Framework (LPF). The PCN considers the project in relation to national or sector objectives, funding authority guidelines, relationship of proposed project to prevailing activities within the sector and the overall justification for the project. The project approach offers a sequential and comprehensive methodology for assessing the viability of management-oriented goals and the feasibility and/or suitability of the project. It therefore shifts the emphasis from basic data collection exercises and encourages wider thinking to cover the scientific, technical, resource and financial aspects.

The Logical Project Framework was developed by the USAID in the late 1960s (Crean, 1994) and adapted by NORAD (1990). It is useful in setting out the design of a project in a clear and logical way so that any weaknesses that exist can be brought to the attention of the planners and remedied at an early stage. The LPF technique also emphasises the value of choosing measurable indicators which can be assessed throughout the life of the project, and also instructs planners to carefully assess the risks and assumptions upon which the project is based. The LPF is a technique which links the various stages of the project approach. The LPF helps to clarify the objectives of and justification for a project and also identifies the information base required. The LPF facilitates communications between formal and informal organisations and the target groups, defines the key elements of the project and identifies how the success or failure of the project should be measured. It also lays out the conditions that pertain to the environment of the project. In practice the LPF should be used as an interactive methodology establishing a partnership between all involved in the design, and funding of the project with potential beneficiaries or losers if the project is implemented (Haywood & Crean, 1998).

The LPF is most effective when applied in group situations where individuals are actively making their plans and concerns known, and all involved are focused on finding a project-based solution to the existing problems (Haywood & Crean, 1998). The LPF, however, has a strong requirement for active participation by all parties at all stages which can be both time consuming and resource intensive (Haywood & Crean, 1998).

Indicators are used to determine the extent to which the objectives have been achieved and can be measured at different times, notably in monitoring of project performance, appraisal and evaluation phases. Following the refinement and quantification of these indicators, the project can be progressed to the preparation, appraisal and implementation phases of the project cycle. Using these phases, the project concept and performance can be sequentially assessed before, during and after its immediate life span (Crean, 1994).

In this study, the PCN and LPF constitute draft proposals for the projects and should not be treated as the final project. Additional information needs to be sought with respect to budgetary requirements, funding authority guidelines, human resources or suitable personnel and legislation before progressing the projects.

CHAPTER FOUR

SPATIAL AND TEMPORAL TRENDS IN WATER QUALITY OF THE DON, ROTHER & DEARNE CATCHMENT

4.1. Introduction

The statutory duty of managing the chronically degraded ecosystem of the Don, Rother and Dearne catchment was passed on to Yorkshire Water Authority in April 1974 (Firth, 1997) and has subsequently been inherited by the NRA and the EA. Each sub-catchment has its own unique water quality problems but the problem of sewage treatment and sewerage are common to all of them. Increasing population pressure meant that new STWs had to be built and existing ones upgraded to treat the increasing discharges to a suitable standard. Considerable changes in water quality were observed by YWA between 1974 and 1983 and by the NRA and EA in more recent years. The proliferation of manufacturing and chemical industries, particularly in the Dearne sub-catchment, and the operation and closure of coal mines in the region contributed to shortfalls in the water quality of the catchment. Other anthropogenic impacts, including the disposal of solid wastes and tipping of industrial and domestic wastes, have all been implicated in the poor water quality status over the years.

The most important sources of metal pollution in rivers include waste waters arising from mining activities such as mine drainage waters, effluents from tailings ponds (where waste crushed ore is settled out) and also drainage from spoil heaps. These sources continue to discharge metals into water courses long after the original mining activities have ceased. Another important source is the industries that use these metals in various processes, especially electroplating and galvanising of iron where waste solutions from the treatment vats are discharged without treatment. In addition, the use of galvanised iron and copper pipes in domestic water supplies contributes to elevated levels of zinc and copper in sewage effluents.

The Don, Rother and Dearne catchment has a legacy of poor water quality and contaminated land resulting mainly from its past industrial and coal mining activities (Section 1.4). Investments in upgrading of sewage treatment works have especially led to considerable improvements to the water quality of the catchment as a whole, resulting in reduced levels of ammonia and biochemical oxygen demand (BOD). The BOD represents the amount of oxygen (expressed in mg l^{-1}) utilised by bacteria to oxidise the organic matter in 1 litre of water within a 5-day period (Lloyd, 1992).

Industrial pollution between 1974 and 1996 principally came from steel, mining, coal carbonisation, chemicals, and textile manufacture. Heavy metal pollution has therefore occurred in the catchment. Other sources impacting on water quality in the catchments are abandoned mines and agriculture. The decline in the steel industry in the catchment area and the shutting down of some coking works and coal mines have generally led to reduced metal contamination in the catchment.

This section reviews the water quality changes that have occurred in the Don, Rother and Dearne catchment over the past decade. The section also reviews the trend in water quality changes with particular reference to metal contamination of the rivers over the past decade. For the purposes of water quality management the catchment is split into 4 sub-catchments, namely the upper Don, lower Don, Dearne and Rother. The changes in metal concentrations over the past decade is reviewed for each sub-catchment.

4.2. Water quality of the Don

The Don catchment

The Don is regulated in its headwaters by reservoirs and as such does not maintain a natural flow regime. As a consequence, fish populations at Dunford Bridge and Soughley Farm have been fairly stable since 1981. There were, however, historical problems with pollution through small sewage treatment works providing inadequate treatment (Firth, 1997; NRA, 1993a). The problem was addressed in 1977 by the building of the Cheesebottom Sewage Treatment Works, and the small discharges upstream were stopped in 1978 as sewage was transferred to the new works. In general, very little change in water quality occurred between 1981 and 1993 (Table 4.1).

Table. 4.1. Water Quality and Fisheries change in the River Don since 1981 (NWC classification)

Site No.	Location	River Quality Objective	Chemical Classification	Biological Classification	Tentative 1993 Fisheries Classification	Fisheries Change since 1981/82
1	Dunford Bridge	1B	1B	B2+	1A/1B	Improvement
2	Soughley Farm	1B	1B	-	1A/1B	Slight improvement
3	Millstone Bridge	1B	1B	-	1B	Improvement
4	Thurlstone	2	3	B2	2/3	Slight improvement
5	Penistone	2	2	B2+	1B/2	Slight improvement
6	Cheesebottom	1B	2	B2	2	-
7	Wortley	1B	2	B2	2/3	Slight Improvement
8	Stocksbridge	2	3	-	2	Improvement
9	Wharncliffe Side	2	3	B3	2/3	-
10	British Tissues	2	3	B3	2/3	-
11	Beeley Woods	2	3	-	2/3	Improvement
12	Hillsborough	2	3	B3	3	Slight improvement
13	Borough Bridge	2	3	B3	2	-
14	Smithfield House	2	3	-	2	Slight improvement
15	Meadowhall	2	3	B3	2	Improvement
16	Blackburn Meadows	2	3	B3	2	Improvement
17	Marsh Street	2	3	B3-	2/3	Not sampled in 81/82
18	Aldwarke weir	2	4	B3-	3	Slight improvement
19	Kilnhurst	2	3	B3	3	Slight improvement
20	Denaby	2	3	-	4	-
21	Sprotborough	2	3		2/3	Improvement
22	Doncaster	2	3	B3-	1B/2	Marked improvement
23	Thorpe Marsh	2	3	-	2	Marked improvement
24	Stainforth	2	3	-	2	Marked improvement
25	Went confluence	2	3	-	3	Improvement

Source: NRA Fisheries Science Report 38/94

Biological surveys prior to 1981 indicated that, apart from the upper reaches which were designated class 1A, most of the River Don was designated as class 3 (Yorkshire Water 1982) with some short stretches of classes 2 and 4. The River Don at Dunford Bridge and Soughley Farm were designated 1A/1B (Table 4.1) (NRA, 1994c) and would indicate an almost pristine site. The water quality classification for Dunford Bridge and Soughley Farm (chemical 1B and biological B2+) appears to be consistent with the fish fauna present (Appendix 1.2)

In the GQA chemical grading scheme, class 3 waters are those in which fish are absent or only sporadically present (Appendix 1.2). The class 3 grading is consistent with the fish status of most reaches of the River Don (Table 4.1).

Flowing down from its source in the high Pennine moorland above Dunford Bridge, the upper Don is mainly rural until it reaches the outskirts of Sheffield. Steel manufacture and its fabrication are the main industries but the most serious source of pollution comes from the sewerage network of the city. The recent decline in the steel industry has led to a reduction in the solid and metal load discharged to the river from various processes such as cooling waters and scrubbing liquors (Firth, 1997). Large quantities of oil are used in the steel industry for quenching and heating, and, as a result spillage and leakage of the oils, have given rise to contamination of surface waters with many incidents occurring during the last 30 years (Firth, 1997).

4.2.1. Trends in ammonia and BOD levels of the Don

The upper Don

Ammonia levels determined at Half Penny Bridge for the upper Don between 1992 and 1997 remained largely within the acceptable EQS limits set by the EA (Fig. 4.1). Half Penny Bridge is located on the Don downstream of Sheffield and upstream of the confluence of the Don with the Rother. This location serves as the water quality monitoring station for the upper Don. Between 1991 and 1992 ammonia levels were frequently over and above the recommended EQS limits (i.e. >1 mg l^{-1}) due possibly to inadequacies in the sewage treatment system. Blackburn Meadows STW, serving the city of Sheffield, is the largest STW in the Don catchment. Improvements and modernisation to the Blackburn STW which started in 1992 were completed in 1994 (Firth, 1997). By 1994, significant improvements were achieved in the quality of effluent from Blackburn Meadows STW and the ammonia and BOD levels dropped considerably (Figs 4.1 & 4.2).

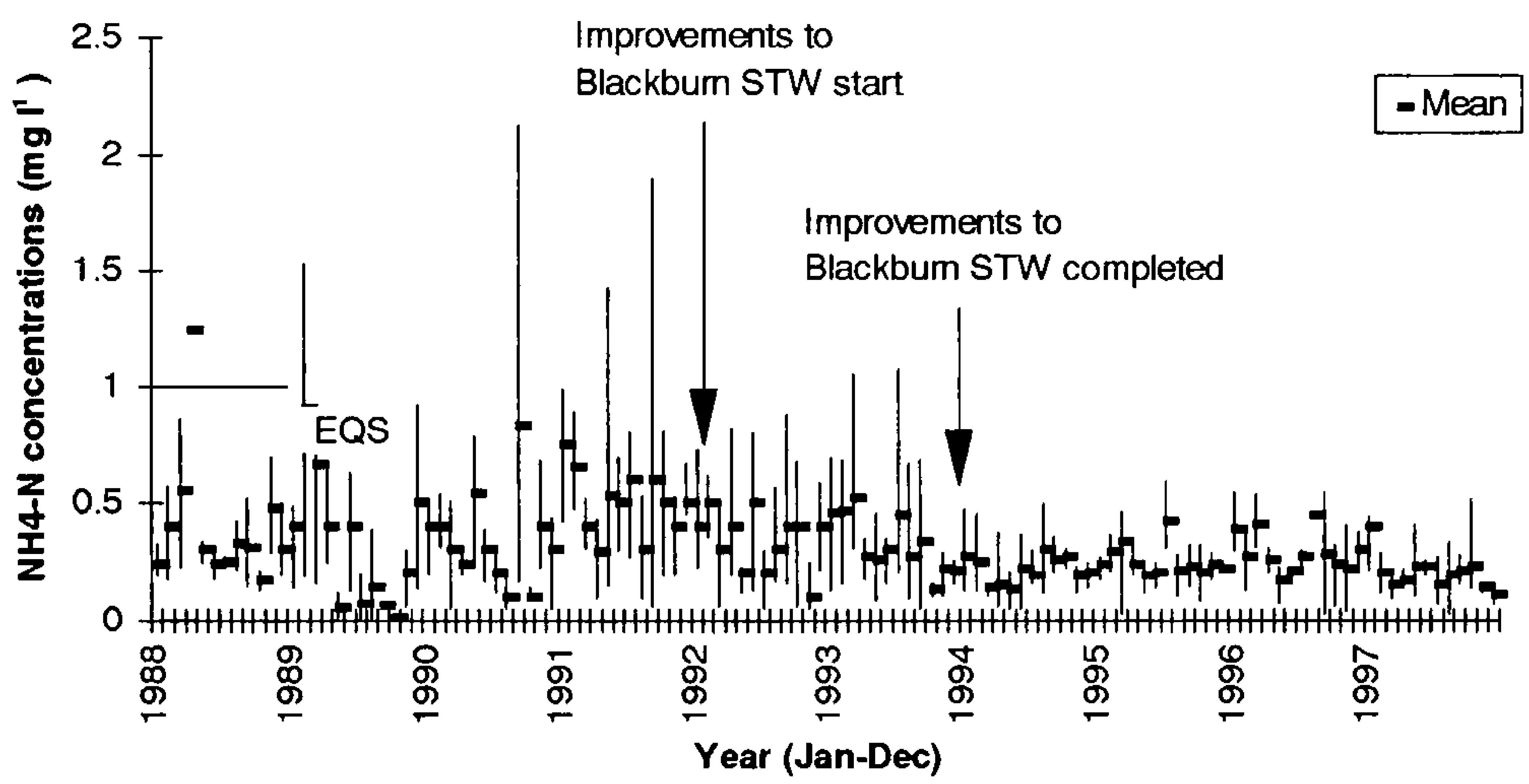


Fig. 4.1. Monthly mean and range of Ammonium-Nitrogen levels of the Upper Don at Half Penny Bridge (1988-1997)

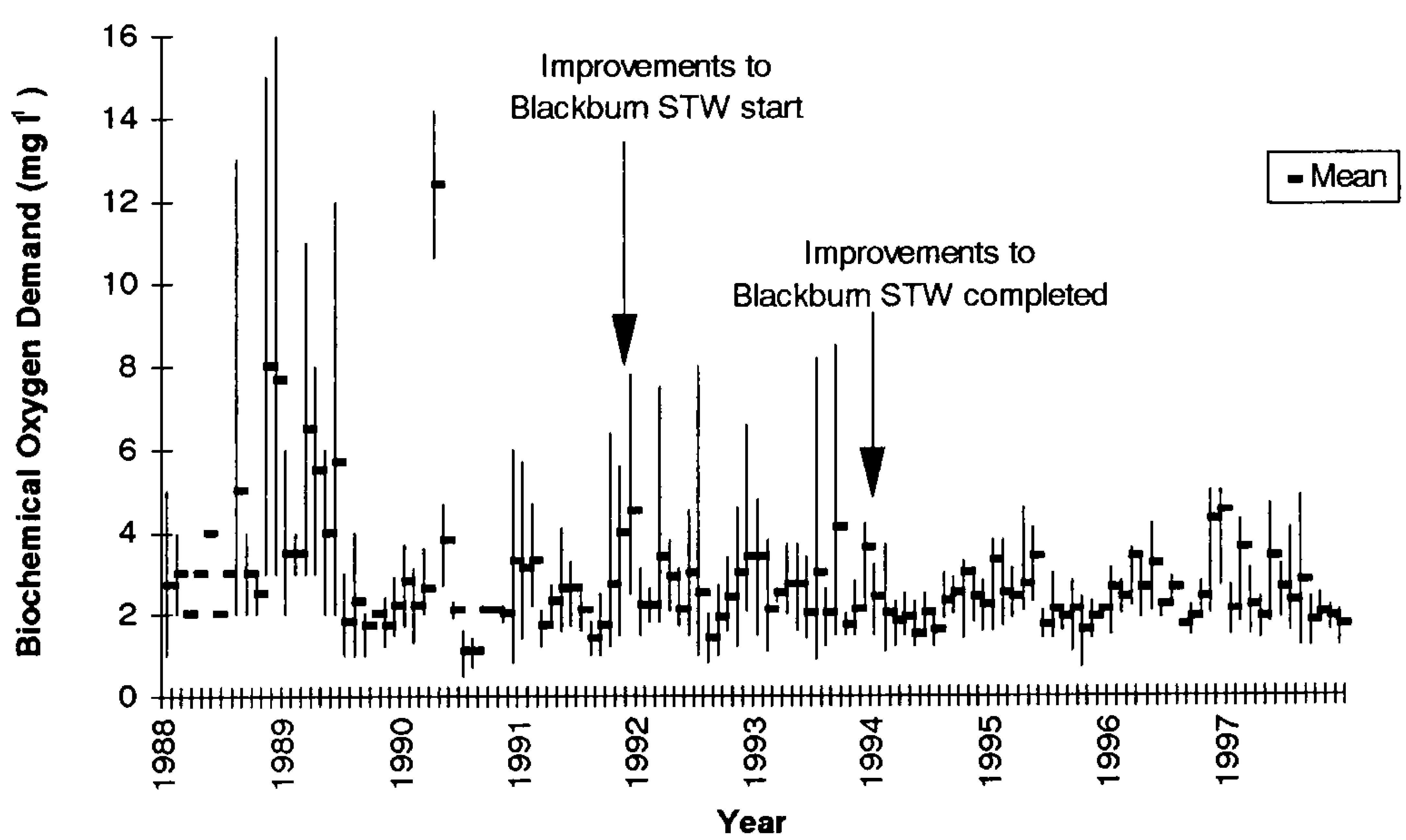


Fig. 4.2. Monthly mean and range of BOD levels of the Upper Don at Half Penny Bridge (1988-1997)

The lower Don

The trends in the water quality of the lower Don depend to a large extent on the anthropogenic events occurring in the Rother, upper Don and the Dearne as these combine to form the lower Don. Consequently improvements in the water quality in the lower Don mainly result from improvements in these watercourses.

The ammonium-nitrogen levels of the lower Don remained high between 1988 and 1992 (Fig. 4.3) due mainly to poor sewage treatment facilities in the catchment as a whole. Increasing human population over the period meant that the existing STWs were inadequate to treat the sewage to acceptable standards.

In 1992 improvements to STWs in the upper Don (Fig. 4.1) and to Darton STW in the Dearne catchment resulted in reductions in ammonium-nitrogen to the lower Don (Fig. 4.3). This was further assisted by improvements to industrial discharges from Prosper De Mulder and John Carr in Doncaster (Firth, 1997). Prosper De Mulder produces bone-meal and animal feeds. The effluents from their operations are treated by the company's own biological effluent treatment plant before being discharged to the River Don at North Bridge in Doncaster.

John Carr, a joinery company, also polluted the land with wood preservatives which contain a number of "Toxic Red List Substances" (Firth, 1997) which should not be allowed into controlled waters. The company now intercepts the groundwater and surface drainage through an activated carbon plant which absorbs the toxic material.

Further improvements to industrial discharges were also embarked upon by Prosper De Mulder in 1995 (Firth, 1997) resulting in the observed decline in ammonia levels of the lower Don (Fig. 4.3). The BOD levels appear to follow a similar pattern to the events described above although they were less clearly marked (Fig. 4.4). The BOD levels have remained fairly steady but with sporadic high values. There is no obvious reason for the observed peaks in BOD (Fig. 4.4), but this might be related to various isolated events in the sub-catchments which impact on the water quality of the lower Don.

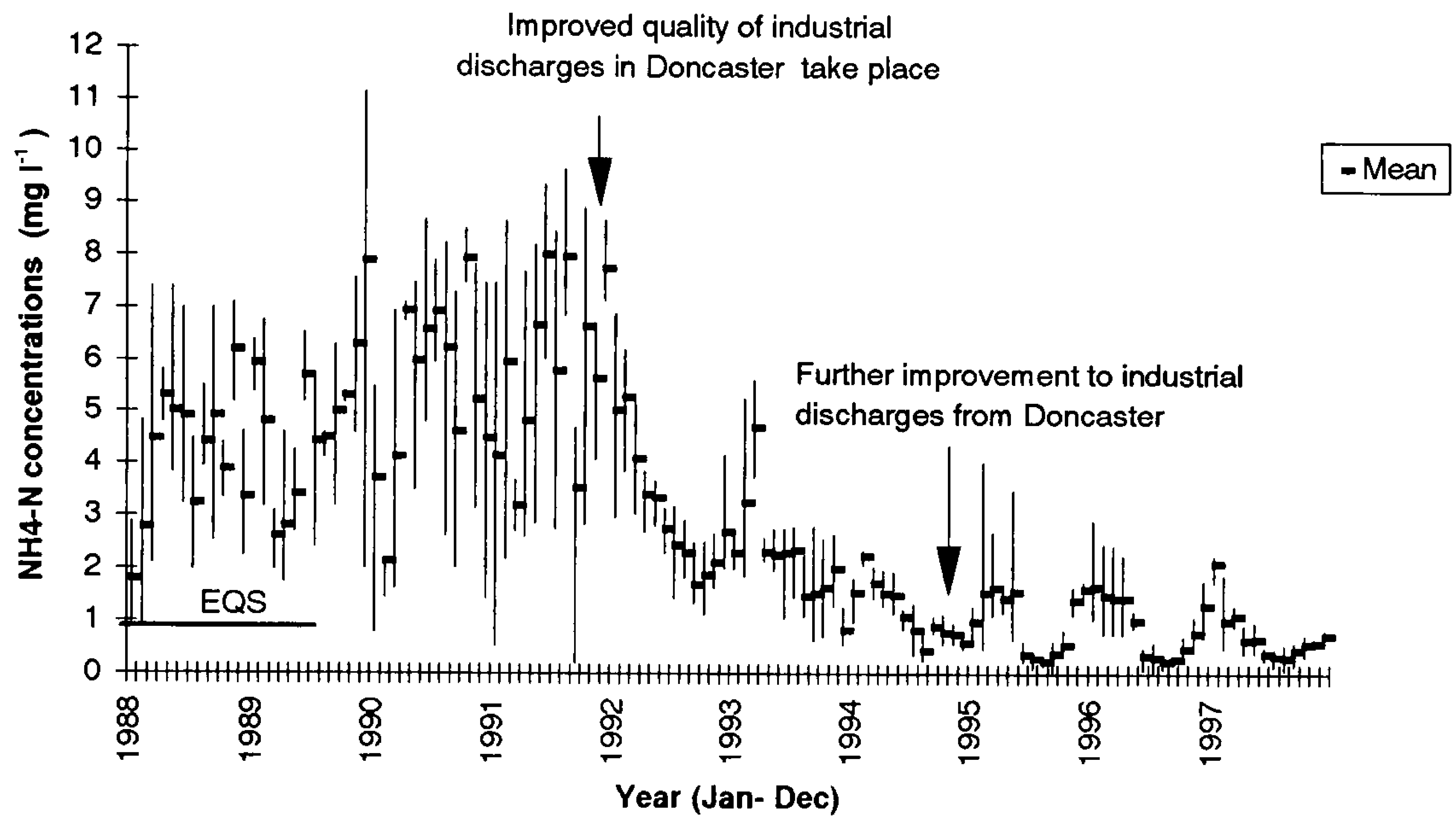


Fig. 4.3. Monthly mean and range of Ammonium-Nitrogen levels of the Lower Don at North Bridge (1988-1997)

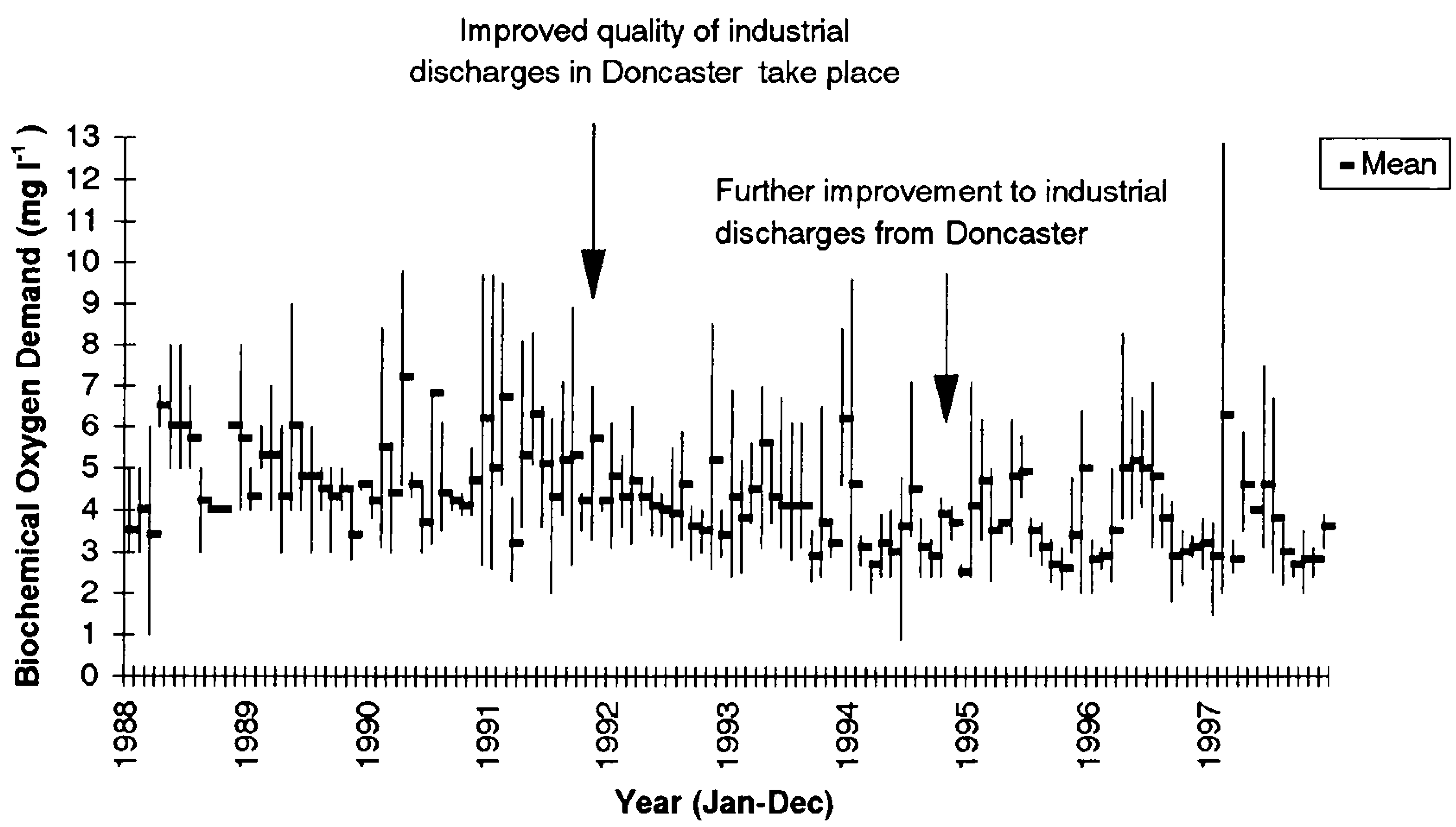


Fig. 4.4. Monthly mean and range of BOD levels of the Lower Don at North Bridge (1988-1997)

4.3. Water quality of the Dearne catchment

Poor water quality appears to be of greatest influence in limiting fish populations of the Dearne catchment. Visual and olfactory evidence of adverse water quality was reported at several sites during historical surveys (Yorkshire Water, 1989), including sewage fungus above Bretton Lakes (site 7) and raw sewage at both Stairfoot and Darfield (sites 15 & 17) (Table 3.4).

Dissolved oxygen concentrations in the River Dearne between 1987 and 1988 were over 50% for most sites (Fig. 4.5a). However, minimum dissolved oxygen levels fell as low as 15% at Star Paper Mill weir (site 13), and to 36% at Cudworth Common (site 16). Redox processes of organic effluents from Star Paper Mill and of sewage effluents at Cudworth Common are implicated in the reduced oxygen levels observed. The water samples were taken during daylight hours of the day (Yorkshire Water, 1989), thus oxygen levels were probably lower in darkness when photosynthesis ceased and normal respiratory processes of the aquatic biota continued. This could cause critical anoxic conditions for fish. Consequently the fish will either leave such habitats or perish.

Between 1987 and 1988 high ammonium-nitrogen (NH_4-N) levels were recorded in the River Dearne at Star Paper Mill weir (site 13), Cudworth Common (site 16), Darfield (site 17) Broom Hill (site 18), Adwick on Dearne (site 20) and Pastures Bridge (site 21) (Fig. 4.5a). These were above the NH_4-N maxima of 1.0 mg l^{-1} level (EQS) set by the EA. These sites receive paper mill (organic) effluents from Star Paper Mill, and sewage effluent discharges from works located at Lundwood and Darfield. Additional impacts from domestic and industrial wastes in the Barnsley area are also received at these sites.

Between 1990 and 1991 the mean NH_4-N maxima levels were above the recommended Environmental Water Quality Standards (EQS) at all sites except those at Parkgate and Denby Dale (Fig. 4.5b). The river from Haigh Roundabout (site 8) to Pastures Bridge (site 21) was impacted by a diverse array of polluting agents including sewage, farm and industrial effluents and mine waters. These discharges in the vicinity (Appendix 1.3) are implicated in the high levels of ammoniacal nitrogen observed in this stretch of the river.

The sites from Broom Hill (site 18) to Pastures Bridge (site 21) are located in a predominantly rural and agricultural area. Agricultural run off from farmland using ammonium-containing fertilisers and pesticides could get carried into the catchment to increase the level of ammonium-nitrogen in the waters. These impacts probably contribute to the high NH_4-N concentrations observed at those sites.

The dissolved oxygen minima for most sites in the River Dearne (Fig. 4.5b) and in the River Dove (Fig. 4.5c) between 1990 and 1991 were over 40% (NWC Class 2 fair quality) which would support a reasonably good fisheries (Appendix 1.2). However, the dissolved oxygen minima recorded at Darton Bridge (site 9), Star Paper Mill weir (site 13) and Cudworth Common (site 16) were below 40%. Sewage effluent from Darton and Lundwood STWs, as well as paper mill effluents from Star Paper Mill, impact on the water quality at these locations resulting in low oxygen levels. Again the decomposition processes of the organic discharges could reduce the dissolved oxygen levels quite considerably, resulting in the low oxygen levels observed. Surveying in different seasons may also account for the dissolved oxygen fluctuations in the River Dearne (Figs 4.5a & 4.5b) as solubility of oxygen decreases with increasing temperatures. Thus more dissolved oxygen would be expected in winter than in summer.

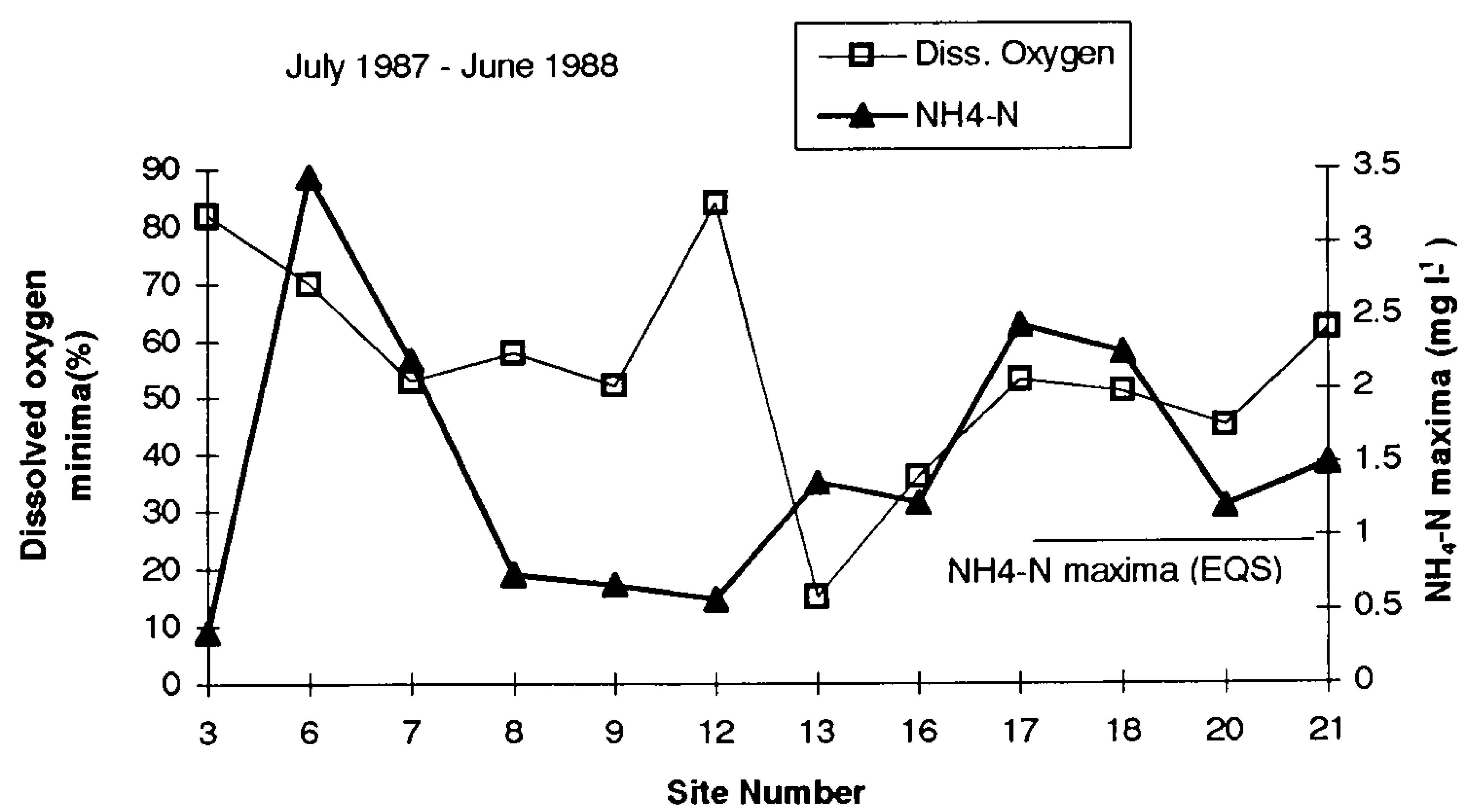


Fig. 4.5a. Chemical water quality of the River Dearne

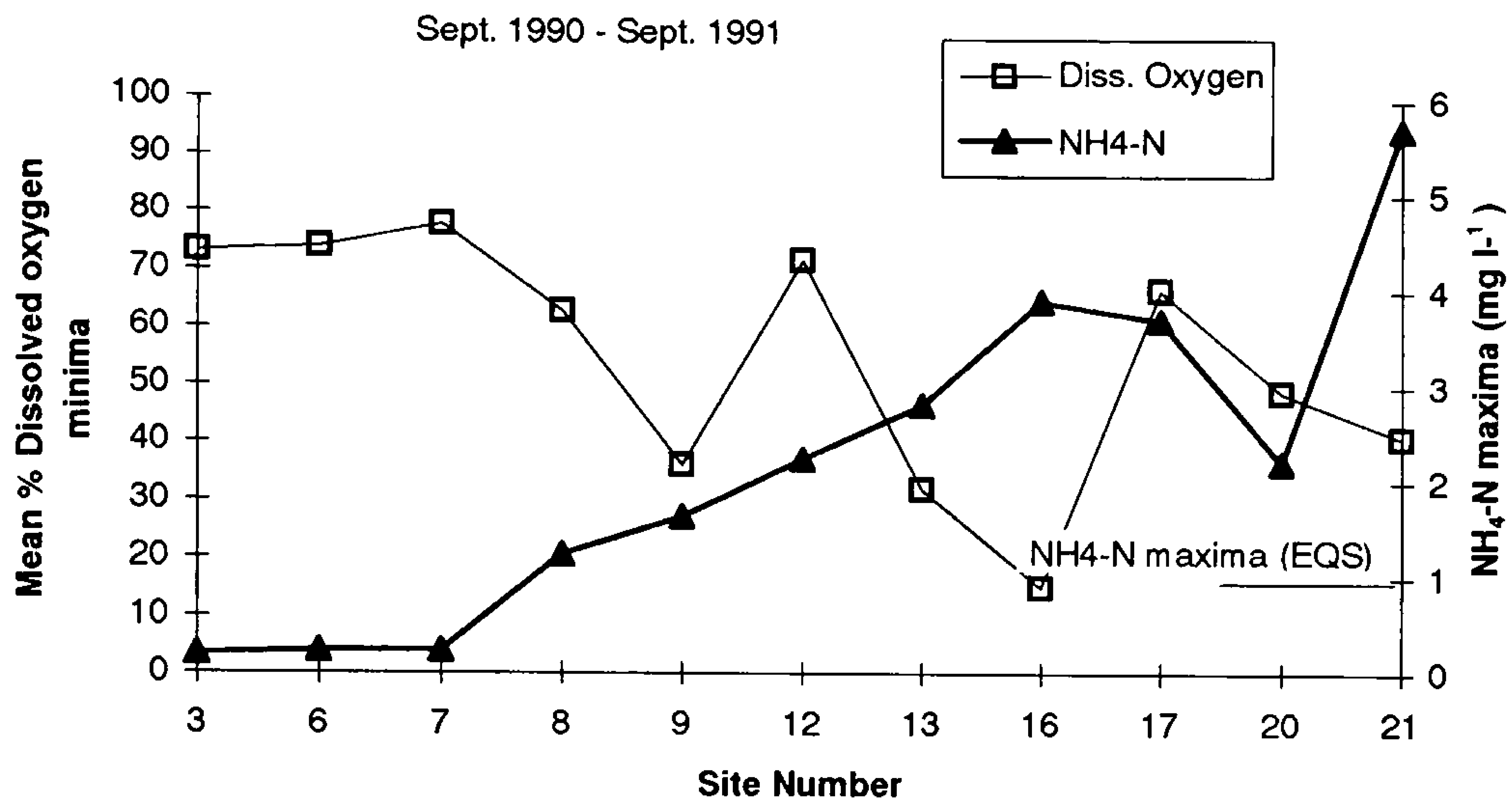


Fig. 4.5b. Chemical water quality of the River Dearne

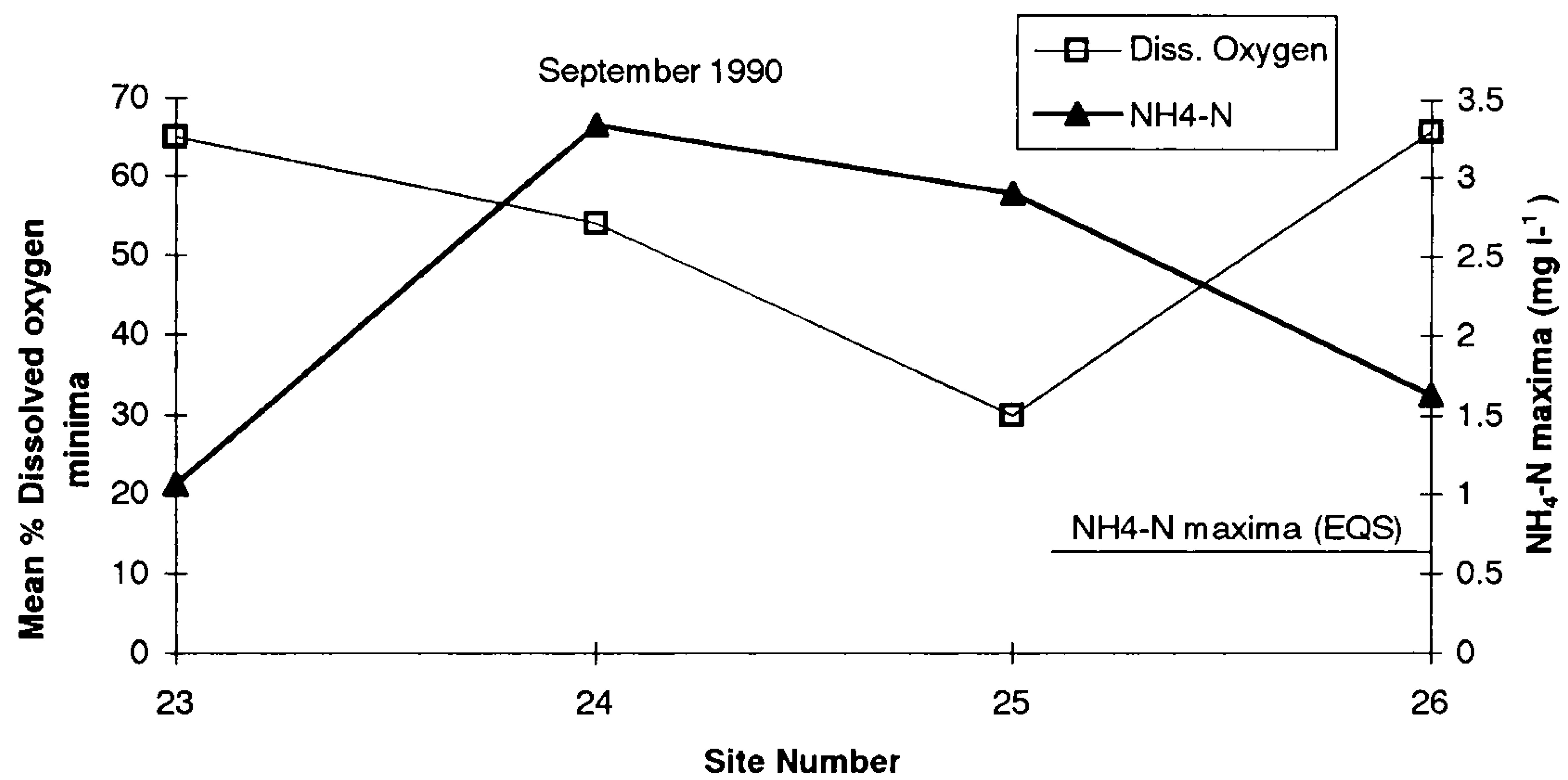


Fig. 4.5c. Chemical water quality of the River Dove

4.3.1. General trends in ammonia and BOD levels of the River Dearne

The Dearne catchment runs through a heavily mined area which makes up the Barnsley Coalfield. In 1974 there were 26 collieries and 57 discharges of mine waters from collieries and pumping stations (Firth, 1997). Mine water is pumped from underground workings to prevent flooding and allow coal to be extracted. The water can be high in ochre/iron hydroxide due to dissolving from the pyrites (iron sulphide) associated with the coal measures. Sewage treatment problems and various pollution incidents from industry and agriculture have impacted on the water quality of the Dearne catchment. This has resulted in set-backs in water quality improvements in the catchment. The levels of ammonia (Fig. 4.6) and BOD (Fig. 4.7) have been consistently well above the recommended EQS, possibly reflecting the events of sewage pollution and other organic discharges from agriculture and industry.

The Dearne suffered a series of acute pollution incidents between 1987 and 1996 with sewage and industry being the main known causes of the incidents. These incidents impact on the ammonia and BOD levels (Figs 4.6 & 4.7) which are already stressed by chronic pollution problems from industrial discharges to the river. The high ammonia and BOD level recorded were possibly related to the sewage pollution from the STWs.

In 1992 the Darton STW improvement scheme was completed and this resulted in reduced ammonium-nitrogen levels (Fig. 4.6), although this appeared to have had little or no impact on the BOD levels (Fig. 4.7). This was possibly due to set-backs from other pollution incidents. In 1996 improvements to the Lundwood STW serving Barnsley begun (Firth, 1997) but only some modest reductions in the ammonia and BOD levels have been achieved so far (Figs 4.6 & 4.7). Further plans for refurbishing the STW at Lundwood have been made by Yorkshire Water PLC and is scheduled to be completed by 1998 (Firth, 1997).

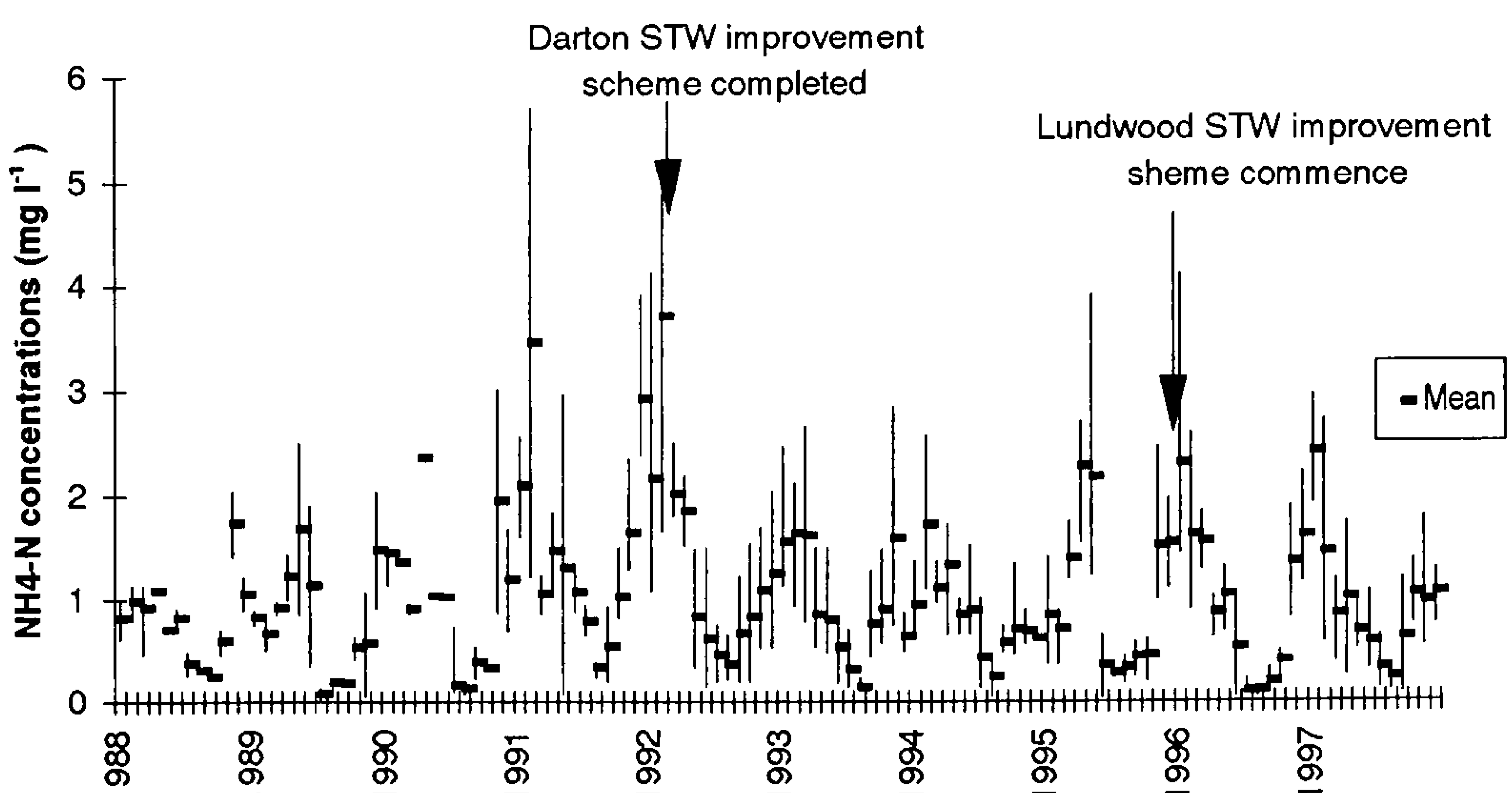


Fig. 4.6. Monthly mean and range of Ammonium-Nitrogen levels of the Dearne catchment at Pastures Bridge (1988-1997)

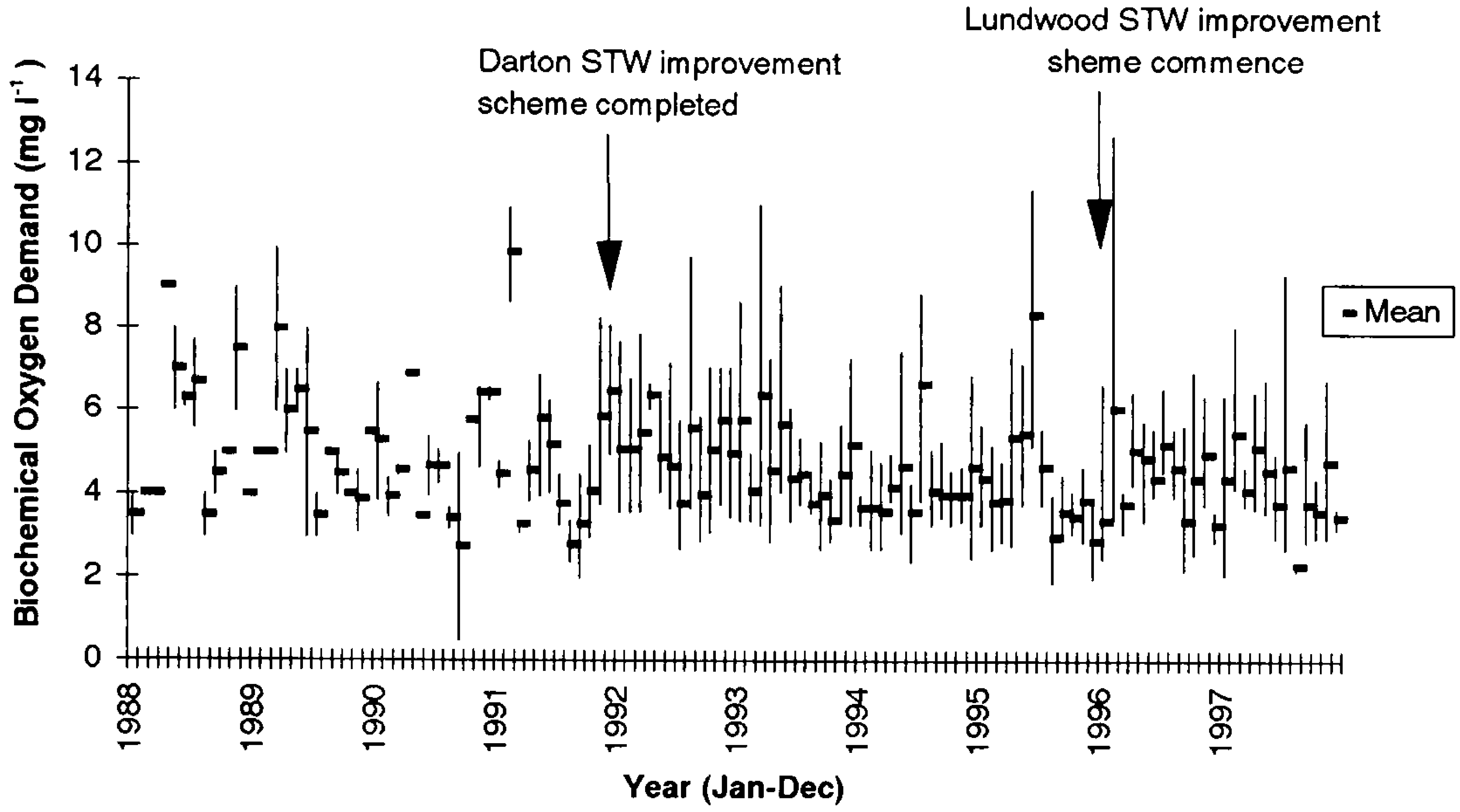


Fig. 4.7. Monthly mean and range of BOD levels of the Dearne catchment at Pastures Bridge (1988-1997)

4.4. Water quality of the Rother catchment

The ammoniacal nitrogen in the River Rother at North Wingfield (site 1) and Birdholme (site 2) in 1988 were in excess of the recommended level and at site 2 almost three times the EQS level (Fig. 4.8). The lack of fish in the River Rother at Birdholme Bridge (site 2) was perhaps more in accordance with a water quality class 4 designation than a class 3 that was the designation at the time of survey. These sites are impacted by sewage and industrial effluents and the high levels of ammoniacal nitrogen can be attributed to these discharges.

The River Doe Lea at Doe Lea Bridge (site 14) was characterised by high NH_4-N levels, well above recommended levels (Fig. 4.8). No fish was found at the River Doe Lea at Netherthorpe (site 15). This site was reported to have very turbid waters, odours from petroleum wastes, and large quantities of domestic waste and garbage (NRA, 1989).

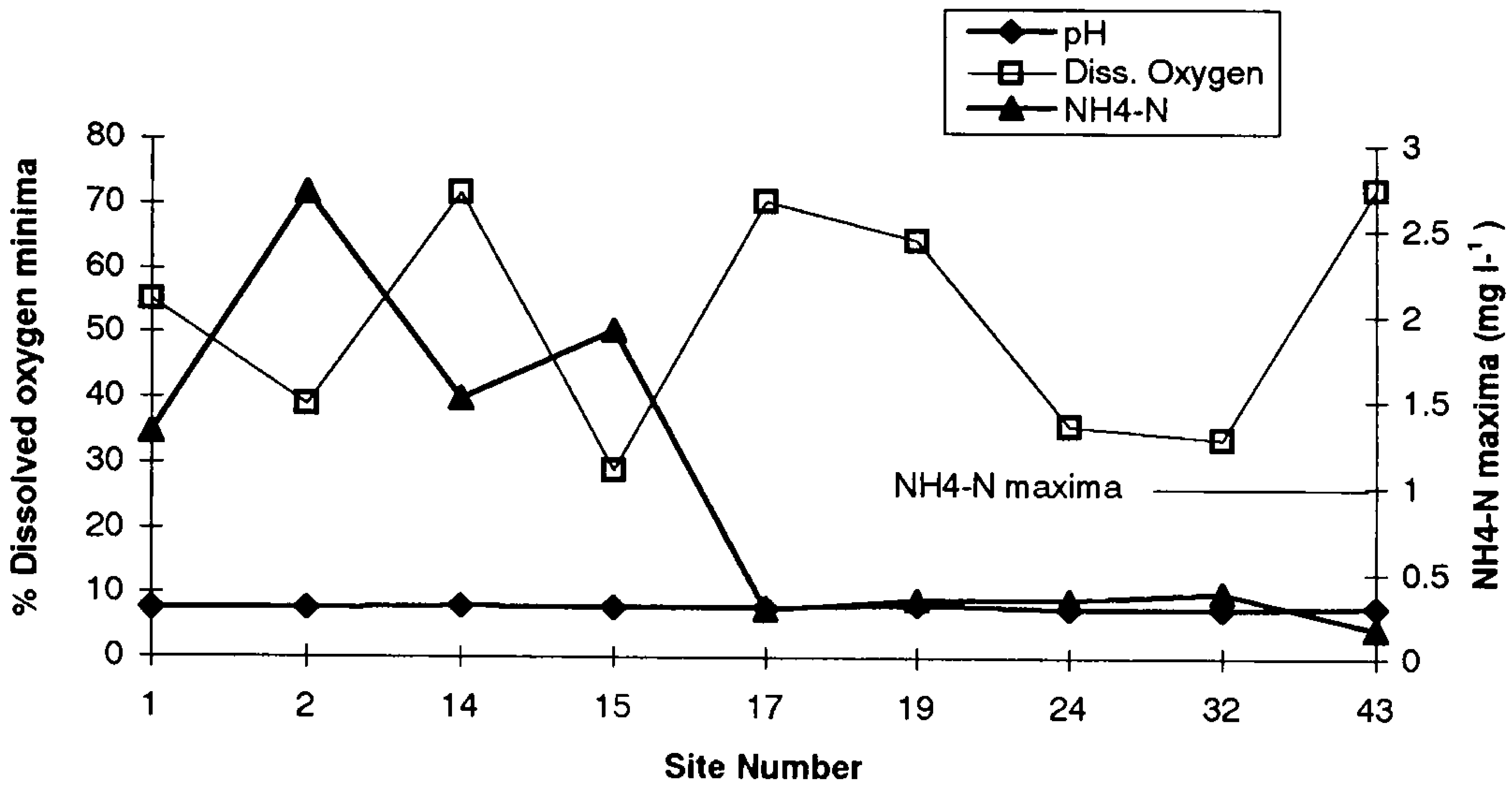


Fig. 4.8. Chemical water quality of the River Rother and some tributaries in November 1988

The River Doe Lea, a tributary of the River Rother, does not meet its water quality target due to sewage effluents from Bolsover STW and the effects of mining from Coalite Complex (EA, 1997).

Ammoniacal nitrogen was satisfactory in the River Hipper at Somersall Lane (site 24). Consequently, the highest density of fish was found in the River Hipper at Somersall Lane, and this was probably linked to the low ammoniacal nitrogen levels at that stretch of the river.

The catch from several sites in the Rother catchment in 1988 (Fig. 5.23) suggested poorer water quality than the prevailing water quality designation. Most sites were designated as 1b. A water quality class 1b, is expected to contain a good fish population. In this survey several sites with water quality class 1b such as Trough Brook (site 32), the Moss (site 38) and Locko Brook (site 17), held few or no fish (Fig. 5.23).

A reasonably good coarse fisheries would be expected in water quality class 2 designation (Appendix 1.2). However, the Shire Brook (site 43), designated as water quality class 2, held no fish. The water quality designation therefore did not reflect the fisheries. Shire brook does not meet its water quality target due to discharges from combined sewer overflows and ingress of leachate from the Beighton Landfill site EA, 1997). The NH_4-N and dissolved oxygen levels at this site were within acceptable limits during the survey of 1988 (Fig. 4.8). The absence of fish might be related to previous shortfalls in water quality which excluded fish from the site (Figs 5.22 & 5.23). The fish populations at Calow Brook (site 19) was poor in 1988. This site was upgraded to water quality class 3 prior to the 1988 survey (NRA, 1989). The poor fish numbers observed in 1984/85 and 1988, however, did not reflect the upgrade.

In 1992, impoverished invertebrate faunal communities together with high water conductivity values (>1000 $\mu S\ cm^{-1}$), indicating chemical pollution, characterised a large number of sites in the Rother catchment. The sites affected were associated with mine and /or industrial discharges, tips and landfill sites. The worst of the polluted stretches in the catchment (classified as B4) were affected by chemical pollution and these include the Rother downstream of Avenue Coking Plant, and the Doe Lea, downstream of Coalite (NRA, 1992).

The macroinvertebrate fauna in the Doe Lea at Renishaw (NRA, 1992) was indicative of gross organic and chemical pollution bordering on chemical class B3-. This was reinforced by the prevalence of sewage litter at the site, and by high water conductivity in excess of 2000 $\mu S\ cm^{-1}$ (NRA, 1992). No improvement in water quality appears to have taken place since 1984, hence the lack of fish in the Doe Lea at Renishaw would be expected. The biological surveys of 1992 indicated that the macroinvertebrate fauna were characteristic of organic pollution. The high conductivity, which was in excess of 2000 $\mu S\ cm^{-1}$, was indicative of chemical pollution which can be explained by the mine water discharges from the Renishaw shaft.

4.4.1. General trends in ammonia and BOD levels of the River Rother

For a long time the sewage treatment facilities in the Rother catchment were inadequate to treat the effluents effectively, thus resulting in high ammonia (Fig. 4.9) and high BOD (Fig. 4.10) levels being recorded in the river between 1988 & 1992.

Between 1991 and 1992 coking works at Orgreave, Brookhouse and Avenue in the Chesterfield area were shut down leaving only the Coalite Works in operation. Improvements to the STW at Old Whittington were also carried out in 1993. The closure of the coking works and the improvements in the STW resulted in a general improvement to the ammonia and BOD levels of the river (Figs 4.9 & 4.10).

In 1994 investment and a gradual tightening of consents under the control of Her Majesty's Inspectorate of Pollution (Firth, 1997) led to a further decrease in the ammonia and BOD levels. From 1995 to 1997, a gradual increase in ammonia and BOD levels were observed (Figs 4.9 & 4.10). This was possibly related to a lack of adequate dilution for the effluents during the drought of 1995-96.

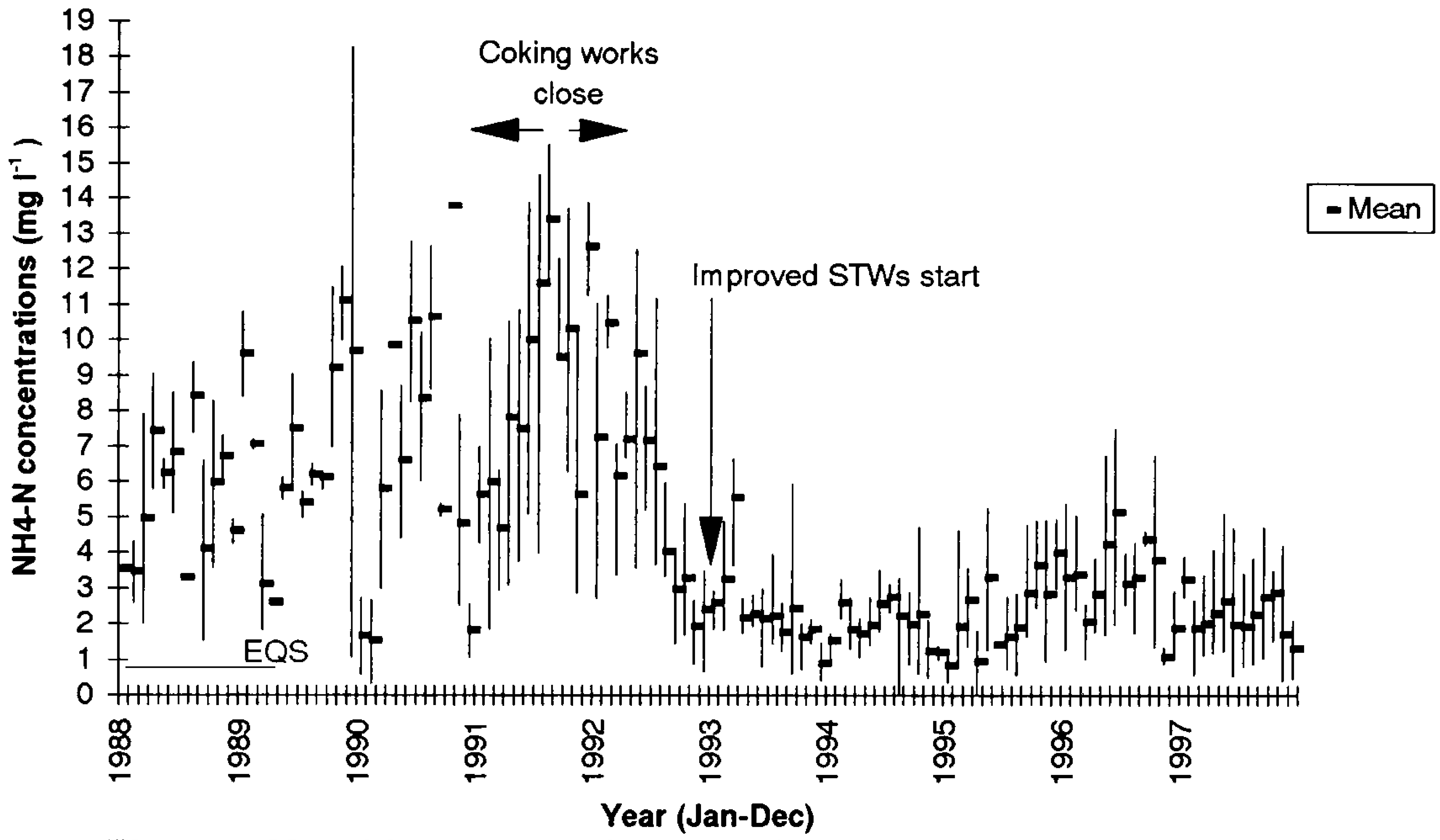


Fig. 4.9. Monthly mean and range of Ammonium-Nitrogen levels of the Rother catchment at Canklow (1988-1997)

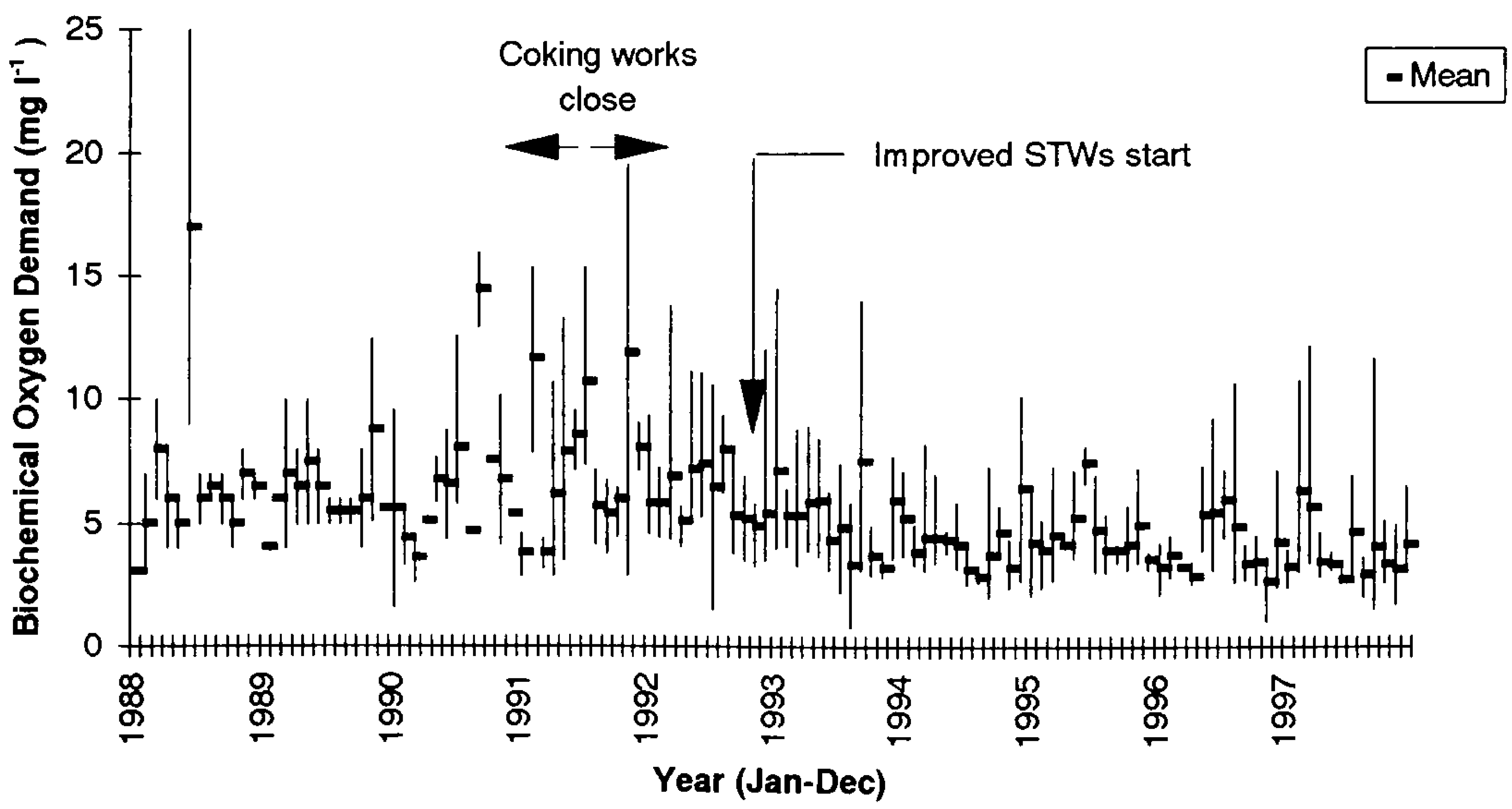


Fig. 4.10. Monthly mean and range of BOD levels of the Rother catchment at Canklow (1988-1997)

4.5. Trends in total metal levels of the Rivers Don, Rother & Dearne.

4.5.1. The upper Don

Trends in nickel and iron levels

The upper Don catchment, particularly around Sheffield, remains highly industrialised. Steel manufacture and fabrication are very important activities in this area. The decline in the steel industry in the upper Don catchment has generally led to considerable reductions in nickel levels discharged to the river (Fig. 4.11). Between 1990 and 1993 total nickel levels were relatively high (Fig. 4.11) reaching just about 70 $\mu g\ l^{-1}$. This was followed by a generally modest reduction in nickel levels from 1994. These reductions were, possibly, also linked to improvements to the Blackburn Meadows STW.

Many gannister mines were found along the upper Don valley and these caused ochreous deposition as a result of uncontrolled discharges (Firth, 1997). The most obvious one is on the Don at Bullhouse near Penistone. Gannister is a refractory siliceous sedimentary rock found below coal seams. It is commonly used as a lining for blast furnaces and as such was important in the development of the steel industries of the Don valley (Firth, 1997). The level of iron remained fairly stable between 1990 and 1997 (Fig. 4.12) with occasionally sharp increases that appear to be linked to the periods of rain or precipitation resulting in flushing of the element into the aquatic environment.

Trends in zinc and copper levels

In those rivers which drain old mining areas, the levels of zinc fluctuates considerably with the rainfall (Lloyd, 1992). The onset of heavy rain may produce a peak concentration from the flushing out of stagnant water from spoil heaps and this will be followed by a decline with the increased dilution by run-off from the surrounding area. This trend of events appears to account for the marked fluctuations in the levels of zinc and copper (Figs 4.13 & 4.14). The major environmental factor which affects the toxicity of zinc and copper to fish is the calcium concentration of the water (Lloyd, 1992).

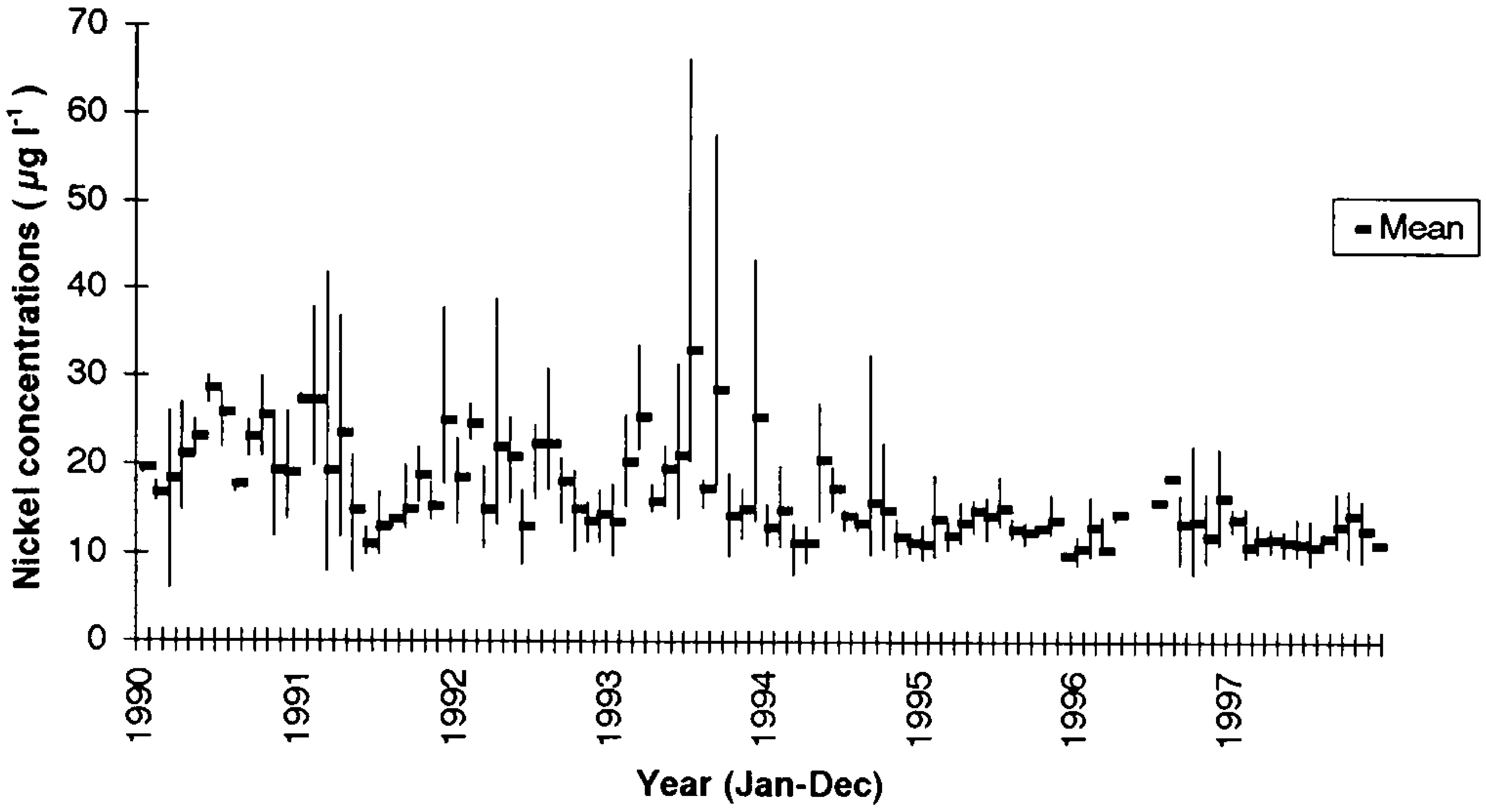


Fig. 4.11. Monthly mean and range of total nickel concentrations of the Upper Don at Half Penny Bridge (1990-1997)

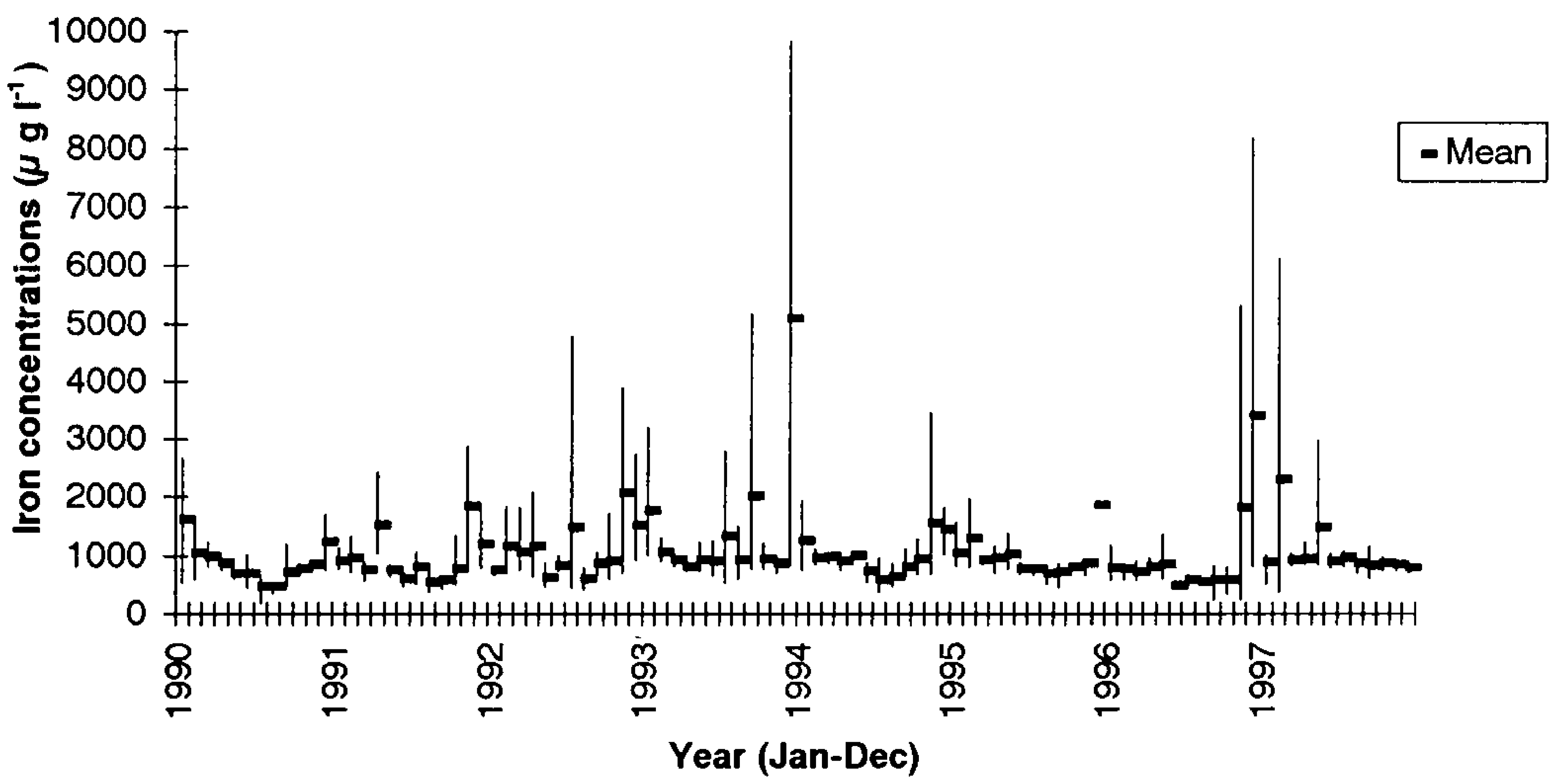


Fig. 4.12. Monthly mean and range of total iron concentrations of the Upper Don at Half Penny Bridge (1990-1997)

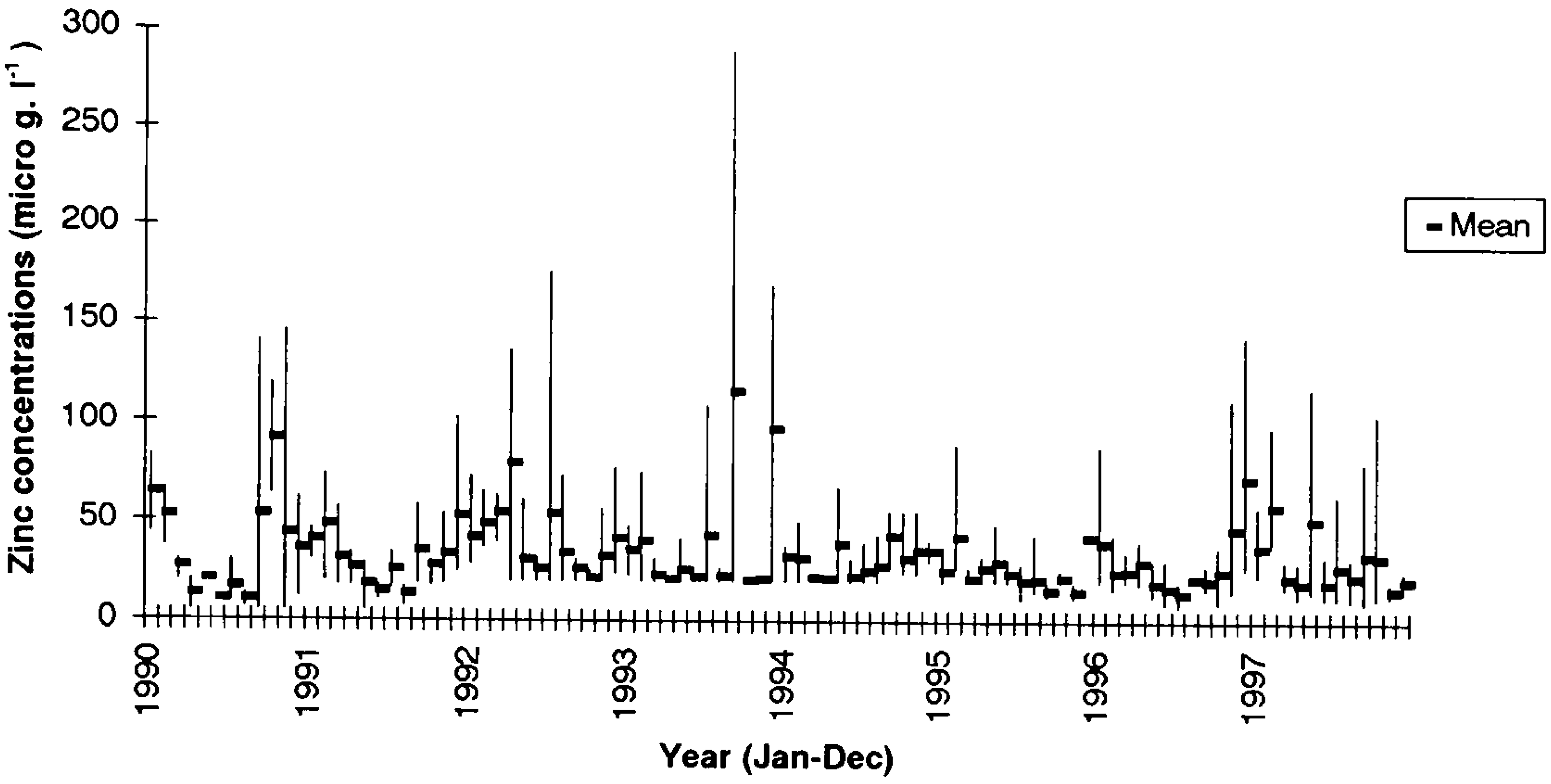


Fig. 4.13. Monthly mean and range of total zinc concentrations of the Upper Don at Half Penny Bridge (1990-1997)

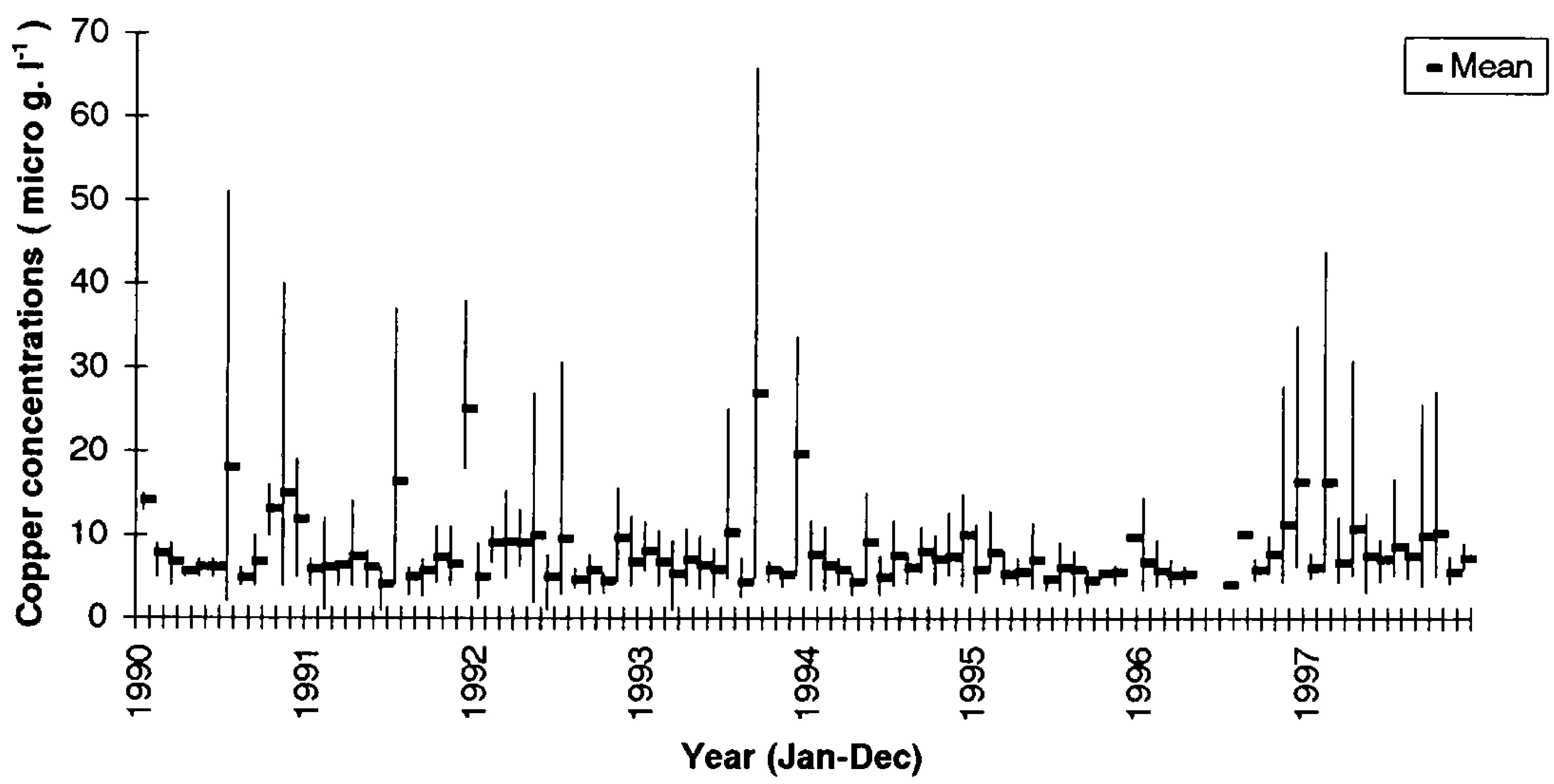


Fig. 4.14. Monthly mean and range of total copper levels of the Upper Don at Half Penny Bridge (1990-1997)

The toxicities of the elements are reduced as the calcium concentration increases (Lloyd, 1992). The EC (1978) Freshwater Fish Directive sets standards for copper that are common to both salmonids and cyprinids and takes into account the effect of water hardness. Similarly, the standards set for zinc in the same Directive takes into account the effects of water hardness but in soft waters these may vary considerably with the rainfall and so it is difficult to define an appropriate standard (Lloyd, 1992).

Trends in lead concentrations

Lead mining was carried out in the catchment in the past (Firth, 1997). Coal mines constitute an important source of lead and this influenced the concentrations of the element in the waters of the catchment. Diffuse inputs of lead into surface waters arising from its widespread use in petrol and batteries may increase the concentrations in sediments.

The total lead concentrations have generally been low and stable since 1990 (Fig. 4.15) with some occasional peak increases possibly associated with overflow from spoil heaps and abandoned mines during wet weather conditions (Fig. 4.15). Lead concentrations were generally insignificant and below 0.3 mg l^{-1} (Dixit & Witcombe, 1983; Balasubramanian *et al.*, 1995), the threshold limit where fish are eliminated or where invertebrates are rarely affected.

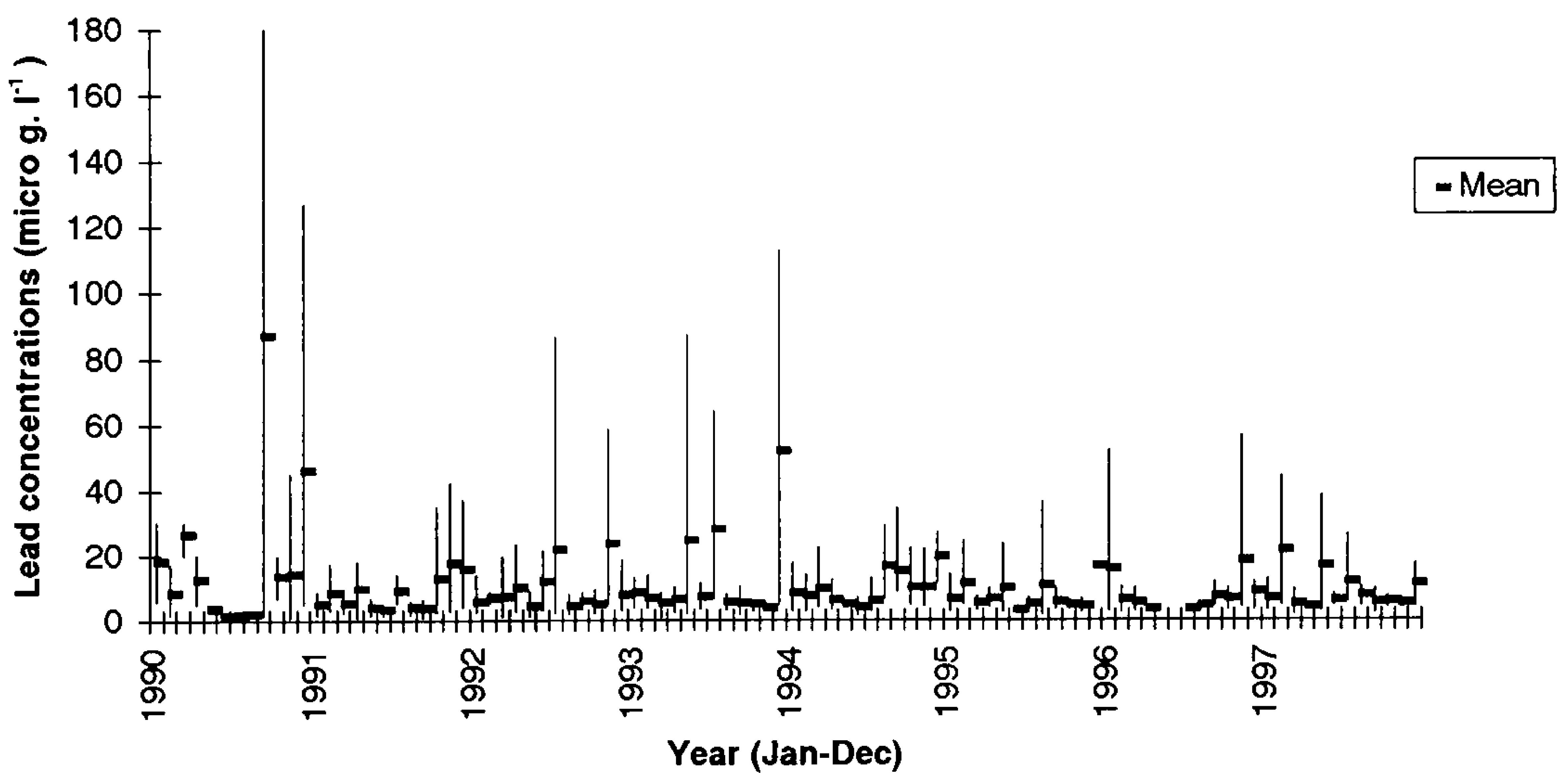


Fig. 4.15. Monthly mean and range of total lead concentrations of the Upper Don at Half Penny Bridge (1990-1997)

4.5.2. The lower Don

Trends in nickel and iron levels

The lower Don contained extensive coal mining sites. Nickel and iron loads to the lower Don arise from mining activities and from the steel industries in the Sheffield area of the upper Don. A general decline in nickel levels took place after 1993 (Fig. 4.16). This relates to the decline in the steel industry which also resulted in the consistently low levels of iron (Fig. 4.17) with occasional peak levels being observed.

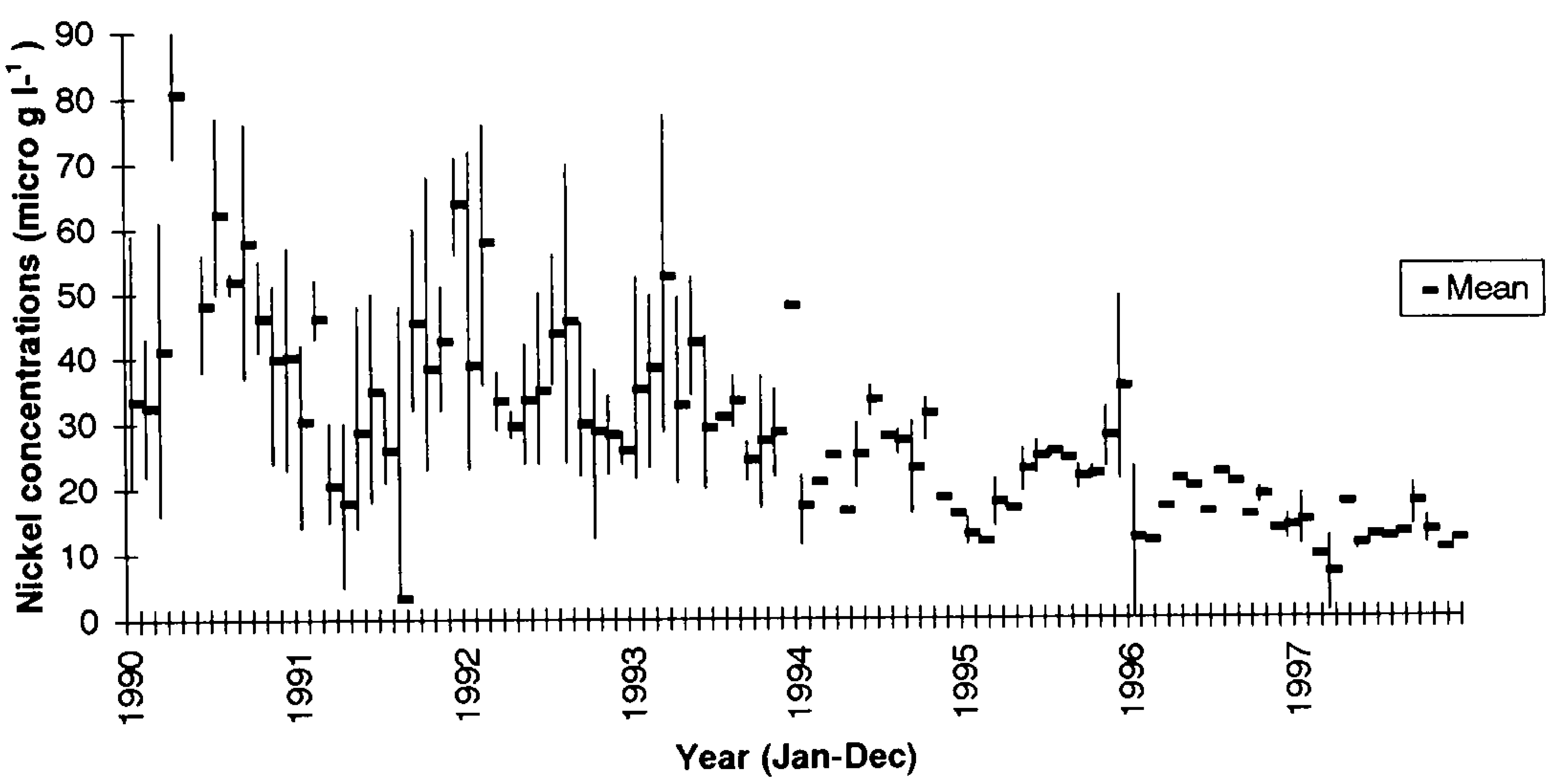


Fig. 4.16. Monthly mean and range of total nickel concentrations of the Lower Don at North Bridge (1990-1997)

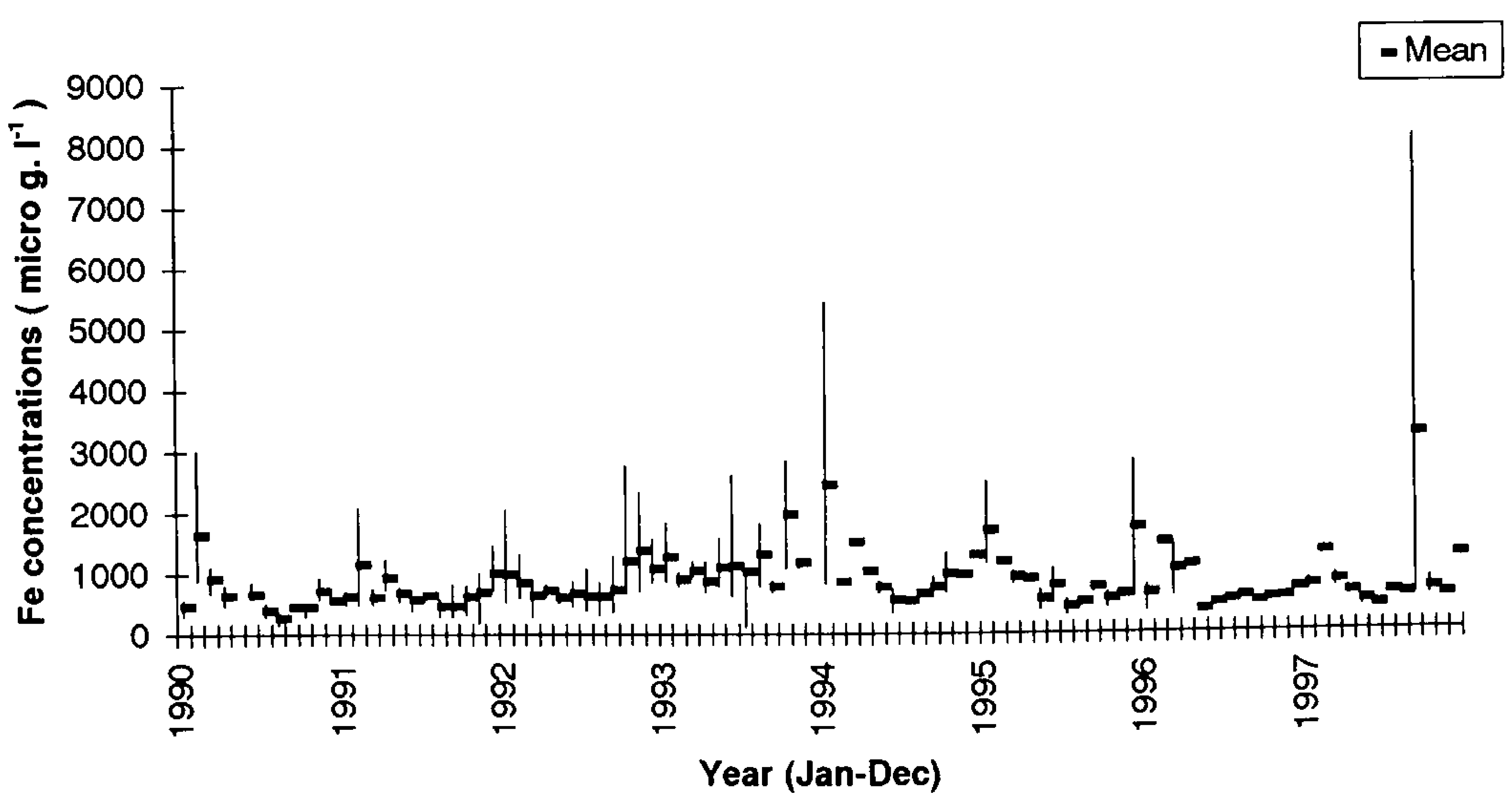


Fig. 4.17. Monthly mean and range of total iron levels of the Lower Don at North Bridge (1990-1997)

The mean levels of zinc and copper remained fairly stable between 1990 and 1997 (Figs 4.18 & 4.19) but with occasional peaks which, possibly, relates to flushing out of the elements during wet weather conditions (Lloyd, 1992).

The decline in steel manufacture and galvanising activities, possibly, reduced further contributions of the elements to the river. Background levels of the elements may account for the steady level in zinc and copper concentrations over the period (Figs 4.18 & 4.19). The generally low levels of zinc and copper might also be related to the geochemical mobility and abundance of the elements in the rocks and sediments (Vivian & Massie, 1977; Dixit and Witcombe, 1983).

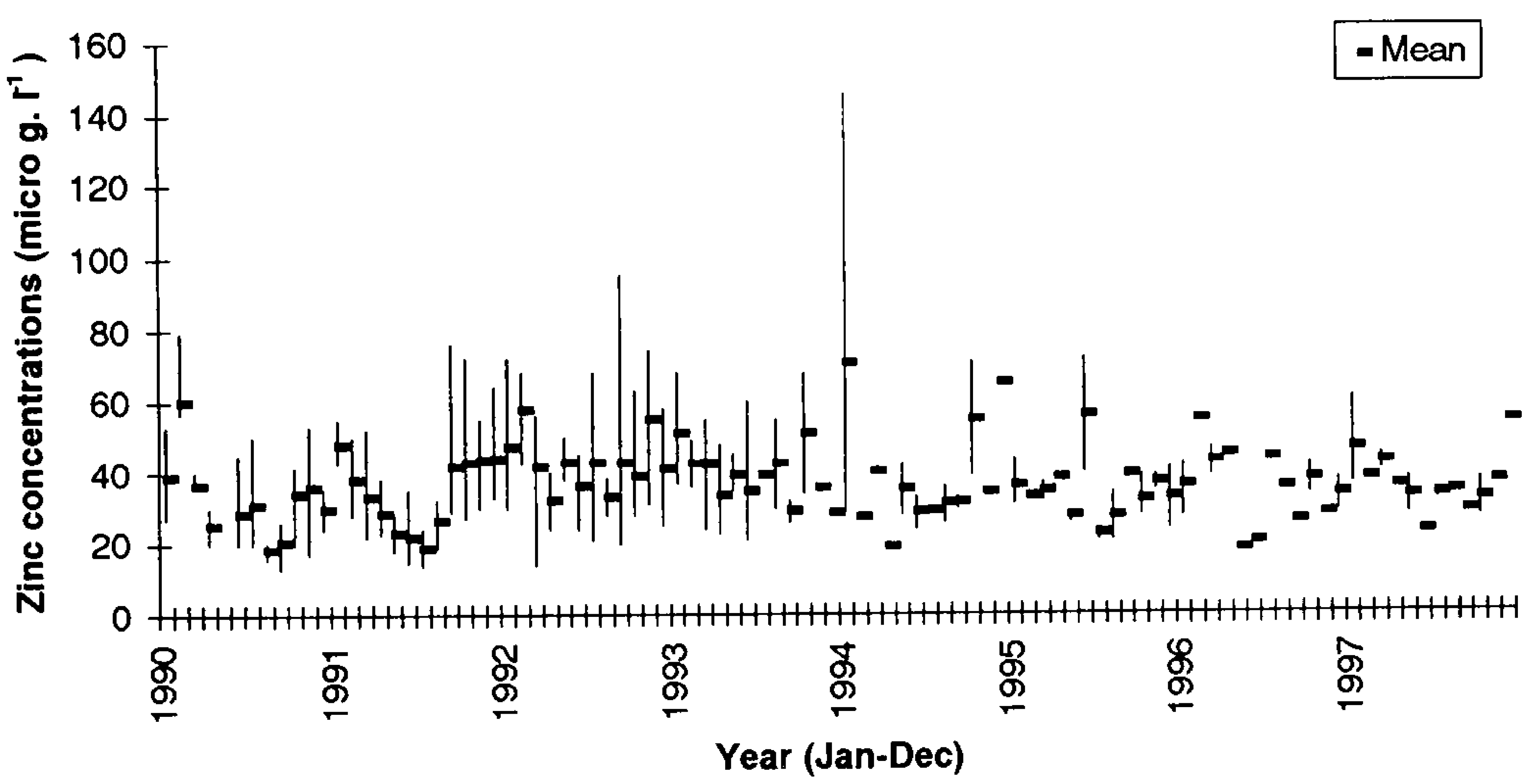


Fig. 4.18. Monthly mean and range of total zinc levels of the Lower Don at North Bridge (1990-1997)

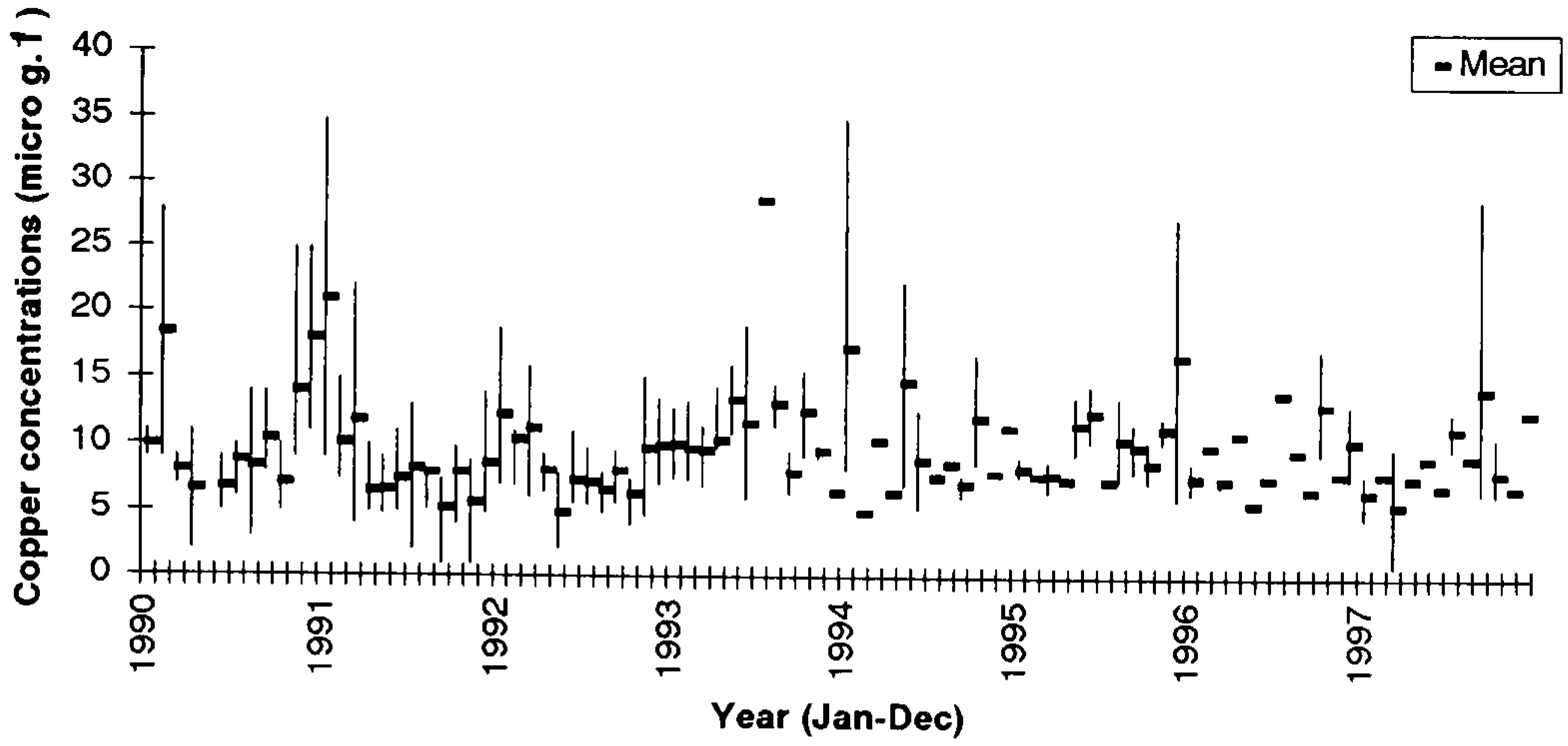


Fig. 4.19. Monthly mean and range of total copper levels of the Lower Don at North Bridge (1990-1997)

There are several major industrial discharges on the lower Don from chemical, glass and animal by-product manufacturers. The legacy of colliery spoil heaps and contaminated land associated with pitheads and coking operations contribute quite significantly to the levels of zinc and copper in the adjacent watercourses.

Trends in lead concentrations

A generally low range in lead concentrations was recorded in the lower Don with mean levels remaining fairly steady during 1990-1997 (Fig. 4.20). As in the upper Don the element is derived from previous mining of the element in the area, and from the Rother catchment.

No obvious reasons could be found for the observed high levels of lead in 1994 and 1996 but this might be related to impacts from leachates from spoil heaps or metal contaminated sites.

Between 1991 and 1993 some coking works in the Rother catchment were shut down and improvements to STW were commenced (Fig 4.9). Improvements to sewage treatment works were also carried out in the Dearne and upper Don. These activities possibly reduced further inputs of lead into the catchment. This might explain the lower ranges of lead after 1994 (Fig. 4.20).

The high peaks of lead also appeared to occur at the beginning or end of year (winter) (Fig. 4.20) but no obvious reasons could be found from the available information. It is, however, probable that these are derived from run-off over waste tips and former colliery mines during the wet winter months.

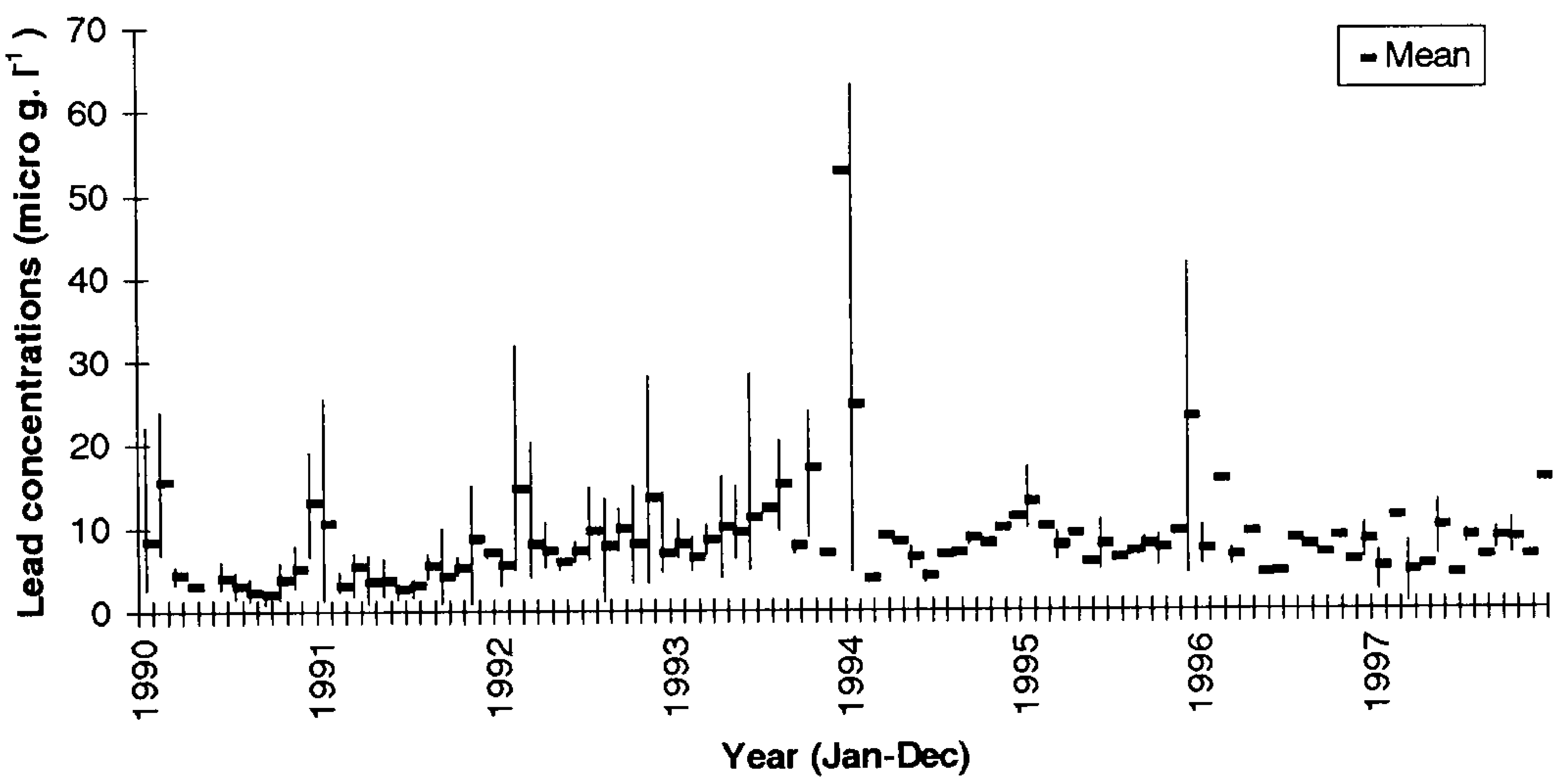


Fig. 4.20. Monthly mean and range of total lead concentrations of the Lower Don at North Bridge (1990-1997)

4.6. The Dearne catchment

Trends in nickel and iron levels

The levels of nickel and iron present in the River Dearne have generally remained low and fairly stable over the years (Figs. 4.21 & 4.22) due to pit closures and mine water treatment plants being constructed (Firth, 1997) to reduce this type of pollution, i.e. North Gawber, Wharncliffe and Silkstone mine water treatment plants. In 1995, there remained just one colliery in the catchment, a private mine located near Scissert, in the upper reaches of the Dearne. The low levels of nickel and iron would be expected under these circumstances.

Trends in zinc and copper levels

The zinc levels fluctuated enormously with occasionally wide ranges between minimum and maximum concentrations discharged (Fig. 4.23). It is probable that the zinc inputs are not derived from stable sources or may have been flushed out from some spoil heaps in the catchment during wet weather conditions. The copper levels of the river remained virtually unchanged between 1990 and 1997 (Fig. 4.24) possibly reflecting the geology of the area, and the lack of exploitation of the element.

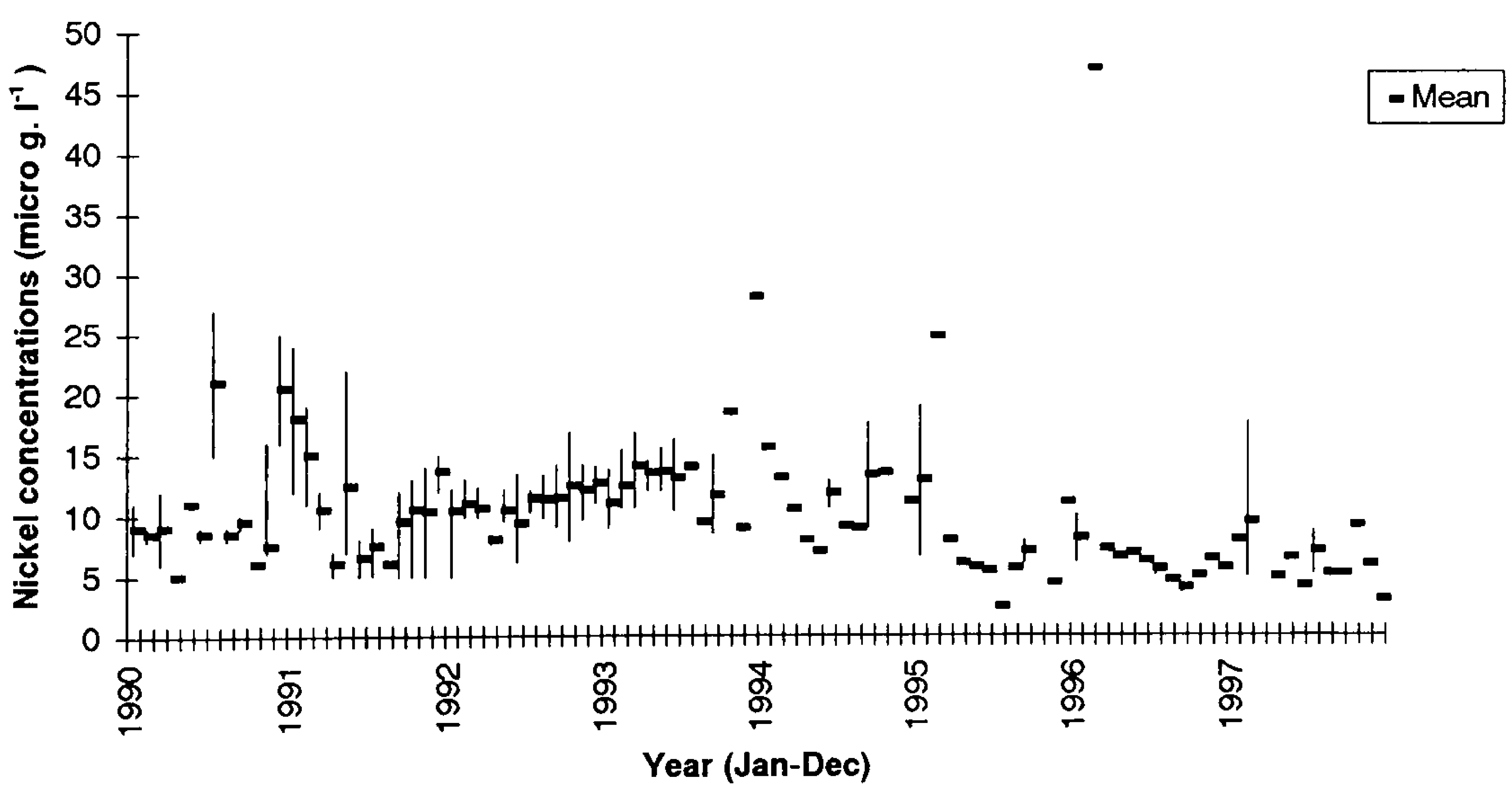


Fig. 4.21. Monthly mean and range of total nickel concentrations of the Dearne catchment at Pastures Bridge (1990-1997)

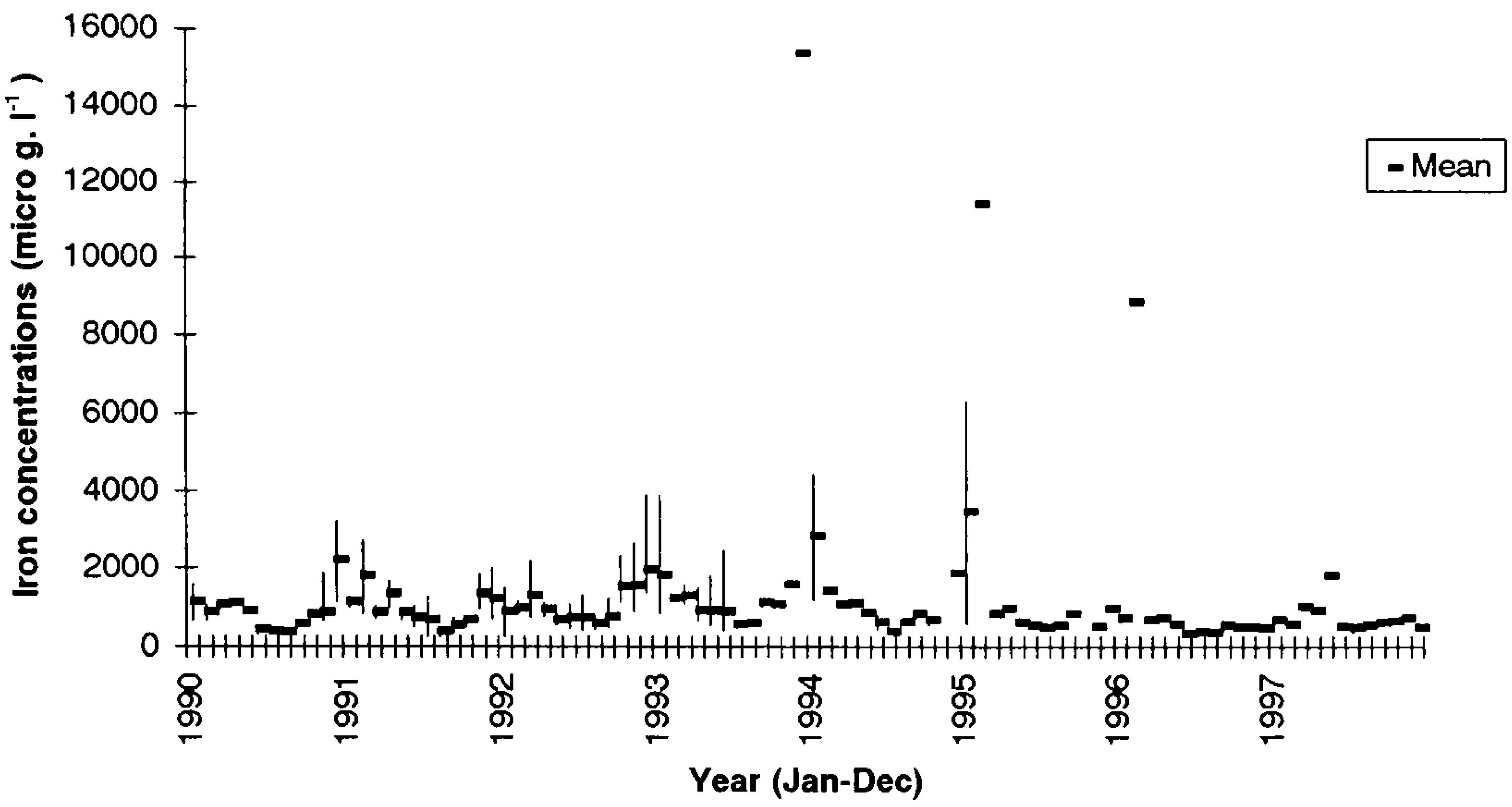


Fig. 4.22. Monthly mean and range of iron concentrations of the Dearne catchment at Pastures Bridge (1990-1997)

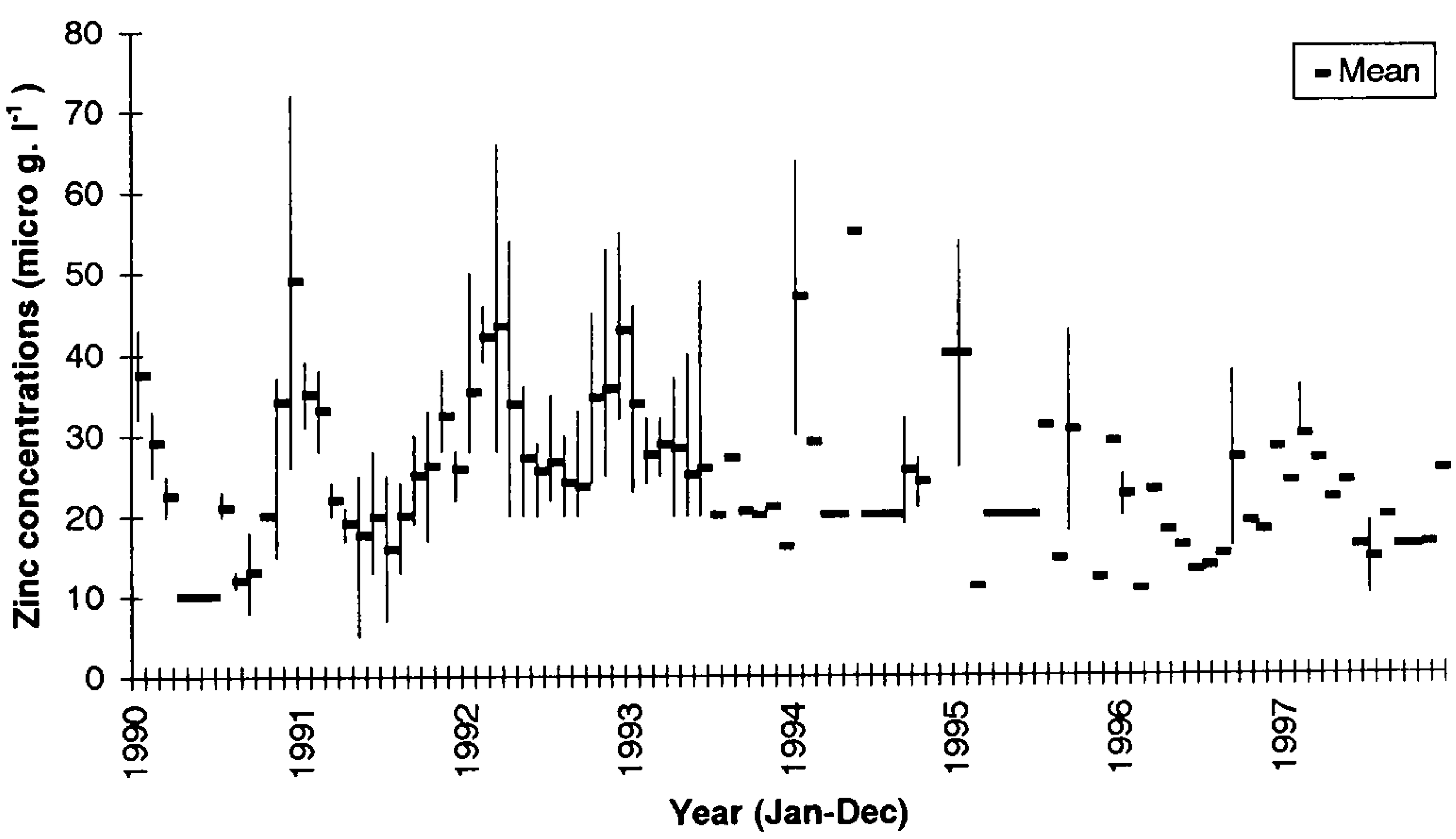


Fig. 4.23. Monthly mean and range of total zinc levels of the Dearne catchment at Pastures Bridge (1990-1997)

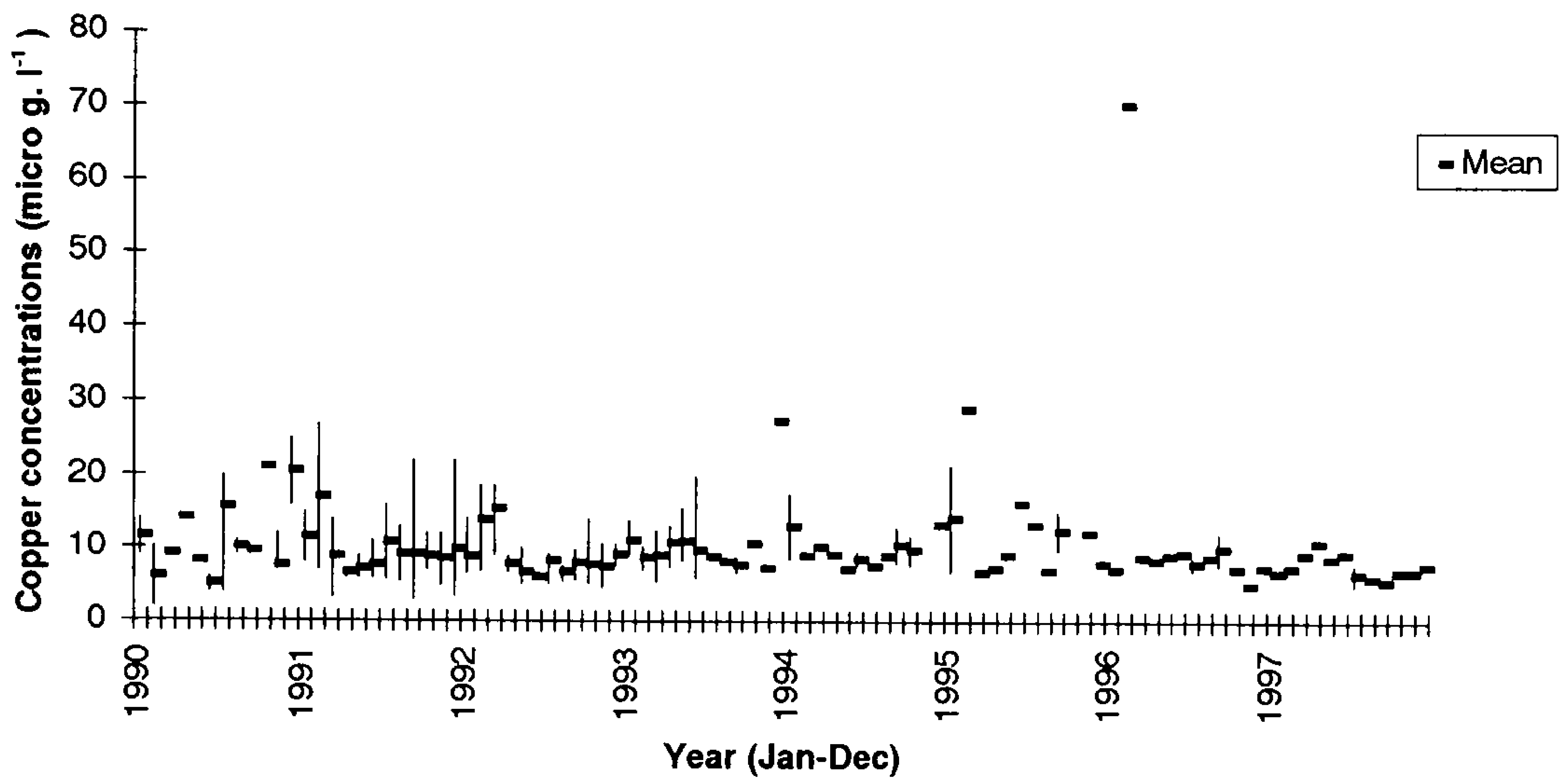


Fig. 4.24. Monthly mean and range of total copper levels of the Dearne catchment at Pastures Bridge (1990-1997)

Trends in lead concentration

Mine waters constitute the main source of lead reaching the River Dearne. Recent reductions in mining activity in the catchment area has resulted in a noticeable decline in the levels of lead in the receiving watercourse (Fig. 4.25).

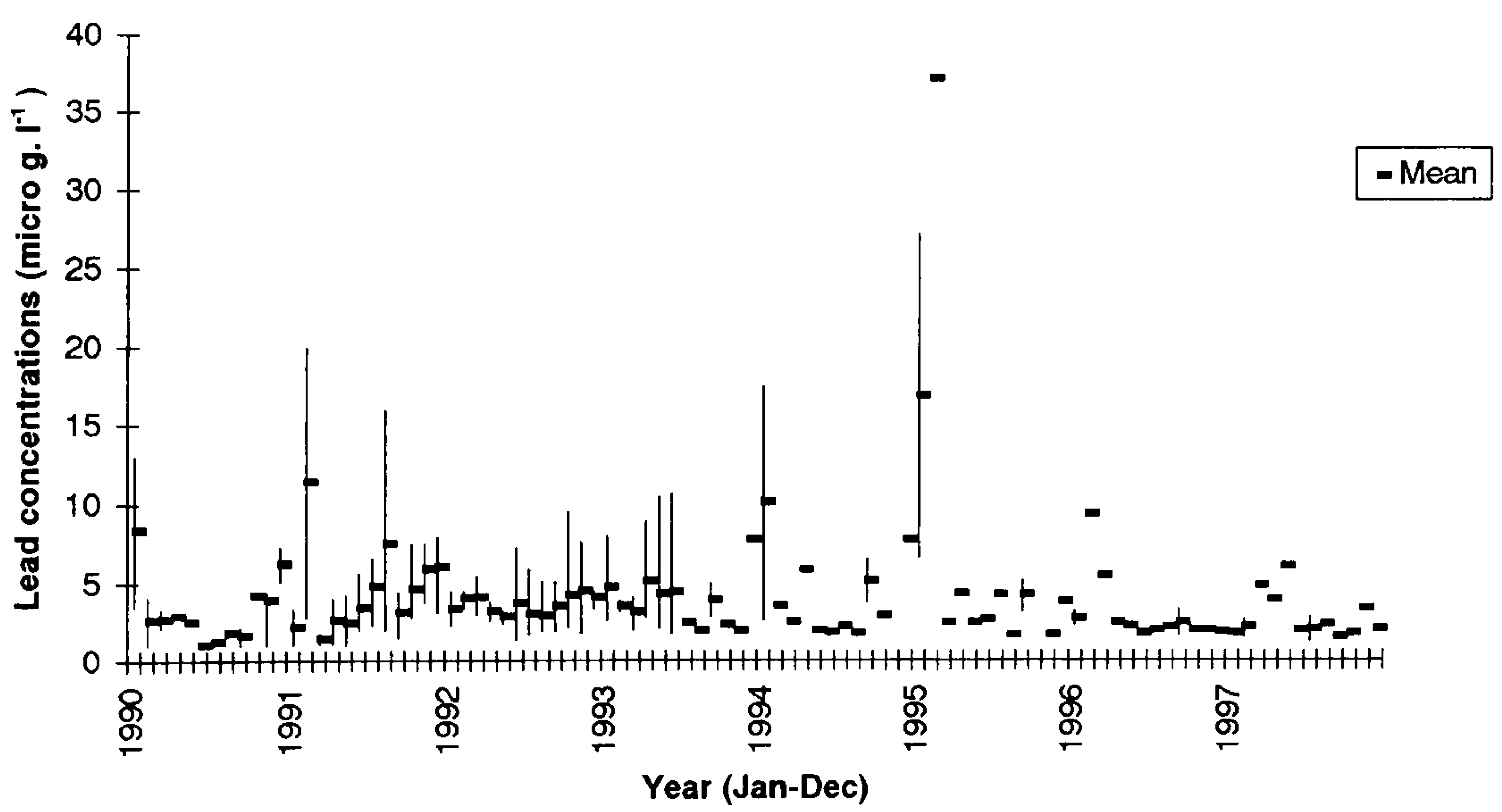


Fig. 4.25. Monthly mean and range of total lead concentrations of the Dearne catchment at Pastures Bridge (1990-1997)

4.7. The River Rother

The River Rother continues to receive discharges from industry, contaminated land and landfill sites, and from coal mining activities. Both chemical and coking industries have flourished in the catchment. These impact on the water quality and the metal loading of the river.

Trend in nickel and iron levels

There were four coking plants in the Rother sub-catchment but in 1991-92, three of these works were shut down (Firth, 1997). The closure of the coking works did not appear to reduce the levels of the elements in the river (Figs 4.26 and 4.27). It appears that past industrial activity has contaminated the land to a considerable extent and it would take more time to notice significant reductions in the levels of these elements in the receiving watercourses. Elevated levels of iron and nickel were occasionally observed (Figs 4.26 & 4.27). These were possibly linked to leachates from waste containment sites which often contain heavy metals. A reduction in dilution effect might be important in explaining the observed relatively high ranges of nickel during the drought of 1995/96 that lasted 20 months (EA, 1997). Flows were reported to be below the expected levels under dry weather conditions (EA, 1997).

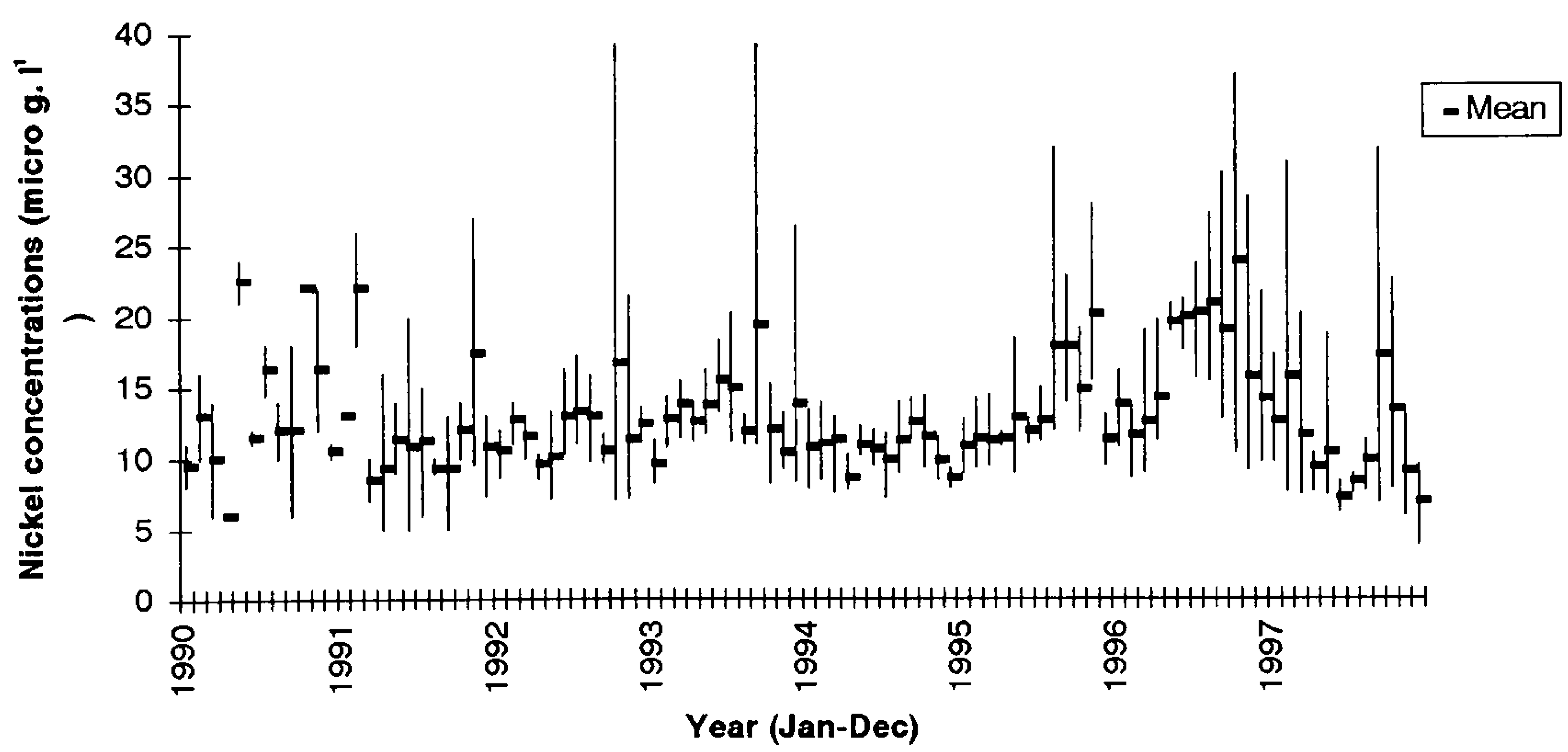


Fig. 4.26. Monthly mean and range of total nickel concentrations of the Rother catchment at Canklow (1990-1997)

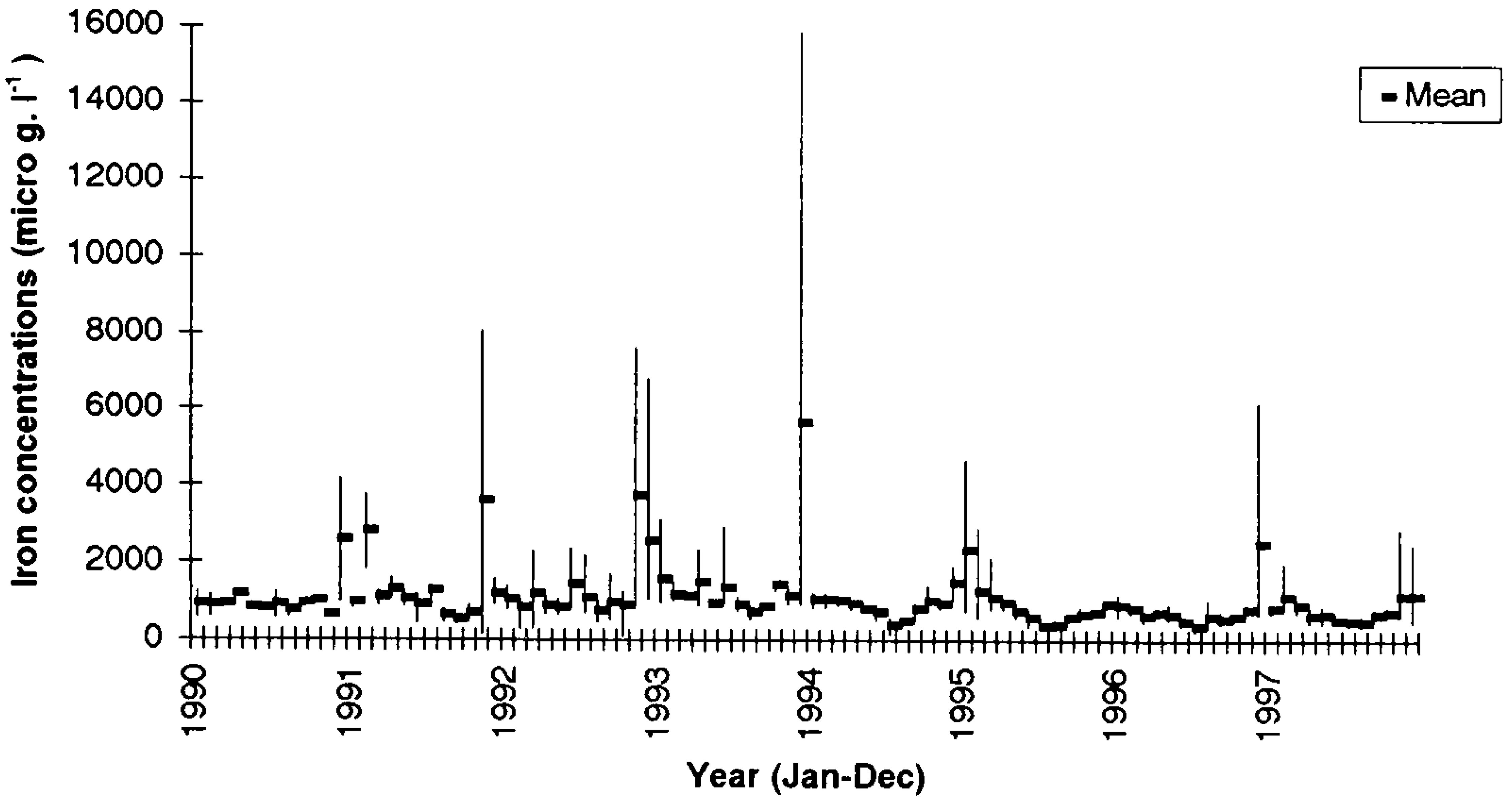


Fig. 4.27.Monthly mean and range of total iron levels of the Rother catchment at Canklow (1990-1997)

Trends in zinc and copper levels

The mean concentrations of zinc and copper remained fairly steady during 1990-1997, although there were large sporadic variations in the minimum and maximum levels over the same period (Figs 4.28 & 4.29). As in the case of iron and nickel, the levels of these elements would possibly be influenced by leachates from waste containment sites in the catchment.

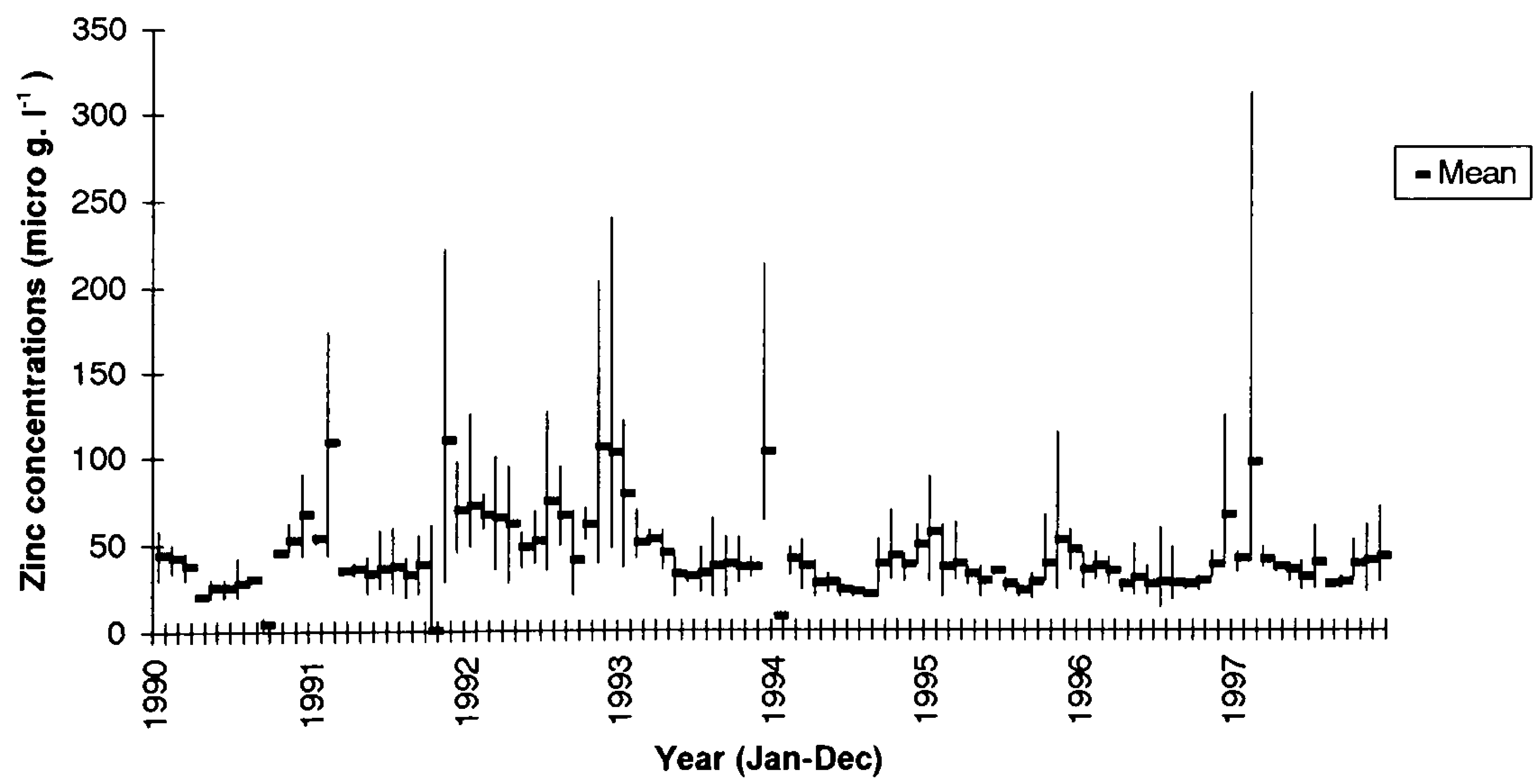


Fig. 4.28. Monthly mean and range of total zinc levels of the Rother catchment at Canklow (1990-1997)

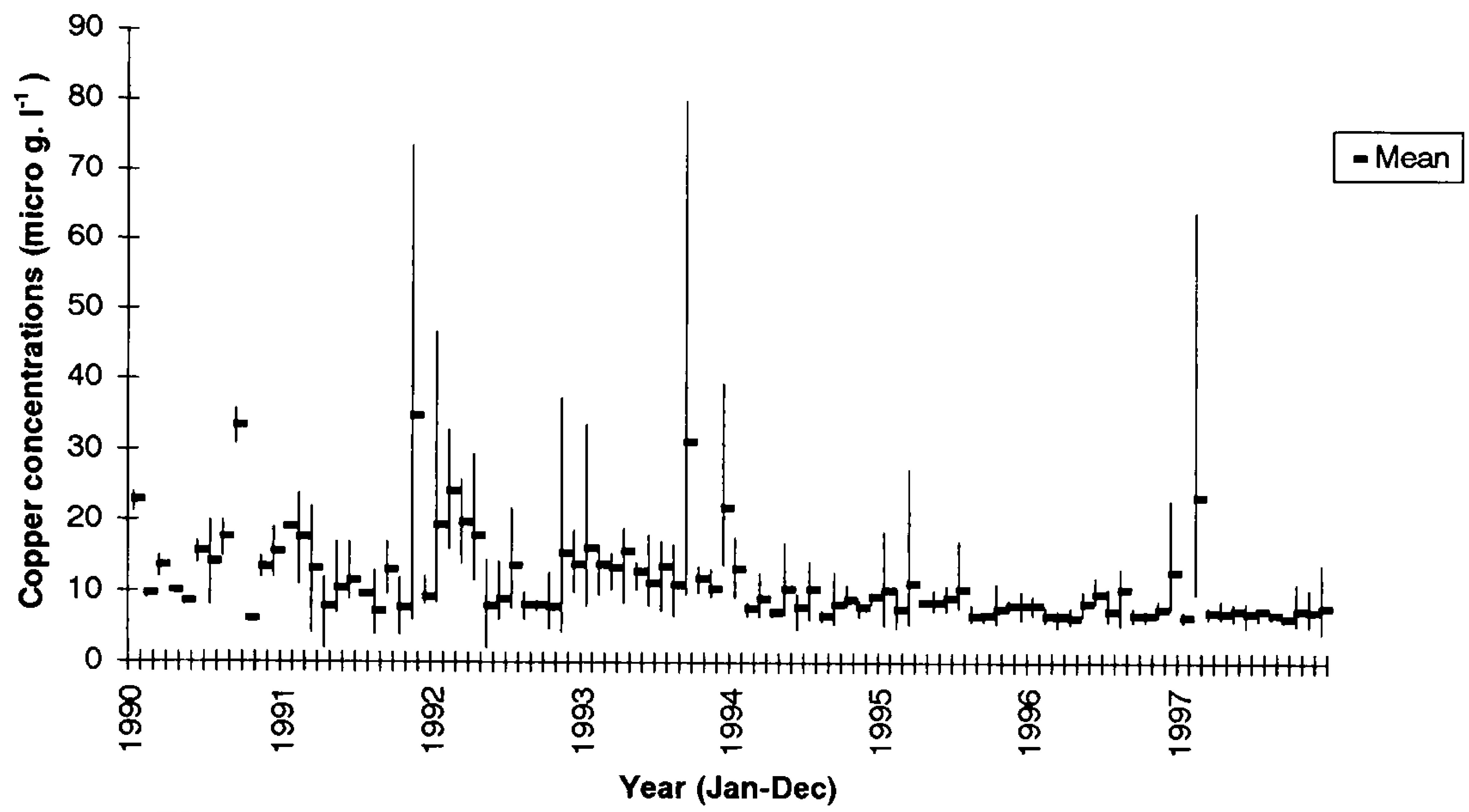


Fig. 4.29. Monthly mean and range of total copper concentrations of the Rother catchment at Canklow (1990-1997)

Trends in lead concentrations

Lead mining has for centuries been practised in the hills to the east of Chesterfield (Firth, 1997) with little or no apparent effect on the watercourses of the catchment. The rapid development of the coal industry made further contributions of the element to the watercourses. Lead levels in the Rother catchment since 1990 have remained generally low and steady (Fig. 4.30) with very few occasions of elevated levels being recorded.

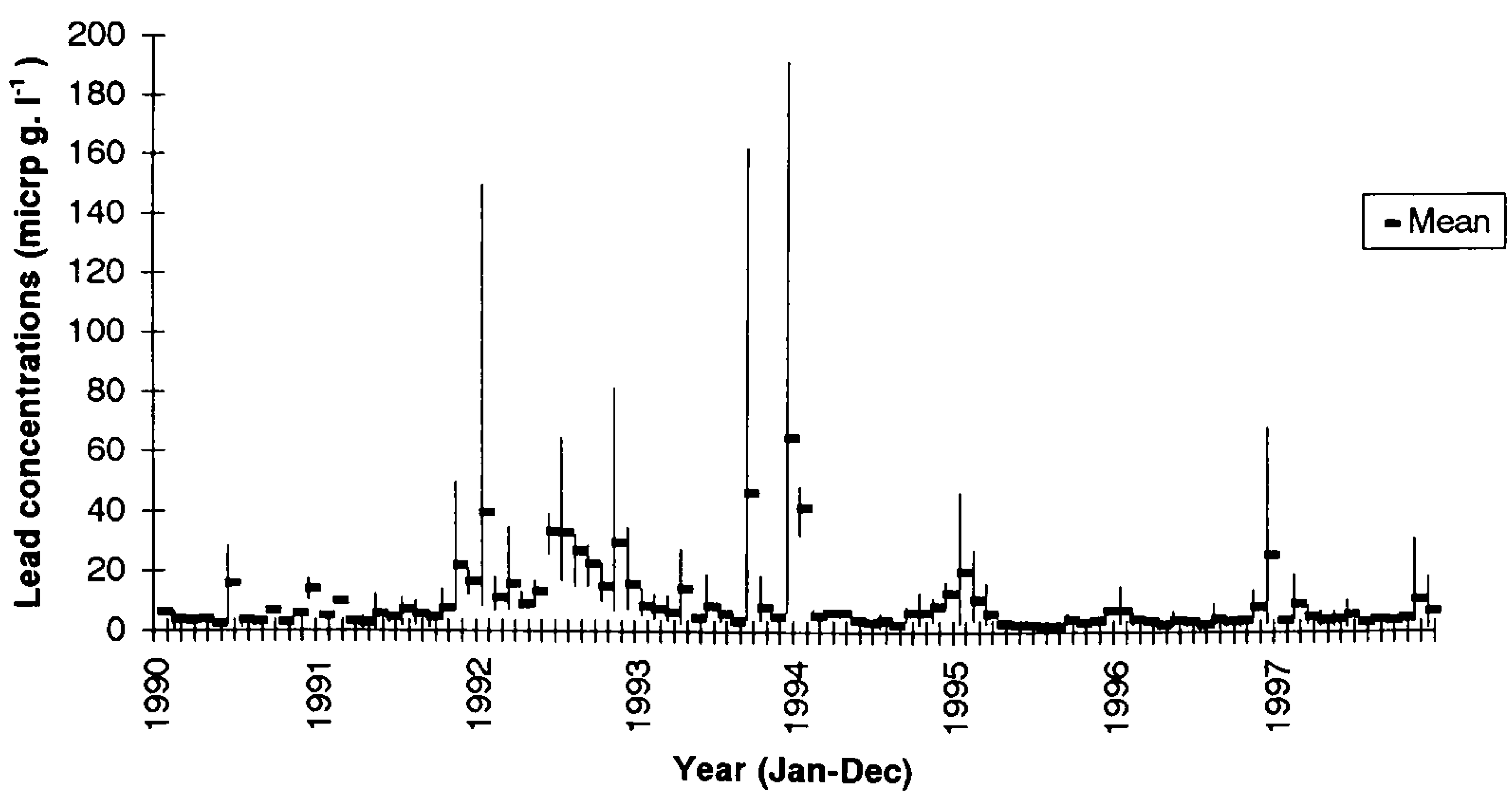


Fig. 4.30. Monthly mean and range of total lead concentrations of the Rother catchment at Canklow (1990-1997)

4.8. Benthic macroinvertebrates of the Rivers Don, Rother & Dearne

4.8.1. Introduction

Benthic macroinvertebrates have been used by the EA and its predecessors for assessing the biological quality of the Rivers Don, Rother and Dearne and their tributaries. The historical information consisted of inventories of macroinvertebrate taxonomic families, BMWP and ASPT scores. It was therefore not possible, based on the available information, to quantify the abundance, diversity, species richness and evenness indices of the fauna in time and space. The macrobenthic invertebrate data collected by the EA and its predecessors were used to derive BMWP and ASPT scores. The scores were applied in the classification of various watercourses in the catchment and to identify the river sections under severe stress from anthropogenic activities.

This section reviews the abundance, diversity, species richness and evenness of the macrobenthic fauna at selected sites in the Don, Rother and Dearne catchment. The list of macroinvertebrates found during the surveys is presented in Appendix 1.4. No current EA data were available for comparison during this period as they are still being processed (F. Cessford, pers. comm).

4.9. The River Don at Penistone

Macroinvertebrate Diversity

The macroinvertebrate fauna in the River Don at Penistone (Figs 4.31a & 4.31b) between February 1996 and July 1997 was generally characterised by pollution-tolerant species. The macrobenthos was generally dominated by Chironomidae, with Asellidae being the next most abundant of the remaining fauna. Chironomid larvae are often the dominant faunal element in muddy sediments, and are a major food source for fish and other organisms in otherwise unproductive waters. They occur in all types of habitats from water butts and gutters to large lakes, although they are less common in fast-flowing waters (Fitter and Manuel, 1986). Many species burrow in mud, and can even survive under anoxic conditions.

Macroinvertebrate abundance and diversity appeared to reflect seasonal changes with the greatest abundance and diversity occurring in May, June and July (summer) when temperatures were relatively high (Fig. 4.31a & 4.31b). On the other hand reduced numbers of invertebrates were found in September and December when temperatures were lower. Although macroinvertebrate numbers were relatively high in February (Fig. 4.31a) the species diversity was low (Fig. 4.31b), possibly reflecting seasonal changes in macroinvertebrate species.

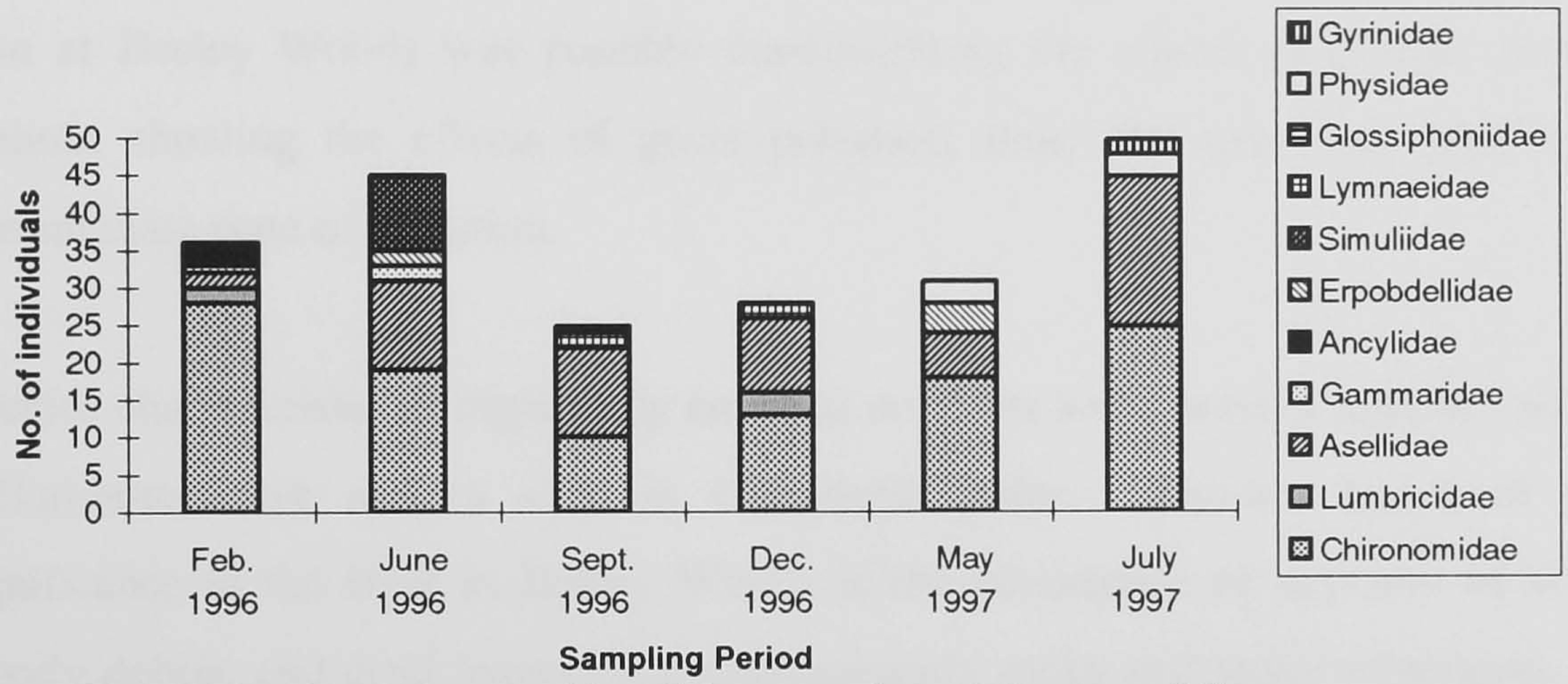


Fig. 4.31a. Abundance of benthic macroinvertebrates of the River Don at Penistone

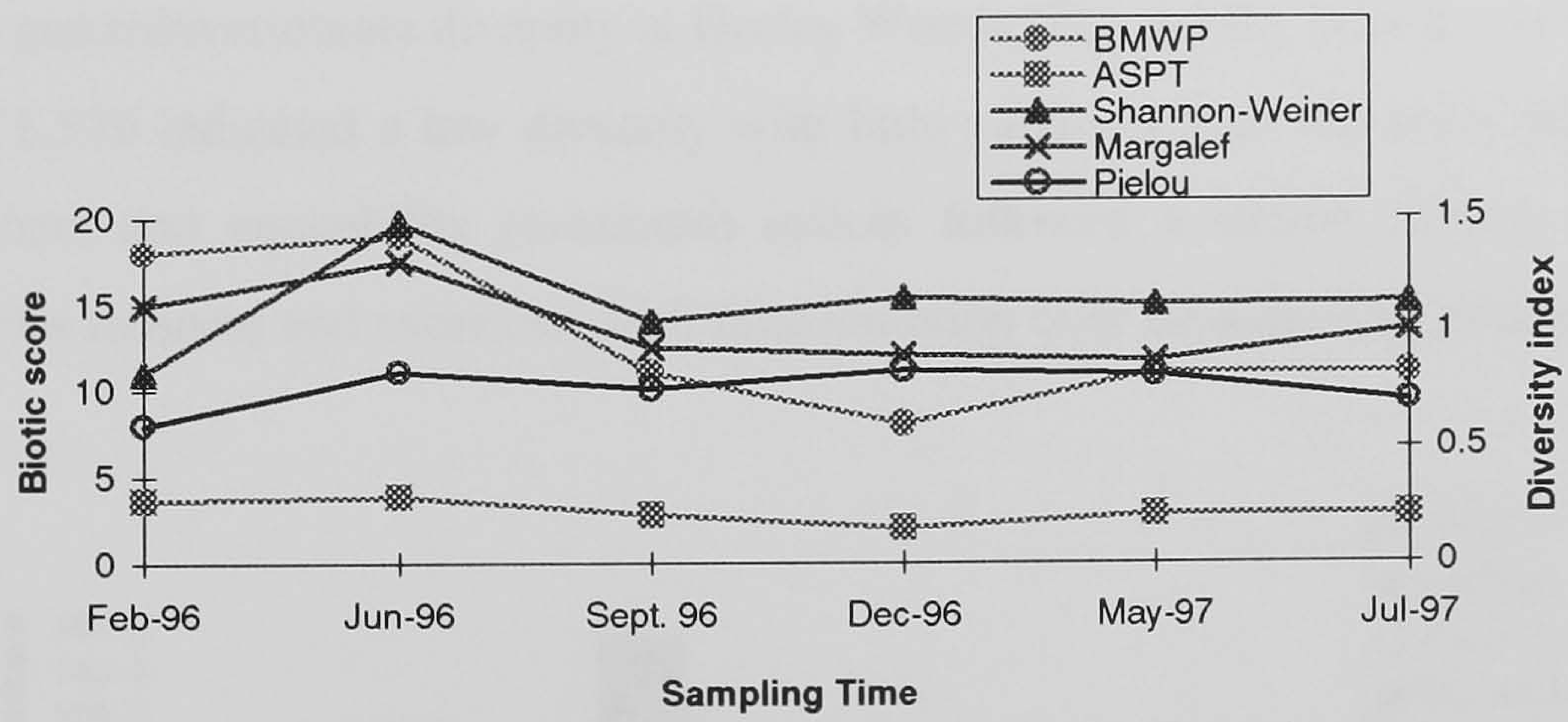


Fig. 4.31b. Macroinvertebrate diversity in the River Don at Penistone

A low species diversity characterised the macrobenthos in the River Don at Penistone with the Shannon-Weiner index ranging between 0.823 and 1.482 (Fig. 4.31b). Similarly, Margalef's index (0.874-1.313)) revealed a low degree of species richness whilst Pielou's index (0.594-0.831) demonstrated an average to high evenness index (Fig. 4.31b), indicating a good equitability of species distribution.

4.10. The River Don at Beeley Woods

Macroinvertebrate diversity

The macrobenthos was mainly pollution-tolerant forms dominated by Asellidae (Fig. 4.32a). Chironomidae and Erpobdellidae also occurred in considerable numbers and constituted the next most dominant groups. Asellidae, Chironomidae and Erpobdellidae occurred in all samples (Fig. 4.32a) but Gammaridae occurred sporadically. The River Don at Beeley Woods was possibly demonstrating the effects of organic enrichment without showing the effects of gross pollution; thus, the river was possibly in an intermediate state of pollution.

Species characteristic of organically enriched sediment were present together with some pollution-sensitive species such as *Gammarus pulex*. Another factor of possible significance in the river at Beeley Woods is the occurrence of deposits of silt, mud, woody debris, and dead leaves on a predominantly rocky and stony substratum. These features provide a greater habitat diversity (Angers, 1975; Read & Renshaw, 1977; Read *et al.*, 1978) and would in theory support a diverse macroinvertebrate fauna.

The macroinvertebrate diversity at Beeley Woods (Fig. 4.32b), which was between 1.148 and 1.579 indicated a low diversity with little variation over the study period. Species richness and equitability (evenness) indices followed a similar pattern reflecting low species richness and evenness, with little variation over the sampling period.

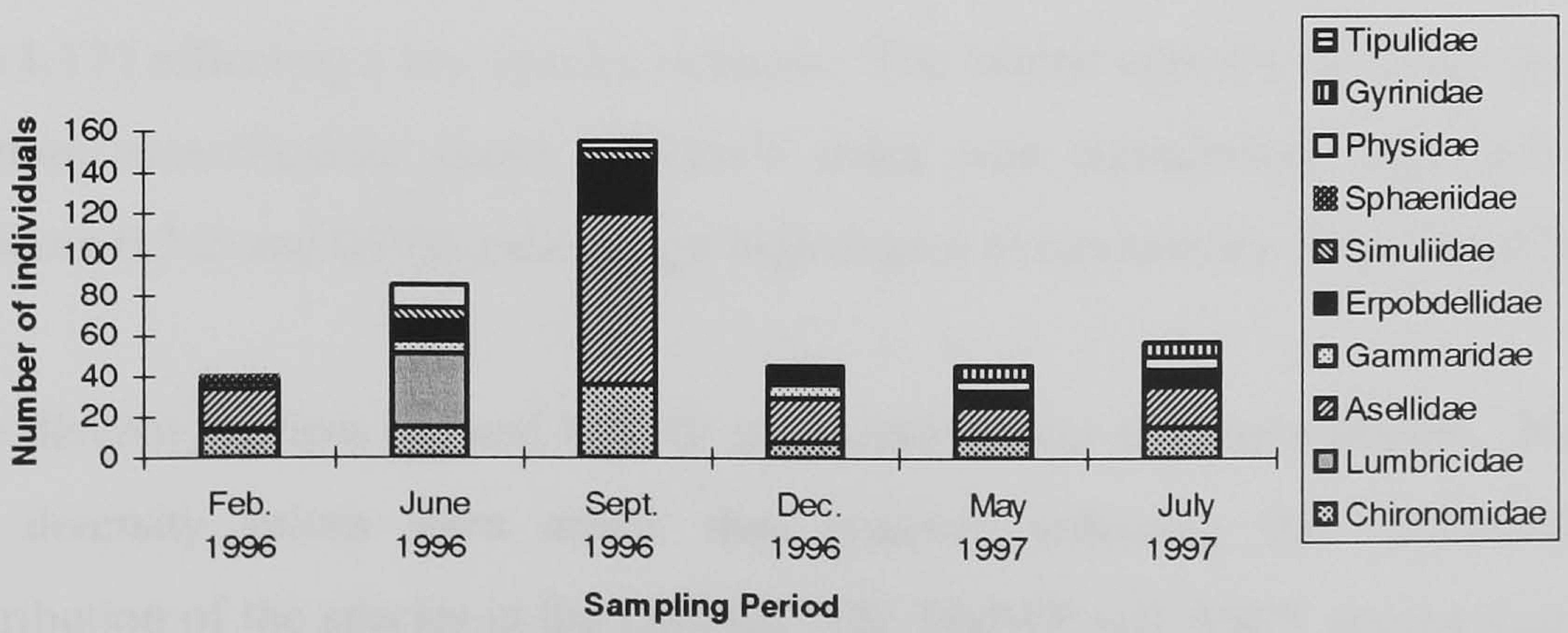


Fig. 4.32a. Abundance of macrobenthic invertebrates in the River Don at Beeley Woods

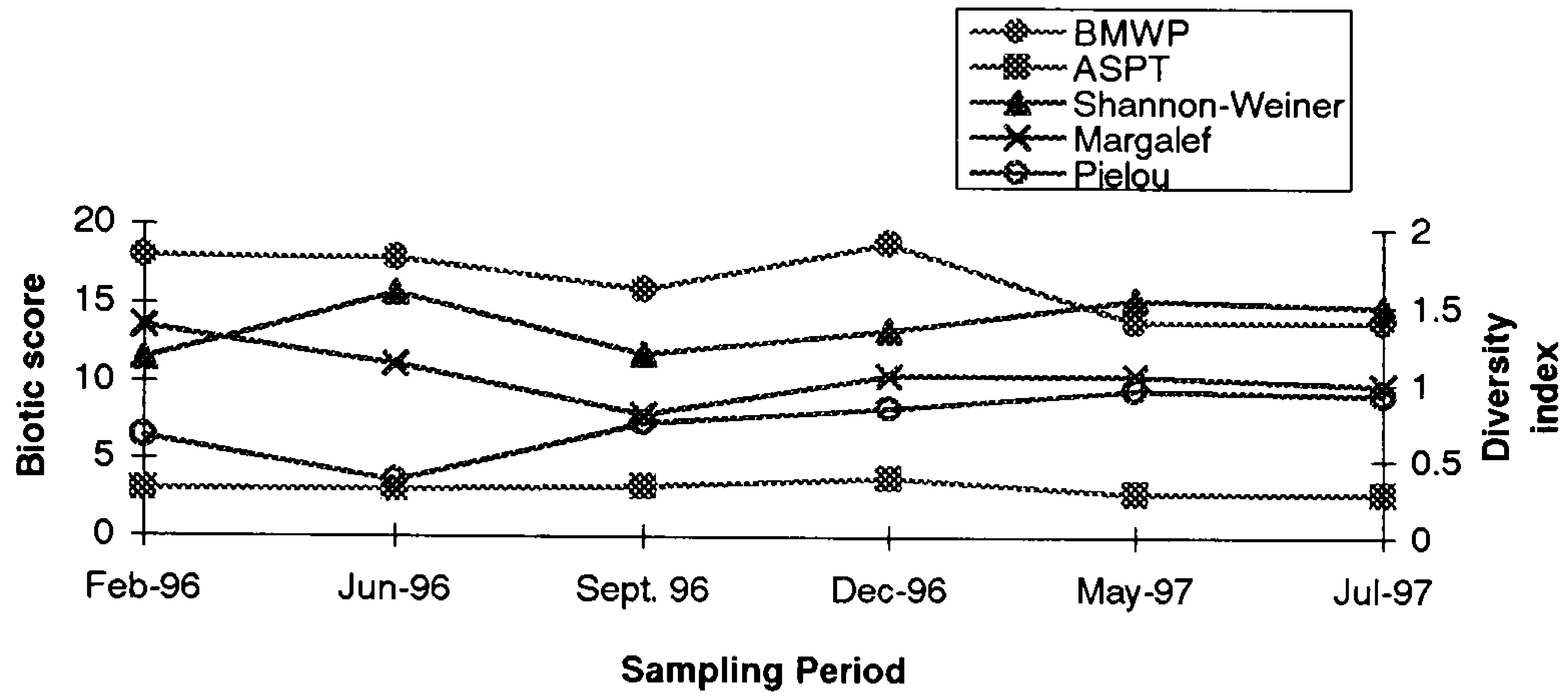


Fig. 4.32b. Macroinvertebrate diversity in the River Don at Beeley Woods

The BMWP and ASPT scores remained low but stable (Fig. 4.32b) during the study indicating poor water quality.

4.11. The River Dearne at Cudworth Common

The macroinvertebrate taxa found in the River Dearne at Cudworth Common were the pollution-tolerant types (Figs 4.33a & 4.33b). No pollution-sensitive species were encountered in the surveys. Asellidae, Chironomidae and Erpobdellidae were the dominant macrobenthos. Whereas these species were abundant, they nonetheless reflected a denuded macroinvertebrate community and poor water quality, and thereby reflected a similar pattern found in the fish fauna.

The Shannon-Weiner index was low (ranging between 1.150 and 1.554) indicating a low diversity of the macrobenthic fauna (Fig. 4.33b). Margalef's index ranged between 0.604 and 1.173 reflecting a low species richness. The habitat appears to favour the pollution-tolerant macrobenthic fauna. Pielou's index was considerably high and measured between 0.715 and 0.918, indicating a high degree of equitability in species distribution.

The diversity indices showed little or no variation over the study period. No trends in the diversity values were noted, thus possibly reflecting the randomness of the distribution of the species in the samples. The BMWP and ASPT scores were low (Fig. 4.33b) with the latter remaining stable throughout the survey. The low BMWP and ASPT scores also reflect the poor water quality of this river.

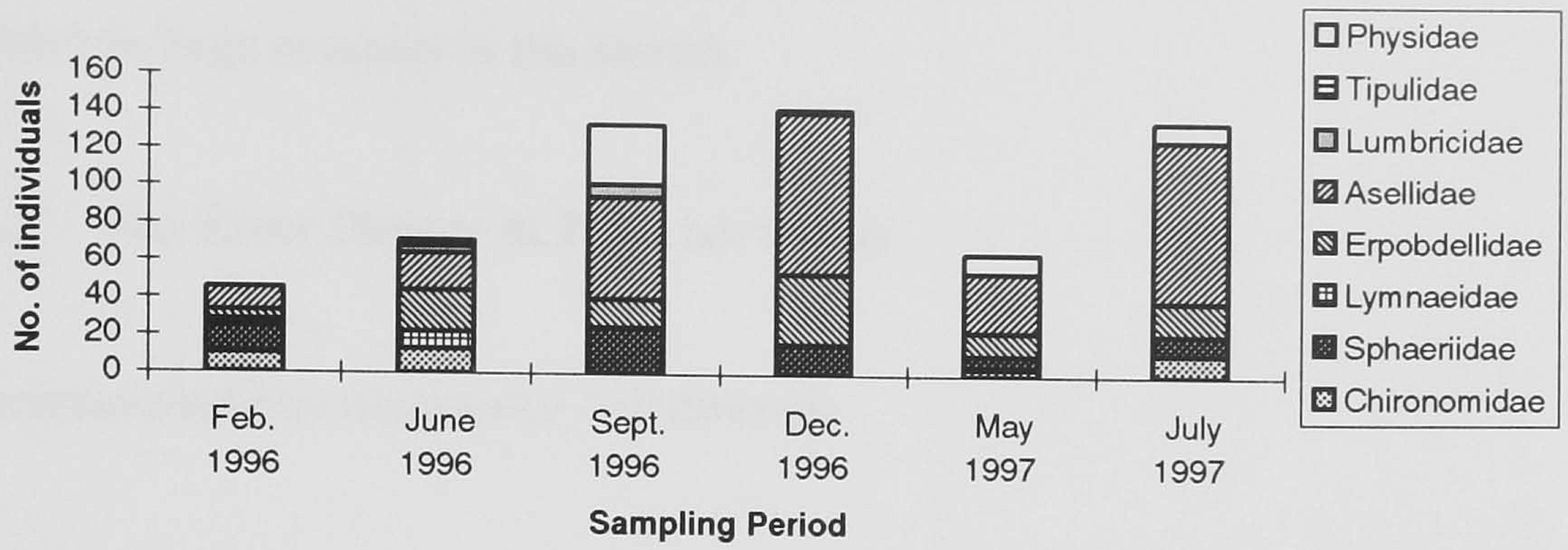


Fig. 4.33a. Abundance of benthic macroinvertebrates in the River Dearne at Cudworth Common

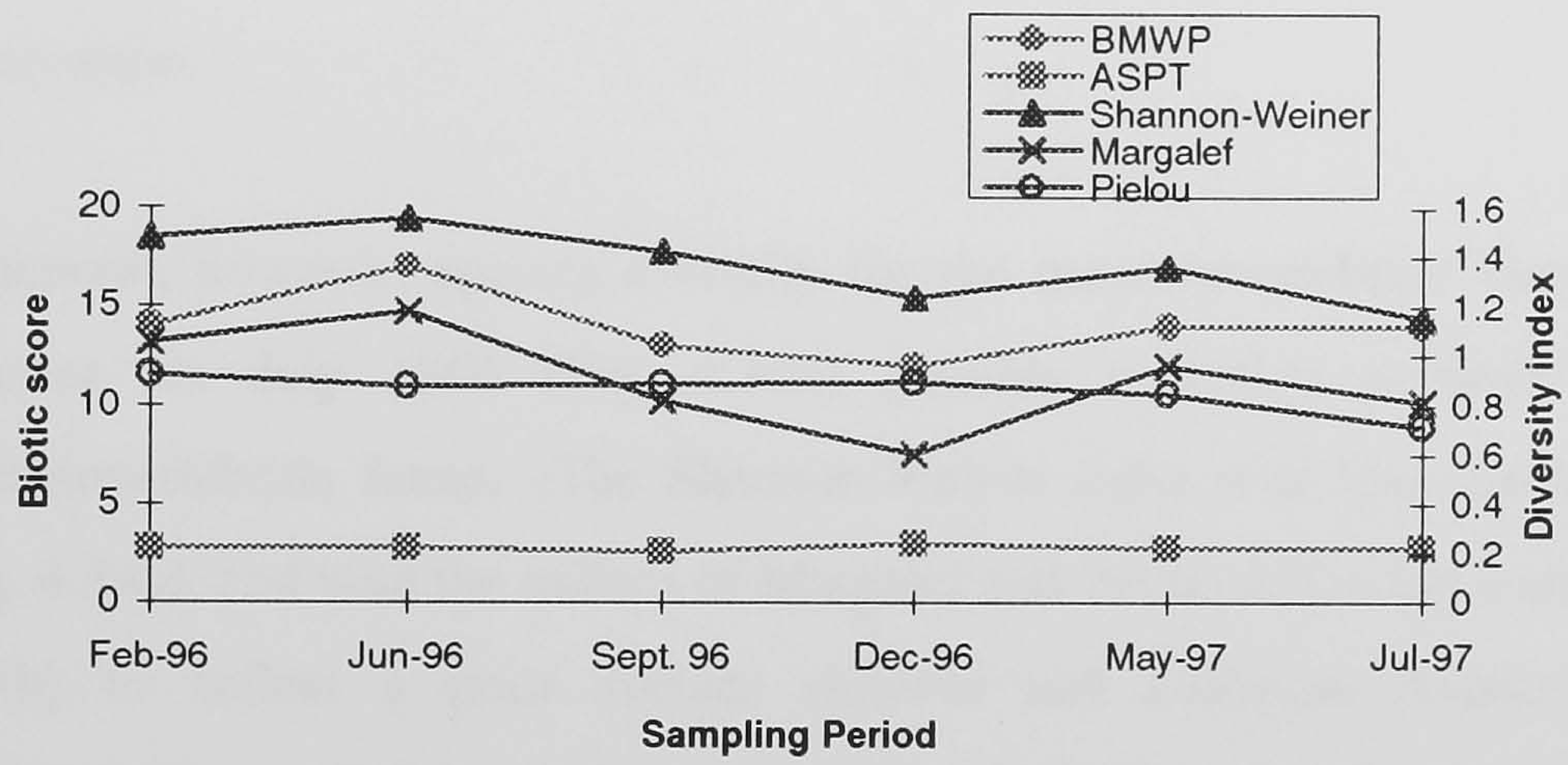


Fig. 4.33b. Macroinvertebrate diversity in the River Dearne at Cudworth Common

Macroinvertebrate numbers did not appear to reflect seasonal changes or isolated events like heavy spates which occurred just before the May 1997 survey. Macroinvertebrate numbers in May was expected to be high, due to flushing out of the macrobenthos, but this was low (Fig. 4.33a). Surveys in December (winter) and July (summer) had similar numbers of macroinvertebrates (Fig. 4.33a) but species diversity in December was lower (Fig. 4.33b). No apparent reasons could be found for this observation.

Organic pollution causes a decrease in diversity (Wu, 1982) as sensitive organisms are lost, an increase in the abundance of tolerant organisms due to nutrient enrichment, and a decrease in evenness (Calow & Petts, 1994). In this study no pollution-sensitive macrobenthic invertebrates were found. This is, possibly, an indication of the deteriorated state of the water quality that can only support pollution-tolerant species. Earlier surveys of this site by the NRA and recent fish surveys yielded few or no fish. It would appear from these findings that until water quality improves, fish are unlikely to survive in large numbers in this stretch.

4.12. The River Dearne at Pastures Bridge

Macroinvertebrate abundance and diversity

The benthic macroinvertebrates were dominated by *Gammarus pulex* (Gammaridae) in each survey (Figs 4.34a), possibly reflecting a relatively clean water. The species was particularly abundant in March and September 1997 but reduced numbers were found in November 1995 and July 1996. No apparent reasons could be found for this observation.

In general, however, species diversity for the macroinvertebrate fauna was highest in summer i.e. July 1996 (Fig. 4.34b) possibly reflecting seasonal changes in the macroinvertebrate fauna. The Shannon-Weiner index was low reaching just over 1.4 (Fig. 4.34b), and with the indices of Margalef and Pielou following a similar pattern (Fig. 4.34b) to reflect a poor species richness and evenness respectively. Asellidae Chironomidae and Sphaeriidae were also present in considerable numbers in all the surveys indicating some organic enrichment in this stretch of the river.

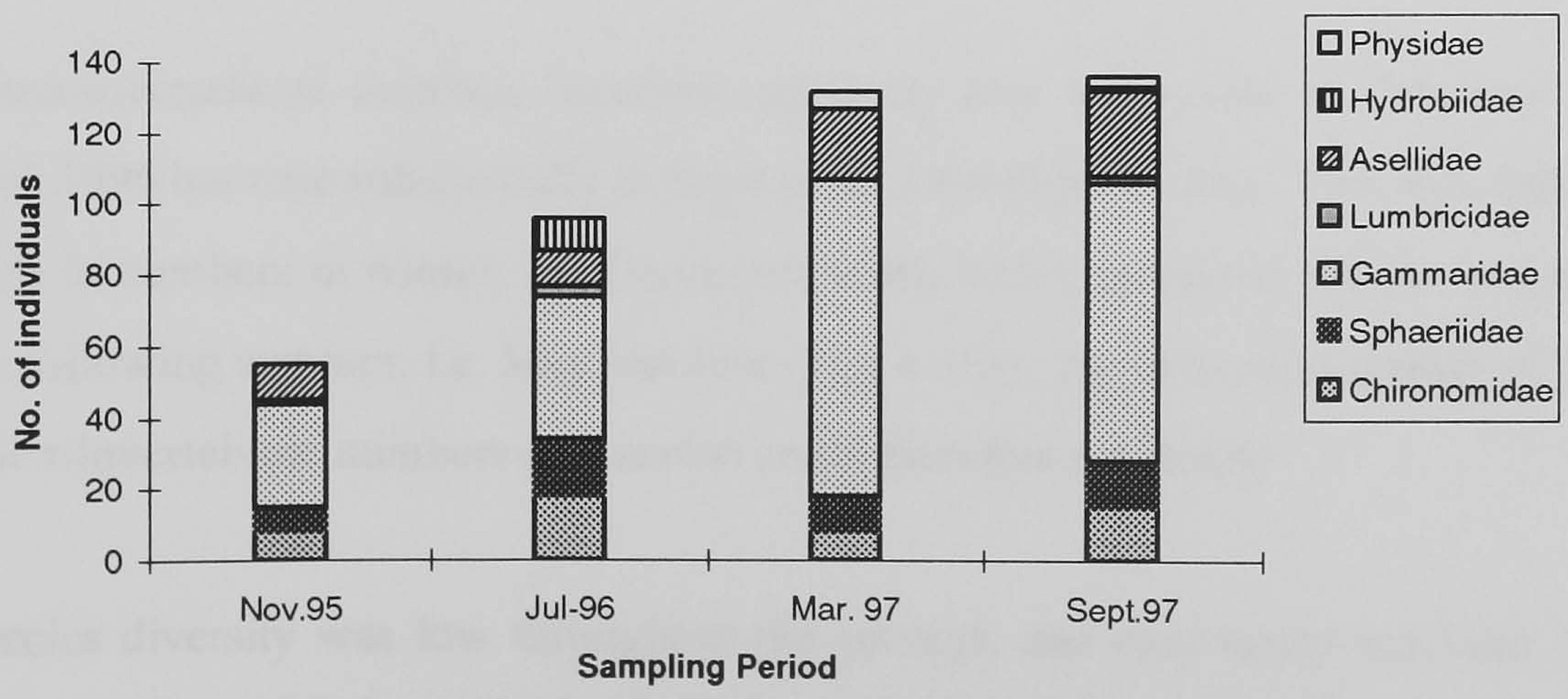


Fig. 4.34a. Abundance of benthic macroinvertebrates in the River Dearne at Pastures Bridge

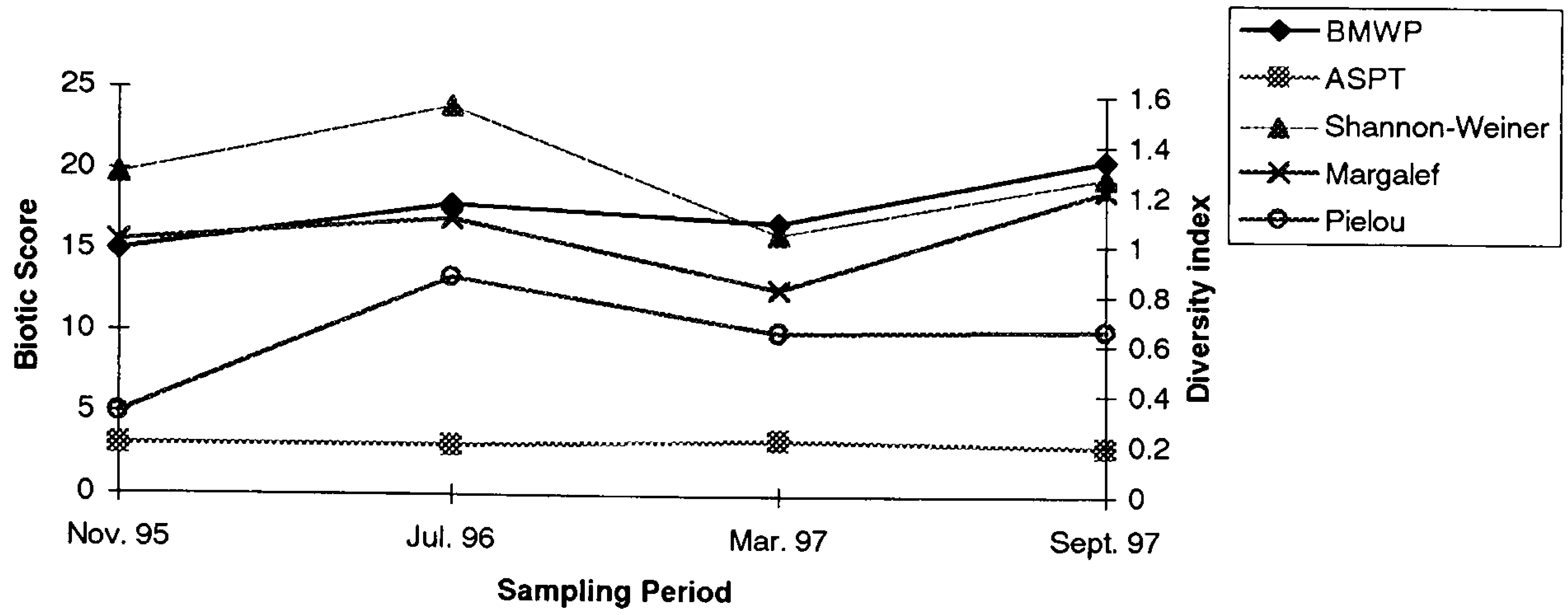


Fig. 4.34b. Macroinvertebrate diversity in the River Dearne at Pastures Bridge

4.13 The River Rother at Birdholme Bridge

Macroinvertebrate abundance and diversity

The macrobenthic invertebrates in the River Rother at Birdholme Bridge were represented by 7 families (Fig. 4.35a). The Chironomidae and the Asellidae formed the main dominant groups throughout the surveys between February 1996 and July 1997.

The Chironomidae was particularly abundant (Fig. 4.35a). These fauna are often associated with pollution and nutrient enrichment, and possibly provide an indication of the polluted state of the river.

Macroinvertebrate numbers remained relatively low and stable in February 1996 and June 1996 but rose substantially in September 1996 (Fig. 4.35a). This was followed by a drop in numbers in winter, i.e. December 1996, which remained almost unchanged into the following summer, i.e. May and July (Fig. 4.35a). No clear relationship of changes in macroinvertebrate numbers and season could therefore be found.

Species diversity was low throughout the surveys, and only rarely reaching 1.4 on the Shannon Weiner index (Fig. 4.35b). Species richness was consistently low throughout the study, reflecting a stressed environment as was found at other sites studied. The evenness index was also low throughout the study, indicating a poor equitability in species distribution.

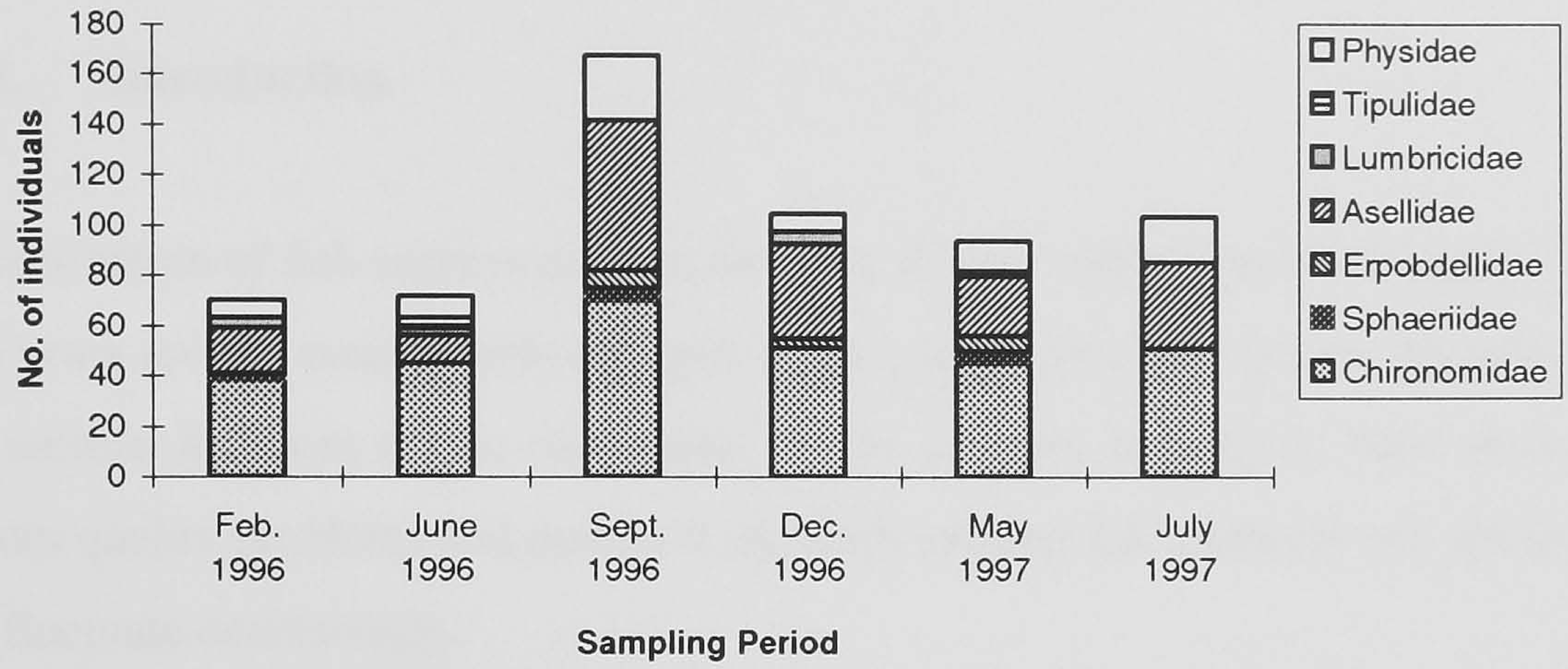


Fig. 4.35a. Abundance of benthic macroinvertebrates in the River Rother at Birdholme Bridge

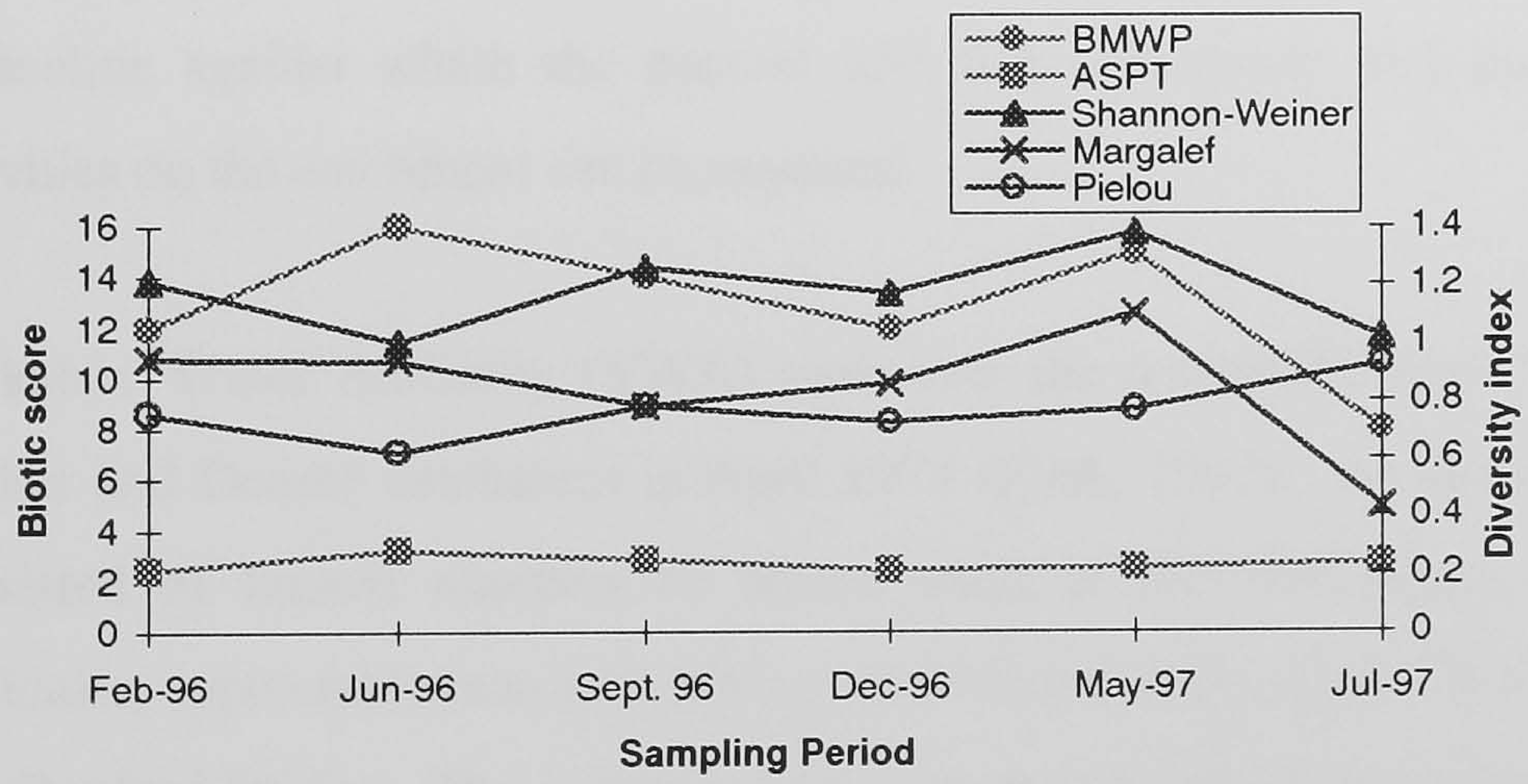


Fig.4.35b. Macroinvertebrate diversity in the River Rother at Birdholme Bridge

CHAPTER FIVE

SPATIAL AND TEMPORAL TRENDS IN FISH POPULATION STRUCTURE OF THE RIVERS DON, ROTHER & DEARNE.

5.1. Introduction

Examination of fish surveys data for the Don, Rother and Dearne catchment over the last 14 years reveals considerable changes in fish populations and species diversity over time at various locations of the catchment. These changes have often been associated with water quality problems and pollution incidents causing fish numbers and species diversity to fluctuate enormously.

5.1.1. Historical trends

The oxygen-rich upland headwaters of the River Don used to be the spawning and nursery areas for the Atlantic salmon prior to 1800 (Firth 1997). This scenario provides a baseline against which the present day fish community and the impact of man's activities on the catchment can be assessed.

Yorkshire Water Authority (YWA) took over the responsibility of managing the Don, Rother and Dearne catchment in April 1974 (Firth, 1997). At this time the River Don consisted of limited numbers of brown trout at the headwaters (Firth, 1997). In particular, appreciable numbers of trout were found in the upper Don between Bullhouse and Dunford Bridge. This section of the river was damaged as a result of siltation whilst the Winscar Reservoir was being constructed in the 1970s (Firth, 1997). Although a loss of the natural spawning gravel ensued (Firth, 1997) during the construction, a small number of wild brown trout survived, probably in small tributaries. These isolated populations of trout have proved important in the restoration of fisheries in the River Don.

The Rother catchment, mainly an industrial area, runs through the urban areas of Rotherham and Chesterfield and carries with it the legacy of contaminated land from the industries located in the area. The water quality of the river was designated as class F or grossly polluted in 1974 when YWA took over the management of the catchment (Firth 1997). The fisheries have been devastated as a result of the poor water quality. The main pollution resulted from coal carbonisation, sewage treatment and chemical manufacture (EA, 1997, Firth, 1997).

During last three decades a massive proliferation of industries in the Dearne catchment took place (Firth, 1997). The Yorkshire Ouse River Board stated in their annual report of 1960 that virtually all industrial effluent was entering the river untreated (Firth, 1997). Discharges into the catchment from mining, paper and textile manufacture and brewing cocktail reduced the river to an open sewer and impoverished the fisheries of the catchment. By 1974 some attempts were made to treat discharges to the catchment, although the water quality remained class E (poor) or F (grossly polluted) for most stretches. The middle Dearne was struck by a series of acute pollution incidents from sewage, mining, industry and agriculture in the late 1980s and early 1990s (Table 5.1).

Table 5.1. Fish mortalities in the Dearne catchment, April 1987 - July 1996

Location	Date	Species Number of Killed	Cause
Hoyle Mill	10.04.87	5*	Colliery waste
	18.06.87	1000*	Colliery waste
	13.08.88	20 roach, 167 gudgeon, 213 stoneloach	Sewage pollution
Pastures Bridge	02.07.87	5*	Sewage pollution
	22.05.89	12 roach	Unknown
Stairfoot	20.08.87	573*	Pump damage
Hoyle Mill	05.09.87	432*	Silage pollution
Clayton West	19.04.87	15*	Unknown
	08.05.88	4*	Unknown
	02.07.89	26 brown trout	Agricultural
	04.07.89	6 brown trout	Unknown
	03.08.89	10 bullheads, 10 sticklebacks	Sewage pollution
	18.05.91	10 brown trout	Agricultural
Darfield	11.07.91	8020 roach, 20 bream, 20 perch	Sewage pollution
	10.08.91	49 roach, 18 gudgeon, 1 pike	Sewage pollution
Denby Dale	17.05.88	8*	Unknown
	29.05.89	14 brown trout, 27 bullheads	Industrial
Wooley	15.08.89	1 brown trout	Industrial
Smithes Bridge	15.06.90	20 gudgeon, 20 roach	Industrial
Low Barugh	21.06.88	1126*	Unknown
Darton (Shaw Carpets)	28.06.88	261*	Industrial pollution
	21.06.89	5 brown trout	Industrial pollution
Broom Hill	21.07.96	2 barbel	Unknown

*The fish species killed in the above incidents were not specified.

These led to further deterioration in water quality and massive fish kills. Fish in the catchment continue to have a precarious existence and various improvement schemes continue to be made to restore the Dearne as a fishery.

As a result of the various anthropogenic impacts on the Don, Rother and Dearne catchment and also fish pathological conditions (Yorkshire Water, 1982, 1985) the fish population structure and species diversity have fluctuated widely over the years. This study attempts to elucidate the spatial and temporal changes in the fish population structure of the Rivers Don, Rother and Dearne.

5.1.2. The River Don

Fish zonation

The abundance, species, and size distribution of fish are constrained by complex interactions of a vast array of biotic and abiotic factors (Cowx & Welcomme, 1998). Each fish species has its own requirements for its various life stages. The presence or absence of these requirements at a site can determine the relative abundance of the species present as they act as bottlenecks to reproduction, recruitment, and growth (Garcia de Jalon *et al.*, 1996).

The results of the historical surveys showed the distribution of brown trout and grayling was mainly confined to the upper reaches of the river (Figs 5.1 & 5.2).

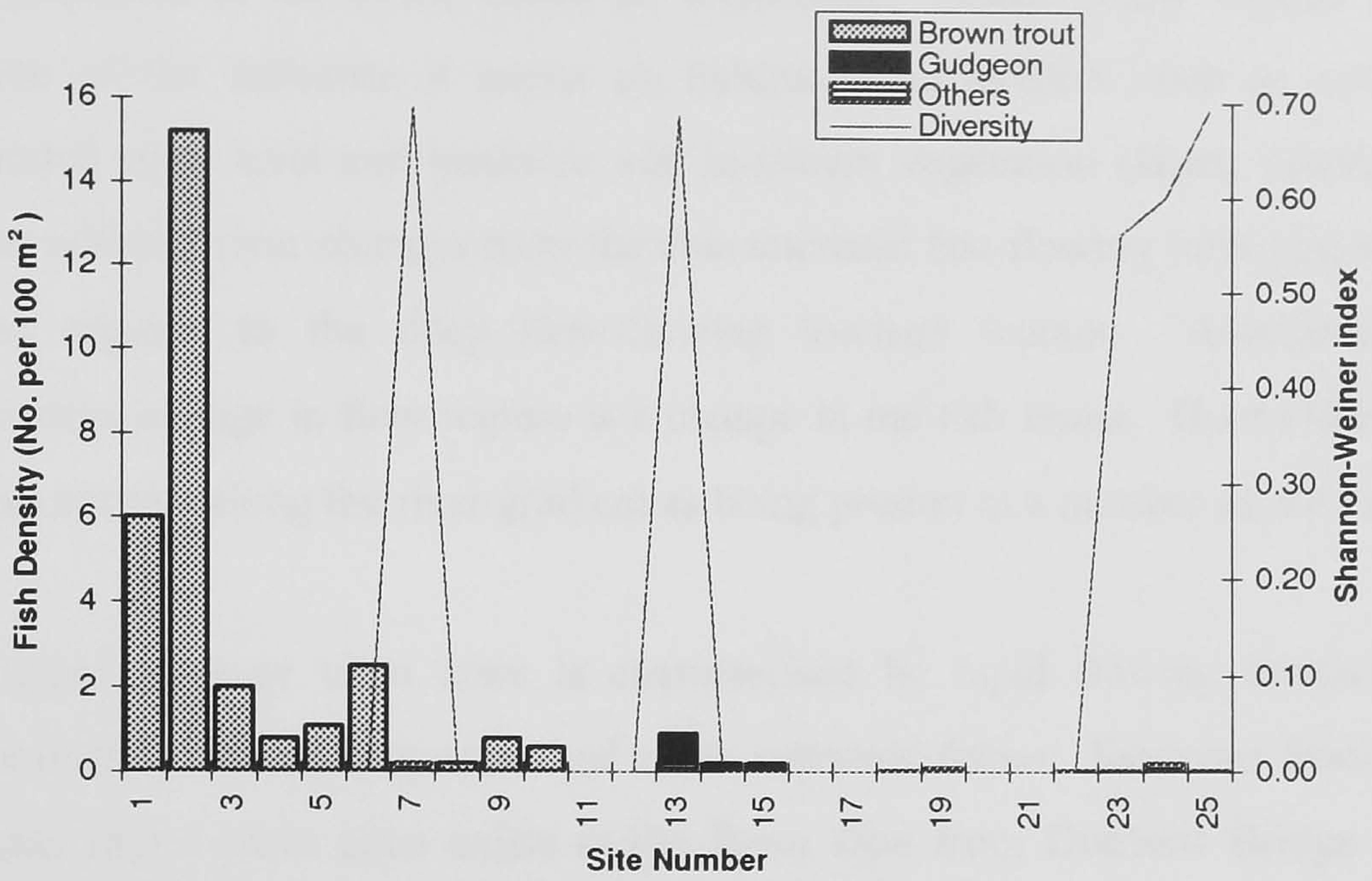


Fig. 5.1. Fish Abundance and diversity in the River Don in August 1981

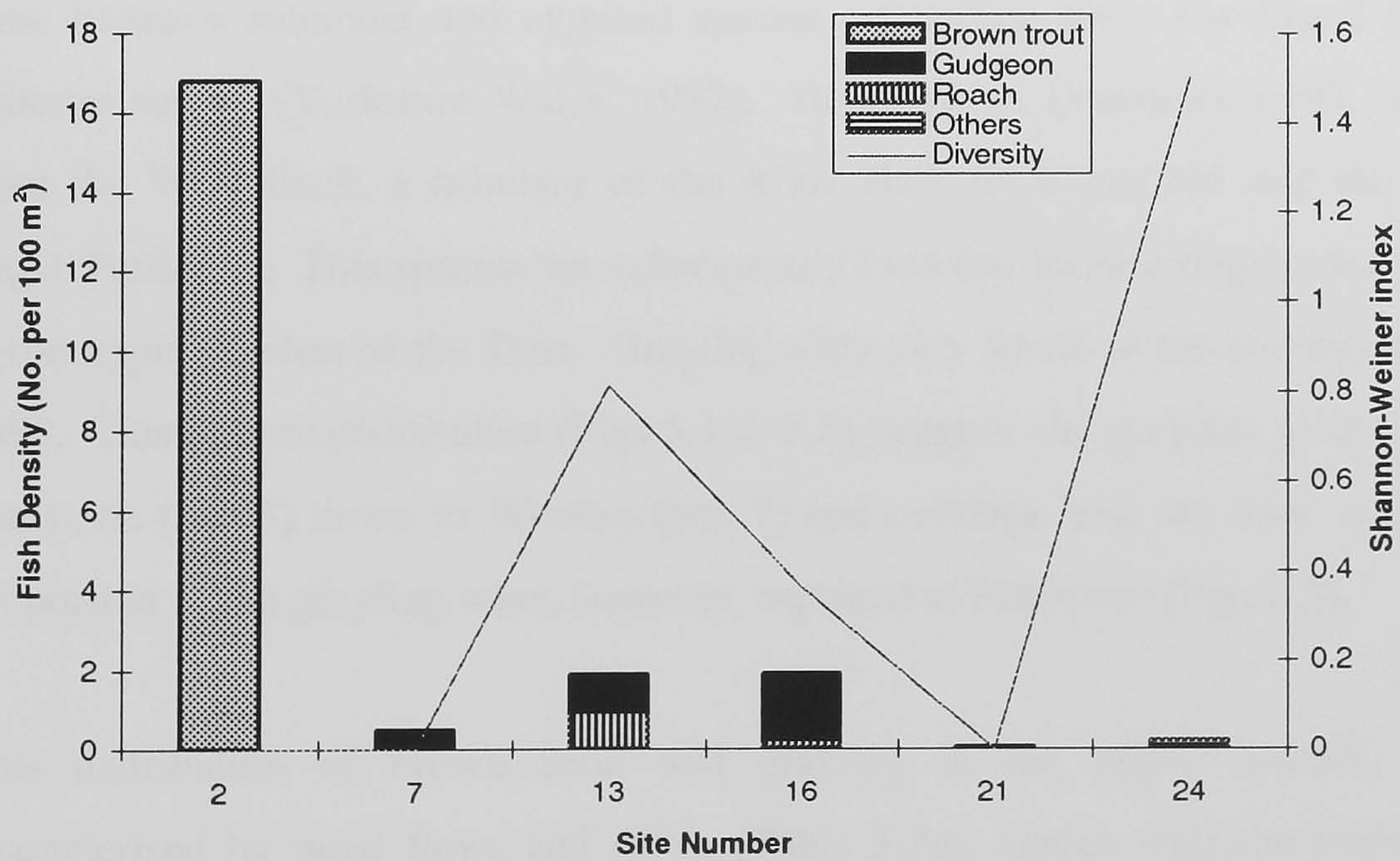


Fig. 5.2. Fish abundance and diversity in the River Don in October 1984

Although some brown trout were found in the middle reaches no grayling was found below Beeley Woods weir (site 11). Small numbers of coarse fish were found in the middle and lower reaches of the river in all the surveys, (Figs 5.1, 5.2, 5.3, 5.4 & 5.5), and in the tidal regions some flounders were also captured.

Flow regime is one of the most influential factors affecting the distribution of riverine species (Cowx *et al.* 1993, Cowx & Welcomme, 1998). Flow regime is important because of the influence it exerts on habitat characteristics such as substrate type, suspended solid level and bankside and in-stream vegetation (Huet, 1949). The flow regime within a river changes from the characteristic fast-flowing turbulent waters of the upland regions to the deep slow-flowing lowland waters. Associated with this progressive change in flow regime is a change in the fish fauna. Huet (1949) described the fish species along the river gradient as being present in a number of zones.

The upper zone or trout zone is characterised by rapid flowing headwaters and is predominantly occupied by trout and other salmonid fishes. Evidence from the surveys suggests that a trout zone exists in the River Don from Dunford Bridge (site 1) and extends downstream to Hillsborough (site 12) (Table 3.2a).

A grayling zone was described by Huet (1949) and was considered to be a transitional zone between salmonid and cyprinid species. Grayling were not found in the 1981 fisheries survey (Yorkshire Water, 1982). However, in December 1983, 200 grayling from the West Beck, a tributary of the River Hull, were stocked into the River Don above Penistone. This species has subsequently bred and formed fragmented populations in the upper reaches of the Don. Grayling were only found in the surveys of 1990 and 1993. This present distribution (Figs 5.4 & 5.5) suggests the grayling zone extends from Penistone (site 5) down to Wortley (site 7) and overlaps with the trout zone. A large proportion of the grayling were, however, captured at Penistone (Fig. 5.5).

This distribution of brown trout and grayling in the upper reaches, which are characterised by rapid flows and riffles (Table 3.2a), agrees with the physical criteria described by Huet (1949). The occurrence of brown trout and grayling would be expected under these conditions.

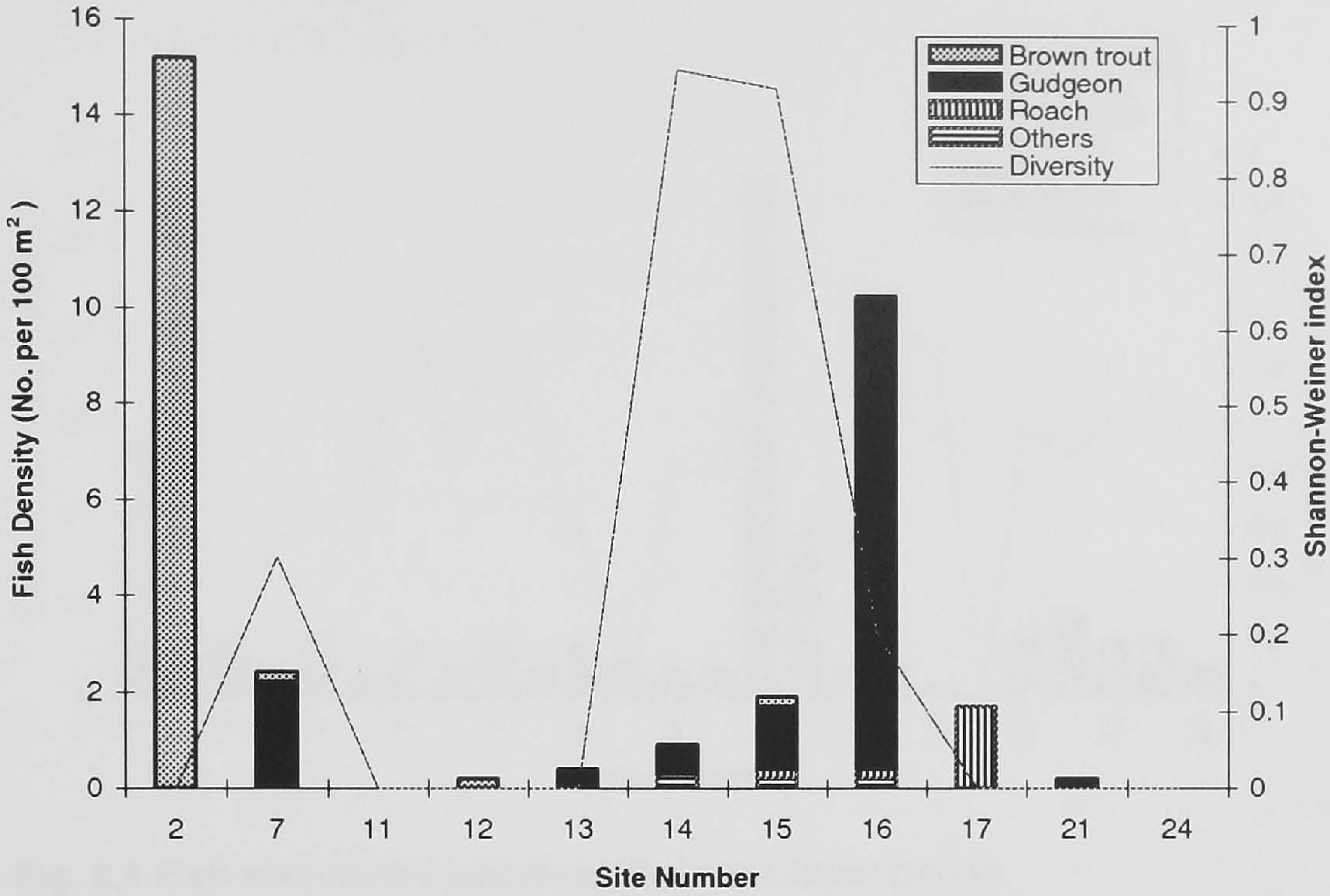


Fig. 5.3. Fish abundance and diversity in the River Don in September 1987

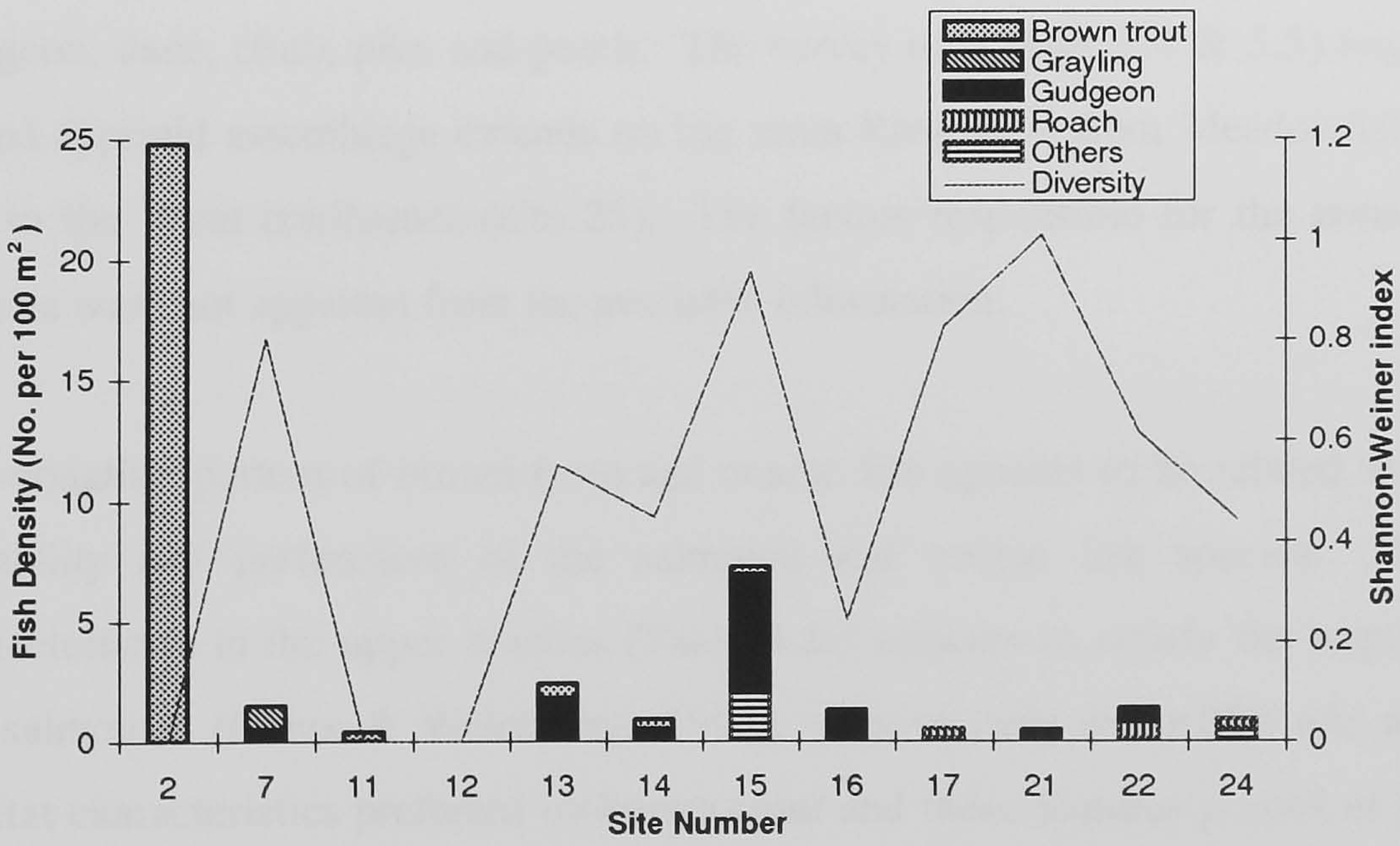


Fig. 5.4. Fish abundance and diversity in the River Don in October 1990

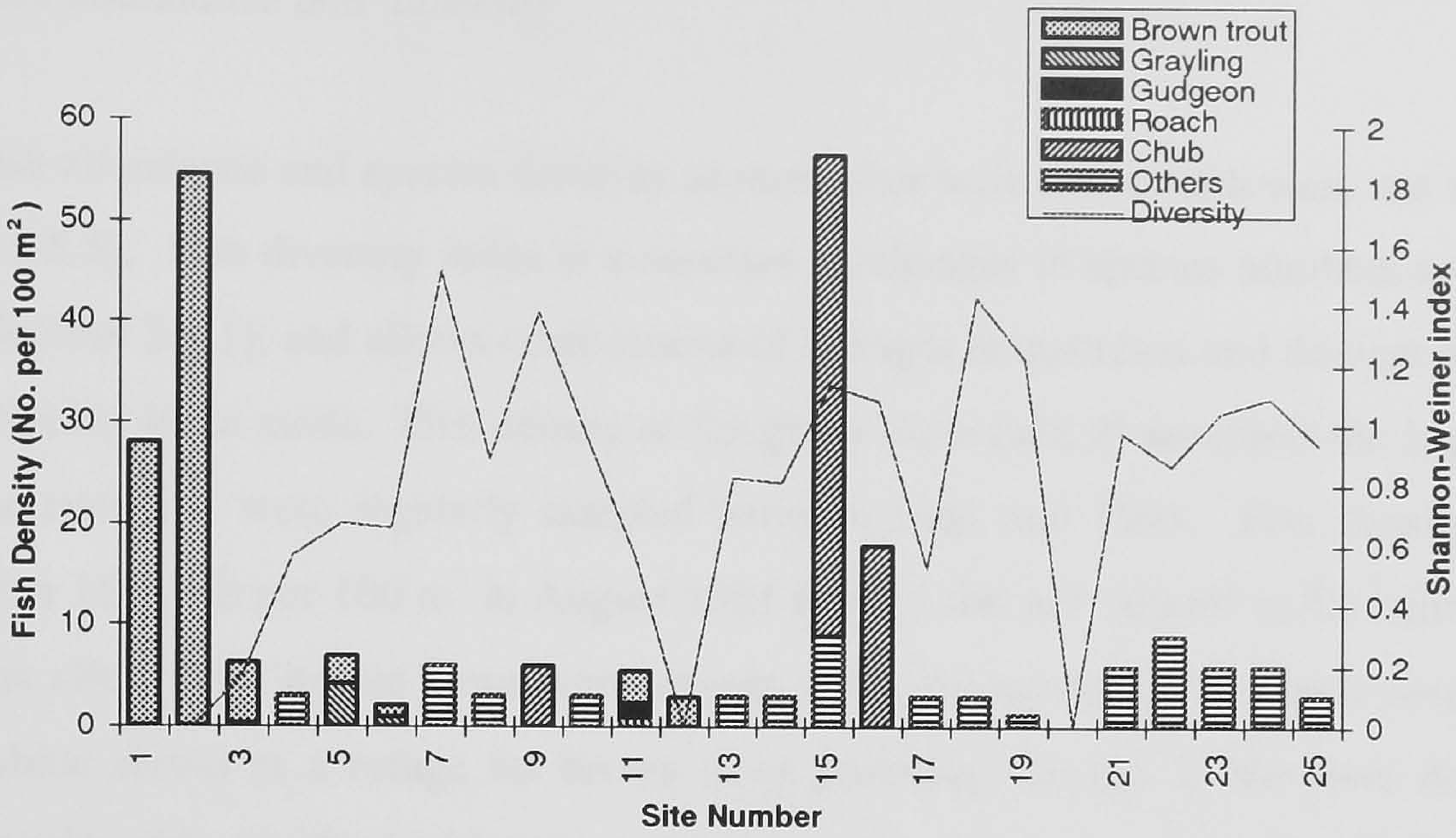


Fig. 5.5 Fish abundance and diversity in the River Don in November 1993

Huet's classification also identified a barbel zone which is characterised by stretches of river with moderate flow and a mixed cyprinid species assemblage which includes roach, gudgeon, dace, chub, pike and perch. The survey data (Figs 5.4 & 5.5) suggest that a mixed cyprinid assemblage extends on the main River Don from Meadowhall weir (site 15) to the Went confluence (site 25). The factors responsible for the zonation of the species were not apparent from the available information.

The zonation pattern of brown trout and coarse fish appears to be related to the habitat suitability and preferences of the salmonid and coarse fish species. The habitat characteristics in the upper reaches (Table 3.2a) appears to satisfy the requirements of the salmonids (Cowx & Welcomme, 1998). Gravel beds and riffles are some of the habitat characteristics preferred by brown trout and these features prevail at most of the sites surveyed. The low salmonid density or their absence at most sites is probably related to water quality problems or perhaps due to lack of suitable holding places.

Fish abundance and diversity

Fish abundance and species diversity at most sites were low or fish were not found (Figs 5.1-5.5). Fish diversity index is a measure of changes in species numbers and evenness (Section 3.6.1), and allows comparisons of changes in upstream and downstream species diversity to be made. Fish density at Soughley Farm (site 2) remained the highest for all the sites that were regularly sampled between 1981 and 1993. Fish density increased from 15.2 fish per 100 m^2 in August 1981 to 54.6 fish per 100 m^2 in November 1993 at this site. Only brown trout were caught in all the surveys. It would seem that this habitat serves as a refuge for brown trout providing recruits to the river downstream. Considerable numbers of brown trout were also captured at Dunford Bridge which is located upstream of this site. As at Soughley Farm, only brown trout were captured. Trout densities were 6.0 fish per 100 m^2 in 1981 and 28.0 fish per 100 m^2 in 1993. Most of the trout at this stretch had probably originated from the cleaner tributaries of the Ewden Beck and the River Rivelin (NRA, 1994c). The fish species diversity index was usually zero at the headwaters where only brown trout was caught between 1981 and 1993. Fish species diversity indices permit quantitative comparisons of species richness, abundance and equitability of distribution (Brownlow & Bolen, 1994), in time and space. They do not, however, provide reasons for changes in fish community structure (Whiteside & McNatt, 1972), or the environmental adaptations of the species.

Coarse fish density and species diversity remained low in the middle reaches of the river. Abandoned mine discharges enter the river downstream of Millstone Bridge (site 3) and these are probably associated with the deterioration of fish stocks at Thurlstone (site 4) (Fig. 5.1 & 5.5). Fish were absent or only sporadically present at Beeley Woods (site 11), and Hillsborough (site 12) in all the surveys (Figs 5.1, 5.3, 5.4 & 5.5). This might possibly be related to pollution problems caused by discharges from British Tissues (now referred to as Jamont Paper Mill), located upstream at Outibridge. Fish kills resulting from discharges from British Tissues were reported in 1985 (Table 5.2) and these possibly affected fish populations in the river below the discharge. The waste produced by the paper manufacture is now treated by an activated sludge processing plant which became operational in 1985. The plant has since produced a good quality effluent (Firth, 1997).

Table 5.2. Fish mortalities in the River Don (April 1984 - June 1997)

Location	Date	Species/No. killed	Cause
Thorpe Marsh	1.6.84	* 5 coarse fish	Unknown
Below Cheesebottom STW	17.12.84	* 6000 fish	Sewage pollution
R. Don, Top	17.4.84	15 brown trout	Unknown
Below British Tissues	17.12.85	* 130 coarse fish	Industrial
Below Outibridge	17.12.85	100 gudgeon, 50 perch, 100 roach, 43 minnows	Industrial
	6.7.95	12 brown trout	Oil spills
Sheffield, below Whitbread Breweries	20.10.86	50 sticklebacks, 1 brown trout, 1 perch, 1 roach	Industrial
Penistone, Oxspring	2.6.87	11 brown trout	Mine effluents
Marsh Lane, Rotherham	3.9.87	12 roach, 100 gudgeon, 5403 sticklebacks.	Unknown
Old Mill Lane, Thurgoland	30.6.89	6 brown trout, 6 grayling	Unknown
Bow Bridge, Rotherham	20.10.91	9 brown trout	Unknown
Sheffield, Bear Thomas	21.10.91	20 gudgeon, 2 roach	Unknown
Sprotborough	12.6.93	* 10 coarse fish	Unknown
Doncaster	31.12.95	7 salmon	Unknown
Meadowhall	28.05.88	200 gudgeon, 1 roach, 1 perch, 1 trout	Industrial
Above Meadowhall	6.6.97	*Many coarse fish	Industrial

* The fish species and/or numbers killed in these incidents were not specified.

The lower reaches were characterised by small densities of coarse fish populations. Fish populations and species diversity in the river between Borough Bridge (site 13), Meadowhall (site 15) and Blackburn Meadows weir (site 16), all in the Sheffield area, have improved considerably since 1981. A new sewage treatment plant was installed in the Sheffield area around this period (Yorkshire Water, 1985). It is suggested that the new sewage works in the Sheffield area may have substantially reduced inputs of storm sewage which resulted in the observed improvement in the fish stocks. In general, coarse fish populations continued to be low and the larger coarse fish present probably did not represent a self-sustaining population.

Above Sheffield (site 12) the coarse fish populations were probably limited by lack of suitable habitats, whilst below Sheffield poor water quality resulting from industrial and sewage discharges might be implicated in the low coarse fish densities.

Fish kills resulting from industrial effluents were reported in the River Don in Sheffield in 1986, 1988 and 1991 (Table 5.2) and these possibly contributed to the observed low fish densities.

The River Don between Marsh Street (site 17) and Denaby (site 20) was characterised by low fish densities and poor species diversity. This stretch of the river runs through Sheffield and its outskirts. The river receives considerable inputs of sewage effluents, industrial and domestic wastes which impact on the water quality and the resident fish populations.

Recruitment and length-frequency distributions

Brown trout showed good recruitment at Soughley Farm as revealed in the survey of the Don in 1993 (Fig. 5.6) most of which possibly originated from the cleaner tributaries of Ewden Beck and the River Rivelin. Considerable numbers of roach were also captured in the River Don at Doncaster (site 22) and Thorpe Marsh (site 23) during the survey (Figs 5.7a & 5.7b).

Roach showed good recruitment at Doncaster and Thorpe Marsh and this is evidenced by a good distribution and representation of length and age classes (Figs 5.7a & 5.7b). The catch at Thorpe Marsh (site 23), however, was dominated by relatively fast-growing roach, possibly indicating the abundance of food and the potential of the river at this stretch to support more coarse fish.

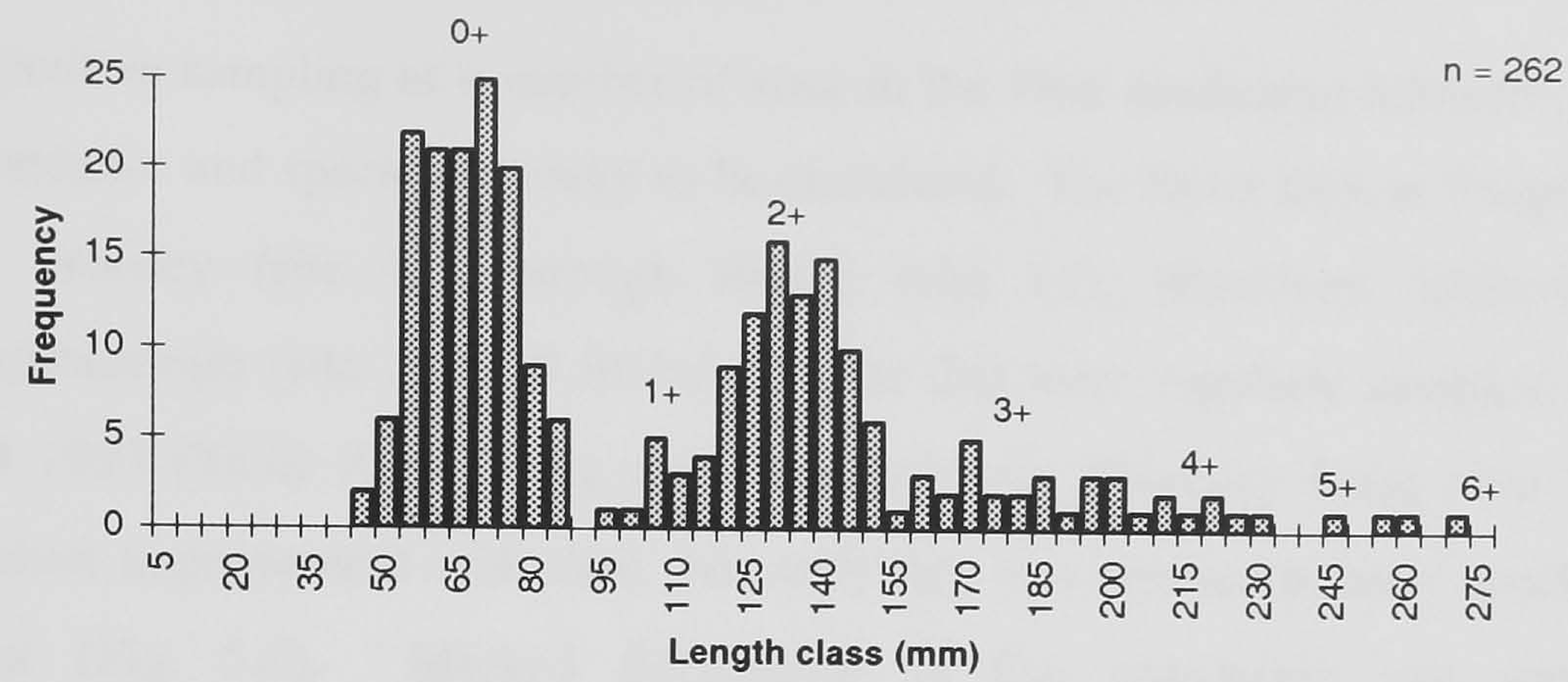


Fig. 5.6. Length-frequency distribution of brown trout in the River Don at Soughley Farm in November 1993

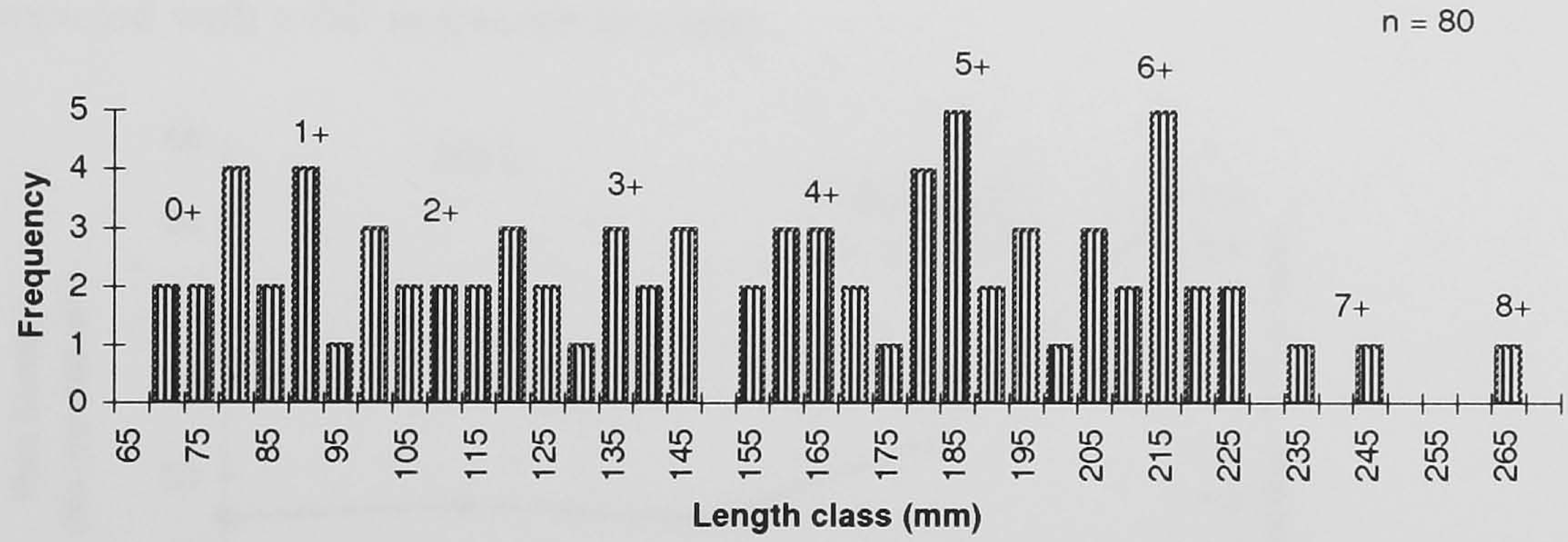


Fig. 5.7a. Length-frequency distribution of roach in the River Don at Doncaster in November 1993

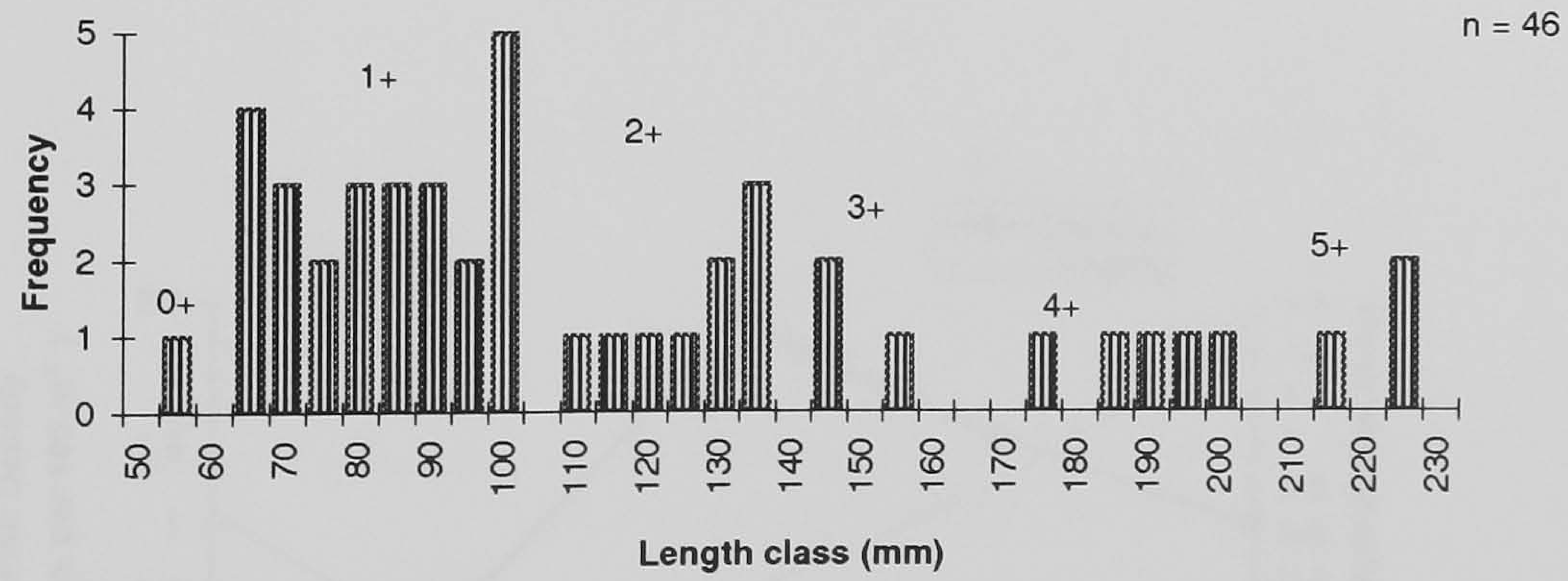


Fig. 5.7b. Length-frequency distribution of roach in the River Don at Thorpe Marsh in November 1993

5.1.3. Temporal trends in fish abundance and species diversity in the River Don

Repetitive sampling at a number of sites in the Don catchment allowed changes in fish abundance and species diversity to be elucidated. The River Don at Soughley Farm (site 2), Wortley (site 7), Borough Bridge (site 13), Blackburn Meadows (site 16), Sprotborough (site 21) and Stainforth (site 24) were regularly sampled between 1981 and 1993 (Table 3.2b). The trout population at Soughley Farm (site 2) exhibited a gradual improvement with time, but with only one species present species diversity is poor (Fig. 5.8). Marked fluctuations in fish population and species diversity characterised sites 7, 13, 16, 21 and 24. Apart from site 2, species diversity generally increased with improving fish populations. However, in October 1984 at site 7 (Fig. 5.9), and in September 1987 at site 16 (Fig. 5.11), increasing fish numbers were associated with a fall in species diversity.

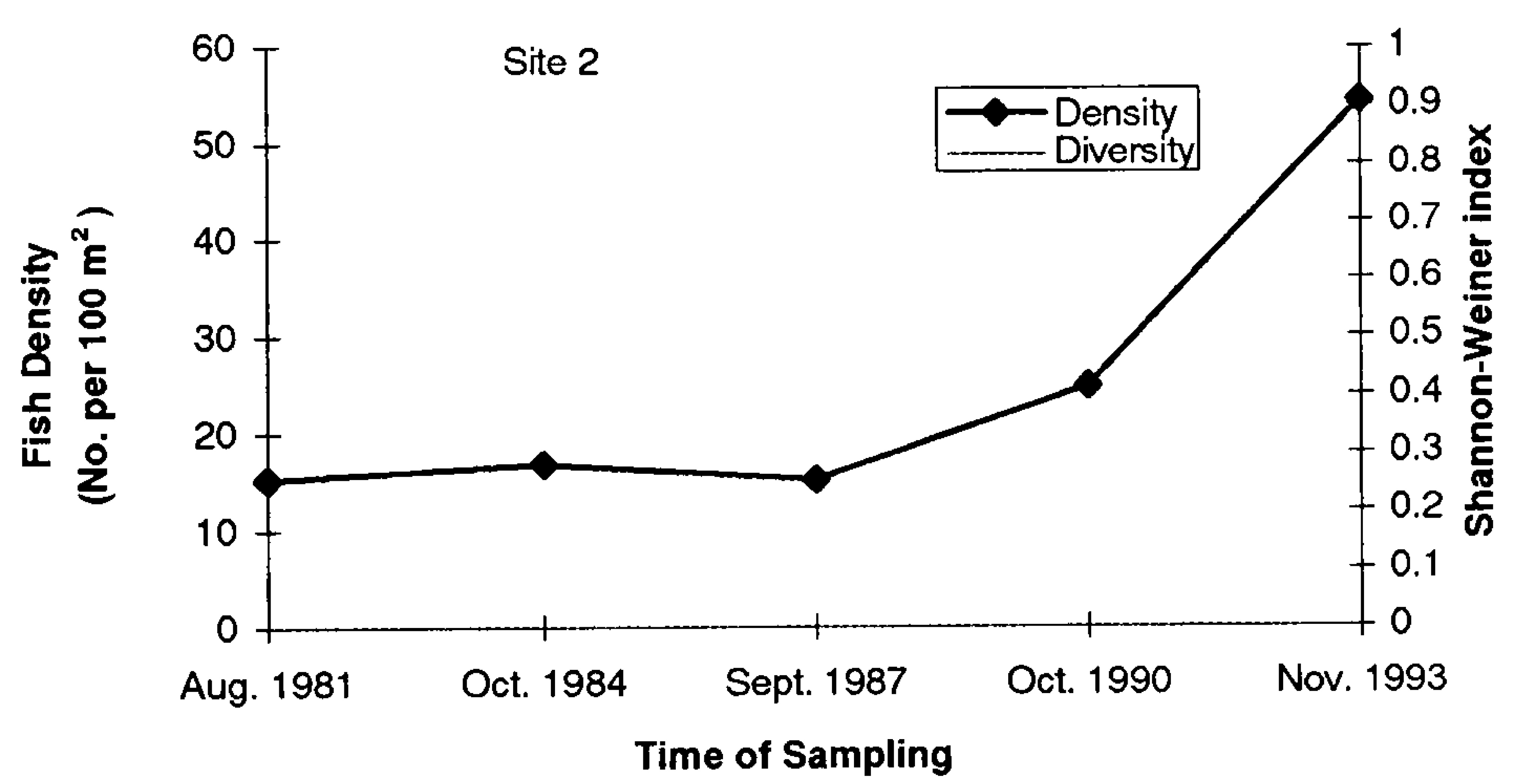


Fig. 5.8. Trends in fish abundance and diversity in the River Don at Soughley Farm

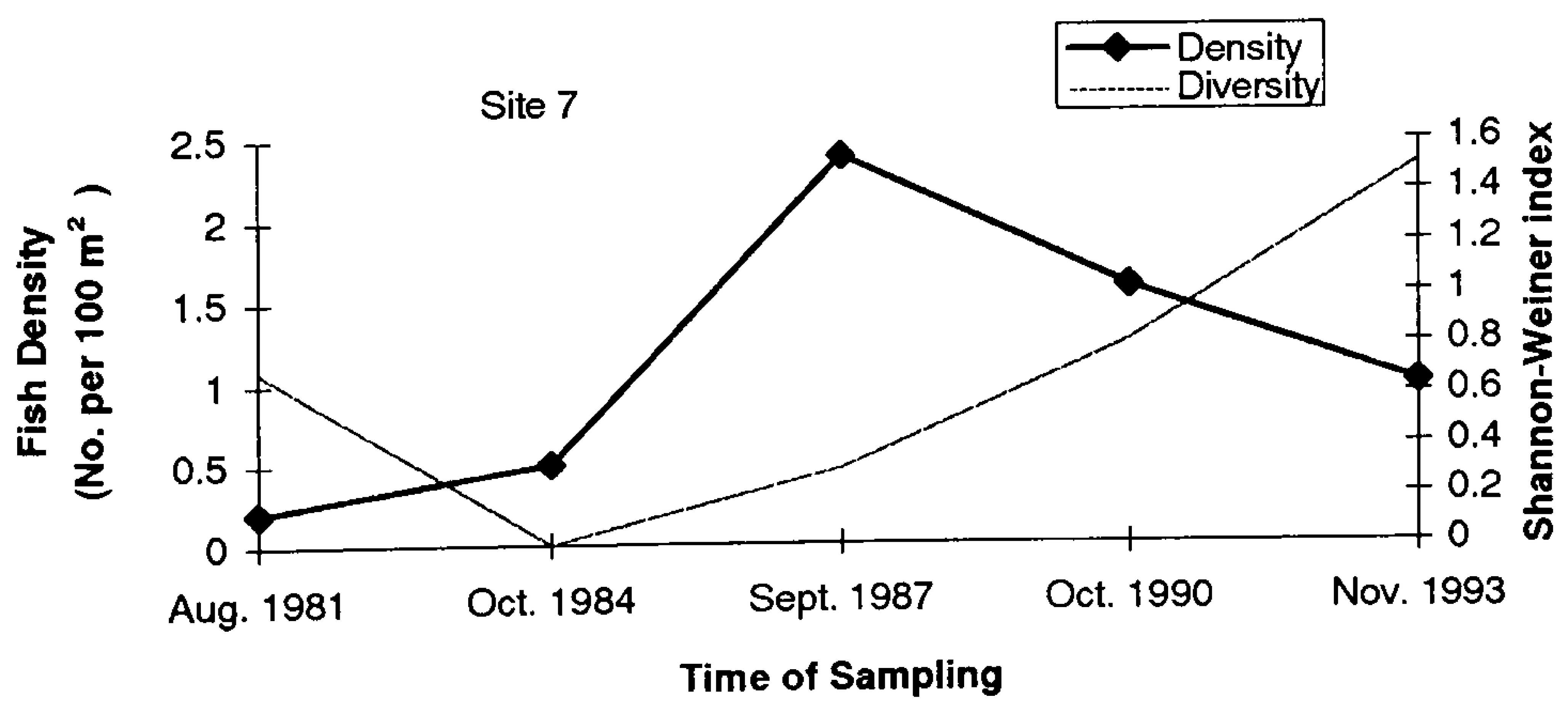


Fig. 5.9. Trends in fish abundance and diversity in the River Don at Wortley

In 1984 the River Don at Wortley (site 7) was affected by a petroleum spillage (Yorkshire Water, 1985) which resulted in a mass mortality of fish. This catastrophe might have contributed to the observed decline in species diversity in 1984.

The deterioration in fish density and diversity in the River Don at Borough Bridge (site 13) in 1987 (Fig. 5.10) was attributed to sampling difficulties resulting from the river conditions prevailing at that time (Yorkshire Water, 1987)

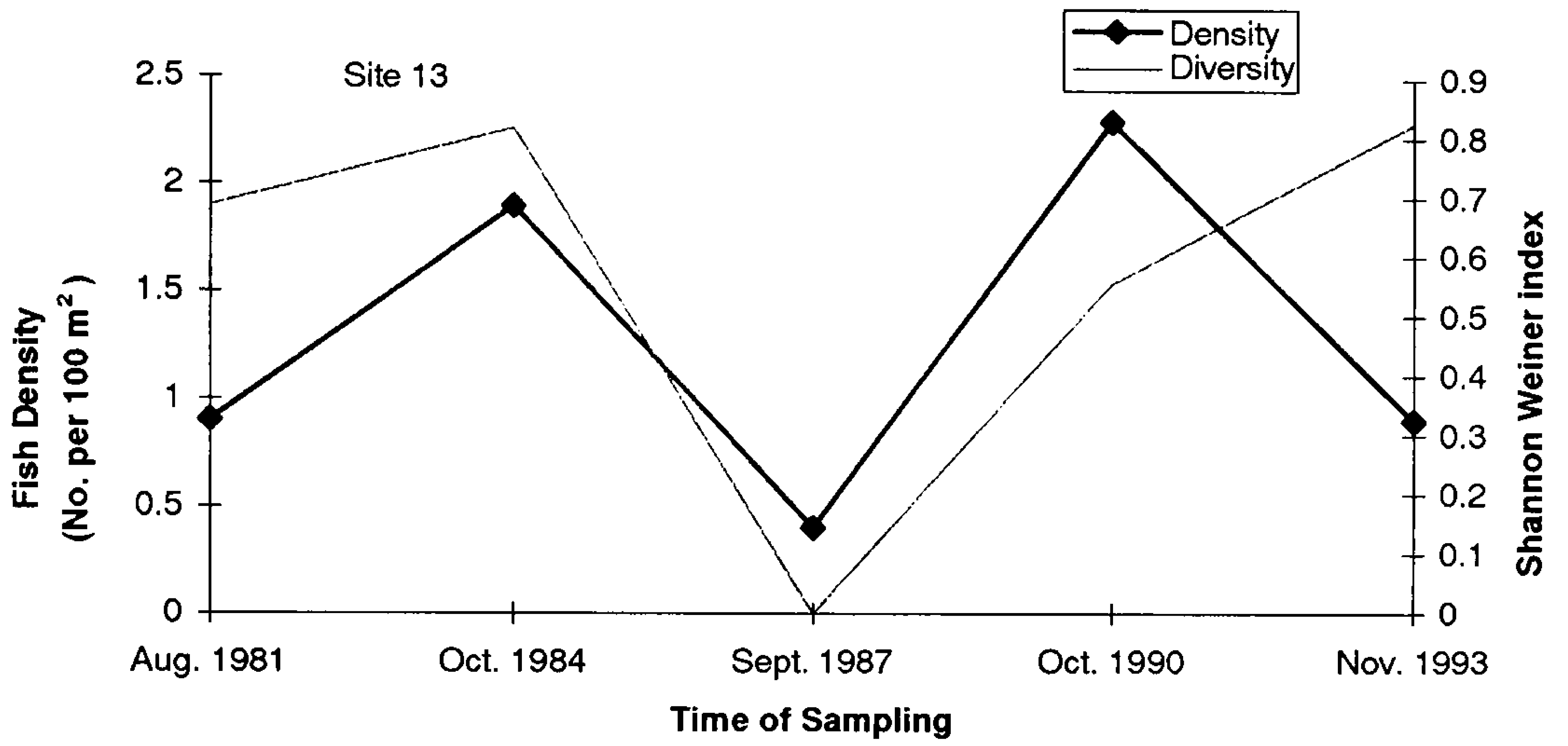


Fig. 5.10. Trends in fish abundance and diversity in the River Don at Borough Bridge

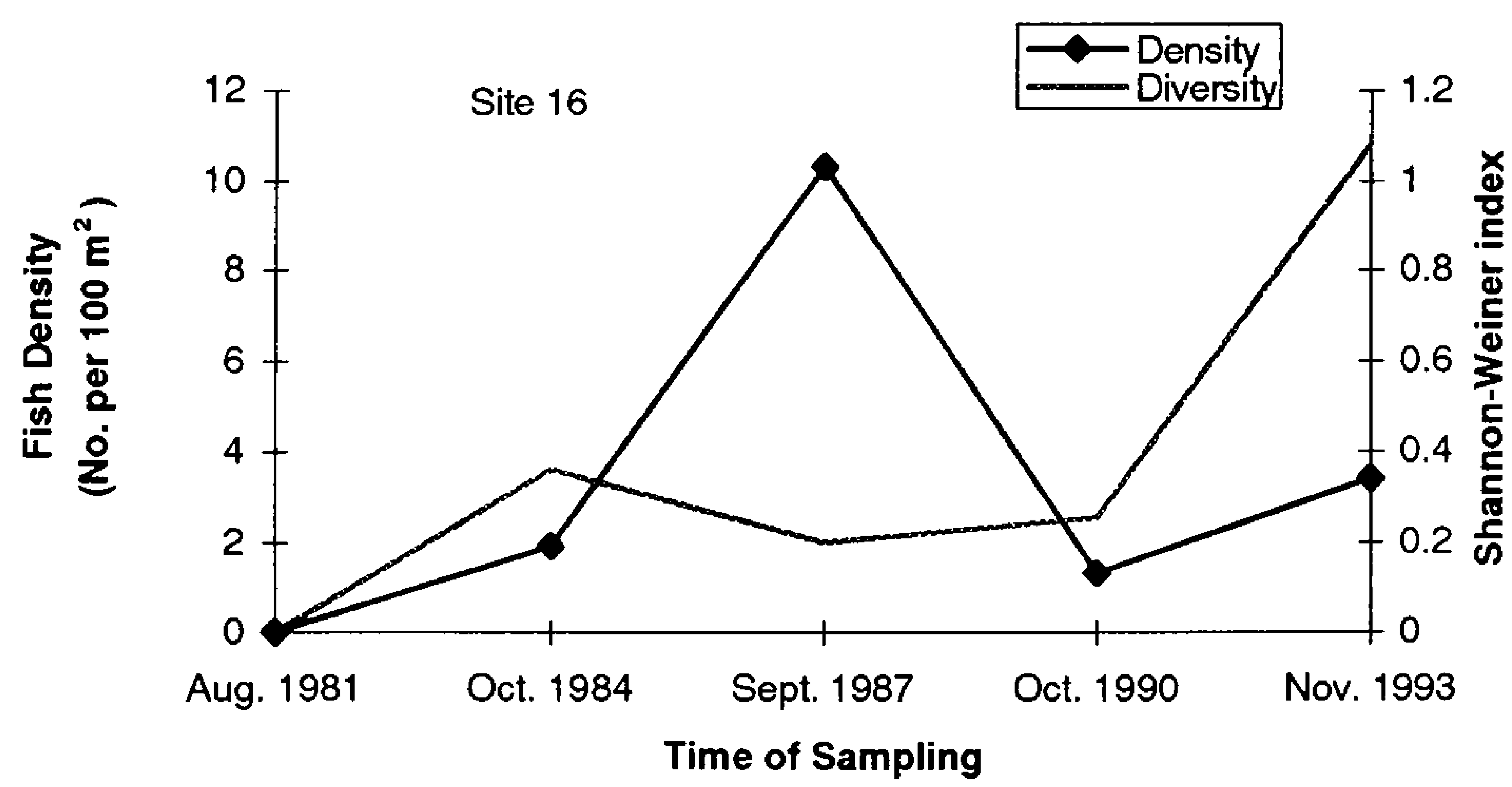


Fig. 5.11. Trends in fish abundance and diversity in the River Don at Blackburn Meadows

Fish density at Blackburn Meadows (site 16) improved considerably in 1987 (Fig. 5.11) due mainly to a coarse fish stocking programme embarked on by Yorkshire Water in 1987-88 (Firth, 1997). The fish, which were obtained from local still waters, were in poor condition (Firth, 1997), and lacked swimming muscle development associated with riverine fishes (Broughton, 1977) making them less adapted to their new environment.

The improvement in 1987 was also possibly due to improvements in water quality as a result of reductions in storm sewage inputs through the construction of the Don Valley Trunk Sewer which diverted water through the reclamation works. However, fish numbers fell back to low levels in 1990-93 (Fig. 5.11). It is not exactly clear why the fish numbers for Blackburn Meadows did not improve at this time but it might be that the stocked fish which were in poor condition (Firth, 1997) did not survive.

This site showed only a moderate improvement in water quality over its previous designation of Water Quality (WQ) class 3 (Yorkshire Water, 1987). The habitat is also characterised by heavily silted pebbles, riffles, and runs (Table 3.2a). It may be that it took some time for fish to immigrate from other regions to colonise and fully utilise the habitat available.

Sprotborough (site 21), which was sampled twice in October 1990 due to problems with the river conditions and sampling difficulties on the first occasion, showed marked improvements in density and species diversity (Fig. 5.12). The lack of fish at Stainforth (site 24) in 1987 (Fig. 5.13) was also due to the difficult river conditions at that time. Sampling difficulties reduced electric fishing efficiency, and yielded a poor catch.

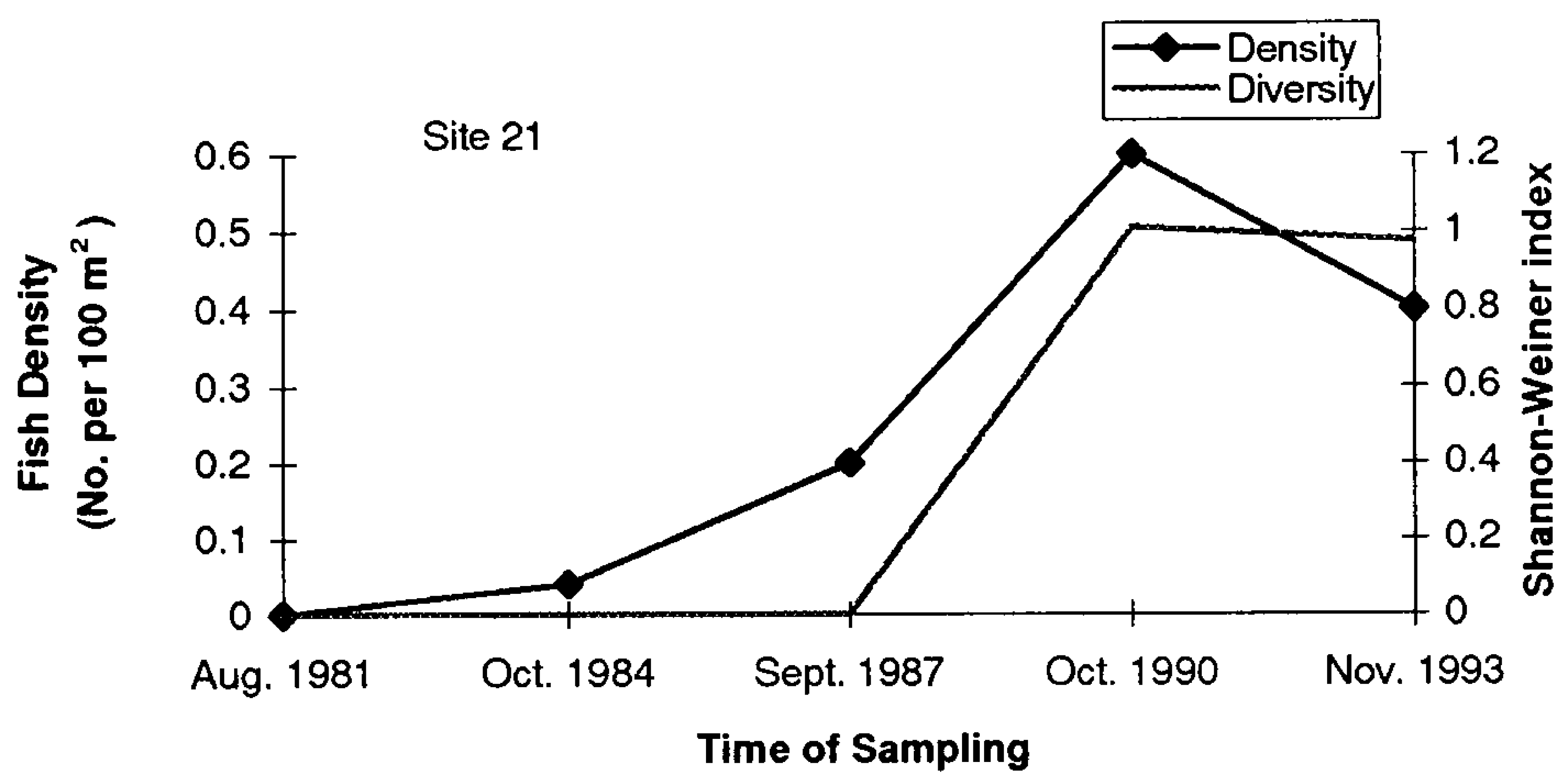


Fig. 5.12. Trends in fish abundance and diversity in the River Don at Sprotborough

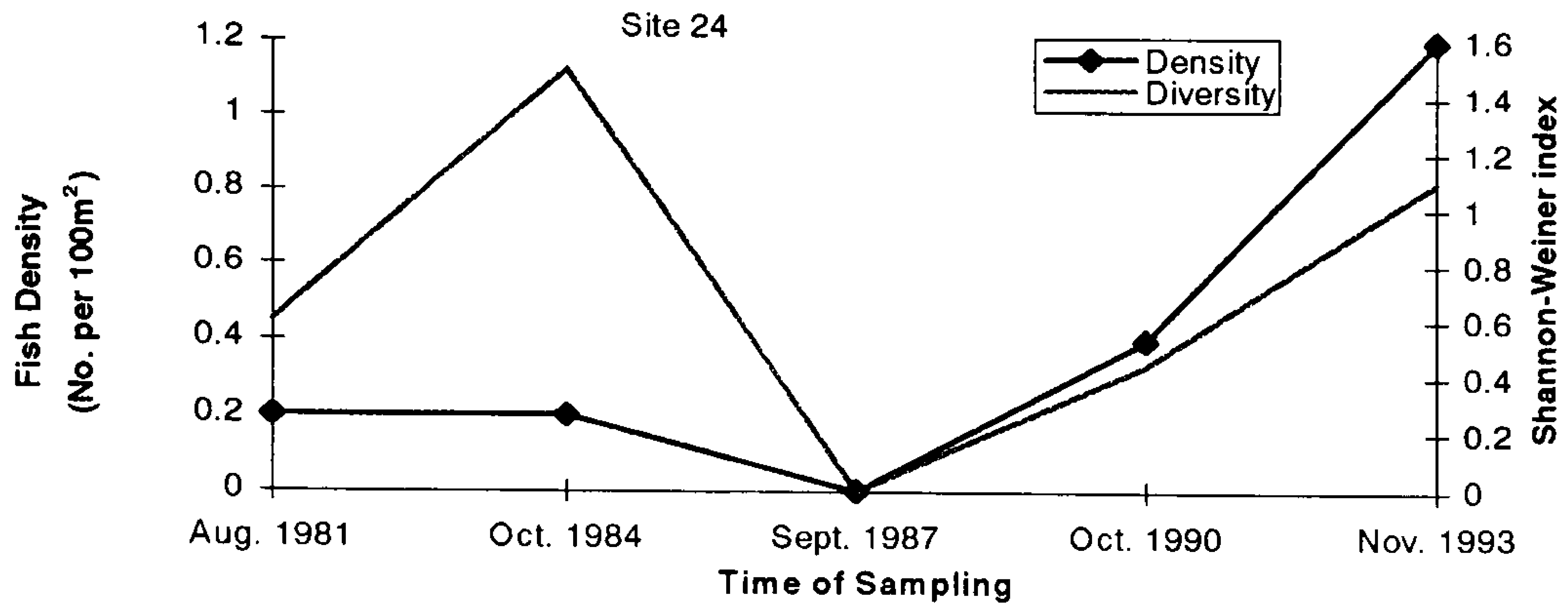


Fig. 5.13. Trends in fish abundance and diversity in the River Don at Stainforth

5.1.4 The River Don tributaries

An ingress of fish from adjoining tributaries could influence fish population and species diversity in the main river. In the survey of the River Don tributaries in January 1986, brown trout were captured at almost all of the 24 sites sampled. Nine sites were, however, devoid of fish (Fig. 5.14). The habitat features of the tributaries (Table 3.3) would appear to provide good habitat for the resident brown trout populations. Gravel beds, boulders, and pebbles with numerous riffles were characteristic of the sites.

Fish zonation in the tributaries of the upper Don

Most of the tributaries appeared to be salmonid streams, although the Rivers Loxley (site T13) below the Rivelin confluence, and the Rivelin at Rivelin Mill (site T19) appeared to support small numbers of coarse fish. The study indicated that a number of tributaries had the potential to provide brown trout recruits to the main River Don. However, there were very limited numbers of coarse fish in the tributaries. Fish zonation was not evident from this study as all tributaries were essentially trout rivers (Fig. 5.14).

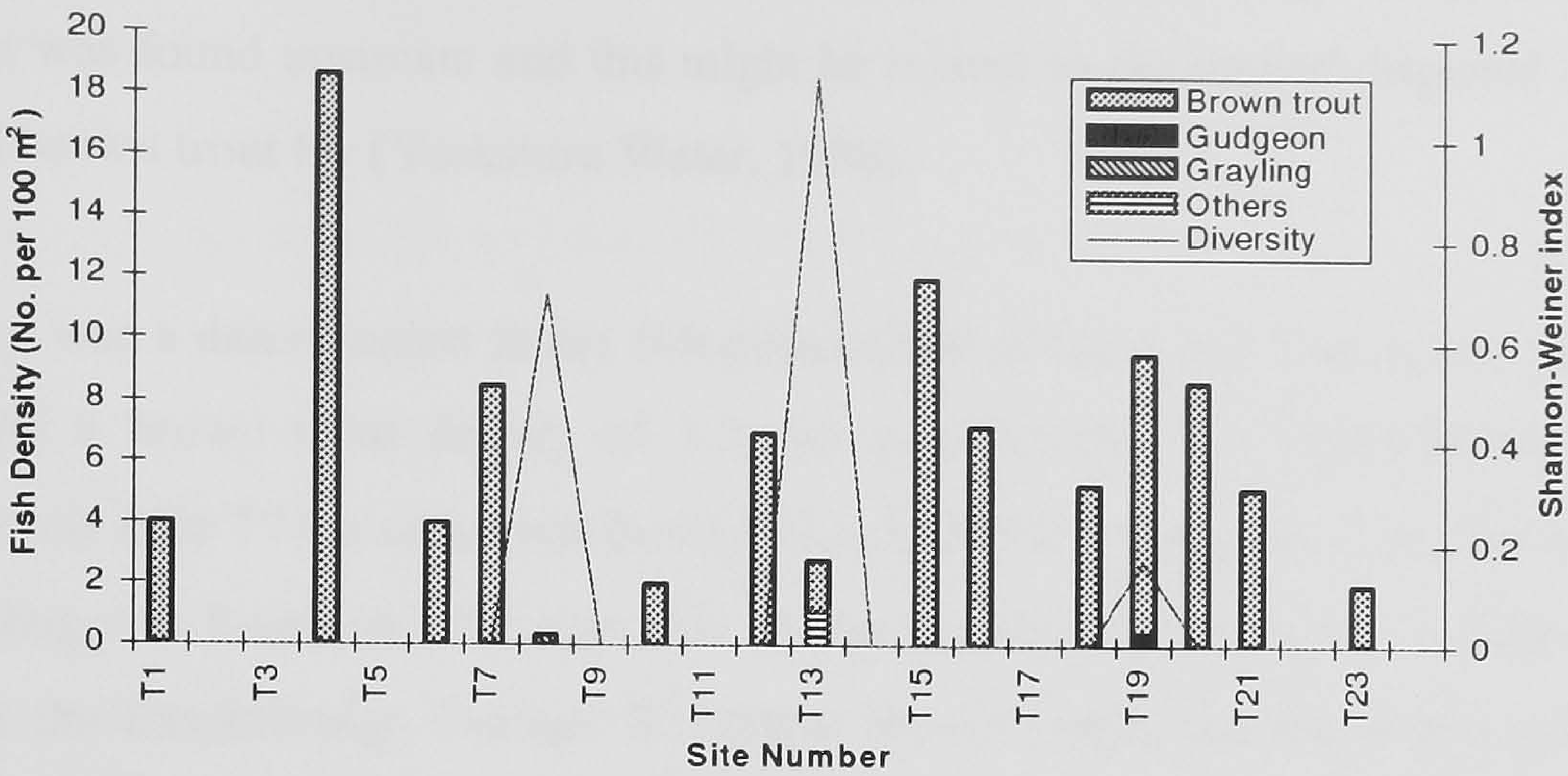


Fig. 5.14. Fish abundance and diversity in some tributaries of the River Don in January 1986

Fish abundance and diversity

For the majority of the tributaries, species diversity was poor due to either the presence of only a single species, very few species, or the total absence of fish (Fig. 5.14).

The upper tributaries located between Sledbrook North (site T1) and Underbank Reservoir (site T7) were characterised by a sporadic occurrence of fish. Cubley Brook (site T4) had the highest fish population density of 18.7 fish per 100 m^2 comprising only brown trout (Fig. 4.14). Fish were absent from the Scout Dyke below Ingbirchworth (site T2), above Penistone (site T3), and Little Don below Langsett reservoir (site T5). Prior to the survey, 8000 brown trout fry were introduced to the vicinity of the Little Don below Langsett reservoir. The fry either did not survive or dispersed.

Large quantities of silt were also reported at sites T2 and T3. It could be that the habitat was unsuitable for the survival of the trout fry. Subsequent to the survey, 5000 brown trout fry were stocked just above Scout Dyke at Ingbirchworth (Yorkshire Water, 1986). It would appear that the stocked fry either again did not survive or were dispersed to other parts of the catchment. The tributaries in the mid-section between Stocksbridge (site T8) and Strines (site T14) held sparse populations of fish, although species diversity was relatively high for those locations. In the spring of 1985, brown trout fry were introduced around the Little Don above Underbank reservoir (site T6) (Yorkshire Water, 1986). Some of the stocked trout were captured on this survey. None of the stocked trout was found upstream and this might be related to the limited dispersal of hatchery-bred brown trout fry (Yorkshire Water, 1986).

There was a deterioration in the fish populations of the Little Don below Stocksbridge. Whilst a brown trout density of 8.5 fish per 100 m^2 was found below Underbank reservoir (site T7), a combined density of only 0.5 fish per 100 m^2 for brown trout and grayling was found on the Little Don below Stocksbridge (site 8). Effluent discharges from the Stocksbridge Sewage Treatment Works impact on the water quality of this stretch of the tributary, and hence the poor fish density would be expected. This stretch was designated as WQ class 3.

Low pH and high metal levels were observed for the Ewden Beck (T9) and Hobson Moss Dyke (T11) (Yorkshire Water, 1986), although the actual metals involved were not specified. The No fish was found at these sites. Turnpenny *et al.,* (1987) showed that acid and metal toxicity can result in the absence of fish. This observation on the Ewden Beck appears to be in agreement with the findings of Turnpenny *et al.,* (1987). The River Loxley above the A61 road (T13) had the highest species diversity of 1.12.

In general, the tributaries in the lower section located between Dale Dyke (site T15) and Abbeydale Park (site T21) held relatively good populations of brown trout. No fish was captured at sites T14, T17, T22 & T24. These sites were characterised by low pH and high metal levels. The result would again be in agreement with the findings of Turnpenny *et al.*, (1987). Strines Dyke at Strines (site T14) had a pH of 3.8 (Yorkshire Water, 1986).

Prior to the January 1986 survey, 5000 brown trout were introduced to the Ughill Brook (site T17) above the waterfall (Yorkshire Water, 1986). However no fish was found. Ughill Brook (site T16), located below the waterfall, held a good brown trout density of 7.2 fish per 100 m^2. It might be that the stocked trout at site T17 dispersed to this site of the river as oxygen conditions enhanced below the waterfalls due to mixing and water turbulence. The waterfall probably prevented re-colonisation of site T17 above the waterfall once the trout had dispersed downstream.

5.1.5 The River Dearne

Fish zonation

Surveys on the River Dearne between July 1988 and September 1994 revealed a zonal fish distribution. A trout zone exists in the headwaters (Table 3.4a) and extends from upstream of Denby Dale (site 2) to Darton (site 9) (Figs 5.16, 5.17 & 5.18). No grayling was present and a transitional zone between trout and cyprinid species was not apparent.

In the past decade the fish populations of the middle reaches of the Dearne have been devastated by various pollution incidents (Table 5.1) leaving many sites fishless (Figs 5.15, 5.16, & 5.17). However, the equivalent of a barbel zone is present on the main river and extends from below Star Paper Mill weir (site 14) to Pastures Bridge (site 21). This stretch is characterised by a mixed cyprinid species assemblage.

Fish abundance and diversity

Fish surveys of the River Dearne between 1985 and 1994 revealed a chronically damaged ecosystem with low fish populations and poor species diversity at most sites. Considerable numbers of gudgeon were present at Hoyle Mill and Stairfoot in 1985. The densities of this species at these locations were 10.6 and 12.0 fish per 100 m^2 respectively. A very small number of gudgeon was found at Broom Hill, with only a limited number of coarse fish being captured at Pastures Bridge. The low fish density at Pastures Bridge in 1985 could be a result of fish mortalities reported at this site in 1984 and 1985 (Yorkshire Water, 1985b).

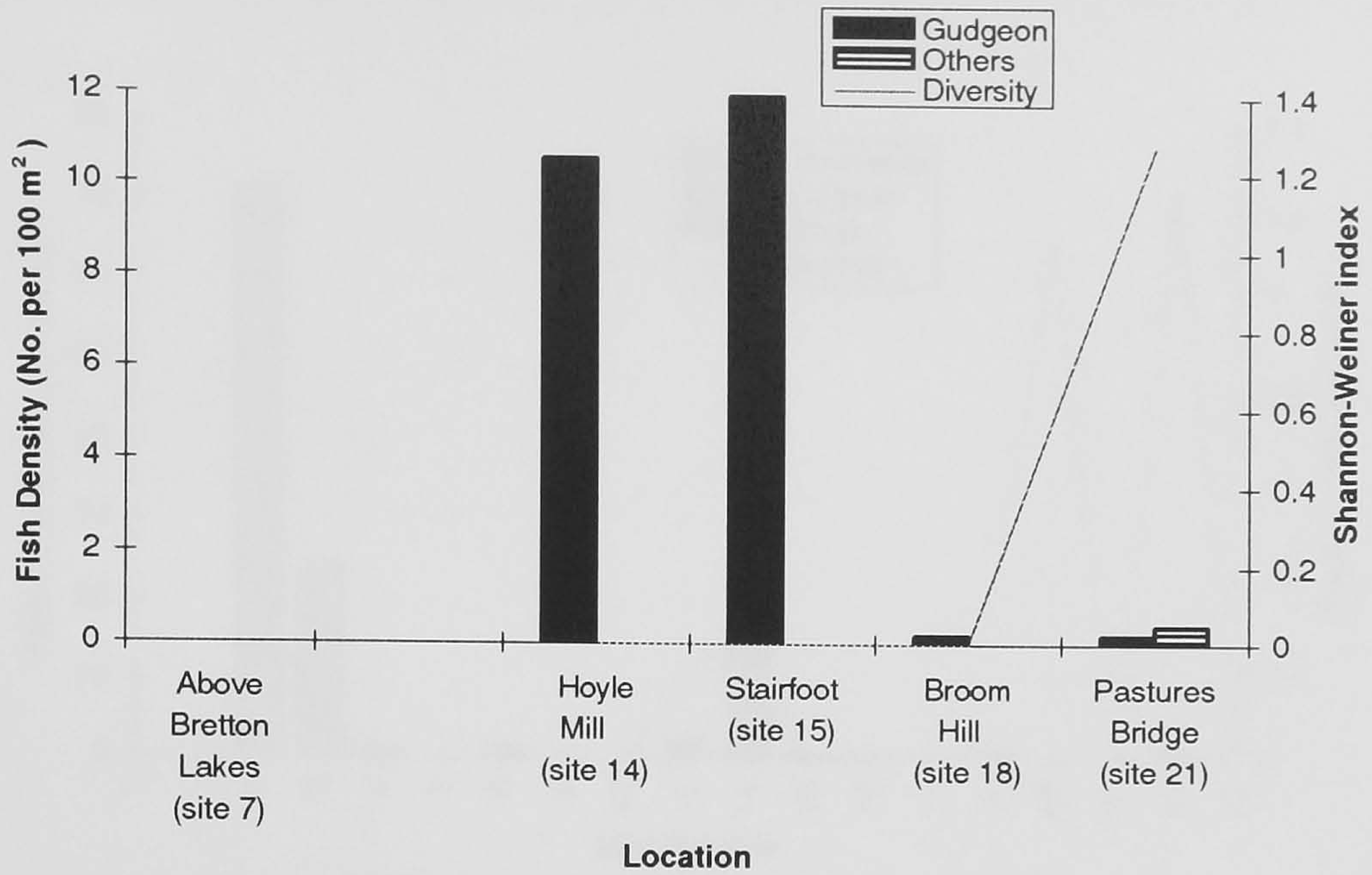


Fig. 5.15. Fish abundance and diversity in the River Dearne in June 1985

The relatively large numbers of gudgeon found were the product of natural recruitment in 1983 (Yorkshire Water, 1985b). A temporary improvement in water quality as a result of increased flows and dilution of pollutants during the wet spring of 1983 (Yorkshire Water, 1985b) probably contributed to this recruitment success. No fish was found above Bretton Lakes.

In 1987 and 1988, the middle reaches of the River Dearne were struck by a series of pollution incidents which resulted in the loss of many thousands of fish (Yorkshire Water, 1985b; Firth, 1997). The effect of these incidents was quite clearly demonstrated in the fisheries survey of 1988 (Fig. 5.16) with most sites being either fishless or characterised by very low fish densities and poor species diversity.

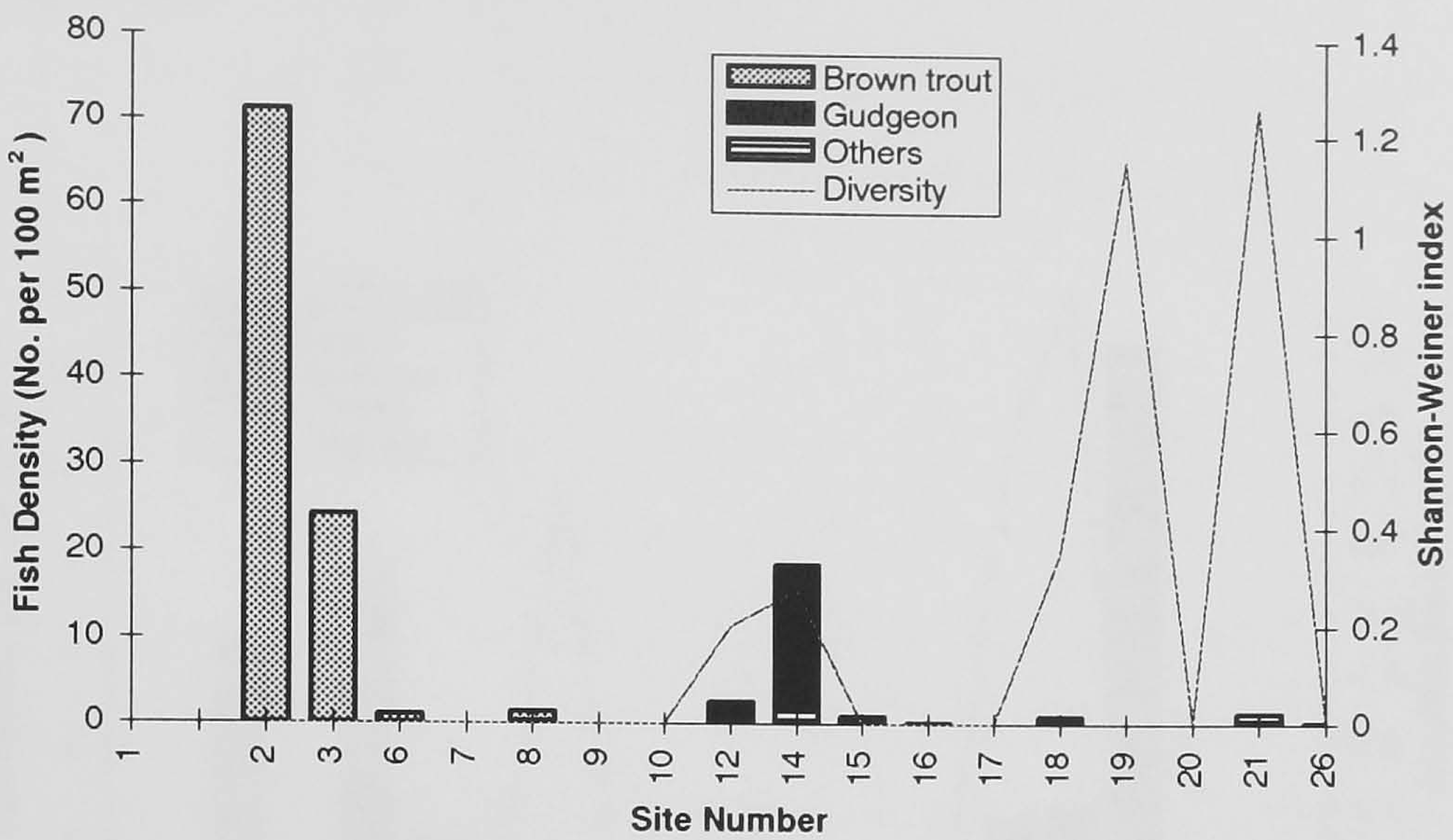


Fig. 5.16. Fish abundance and diversity in the River Dearne in July 1988

The brown trout populations of the Dearne were mainly confined to upstream (site 2) and downstream Denby Dale (site 3) with densities of 71.3 and 24.2 fish per 100 m^2, respectively. The trout captured at both sites were predominantly one-year-olds. These could be the survivors of fish stocked in this part of the river in 1987. The low trout density at Haigh Roundabout (site 8) (1.0 fish per 100 m^2) was probably due to lack of suitable habitat for the species, and extensive algal growth which reduces oxygen levels at night.

At Star Paper Mill (site 14), fish were only captured in a pool below the weir (Yorkshire Water, 1989). Enhanced oxygenation often occurs below weirs, and this probably explains the presence of the large numbers of gudgeon. Large numbers of stoneloach were observed at Haigh Roundabout (site 8) possibly, indicating signs of organic pollution (Yorkshire Water, 1989). Small numbers of coarse fish were captured between Bolton-on Dearne and Pastures Bridge, but these showed no evidence of a self-sustaining community as no fish younger than 3+ years old was caught.

The survey of 1991 confirmed that the middle section of the River Dearne through Barnsley was suffering from severe water quality problems from a diverse range of polluting discharges and sewage pollution. The fish populations of the middle reaches were affected by extensive sewage pollution in the area. Few fish were found in the middle reaches, and in some cases sites which had previously held fish were devoid of fish (Fig. 5.17).

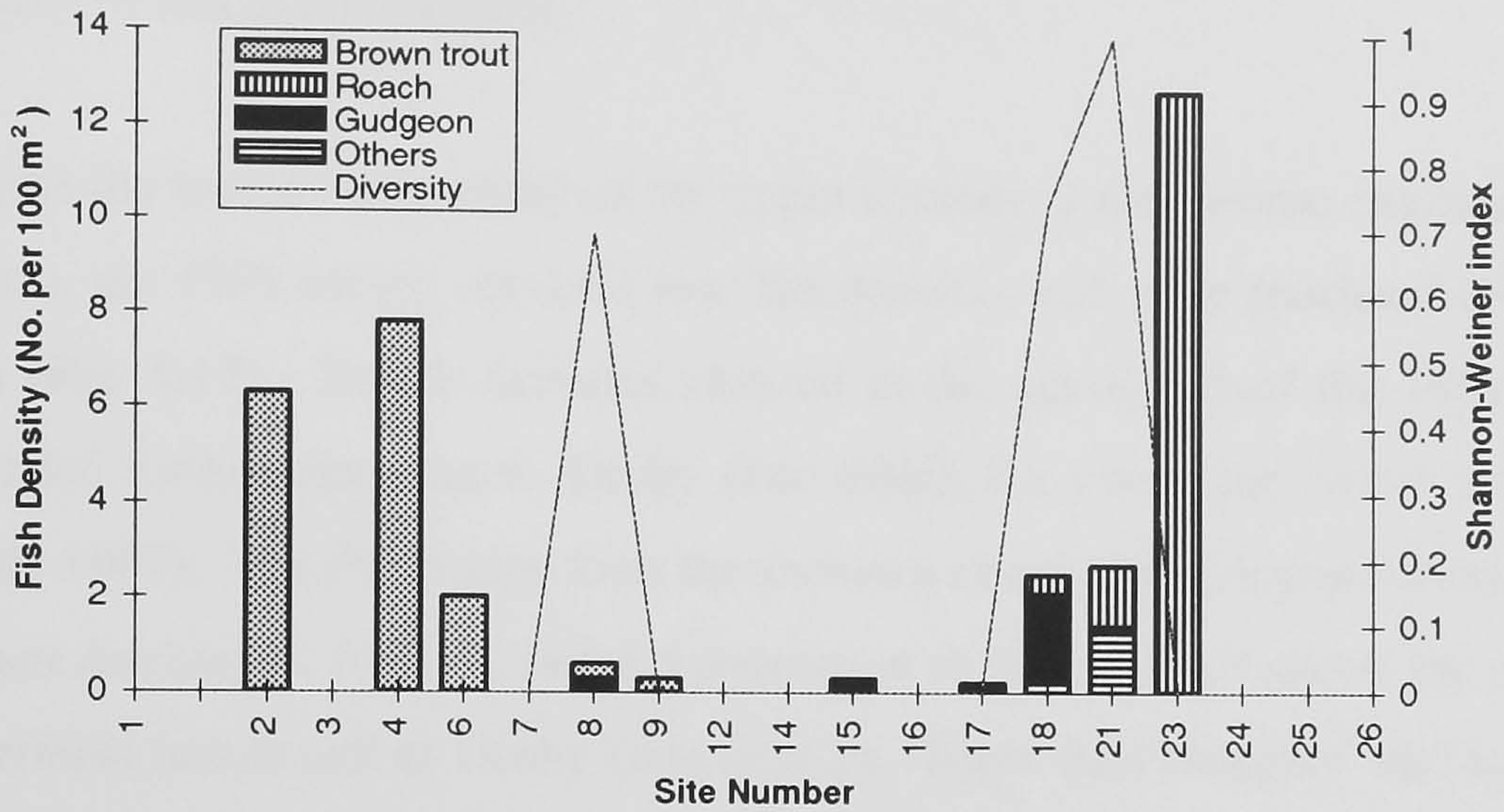


Fig. 5.17. Fish abundance and diversity in the River Dearne in September 1991

In 1991 the stretch between Low Barugh (site 12), Star Paper Mill weir (site 14), and Cudworth Common (site 16), though suitable for a mixed fishery, held no fish. It appears that intermittent pollution contributed to the very poor fish density (Fig. 5.17). Low Barugh lies below discharges from BXL Plastics and Shaw Carpets, and receives effluents from both industries. These impact on the water quality and the resident fish populations leading to the situation observed.

Organic effluents from Star Paper Mill impact on the water quality downstream and thus explain the absence of fish at this site. The principal feature of paper mill effluents is the occurrence of very high solids content composed chiefly of cellulose fibres (Mayack and Waterhouse, 1983; Dines & Wharfe, 1985). Deoxygenation, blanketing by solids and toxicity become important in limiting fish populations in the river as observed at Star Paper Mill (site 14). Mayack and Waterhouse (1983) also reported moderate decrease in invertebrate diversity which correlated with increased levels of particulates and substrate debris. Predators, including fish, showed a moderate reduction in density in response to the mill effluent. This scenario appears to explain the observed absence of fish below Star Paper Mill.

Cudworth Common receives sewage effluent discharges from Lundwood STW located upstream. Again this discharge caused a deterioration in water quality and resulted in the absence of fish at this location.

Despite the extensive stocking of the upper reaches of the Dearne catchment in the last decade, the 1991 survey revealed low fish densities and poor species diversity for most sites (Fig. 5.17). Textile factories situated in the upper part of the Dearne valley had extended further upstream to Denby Dale within 2.5 km of the river's source by 1990 (Firth, 1997). The discharges from the factories eliminated fish populations downstream of their discharges. A small, isolated population of fish survived above the location of the uppermost textile mill at Denby Dale (site 2). These fish, however, had limited chances of influencing downstream populations as the textile factory operators dammed the water course to conserve water when building the mills (Firth, 1997).

Parkgate Dyke (site 1) held no fish. This tributary of the Dearne has suffered several ochreous discharges in the past (NRA, 1993a). River flow at the time of survey was low (NRA, 1993a). These factors contributed to the lack of fish at this site. No fish was caught at Denby Dale (site 3) possibly because of an upstream industrial discharge which is known to have caused fish mortalities in 1989 (Table 5.1).

Fish density and species diversity between Bretton Lakes (site 7) and Darfield (site 17) remained poor with almost no fish captured except a very few gudgeon and brown trout (Fig. 5.17).

For many years the effluents from Darton STW (site 9) failed to meet its water quality standards. This was due to the discharge of a strong industrial effluent from a carpet manufacturing work (Firth, 1997). The effluent, which had a red coloration, accounted for approximately 40% of the biochemical oxygen demand (BOD) load received at the works (Firth, 1997) and were difficult to treat biologically. The poor fish density at Darton and the lack of fish at the two sites immediately below Darton, namely Low Barugh and Star Paper Mill, were, possibly, linked to the impacts described above. In

1992 (i.e. a year after the survey) improvements to the Darton STW were completed. As a result, Darton STW met a discharge consent of 40 mg l^{-1} of suspended solids, 30 mg l^{-1} BOD and 15 mg l^{-1} of NH_3 (Firth, 1997). The improvement resulted in the disappearance of the red colour in the effluent. On the basis of water quality standards these discharge levels are still too high (Appendix 1.1 and 1.2) and further improvement to the quality of effluent discharged is recommended.

In the lower reaches of the River Dearne, at Broom Hill (site 18) and Pastures Bridge (site 21) a relatively high species diversity of cyprinids was found although fish densities were only 2.3 and 2.4 fish per 100 m^2 ,respectively (Fig. 5.17). The improved catch at Pastures Bridge might be attributed to the stocking of the main river, or by escapees from the nearby Worsborough Reservoir.

In 1994 (Fig. 5.18) there were considerable improvements to the fish populations of the upper Dearne sites located upstream of Bretton Lakes, a stable but restricted fish community in the middle reaches and only a marginal improvement in the lower river.

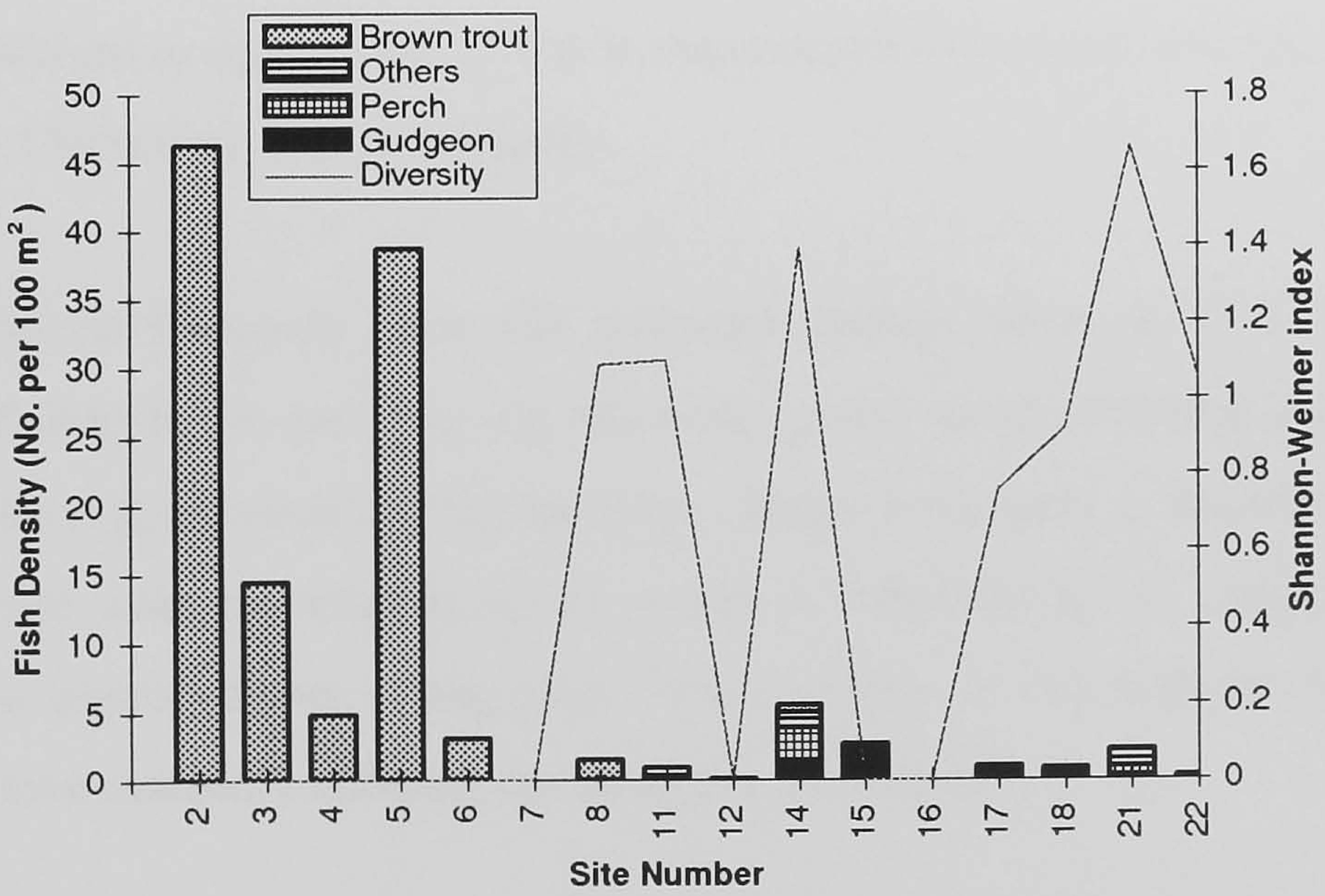


Fig. 5.18. Fish abundance and diversity in the River Dearne in September 1994

Above Bretton Lakes (site 7), however, fish were absent possibly due to poor water quality resulting from the discharge of sewage effluents from Clayton West STW located upstream and mine discharge from Park Mill Colliery. Inert suspensions of finely divided matter result from many types of mining such as coal. If the inert solids are finely divided, as are some mine slurries, they do not settle readily but make the river water opaque, hence reducing visibility and perhaps feeding efficiency of fish. There seems to be little evidence of any direct effect of suspended solids on fish (Alabaster & Lloyd, 1980), although in Denmark fish have been reported to have suffocated due to gill damage by ochre produced by drainage from a lignite mine (Larsen & Olsen, 1950). Paul (1952) reported that quartz grit from stamping mills damaged fishes in California by abrasion. Generally, however, fish are only harmed by concentrations of suspended solids which could occur in a river under very exceptional conditions (Hynes, 1978). When suspended solids settle to the stream bed, they may alter the nature of the substratum and possibly smother eggs of fish. Fish generally avoid such habitats. This could be one of the factors accounting for the lack of fish at site 7.

Although the middle Dearne showed indications of modest improvements in the general status of the fishery in 1994, little evidence was found to suggest that it was becoming self-sustaining. Major refurbishment of the sewage treatment plant at Darton was completed in 1992 (Firth, 1997), and the results of the improved effluent quality might explain the re-appearance of fish in considerable numbers below the Star Paper Mill weir (site 13) in the centre of Barnsley.

Cudworth Common (site 16) remained fishless between 1988 and 1994. Clearly implicated in the problem was the poor quality water discharged by sewage treatment works at Lundwood serving Barnsley. Major investment is planned by Yorkshire Water plc and work on refurbishing the works is scheduled to be completed by 1998. With these improvements taking place, water quality in this section of the Dearne should improve markedly allowing the fishery to re-establish.

In 1994 the water depth between Pastures Bridge (site 21) and the Don confluence (site 22) was reported to be > 2 m, consequently electric fishing efficiency was low (NRA, 1995a) and may account for the poor catches which probably did not reflect fish population status at the time. Water depth can be a limiting factor for success of fishing. At depths greater than 2 m many fish are not in the effective zone of the electric fishing gear (Zalewski & Cowx, 1990; Harvey & Cowx 1996). This is especially apparent in channelised rivers for navigation purposes where depths in the centre of the water course are too great for effective fishing. However, the river in this region was also heavily channelised and may have contributed to the poor fish status observed.

5.1.6. Trends in fish abundance and diversity in the River Dearne

Four sites, at Bretton Lakes (site 7), Stairfoot (site 15), Broom Hill (site 18) and Pastures Bridge (site 21), were regularly sampled between 1985 and 1994 (Table 3.4b). No fish was captured at Bretton Lakes during the surveys. The site suffered chronic water quality problems and was designated WQ class 3.

A sharp decline in fish density occurred at Stairfoot (site 15) between June 1987 and July 1988 (Fig. 5.19). This was probably due to a fish kill (573 recorded) in August 1987 (Table 5.1) as a result of pump damage which disrupted the pumping of mine waters at Barnsley Main Minewater located upstream of Stairfoot. The residual effect of the mine water pollution probably led to a general exodus of fish from this site leading to yet another decline in fish density in 1991.

The fish populations showed signs of recovery in 1994. This was probably due to a reduction in mine water discharge. The fish community was based exclusively on gudgeon and might be due to pollution problems at this stretch of the river. Broom Hill (site 18) showed a rapid improvement in fish density and diversity between 1985 and 1991 (Fig. 5.20). This was followed by a sharp drop in fish density by 1994, although a steady increase in species diversity was observed.

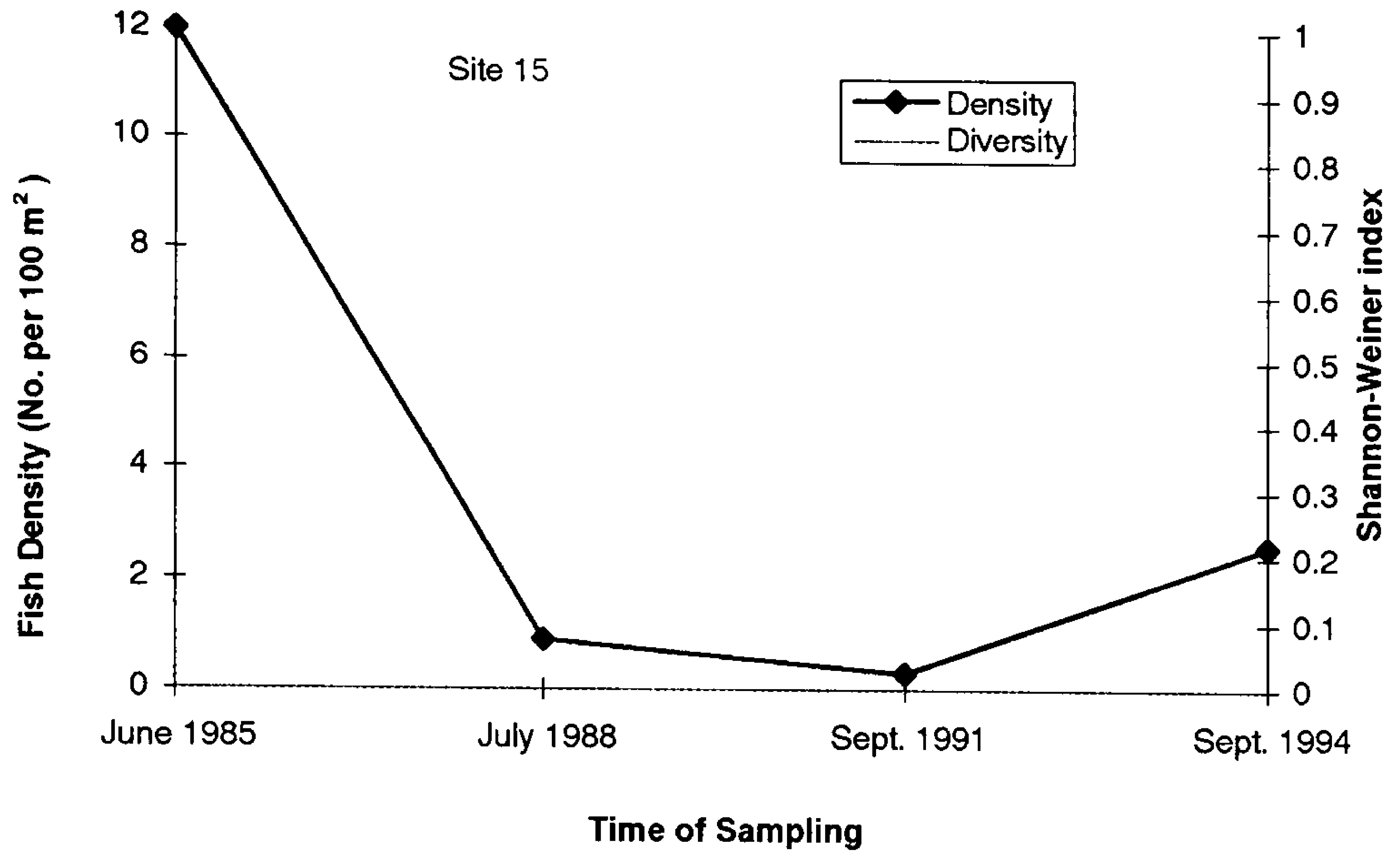


Fig 5.19. Trends in fish abundance and diversity in the River Dearne at Stairfoot

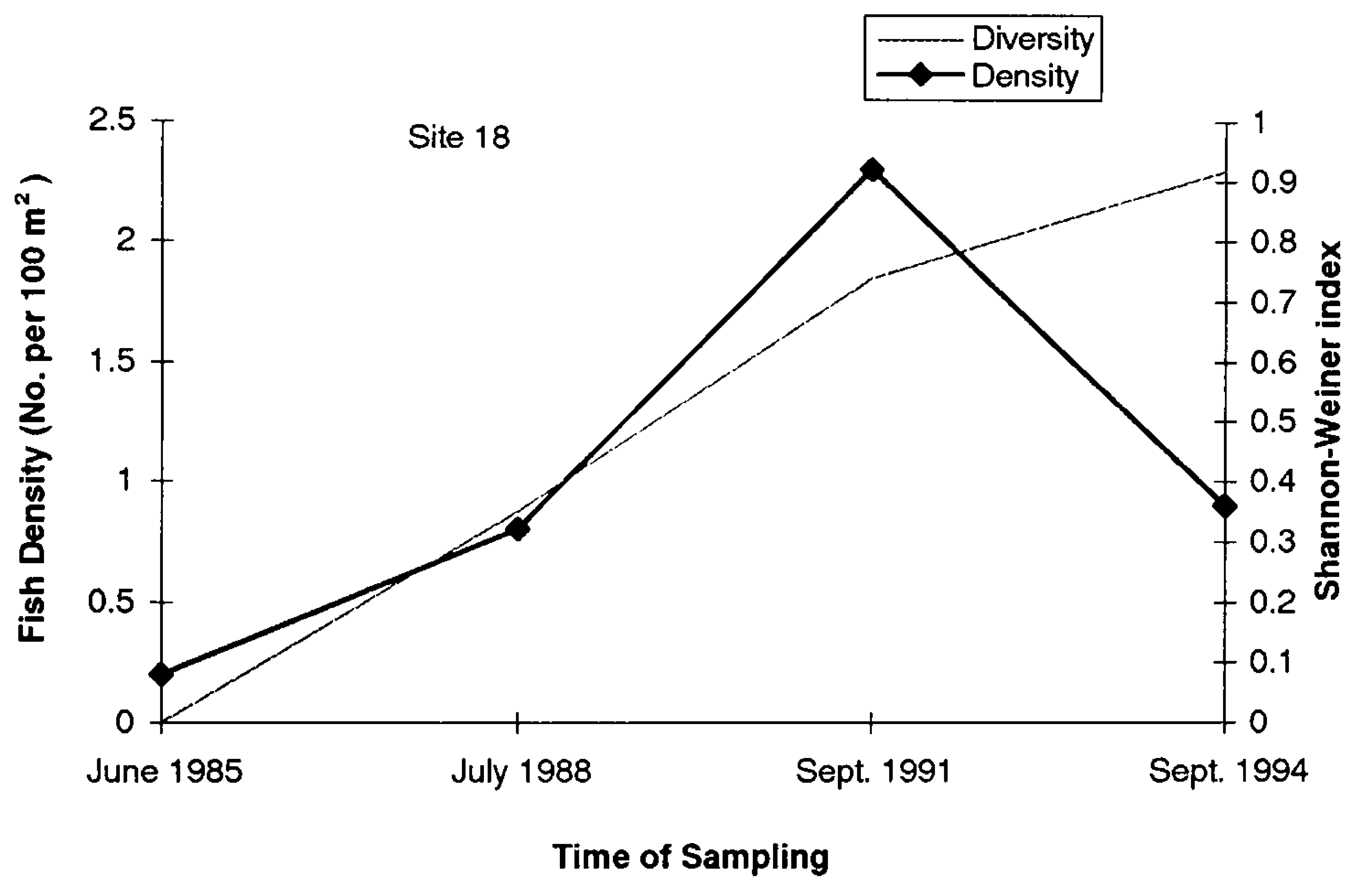


Fig. 5.20. Trends in fish abundance and diversity in the River Dearne at Broom Hill

The catch was predominantly gudgeon although some roach and other coarse fish were captured (Figs 5.15 - 5.18). The apparent improvement in fish populations between 1985 and 1991 may have been the result of downstream displacement (Firth, 1997) of fish attempting to avoid the effects of Barnsley's pollution dropping downstream. The reason behind the sharp fall in fish populations at Broom Hill in 1994 is unclear but it is possibly due to emigration of fish to other parts of the river.

At Pastures Bridge (site 21), a gradual improvement was followed by a sharp increase in fish numbers from 1985-91 (Fig. 5.21), after which density stabilised between 1991 and 1994. These changes were reflected in species diversity which remained fairly constant between 1985 and 1988, declined slightly after 1988 only to rise again by 1994. The high diversity in 1985-88 might be due to stocking but there is no data on the fish species stocked prior to this time. It is probable that the fish stocked prior to 1985 were already present in the river and hence did not affect the species diversity.

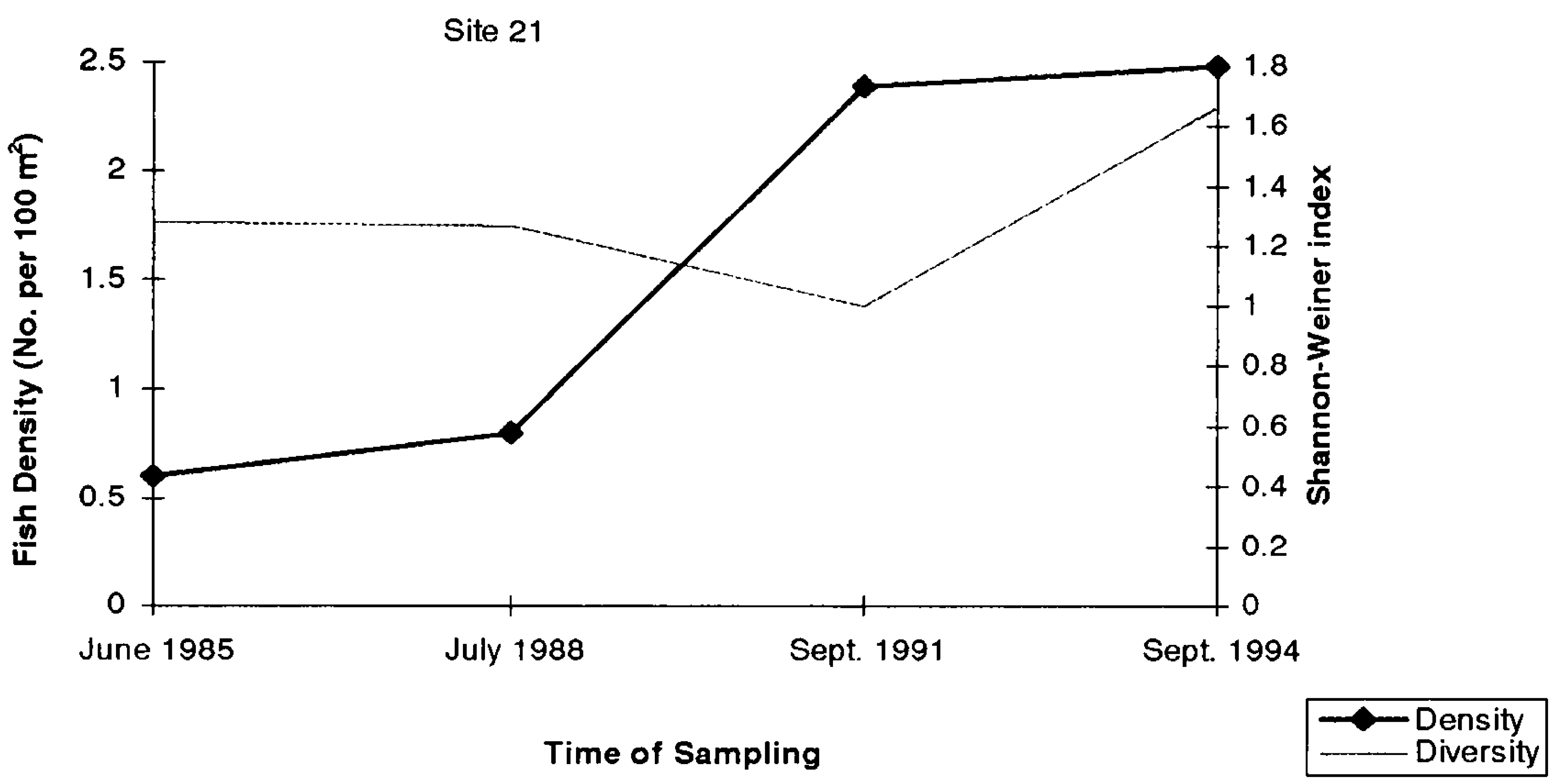


Fig. 5.21. Trends in fish abundance and diversity in the River Dearne at Pastures Bridge

Between 1983 and 1988, considerable effort was made by YWA and local angling interest groups to re-develop the fish stocks of the lower Dearne. Over 12000 fish were stocked in the river between Bolton-on-Dearne and Denaby (Firth, 1997), which includes Pastures Bridge. The sharp increases in fish density and diversity between 1988 and 1991 were likely to be the result of this massive stocking of the river in this area. The reasons for the shifts in species diversity are not clear but it is likely to be a result of some species moving in and out of the site in response to changing water quality in the catchment, possibly a reflection of the re-colonisation process which follows this type of pattern.

5.1.7 The River Dove

Water quality and fisheries of the River Dove

The River Dove is a tributary of the River Dearne (Appendix 1.3). The relatively high density of roach (12.8 fish per 100 m^2) captured downstream of the River Dove at Worsborough Reservoir (site 23) in 1991 possibly originated from the reservoir (NRA, 1993a). No fish was found in the River Dove from Worsborough Dale (site 24) to Low Valley (site 26) (Fig. 5.17) suggesting limited fish populations in the river. The physical habitats at these sites appeared suitable for fish (NRA, 1993a). It was probable that adverse water quality constrained the fish populations.

Organic enrichment, indicated by massive growths of the alga *Cladophora glomerata* (blanket weed) was evident. At night when no photosynthesis is taking place, large masses of *Cladophora* tend to deoxygenate the water by the normal respiratory processes (Butcher *et al.*, 1973). Massive development of *Cladophora* is associated with rapid falling of BOD and the complete mineralisation and release of nutrient salts (Hynes, 1978). The BOD at these sites on the River Dove was possibly low, although nutrient enrichment may have been enhanced. The growth of *Cladophora* does not diminish as BOD falls but extends into reaches where its level is quite low but where the concentration of nutrient salts is still relatively high.

The scenario in the River Dove was worse than in the main river, with generally low dissolved oxygen minima (< 70% saturation) (NRA, 1993a). On the other hand all the sites had ammoniacal nitrogen levels exceeding the recommended EQS (NRA, 1993a). Again sewage effluents located in the vicinity such as those at Darfield and Worsborough, are implicated in the high levels of NH_4-N observed. The maximum ammoniacal nitrogen recorded exceeded the recommended water quality standards.

The low fish populations and poor species diversity encountered in 1991 could be attributed to poor water quality. A number of fish mortalities also occurred between 1989 and 1991 (Table 5.1), and these affected the fish populations in the catchment.

5.1.8 The River Rother

Fish zonation

The fish surveys of the Rother catchment between 1984 and 1995 revealed a grossly polluted catchment with very low fish densities and an equally poor species diversity. The sites sampled over the period are described in Table 3.5. The results of the surveys showed no distinct zones of fish species distribution in the catchment as described by Huet, (1949) as many sites were fishless. It appears that all fish species tended to cluster in relatively cleaner habitats, hence salmonids and coarse fish were found throughout headwaters, middle and lower reaches (Figs 5.22 - 5.26), and no clear delineation of zones was apparent. Huet's physical criteria for fish zonation was therefore not apparent.

Fish abundance and diversity

In 1984 brown trout, roach, gudgeon and perch were found. Brown trout densities were highest in the River Hipper at Somersall Lane (site 24) (6.8 fish per 100 m^2), and at Barlow Brook at Commonside (site 20) (6.4 fish per 100 m^2, Fig. 5.22).

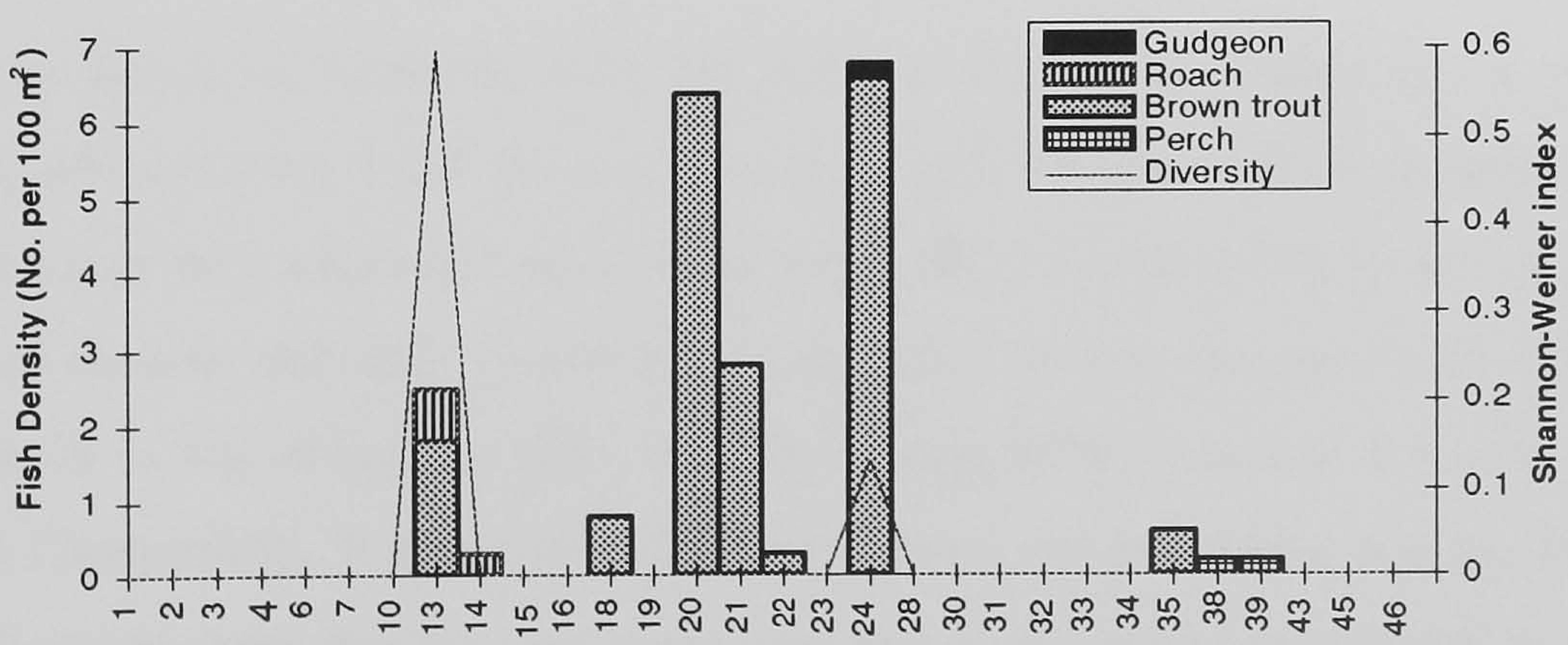


Fig. 5.22. Fish abundance and diversity in the Rother catchment in December 1984

Coarse fish densities were low and sporadic in their distribution. Coarse fish were only found in the upper reaches of the River Doe Lea (sites 13 & 14), the River Hipper (site

24) and in the Moss (site 38) at Eckington. Most of these fish probably originated from the nearby still waters (Yorkshire Water, 1985c) connected to the river by overflows. They therefore did not represent a self-sustaining population. A range of sizes of bullheads, stoneloach, and minnows was reported for all the sites (Yorkshire Water 1985c) except in the River Whitting at Old Whittington (site 30) where no fish was found. The different range of sizes would possibly indicate successful recruitment of these minor species.

Species diversity was poor at all sites due to lack of fish, the occurrence of a single or few species (Fig. 5.22). Many sites were fishless due primarily to water quality problems, with most sites designated water quality class 4 (Appendix 1.2).

No fish was captured from the River Doe Lea at Netherthorpe (site 15) and Renishaw (site 16). For a long time the water quality in the Doe Lea was impacted by discharges from Coalite Chemicals around the town of Bolsover. These sources would possibly restrict the downward movement of fish towards the main river.

On the main River Rother, no fish was captured between North Wingfield (site 1) and Woodhouse Mill (site 10). The Rother at North Wingfield was exposed to intermittent pollution (NRA, 1989) from sewage and industrial sources and this probably explains the lack of fish at this site.

Smithy Brook at Renishaw (site 34) held no fish. This stretch had a water quality designation of class 3 and this was consistent with the status of the fisheries at this time. Absence or only a sporadic presence of fish would be expected in waters of class 3. For similar reasons and lack of suitable holding places for fish, the sites below Pigeon Brook (sites 39 to 46) all held no fish. Old Whittington STW (near site 30) treats the sewage from Chesterfield. It is located north of the town and discharges into the River Rother. Until recent years this sewage works was one of the main contributors to the polluted state of the river (Firth, 1997).

In 1988, Yorkshire Water carried out a survey to monitor the status of fish populations in the catchment. Little or no improvement had taken place in the status of fish populations (Fig. 5.23).

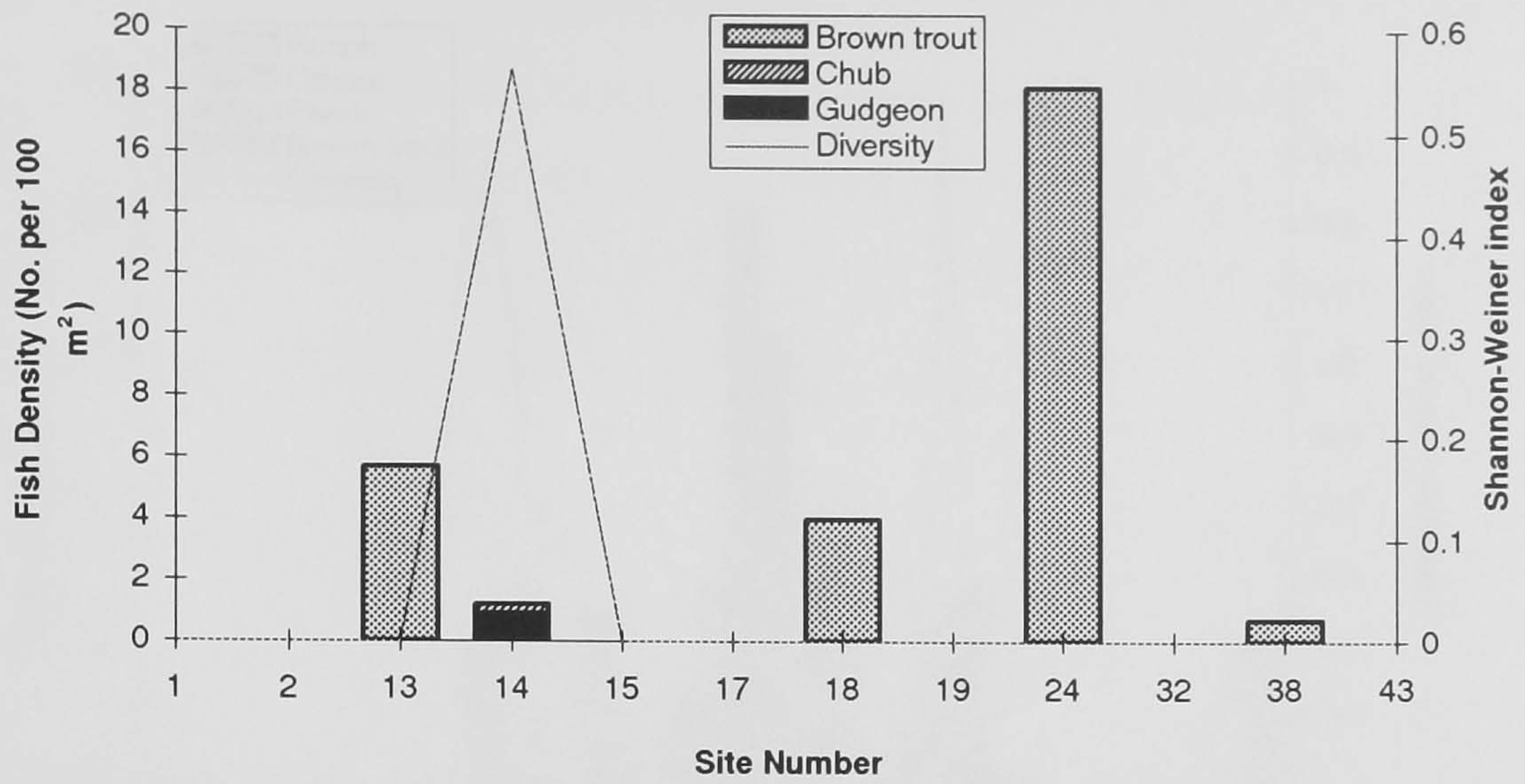


Fig. 5.23. Fish abundance and diversity in the Rother catchment in November 1988

Fish diversity was poor at nearly all sites except in the River Doe Lea at the Doe Lea Bridge (site 14) where brown trout and other coarse fish were captured. No fish was found in the Doe Lea at Netherthorpe (site 15). The River Doe Lea at Netherthorpe was reported to have very turbid waters, odours from petroleum wastes, and large quantities of domestic wastes (NRA, 1989). High levels of ammonium were also recorded at this site. The lack of fish at this would therefore be expected.

The River Hipper at Somersall Lane (site 24) maintained the highest fish density from 6.8 fish per 100 m^2 in 1985 (Fig. 5.22) to 18.2 fish per 100 m^2 in 1988 (Fig. 5.23)

The River Rother was also surveyed in 1994 to assess changes in fish populations following improvements to sewage and industrial discharges in the catchment. No fish was found in the main River Rother at North Wingfield (site 1) down to the River Rother at Catcliffe (site 11), (Fig. 5.24). Fish were captured at only one site just above the confluence with the River Don (site 12) but total density of fish was negligible (0.04 fish per 100 m^2) comprising only one pike and one roach.

Poor water quality and lack of suitable holding places might be implicated in the lack of fish in the main river. The River Rother at Birdholme (site 2), Slittingmill (site 6) and Holdbrook (site 7) lacked suitable holding places for fish. The sites were characterised by high water velocities (NRA, 1994d) which probably rendered the habitat unsuitable for some species requiring fairly slow to lentic conditions.

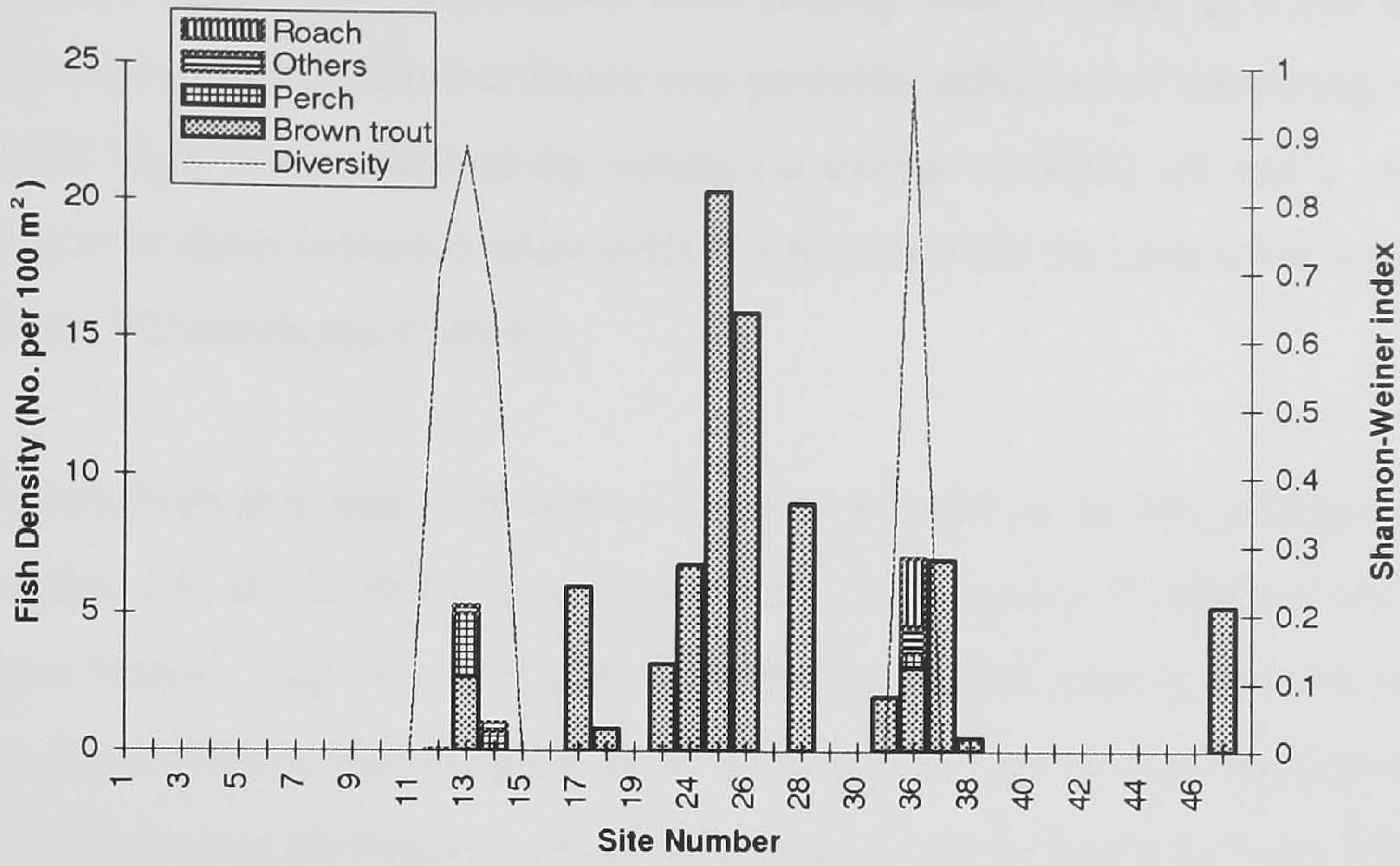


Fig. 5.24. Fish abundance and diversity in the Rother catchment in February 1994

By 1994 fish populations in the upper reaches of the Doe Lea (sites 13 and 14) improved considerably (5.3 fish per 100 m^2 at Stainsby, and 1.0 fish per 100 m^2 at the Doe Lea Bridge (Fig 5.24). These improvements might be associated with increased dilution to discharges from collieries (EA, 1997) that impact on water quality and with the pumping of mine waters at Markham and Bolsover. Fish species diversity was poor for all the tributaries surveyed (< 1.0 at all sites).

The River Doe Lea at Netherthorpe (site 15) and at Renishaw (site 16) held no fish but brown trout density of 6.0 fish per 100 m^2 was determined for the Locko Brook (site 17). These trout probably originated from a previous stocking (NRA, 1994d) in April 1990. Pollution-sensitive macroinvertebrates were found in the Locko Brook. The presence of salmonids coupled with the presence of pollution-sensitive macrobenthos might be an indication that water quality had improved.

The density of brown trout in the Redleadmill Brook at Tupton (site 18) was 0.8 fish per 100 m^2. This site had previously been stocked with brown trout but water flow thereafter had been very low in the brook. This could possibly be an important factor limiting fish populations in the brook. The fish had probably moved away into deeper waters with enhanced flow. Only sticklebacks were found at Calow Brook (site 19), and was probably indicative of the start of a re-colonisation process.

In Muster Brook (site 23) brown trout density was 3.2 fish per 100 m^2. The re-appearance of trout in Muster Brook was probably indicative of improving water quality. In 1992 high water conductivity values (in excess of 2000 $\mu S\ cm^{-1}$) were reported. Chemical analysis indicated saline pollution that could be traced to mine water discharges from the Williamthorpe Colliery.

Relatively high densities of brown trout were recorded in the River Hipper at Somersall Lane (site 24) and at Holymoorside (site 25). Brown trout densities were 6.8 and 20.4 fish per 100 m^2, respectively (Fig. 5.24). The highest fish density was therefore recorded in the River Hipper, indicating the continuing high quality of this tributary of the Rother. The 1992 routine biological surveys classified the upper reaches of the River Hipper as B1A at Holymoorside, and B1B downstream of Brookside Beck (site 26) where trout density was 16.0 fish per 100 m^2. These water quality designations would appear to be consistent with the large numbers of brown trout found at those sites. The trout captured in Brookside Beck at Somersall Lane (site 26) probably originated from a stocking of this part of the river in 1993 (NRA, 1994d). No fish was found in the Brookside Beck at Westmill farm (site 27), although the physical habitat was suitable for brown trout (NRA, 1994d). The lack of fish might be attributed to poor water quality resulting from agricultural effluents discharged into the river from nearby farmlands.

In Holme Brook below Linacre reservoir (site 28) the density of brown trout was 9.0 fish per 100 m^2. The same brook in Chesterfield (site 29) and also the River Whitting in Chesterfield (site 30) held no fish. The absence of fish in the Chesterfield tributaries could be due to various industrial discharges in the Chesterfield area which impact on the water quality.

A brown trout density of 2.0 fish per 100 m^2 was recorded at Birdholme Brook (site 35). Whilst only brown trout were captured in the Moss at Ford (site 37), both coarse fish and brown trout were captured upstream at Povey Farm (site 36). The fish at both sites possibly originated from the Ford dam. From the Pigeon Brook at Aston (site 39) to the Whiston Brook at the Stables Track Bridge (site 46) no fish was found. However, Whiston Brook at Whiston (site 47) held a brown trout density of 5.3 fish per 100 m^2. The trout probably originated from a previous stocking in 1991. Sewage litter was observed at Pigeon Brook and the macroinvertebrate fauna was indicative of organic pollution. The Ochre Dyke at Crystal Peaks (site 40) was fishless. The dyke was narrow with little flow and there was very little cover for fish (NRA, 1994d). The limited flow and the lack of cover were possibly important limiting factors in the lack of fish at that site.

Smithy Brook (site 41) downstream of the sewage treatment discharge held no fish. This might be linked to a deterioration in water quality from the sewage effluents rendering it unsuitable for fish habitation. The same brook held no fish above the sewage treatment works (site 42) for no obvious reasons. Shire Brook at Beighton (site 43) and Normanton Spring (site 44) both located above a former discharge from Coisley Hill STW held no fish for no apparent reasons. Similarly, Ulley Brook (site 45) and Whiston Brook at the Stables (site 46) were fishless. The lack of fish at Whiston Brook however might be attributed to poor water quality as storm sewage was observed in the river. The same river at Whiston held brown trout (Fig. 5.24).

Between September and October 1995, a survey was conducted to assess the survival and growth of some coarse fish stocked at some sites of the River Rother. No fish was found at the confluence with the Moss Brook (site 48), (Fig. 5.25). The river at this site was slow flowing and fairly deep (>1 m) and with no riffles nor shallow areas. A lack of suitable holding places for fish might be an important factor constraining the existence of fish at this location. The Moss is also one of the tributaries of the Rother that does not meet its water quality target due to various intermittent discharges (EA, 1997), and the lack of fish would be expected.

Above the weir at Rother Valley Country Park (site 49) total fish density reached 0.4 fish per 100 m^2, with chub constituting 60% of the catch. The low fish density at this site might be linked to low oxygen levels as the water is deep and slow-flowing.

Downstream of the weir at Rother Valley Country Park (site 50), total fish density was 2.2 fish per 100 m^2 with gudgeon dominated (0.8 fish per 100 m^2). Chub (0.4 fish per 100 m^2), barbel, dace, and a small number of brown trout were also captured below the weir. The diversity index was relatively high and reaching 1.51. The fish were captured in the pool below the weir (NRA, 1995) where the elevated oxygen levels possibly enhanced the conditions. The site below the weir was characterised by strong flow with a clear substrate of sand, gravel and rocks providing suitable habitat conditions for the species captured.

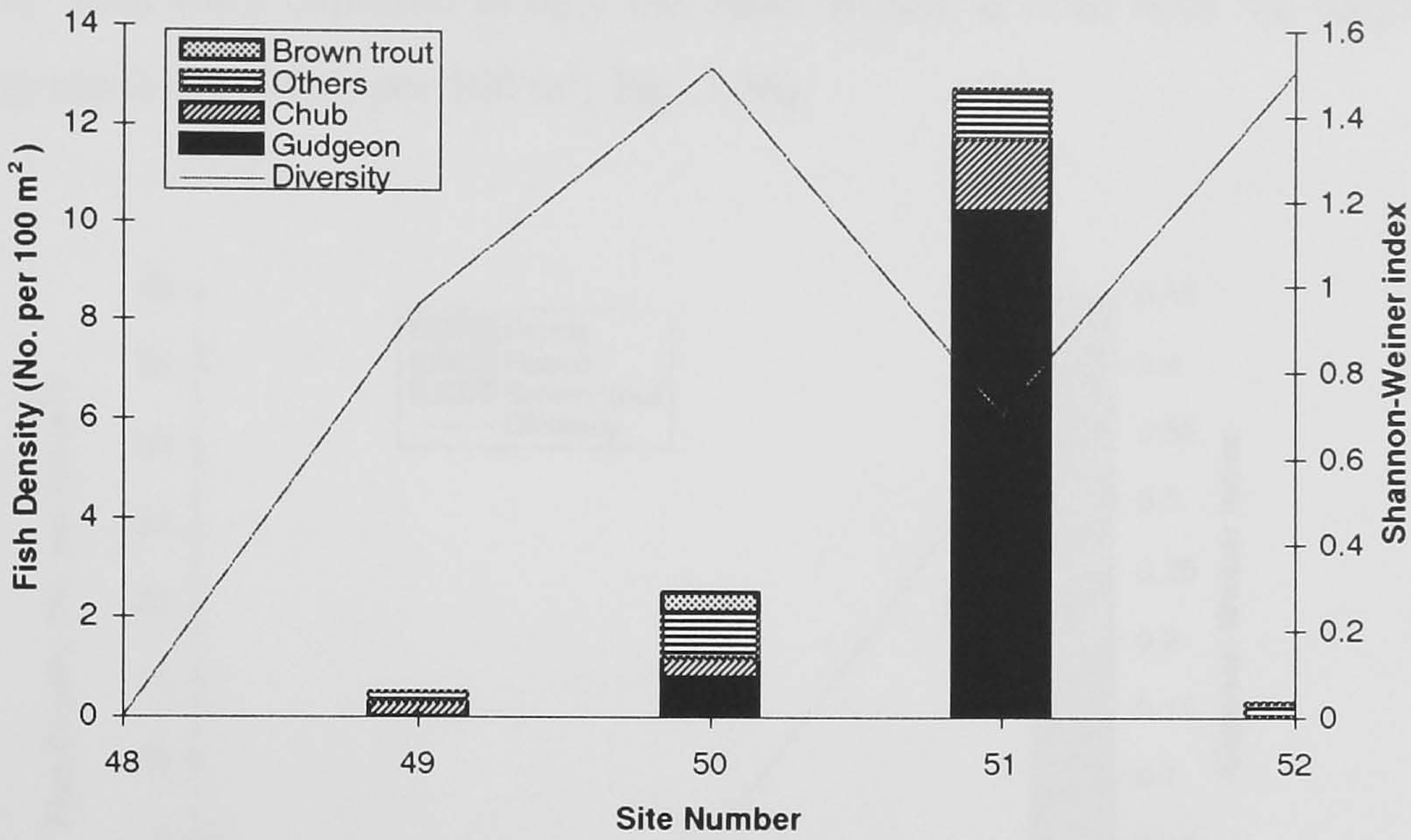


Fig. 5.25. Fish abundance and diversity in the Rother catchment in September 1995.

In the Rother at Woodhouse washlands below the riffles (site 51), gudgeon was the dominant species (10.3 fish per 100 m^2, (Fig. 5.26). Chub, brown trout, barbel, dace, and roach were also captured. Total fish density and species diversity were 12.9 fish per 100 m^2 and 1.5 respectively, perhaps reflecting the high suitability of the habitat for the fish. The Woodhouse washlands development site (site 52) held a rather sparse population of fish. The total fish density was only 1.1 fish per 100 m^2 comprising brown trout, chub, dace roach and gudgeon. Lack of suitable holding places for fish below the riffles might be a key factor limiting fish populations at this site. Habitat improvement schemes are planned for this site (EA, 1995)

5.1.9. Fish abundance and diversity in some tributaries of the River Rother

The survey of the Rother catchment between December 1984 and January 1985 recommended limited stocking of some tributaries. Four tributaries comprising Locko Brook, the Moss, Redleadmill Brook, and the River Doe Lea at Stainsby were consequently stocked with brown trout after that survey. In November 1990 (NRA, 1993b), it was observed that the stocked brown trout had become established in the Locko Brook but survival rates at the other sites was low. Further stocking of the Moss, Redleadmill Brook and the River Doe Lea with larger brown trout was carried out in April 1991. In January 1992 a survey was carried out to monitor progress of the stocked trout. Fish were captured in only the Moss Brook at Ford with the largest proportion being roach (36.4 fish per 100 m^2, Fig. 5.26).

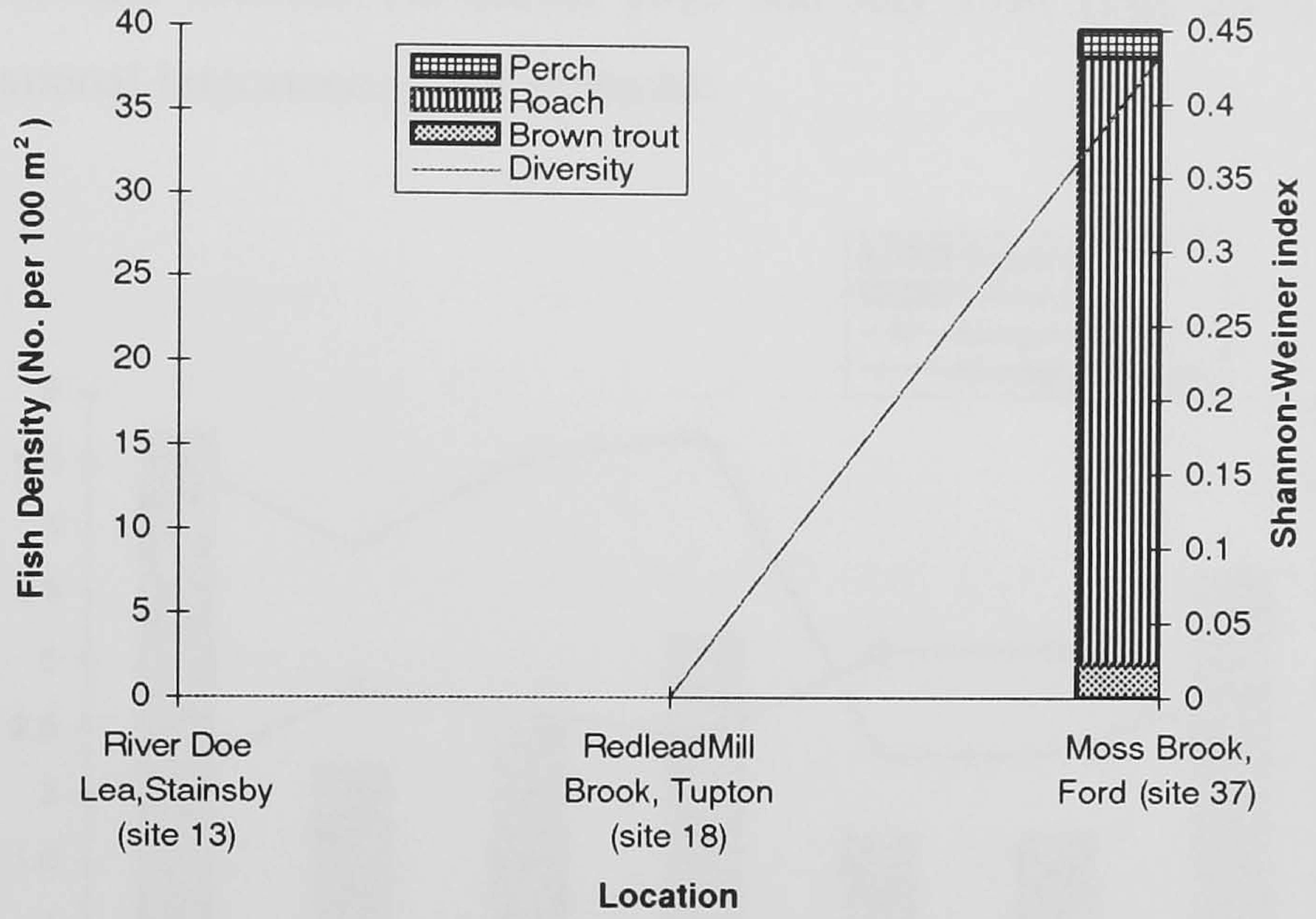


Fig. 5.26. Fish abundance and diversity in some tributaries of the River Rother in January 1992.

Other species captured were brown trout and perch with densities of 2.0 and 1.6 fish per 100 m^2, respectively. Species diversity was poor (0.434). No fish was captured in the River Doe Lea at Stainsby nor in the Redleadmill Brook at Tupton in 1992. Brown trout were captured in the Doe Lea at Stainsby during the surveys of 1985 and 1988. It might be that an unreported pollution incident occurred at this site or perhaps the fish moved away.

During the surveys in 1992, river flow was very low in the Redleadmill at Tupton (NRA, 1993b), and the brook was almost dry. Water quantity is important in the choice of habitats by fish. This might partly account for the lack of fish which had probably moved to deeper water. The results of the 1992 survey showed that the fish stocking was not successful.

5.2. Recent changes in fish populations in the Rivers Don, Rother & Dearne (1995-1997)

5.2.1. The River Don at Penistone

Fish abundance and diversity

Brown trout and grayling were the only important fish species captured in the River Don at Penistone between November 1995 and July 1997 (Fig. 5.27). No coarse fish of recreational importance were captured.

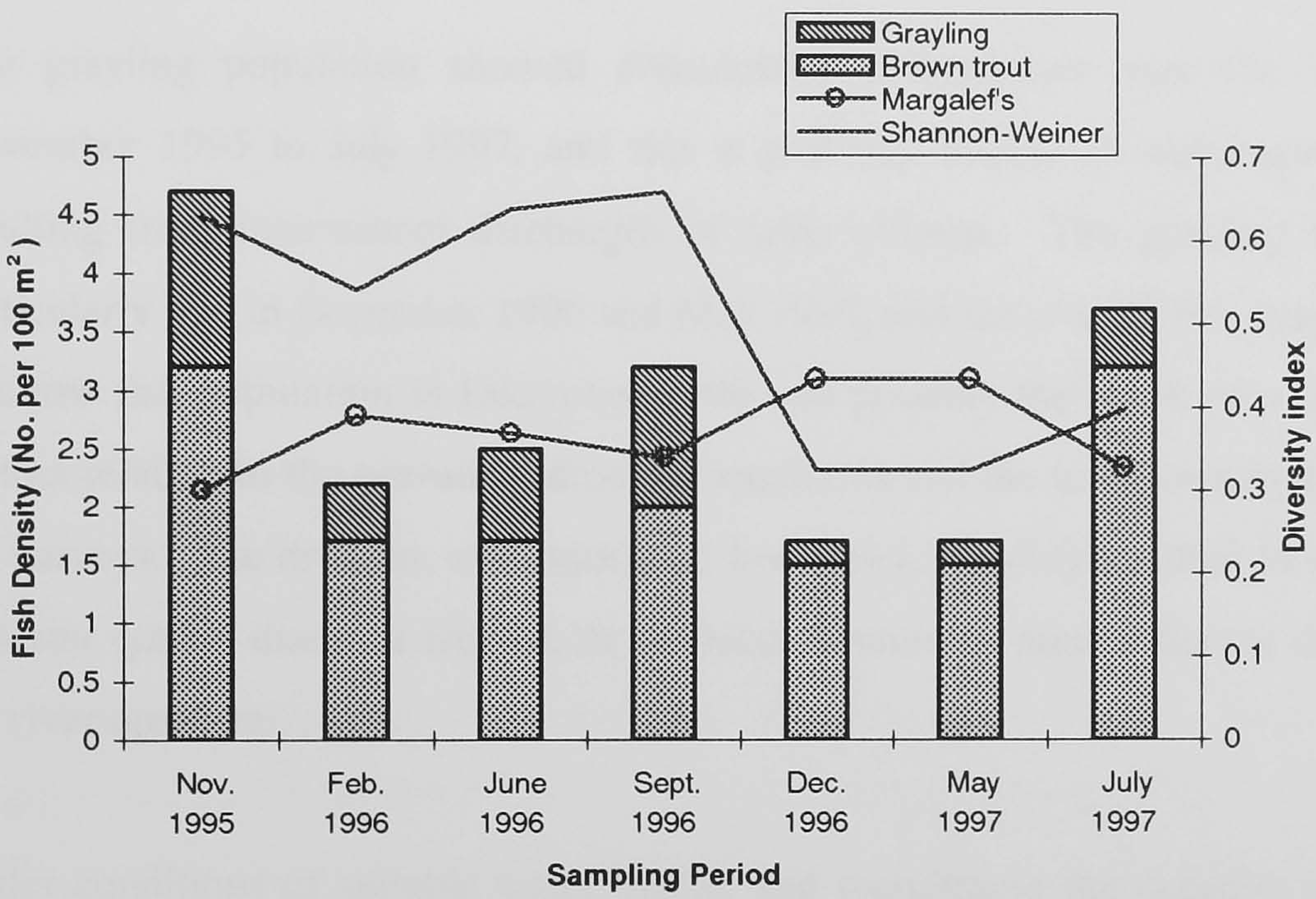


Fig. 5.27. Fish abundance and diversity in the River Don at Penistone

The catch, in all the surveys, was dominated by brown trout. It is possible that these fish originate from stocking programmes as grayling and brown trout have been regularly stocked into the River Don at Penistone over the last decade (C. Firth, pers. comm.).

Brown trout densities in the River Don at Penistone were highest in November 1995 (4.7 fish per 100 m^2) and July 1997 (3.7 fish per 100 m^2). The trout population remained fairly stable between February 1996 and May 1997 (Fig. 5.27). In November 1993, 6.8 fish per 100 m^2 were recorded, suggesting a decline in fish numbers in 1995. However, the species present (brown trout & grayling) remained unchanged. Reduced numbers of trout and grayling were captured during the survey of February 1996 (Fig. 5.27). Heavy snowfalls occurred prior to the survey and this probably explains the poor catch. It was probable that the fish had dispersed into deeper waters downstream. It is known that grayling are sensitive to temperature changes and for this reason their favoured sheltering places vary within rivers and streams as the seasons change (Louw & Jenkins, 1990). During winter cold periods grayling form shoals and move into deeper water such as pools (Louw & Jenkins, 1990). They hold positions close to the river bed and they are rarely found above mid-water. They almost never remain stationary near the surface for long periods of time. In June 1996, brown trout numbers remained the same as in February 1996 but a marginal increase in grayling numbers was observed (Fig. 5.27).

The grayling population showed considerable fluctuations over the survey period November 1995 to July 1997, and this is probably related to water quality problems resulting from intermittent discharges of mine effluent. The grayling numbers were particularly low in December 1996 and May 1997, and the overall fish density was poor. The low fish population in December 1996 was possibly the result of a combination of factors relating to the prevailing drought conditions and the low flows in the river during the surveys. The drought, and associated low flows, possibly resulted in a deterioration in water quality due to a lack of, or reduced, dilution of mine effluents discharged into the river upstream.

Under conditions of suitable water quality and recruitment the capacity of a stream to hold fish is largely a function of discharge and the physical structure of the stream channel (Milner *et al.*, 1985). The River Don at Penistone is characterised by rocks, boulders with numerous riffles and gravel beds (Plate 1). These habitat features appear to enhance the capacity of the river at Penistone to hold brown trout and grayling. The value of cover from riparian vegetation along the bank has been widely recognised (Cowx & Welcomme, 1998). The amount of permanent bank cover is known to strongly influence brown trout populations and the carrying capacity of a stream (Hunt 1976; Gorman & Karr, 1978). The physical habitat in the River Don at Penistone has considerable bankside cover and some sparse in-stream vegetation. The occurrence of brown trout and grayling in all the surveys was therefore expected.

Between December 1996 and May 1997 (Fig. 5.27), fish density was at its lowest. In May 1997 a rise in water conductivity from 520 to 640 $\mu S\ cm^{-1}$ was noted. The rising conductivity possibly resulted from various ionic inputs from old mine discharges at Bullhouse and Sheephouse Wood located upstream. The entire river bed at this time was covered with an orange-to-rust coloured material (ochre) possibly derived from various oxides and hydroxides of iron. Water coloured by iron salts drains into the River Don at Penistone blanketing the river bed with rust coloured iron deposits or ochre. It smothers aquatic biota and restricts fish survival, spawning and recruitment. The pollution is caused by water building up inside the old Bullhouse colliery workings and exuding to the surface through drainage adits. This discharge has been described as the worst in England and Wales (Environment Action, 1996). No one has legal liability for discharges from long abandoned mines. The discharge from Sheephouse Wood workings is also known to have considerable impact on the river biota.

The Bullhouse site has been quarried from the surface by Hepworth Building Products for clay that lays beneath the coal. The quarry is now worked out, and about 30 acres have been restored but 5 acres have been set aside to build a lagoon system capable of cleaning up the discharge (Environment Action, 1996). The water from the mine workings will be diverted to the treatment plant and then discharged into the river. The lagoons will be built in the quarry and will contain mine water which will react with the air causing the ochre to precipitate. After treatment in the lagoons, the water will pass through an existing reed bed pond which will trap fine particles (Environment Action, 1996).

It is envisaged that if the discoloured mine water discharges from Bullhouse and Sheephouse Wood could be stopped, then natural clean up of the river could be achieved. A £1 million project with funding from the European Union has been put in place to tackle the project to prevent the River Don being polluted by water from old mine workings (Environment Action, 1996). To this end the EA has created a joint partnership with Hepworth Building Products, the Coal Authority and Barnsley Council to tackle the project which is a European pilot scheme.

By July 1997, the rust colour of ochre in the surface waters had reduced considerably. Fish numbers coincidentally rose possibly due to improved water quality but this is unclear and such a rapid response is unexpected.

Considerable numbers of bullheads were captured in all the surveys of the Don at Penistone. These species are known to be sensitive to various forms of organic pollution and their prevalence at that site was possibly an indication of good water quality. However, bullheads are often confined to places where large stones provide them with shelter, and are absent from clean-swept gravel where there are no crevices in which to hide from the water current. The site at Penistone also provides the preferred physical habitat for the bullheads (Horton, 1994; Mangion-Horton, 1997).

5.2.2. The River Don at Beeley Woods

Fish abundance and diversity

The surveys of the River Don at Beeley Woods resulted in the capture of both brown trout (salmonid) and coarse fish species (Fig. 5.28). Grayling were also captured.

Stocking of brown trout fry was undertaken at Beeley Woods below the weir in the spring of 1993 (NRA, 1994c). The low numbers of brown trout captured in the November 1995 survey suggests that the stocked fry did not survive or dispersed to other parts of the river. The river at Beeley Woods receives effluents from Jamont Paper Mill (formerly British Tissues) which is located upstream of the weir. This discharge is known to severely affect fish populations (NRA, 1994c). It is probable that the trout fry moved away from the effects of the discharge. A yellow-to-rust coloured ochre was also found on the left bank of the river (Plate 2). This impacts on the water quality and possibly on the fish community.

Roach dominated the catch of 1995, with gudgeon, dace and perch also being captured (Fig. 5.28). Roach density declined markedly in February 1996 but the reason was unclear.

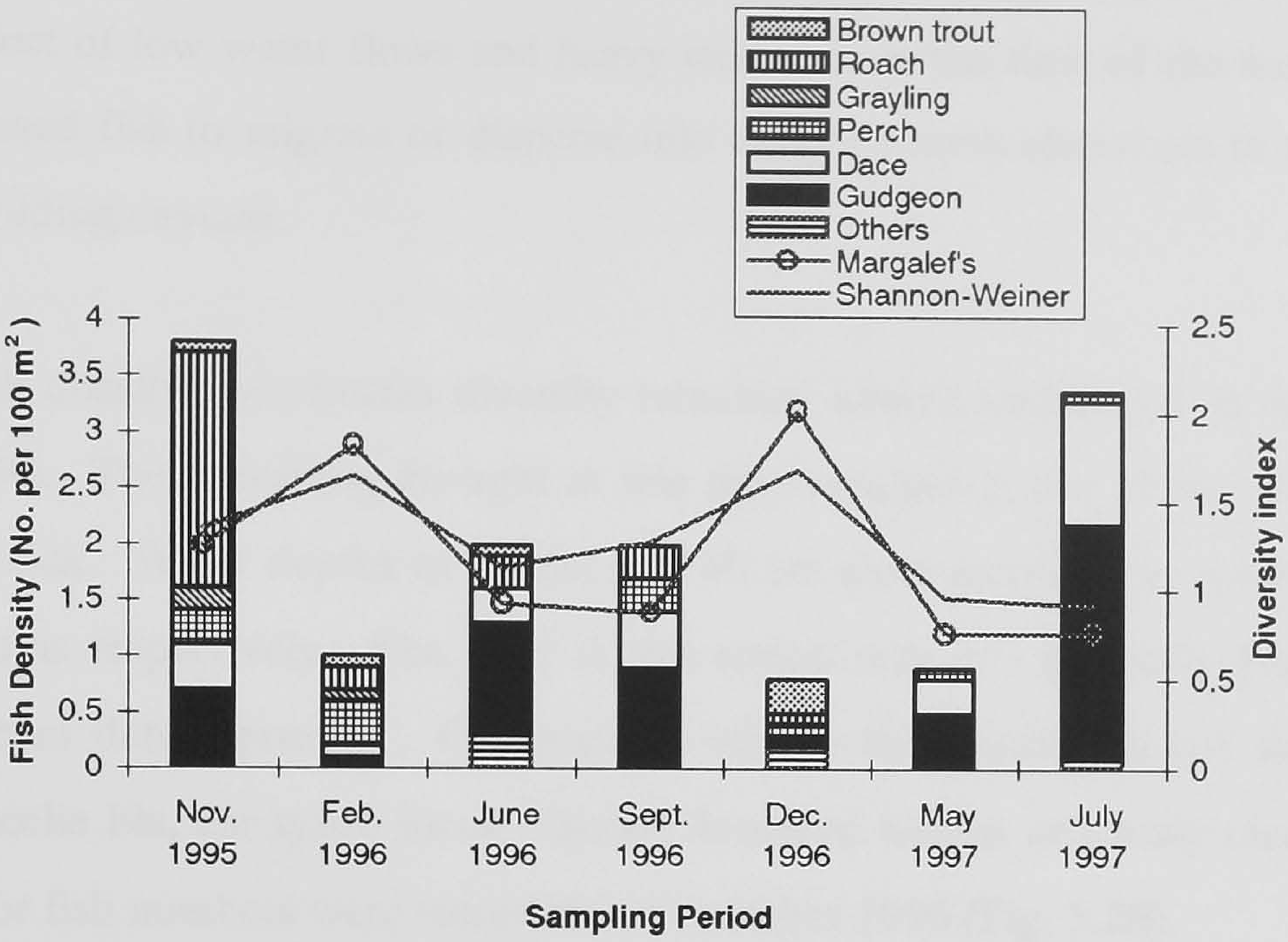


Fig. 5.28. Fish abundance and diversity in the River Don at Beeley Woods.

All the perch were captured among the in-stream vegetation in the relatively slow-flowing regions where large shoals of minnows were present. Perch are piscivores, preying on other fish species when of a suitable size. Young perch feed on Cladocera and other tiny Crustacea but they soon recruit to feed on insect larvae and chironomids. In the presence of other small fish species, perch switch to a diet of fish (Louw & Jenkins, 1990). Young perch hunt in schools, lying in wait among macrophyte cover until small fish such as minnows or roach strays too close. This behaviour of perch possibly explains why they were captured at the sites where large numbers of minnows were found.

Although fish density showed a decline in February 1996 from that of November 1995, the species diversity and the species richness showed an increasing trend (Fig 5.28), possibly reflecting migrations and shifts in species abundance. Many elements of the fauna migrate both longitudinally and laterally within the system for breeding, feeding or refuge (Welcomme, 1995), and this might explain the observed changes in fish numbers and species diversity. Any interruptions in the migratory pathways, as posed by weirs, could result in the elimination or disappearance of some mobile elements (Welcomme, 1995) such as fish. The weir at Beeley Woods imposes considerable restrictions on fish movements and hence impacts on the fish populations and species diversity at this site.

The poor fish density observed in February 1996 was, perhaps, related to the combined effect of low water flows and heavy snowfalls at the time of the survey. This possibly caused fish to migrate or disperse into deeper waters elsewhere in the catchment, thus avoiding capture.

Fish density and species diversity remained almost unchanged in June and September 1996. The prevailing drought at this time resulted in low flows in the river at Beeley Woods. Water depths of 20 cm and 40 cm were recorded as minimum and maximum depths respectively. The river in this region was in a generally poor state with much human debris present. Conspicuous among the massive debris in the river were, a wheelie bin, car tyres, metal objects, domestic wastes and rusty electrical wires. Very poor fish numbers were recorded in December 1996 (Fig. 5.28).

The survey of May 1997 was carried out after a massive spate in the river had receded. An apparent reduction in species diversity was observed (Fig. 5.28). Downstream displacement or upstream re-colonisation of some fish species probably took place during the spate leading to a very limited improvement in fish numbers.

Species diversity remained unchanged in July 1997 although a remarkable increase in fish population density had taken place over the period. Gudgeon and dace provided the major contributions to the catch in July 1997 (Fig. 5.28). Gudgeon and dace were captured in all the surveys (Fig. 5.28). It is, however, unclear why these species dominated the catch at this time but might be due to migrations and shifts in species abundance.

Grayling disappeared from the catch after February 1996, and in May 1997 brown trout were also absent. The disappearance of both species was possibly linked to a deterioration in water quality as these species prefer clean waters. Of all the native British fishes, grayling are the most sensitive to pollution, disappearing long before trout or chub (Louw & Jenkins, 1990). This appears to be the case in this study. It would appear from the survey of July 1997 that fish numbers were beginning to recover but with no improvement in species diversity.

Perhaps the most alarming finding of the present study is the downward trend of species diversity in the River Don at Beeley Woods. The disappearance of brown trout and grayling in the catch might be related to declining water quality as these species are intolerant to various forms of organic pollution. These changes may be explained by loss of species and/or predominance of a single species, both of which may result in a simpler population structure. Poor water quality and habitat conditions appear to be responsible for the loss of diversity as sensitive species tend to move away to cleaner waters and suitable habitats. Reductions in species diversity also become significant where important angling species are being lost. Whilst brown trout and grayling may not constitute important angling species, their disappearance could be an indication of declining water quality.

5.2.3. The River Dearne at Cudworth Common

Fish abundance and diversity

Most of the surveys of the River Dearne at Cudworth Common yielded very few or no fish. In the survey of November 1995, 3 gudgeon, all aged 2 years old, were captured. In February 1996 only a single yearling roach was captured at the same site. Subsequent surveys carried out at quarterly intervals between June 1996 and July 1997 yielded no fish. Poor water quality might be responsible for the poor fish populations at this site.

This River Dearne at Cudworth Common (Plate 3) is located downstream of the discharge from Lundwood STW in the Barnsley area. There are, in addition, other discharges such as the Darton sewage treatment works, the North Gawber mine water, and the Star Paper Mill which are also located above the Lundwood sewage treatment works. Effluents from the sewage works, mines and the paper mill impact on the water quality of the river resulting in poor fish numbers or the lack of fish.

5.2.4. The River Dearne at Pastures Bridge

Fish abundance and diversity

The fish community at Pastures Bridge was dominated by roach in all the surveys, except in March 1997 (Fig. 5.29) when no roach was found. No obvious reasons could be found for the absence of the species in that survey. River flow was, indeed, lower in March 1997 than was observed in November 1995. It might be that the low flows at this time resulted in the dispersion of the species to deeper waters elsewhere, or perhaps roach had emigrated to spawning areas. The roach numbers, however, remained unchanged in November 1995 and July 1996 (Fig. 5.29).

In general the catch of March 1997 was the poorest in abundance and species diversity (Fig. 5.29). The survey of July 1996 resulted in the largest catch and highest Shannon-Weiner index. The highest species richness index was, however, recorded in November 1995. Gudgeon were captured in all the surveys (Fig. 5.29) and this might possibly reflect the hardy nature of the species to survive in varying aquatic environments (Cowx *et al.*, 1993). The River Dearne at Pastures Bridge was re-engineered in 1995 (Firth, 1997) to create a series of meanders mimicking the original river (Plates 5 & 6). Most of the fish species were captured in the meandering sections during the 1995-1997 survey.

The results of fish surveys of the re-engineered section of the river (Fig. 5.29), showed only a marginal improvement in fish population density over the survey by the NRA in 1994. Fish population density in 1994 was 2.5 fish per 100 m^2 with and diversity index was about 1.66 (Fig. 5.21). In the survey of 1995, fish population density was about 3 fish per 100 m^2 although the Shannon-Weiner index was about 1.05 (Fig. 5.29), thus below the observed value in 1994.

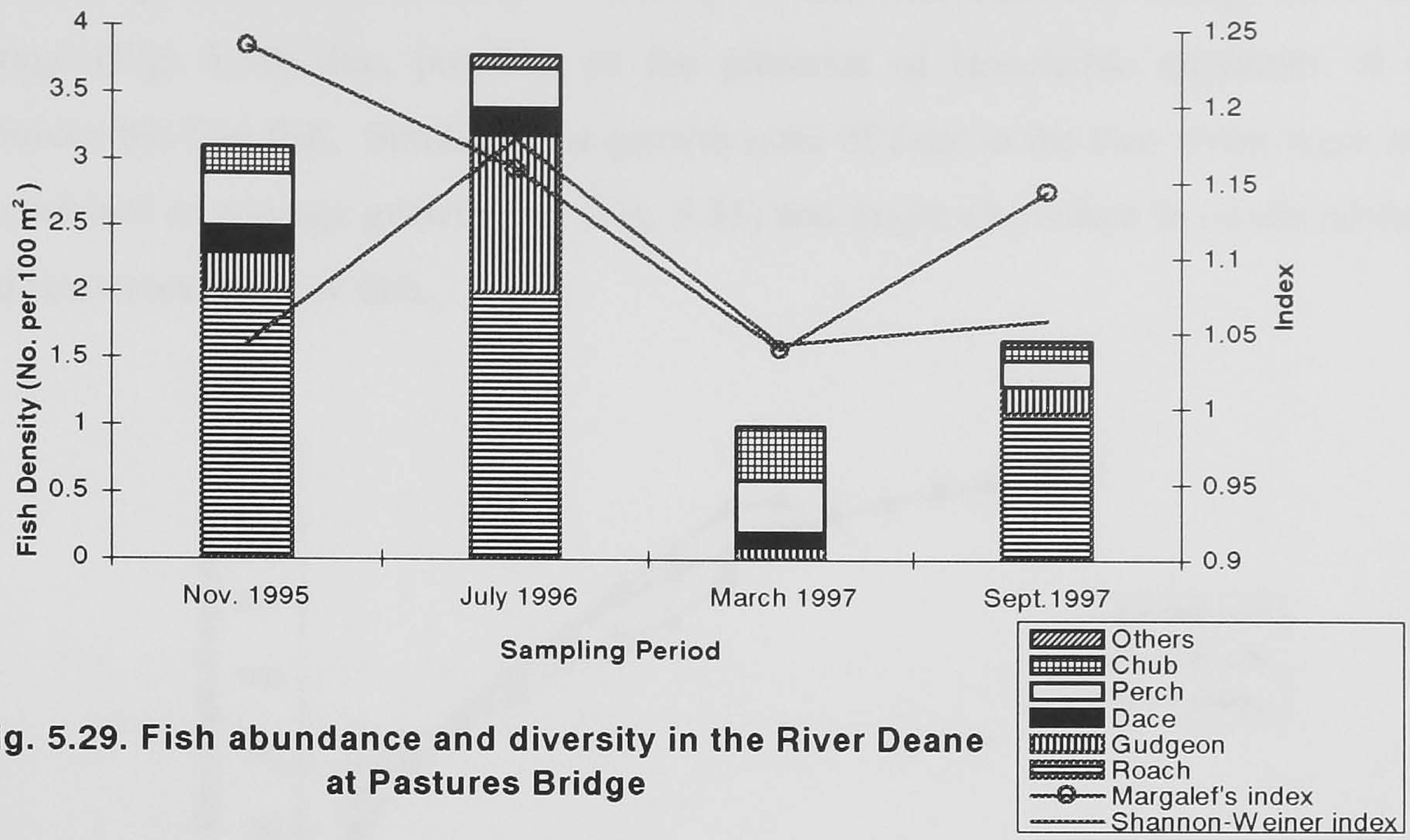


Fig. 5.29. Fish abundance and diversity in the River Deane at Pastures Bridge

5.2.5. The River Rother at Birdholme Bridge

No fish was found in the River Rother at Birdholme (Chesterfield) between November 1995 and July 1997. The river was littered with various domestic wastes, concrete bricks, empty cans, polythene wrappers and bags. Faecal matter and concrete washings from a building site (Plate 4) were observed and the bottom sediments carried considerable quantities of used motor oil. It was easy to perceive how society used the river as a cheap means of disposal of their unwanted wastes. The lack of fish would be expected under the prevailing conditions. Poor water quality, contaminated land and habitat degradation might be responsible for the lack of fish in the River Rother at Birdholme Bridge.

5.3. Age & growth of fish in the Rivers Don, Rother & Dearne (1995-1997)

Fish numbers for the various species were frequently low. Back-calculated growth history determined for the various fish species (Section 3.5.1) are presented in Appendix 1.7. The maximum attainable size of the fish species ($L\infty$), and rates of growth towards the asymptote (K) are presented (Appendix 1.7). No fish was captured in the Rother at Birdholme Bridge during the surveys. Growth curves for roach, dace, perch, chub, brown trout and grayling are presented to show variation in growth rates in relation to standard or average growth rates for the species (Figs 5.30, 5.31, 5.32, 5.33, & 5.34).

The early growth rates of roach at Beeley Woods and Pastures Bridge were above average (Fig. 5.30) due, possibly, to the presence of reasonable quantities of food resources but few fish. Similarly, the growth rates of dace in the two rivers were above the standard or average growth rate (Fig. 5.31) and might also relate to an abundance of food resources and few fish.

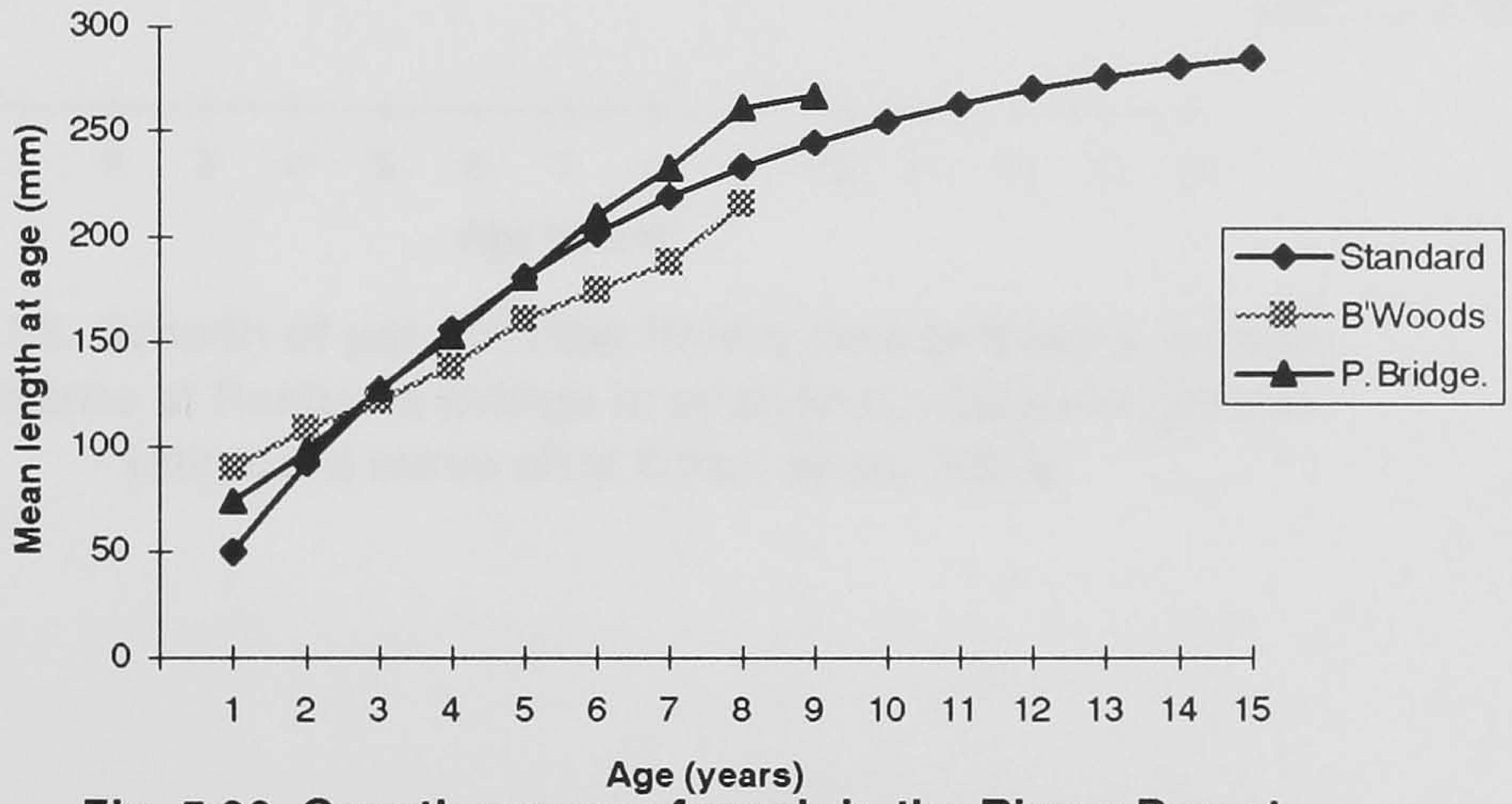


Fig. 5.30. Growth curves of roach in the Rivers Don at Beeley Woods and Dearne at Pastures Bridge in relation to standard growth (standard curve after Hickley & Dexter, 1979).

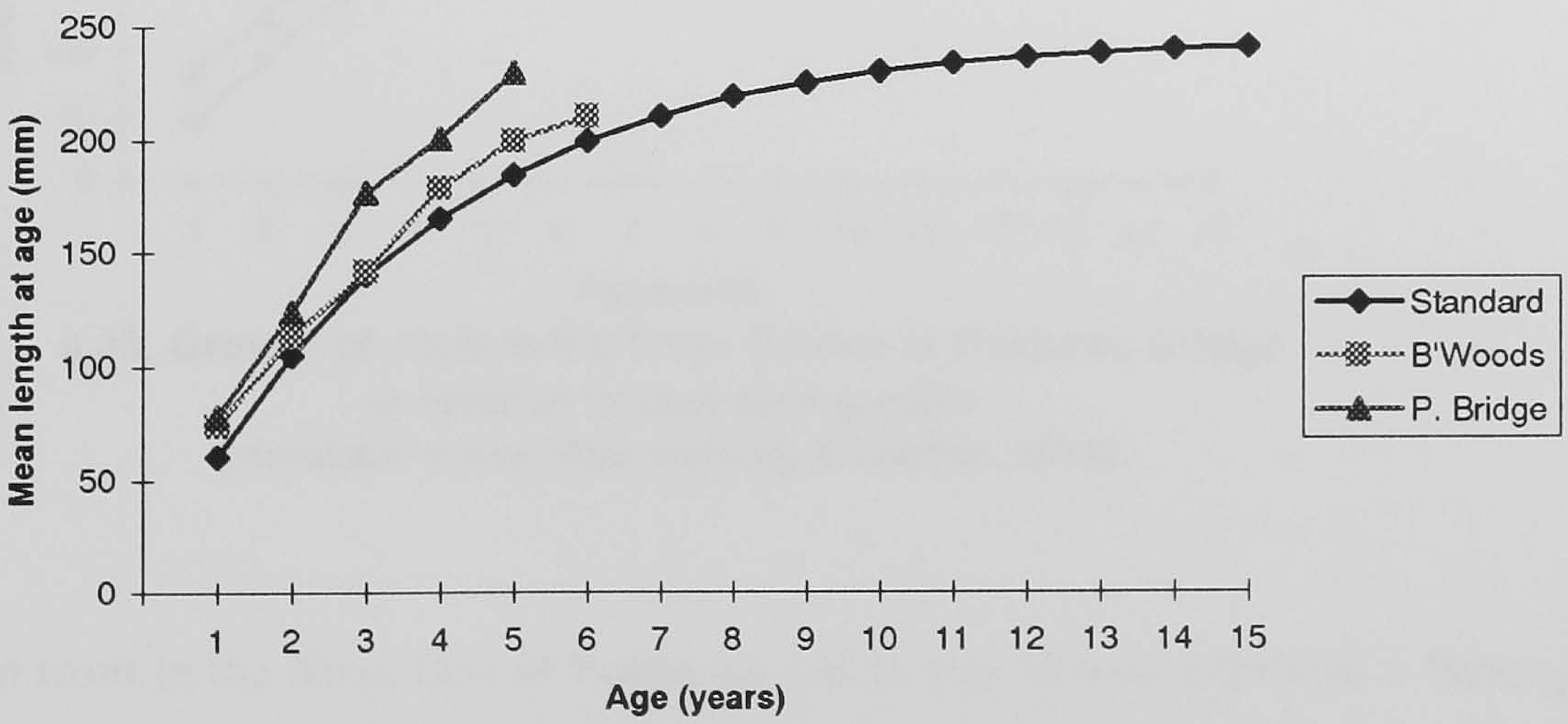


Fig. 5.31. Growth curves of dace in the Rivers Don at Beeley Woods and Dearne at Pastures Bridge in relation to standard growth (standard curve after Hickley & Dexter, 1979)

The growth rates of perch in the Rivers Don at Beeley Woods and Dearne at Pastures Bridge were above the average or standard growth rate (Fig. 5.32). Similarly, the growth of chub in the latter was above the standard growth rate (Fig. 5.33) suggesting faster growth rates for the species in these waters.

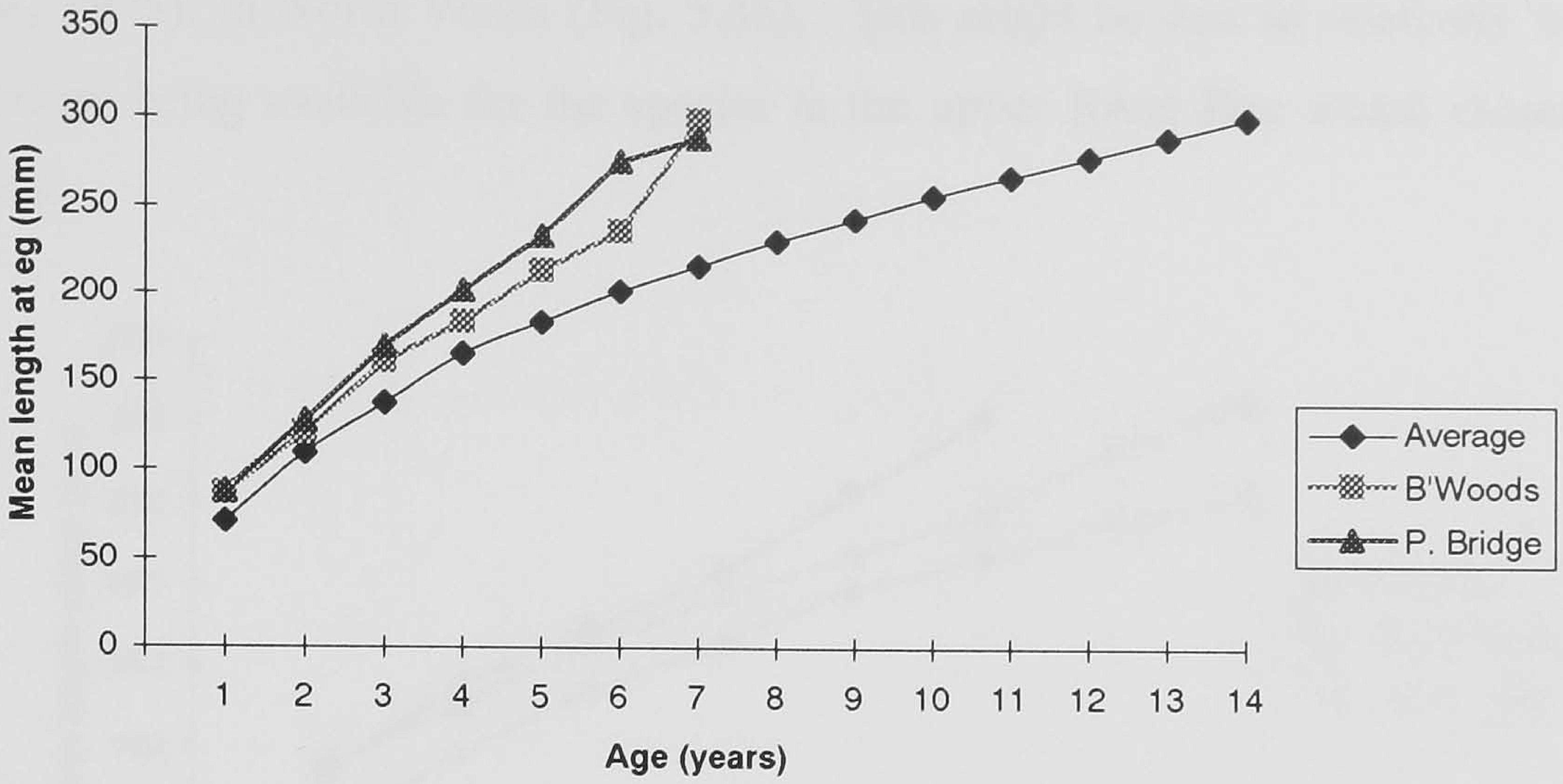
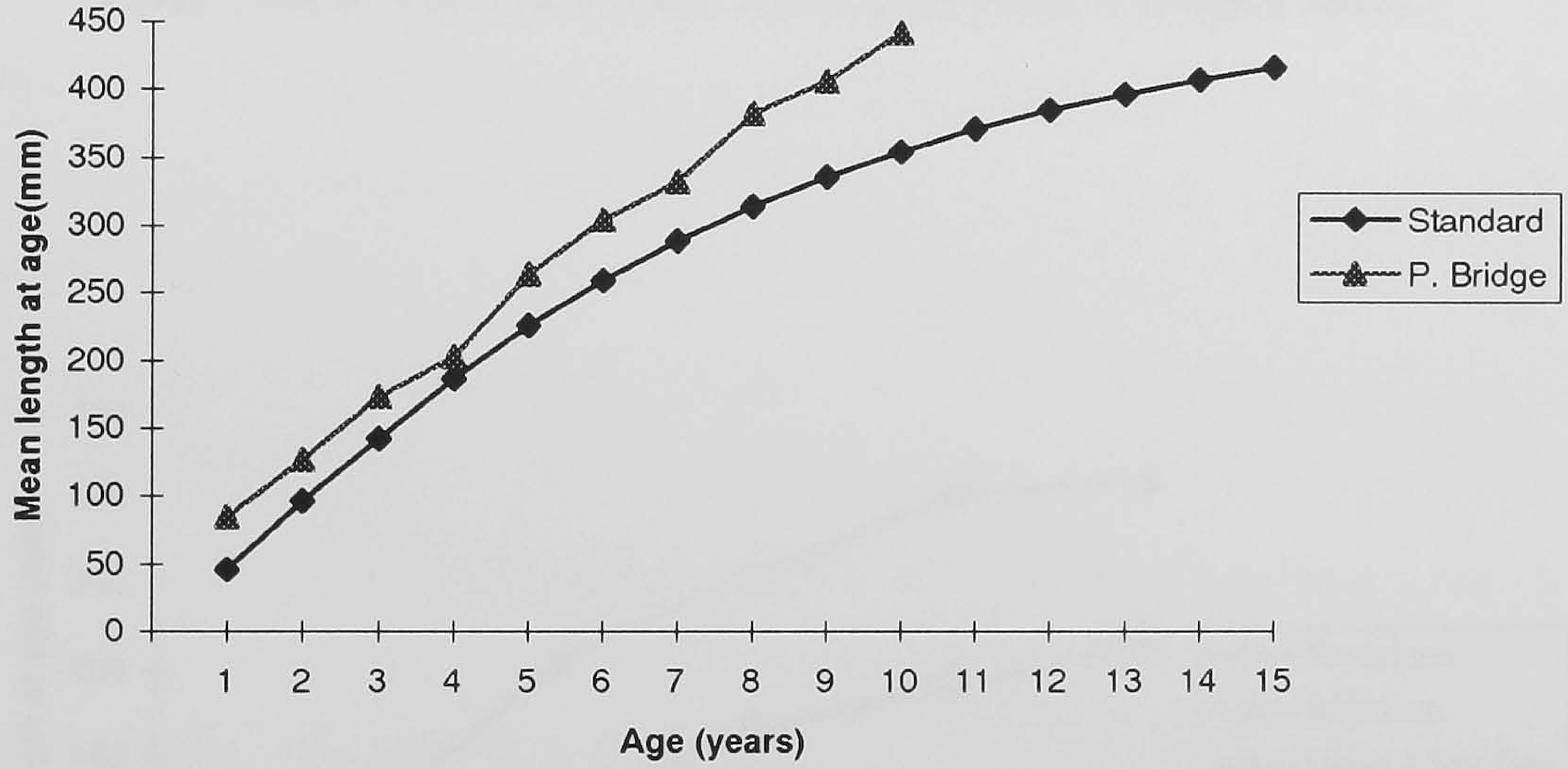


Fig. 5.32. Growth of perch in the Rivers Don at Beeley Woods and Dearne at Pastures Bridge in relation to standard growth (standard curve after Cowx *et al.*, 1993)



5.33. Growth of chub in the River Dearne at Pastures Bridge in relation to standard growth (standard curve after Hickley & Dexter, 1979).

Brown trout in the River Don at Penistone and Beeley Woods exhibited a faster growth rate than was observed in the upper River Tees in Yorkshire (Fig. 5.34). This might be due to an abundance of food for the species, and with the low numbers of fish in the rivers (Appendix 1.7) growth was enhanced.

No differences in growth rates of grayling in the River Don at Penistone and Beeley Woods were apparent (Fig. 5.35). However, growth rates of grayling were slower in relation to the observed growth rates of the species in the Upper River Dee (Woolland &

Jones, 1975), in North Wales (Fig. 5.35). This might be due to relatively more food resources being available for the species in the upper River Dee which enhanced their growth.

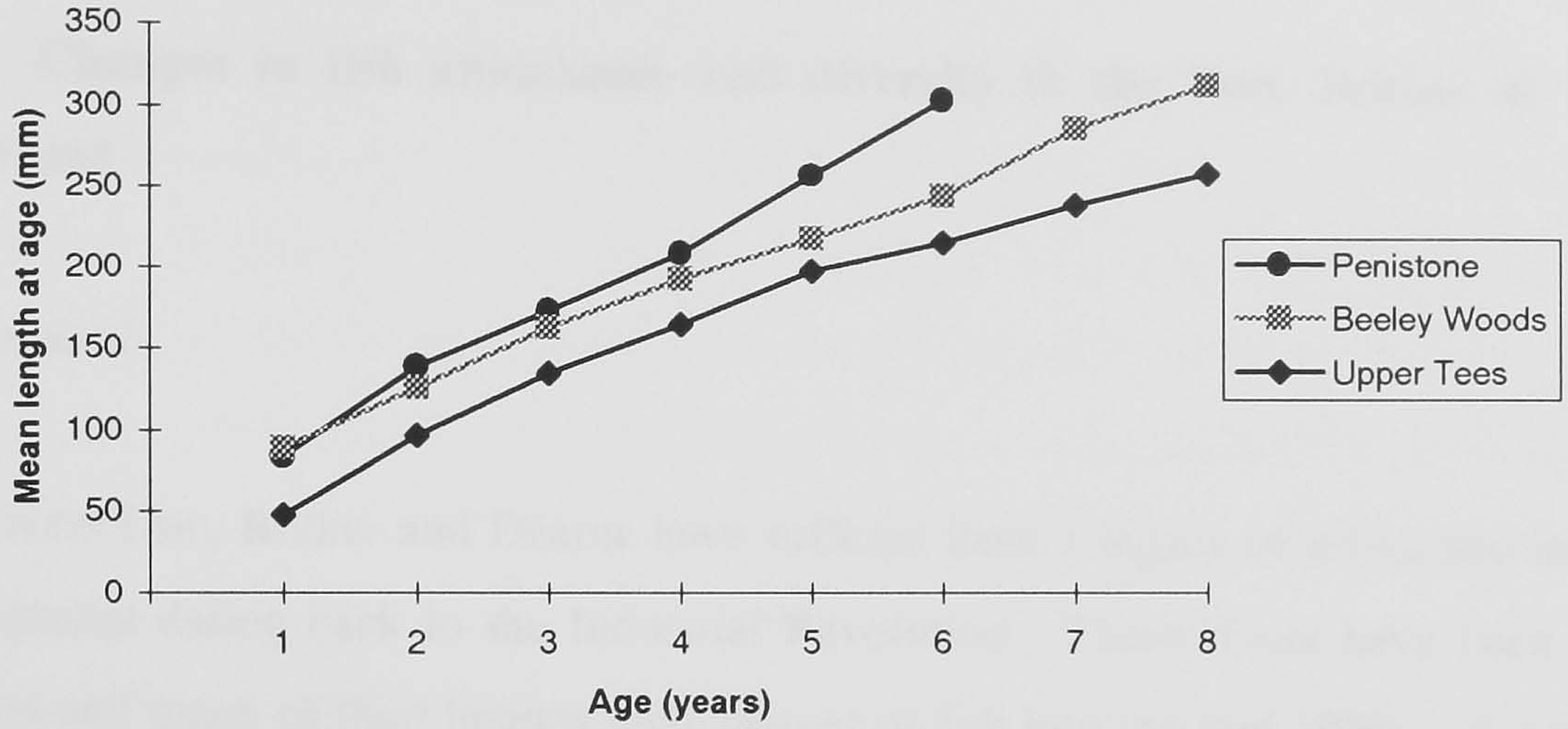


Fig. 5.34. Growth curves of brown trout in the River Don at Penistone and Beeley Woods in relation to growth in the upper River Tees in Yorkshire (Tees curve after Frost & Brown, 1973).

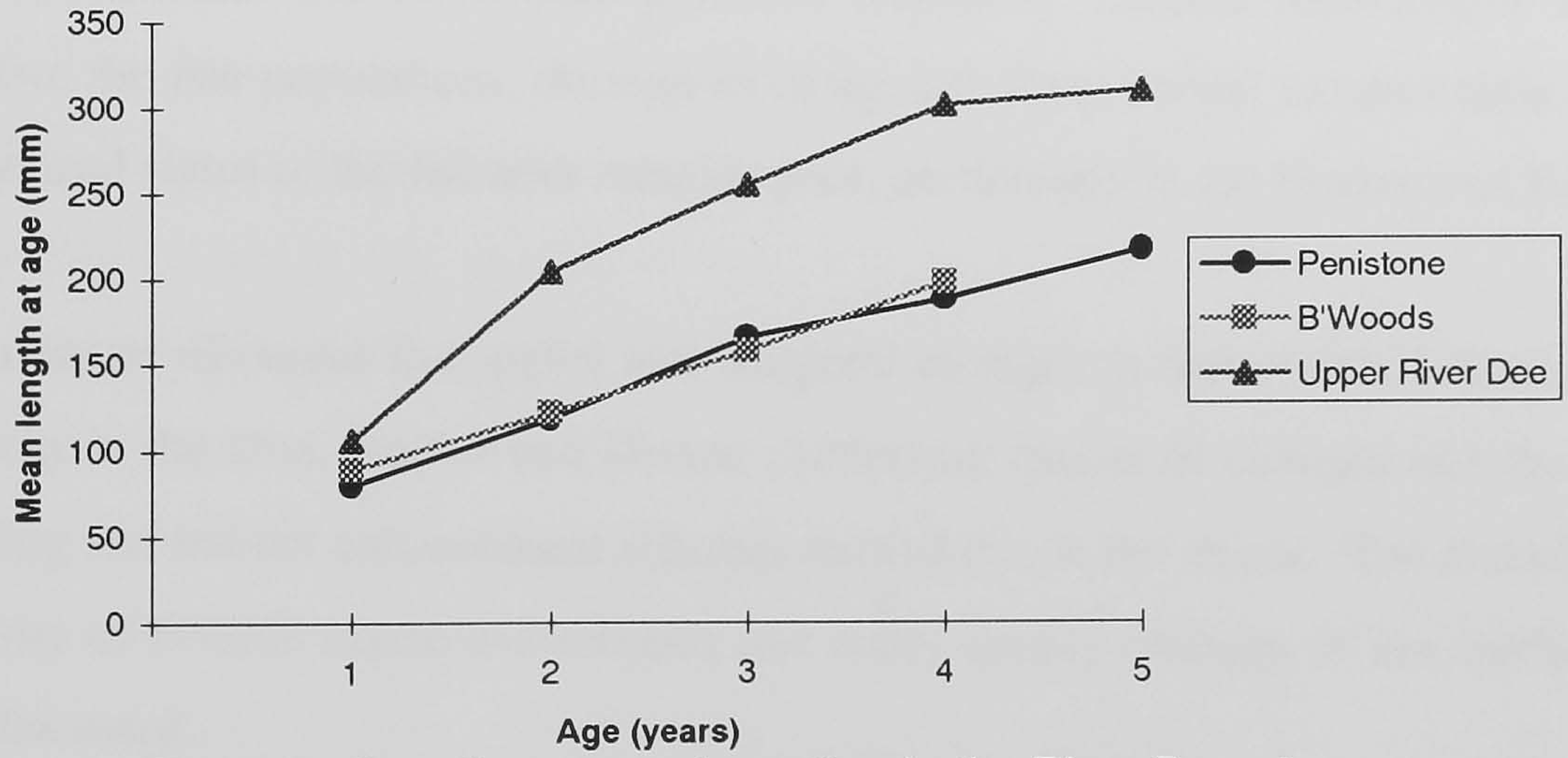


Fig. 5.35. Growth curves of grayling in the River Don at Penistone and Beeley Woods in relation to the upper River Dee (River Dee curve after Woolland & Jones, 1975)

CHAPTER SIX

DISCUSSION

6.1. Changes in fish abundance and diversity in the Don, Rother & Dearne catchment

Background

The Rivers Don, Rother and Dearne have suffered from a legacy of urban and industrial development dating back to the Industrial Revolution. These rivers have been grossly polluted and much of their lengths were devoid of fish into the mid 1980s. A concerted programme to improve effluent discharge from the large number of sewage works serving the urban centres of South Yorkshire, coupled with a decline in coal and manufacturing industries, have resulted in considerable improvements in water quality of the rivers. As a consequence, fisheries of the rivers have shown some evidence of recovery. These improvements are, however, localised and the fish populations suffer periodic setbacks due to isolated pollution incidents. Despite considerable efforts to improve the fish populations, through stocking and some habitat enhancement schemes, the general status of the fisheries remains poor, particularly in the Dearne and Rother.

This chapter discusses the spatial and temporal changes in fish populations and species diversity in the Don, Rother and Dearne catchment, causes of changes and the value of stocking and habitat enhancement schemes carried out in the rivers. The abundance and diversity of benthic macroinvertebrates and water quality changes in the catchment are also discussed.

6.1.1. The Don catchment

Fish zonation

Flow regime is a critical factor determining both physical habitat structure and diversity in rivers, which in turn influence the fish community present (Cowx *et al.*, 1993; Cowx & Welcomme, 1998). These differences have been used by various workers to describe changes in fish community structure in relation to flow and habitat (Huet, 1949, 1959; Vannote *et al.*, 1980; Zalewski & Naiman, 1985). Flow characteristics define the environmental domains within which biological communities develop (Cowx & Welcomme, 1998). The downstream progression with flows becoming slower is associated with a gradual change in the fish community structure, with trout and grayling in the upper reaches whilst the barbel zone and bream zones are represented further downstream. Evidence from this study showed that the longitudinal distribution of fish species in the River Don exhibited a zonation pattern similar to that described by Huet (1949, 1959). The factors structuring the distribution of the species were, however, not apparent.

Fish abundance and species diversity

In general, fish population densities were low and species diversity was poor for most stretches of the River Don (Section 5.1.2). The upper reaches were characterised by the presence of only brown trout with considerable numbers of the species being found at Dunford Bridge and Soughley Farm (Figs 5.1-5.5). Most of the trout probably migrated from the relatively cleaner tributaries such as Ewden Beck and the River Rivelin (NRA, 1994c).

The middle reaches of the River Don have been impacted by discharges from abandoned mines resulting in a deterioration of fish stocks. Pollution of streams by mine drainage is generally considered to be the most serious water pollution aspect of mining operations (Nelson *et al.*, 1991). Effluent waters from abandoned mines may have low pH (2.0-4.5) which is directly toxic to most forms of aquatic life (Hill, 1974), it is conducive to the mobilisation of toxic metals (Fuller *et al.*, 1978), and can form ferric hydroxide ($FeOH_3$) which is precipitated as ochre. Thus, the aerobic oxidation of pyrite (iron sulphide) to ochre (Nelson *et al.*, 1991) may be summarised as follows:

$$1.\ 2FeS_2 + 7O_2 + 2H_2O \rightleftharpoons 2Fe^{2+} + 4SO_4^{-2} + 4H^+$$

$$2.\ 4FE^{2+} + O_2 + 4H^+ \rightleftharpoons 4Fe^{3+} + 2H_2O$$

$$3.\ Fe^{3+} + 3H_2O \rightleftharpoons Fe(OH)_{3\downarrow} + 3H^+$$

Thus, pyrite readily oxidises in water to form sulphuric acid when it is exposed to atmospheric oxygen. Anaerobic production of acid may also occur through oxidation by the anaerobic bacteria *Ferrobacillus ferroxidans*, (Nelson *et. al.*, 1991; Geertz-Hansen

& Rasmussen, 1994), which influences the rate of iron sulphide (pyrite) oxidation to sulphuric acid, and thus lower the pH of the water. Thus,

$$FeS_2 + 14Fe^{3+} + 8H2O \rightleftharpoons 15Fe^{2+} 2SO4^{-2} + 16H^{+}$$

Abandoned mine discharges enter the River Don downstream of Millstone Bridge and the formation of ochre was observed in the River Don at Penistone and Beeley Woods during the study. Pollution problems caused by industrial discharges from Jamont Paper Mills (formerly British Tissues) also impact on the water quality of the middle reaches, particularly at Beeley Woods (Section 5.1.2). These impacts are also associated with the deteriorating fish stocks in the middle reaches. Improvements to discharges from Jamont Paper Mill took place in 1985 (Firth, 1997) resulting in good quality effluent to the river below Outibridge.

Below Sheffield (site 12), poor water quality resulting from discharges from sewage and industry causes a deterioration in fish population densities and species diversity (Figs 5.1-5.5). Upstream of Sheffield fish numbers are constrained by lack of suitable habitats. Sewage and industrial effluents are the primary factors responsible for large scale changes in water quality which have resulted in deterioration of fish stocks (Cowx *et al.*, 1993; Cowx & Welcomme, 1998). The lower reaches of the River Don are characterised by low densities of coarse fish populations (Section 5.1.2).

Fish in rivers depend on undamaged interactive pathways for the successful completion of their life cycles (Cowx & Welcomme, 1998). Thus, uninterrupted or unhindered access to feeding, spawning and nursery areas are important for the successful recruitment of fish. Dams, weirs and other barriers restrict longitudinal movements of fish therefore restricting access to suitable feeding and spawning habitats. Fish movements are limited by weirs or flow control structures in the River Don at Sprotborough, Aldwarke and Beeley Woods. Considerable degradation of fish habitats resulting from the disposal of solid wastes such as scrap metal and rubble in the catchment, e.g. at Deepcar and Hampole, also contributes to the disruption of these pathways. Solid wastes may degrade spawning substrate and smother food of fish. The physical habitat of the lower reaches of the River Don has also been degraded due to culverting and channel modification, e.g. the River Don through Sheffield and Rotherham. As a consequence fish population and species diversity above Sheffield are limited by lack of suitable habitats. Lack of riparian and instream vegetation in many locations in the catchment could affect larval fish which tend to live at stream edges (Tales *et al.,* 1996; Jurajda *et al.,* 1997). Riparian and instream vegetation also provide areas for shelter, cover and refuge during adverse flow conditions and predation (Swales & O'hara, 1983; Grimm, 1993). They also constitute an important food resource for fish (Swales & O'hara, 1983,

The devastation of the Don catchment by various pollution incidents (Table 5.2) has contributed to the low fish abundance and poor diversity in the middle and lower reaches. Marked fluctuations in fish abundance and species diversity characterised the regularly sampled sites of the River Don (Section 5.1.3). Isolated pollution incidents, sampling difficulties and water quality problems contributed towards these fluctuations in density and diversity of the fish stocks (Section 5.1.3).

Fish stocks of the River Don tributaries

The majority of the tributaries of the upper Don appear to be salmonid streams which hold the potential of providing brown trout recruits to the main River Don. Some tributaries, e.g. Rivers Loxley and Rivelin, however, hold limited numbers of coarse fish.

Mining may introduce toxic metals into streams through acid-stimulated mobilisation of metal ions from metalliferous minerals, particularly if discharge occurs through waste piles (Fuller *et al.,* 1978), or from an abandoned mine (Duaime *et al.,* 1985). Most tributaries in the lower section were characterised by low pH and high metal levels (Section 5.1.4) with no fish present (Fig. 5.14), possibly, reflecting acid-metal toxicity impacts on the fish stocks. Information on the actual metals involved was lacking but this could possibly be due to effluents from mines or due to leachates from waste containment sites. Stocking programmes to the tributaries in the lower section have not been successful and fish populations remain low with poor species diversity again due possibly to the low pH and metal toxicity problems.

6.1.2. The Dearne catchment

Fish zonation

The longitudinal distribution of fish in the River Dearne was characterised by only trout and barbel zones being represented (Section 5.1.5). The River Dearne has severe water quality problems for most of its length resulting from sewage discharges and past industrial activity. No grayling was found in the Dearne and a transitional zone between trout and cyprinids was not apparent (Section 5.1.5). In addition, unlike the River Don, no grayling has been stocked in the River Dearne in recent times.

Fish abundance and diversity

The Dearne catchment is characterised by low fish population densities and poor species diversity. The upper reaches of the catchment sustain small numbers of brown trout (Figs 5.16, 5.17 & 5.18). Extensive fish stocking programmes in the upper reaches of the Dearne over the last decade have not been successful due to effluent discharges from industry and sewage treatment works which impact on the water quality. However, there has been considerable improvement to the fish populations of the sites located upstream of Bretton Lakes (Fig. 5.18) since 1994.

The middle reaches of the River Dearne suffered a considerable number of pollution incidents (Table 5.1) which resulted in the devastation of fish populations (Figs 5.16, 5.17 & 5.18). Fish numbers and diversity remain stable but restricted in the middle reaches. Many industries and sewage treatment works are located in the Dearne catchment (Appendix 1.3). These impact on the water quality and have been implicated in the pollution incidents of the middle Dearne. Until 1992, the final effluent from Darton STW (Appendix 1.3) was considered unsatisfactory (Section 5.1.5) and further improvements have taken place.

The Dearne catchment runs through Barnsley Coalfield (Section 4.3.1). Mine effluents from the North Gawber Mine, Barnsley Main Mine, Dearne Valley Colliery and Houghton Main Colliery (Appendix 1.3) impact on the water quality of the middle

Dearne and impoverish the fish stocks.

The lower reaches of the River Dearne between Broom Hill and Pastures Bridge was characterised by relatively low numbers, but high diversity, of cyprinids. The fish stocks in the lower Dearne are also impacted by diverse pollution sources from sewage works, industry and mining (Appendix 1.3), and only marginal improvements in fish abundance have been observed so far.

Sewage effluents

The impact of sewage effluent on water quality and fisheries has been extensively reviewed (Hynes 1978; Gray, 1997; Hall *et al.*, 1997), and can be seen in the Dearne catchment. The sites with no fish or with low fish densities were invariably those immediately downstream of sewage treatment works (Appendix 1.3).

A detrimental effect of sewage effluent is increased oxygen demand which results in lower oxygen levels available for the fish. In a detailed study of the physiological response of carp, *Cyprinus carpio,* exposed to raw sewage Kakuta & Murachi, (1997) showed that there is a very complex relationship between the constituents. Thus quite a small amount of CO_2 increases the susceptibility of fishes to anoxia which itself increases the toxicity of un-ionised ammonia. The toxicity of ammonia is, however, reduced by the presence of carbon dioxide, which by lowering the pH causes the formation of the less toxic ammonium ion (NH_4^+).

Sewage fungus

Between 1985 and 1994, fish were absent from the River Dearne above Bretton Lakes where sewage fungus was found, and from the same river at Darfield where raw sewage was found. Fish and fish eggs do not survive under a carpet of sewage fungi nor amidst raw sewage (Hynes, 1978) even if the water remains well oxygenated (Kakuta & Murachi, 1997). The presence of sewage fungus may provide some food for fish but it also places a restriction on spawning habitats.

Organic effluents

Pollution from organic sources resulted in catastrophic mortalities of fish in the Dearne catchment between 1987 and 1991 (YWA, 1989). In 1985, 261 fish were killed by a discharge from Shaw carpets at Darton (Table 5.1). This was a typical example of a severe organic pollution input. Fishes are generally eliminated for long distances by severe organic pollution, but the reason why this occurs is not always clear (Hynes, 1978). Fish populations below Darton and Star Paper Mill were poor and species diversity was low due to the poor water quality. This observation agrees with the findings of some investigators who observed poor fish densities or absence of fish below the outfalls of organic discharges (Otway *et al.*, 1996; Hall *et al.*, 1997).

6.1.3. The Rother catchment

The Rother catchment has a legacy of land contamination that dates back many years. The clean air campaign of the 1960s aimed at reducing air pollution in Britain (Firth, 1997). The massive demand for smokeless fuels led to the proliferation of coal carbonisation plants in the Rother Valley, hence making the catchment one of the world's largest concentration of such industries (Firth, 1997). The removal of toxic by-products through various decontamination processes resulted in some of the leachates finding their way into the Rother catchment. This legacy of land contamination has proved to be one of the biggest problems over the last 20 years. The development of a fishery will depend to a large extent on the maintenance of consistently good water quality and in the effective control of intermittent pollution problems.

Fish zonation

No distinct zones in the longitudinal distribution of the fish species were found in the River Rother. The water quality and land contamination problems of the catchment appear widespread and fish tended to aggregate in relatively cleaner habitats. Salmonids and coarse fish were found at the headwaters, middle and lower reaches (Section 5.1.8) with no apparent delineation of zones.

General trends in fish abundance and diversity

Fish populations were low and sporadic in their distribution with little or no improvement over the years. Species diversity was poor rarely exceeding a Shannon-Weiner index of 1.5 in both the main river and in the tributaries. The upper reaches of the Rother from North Wingfield (site 1) to Catcliffe (site 11) were devoid of fish due to habitat and water quality problems.

In 1984, many stretches of the River Rother were designated water quality class 4 (Appendix 1.2) and many sites were fishless (Figs 5.22, 5.23 & 5.24) due to water quality problems arising mainly from intermittent pollution from STWs and industrial sources. Lack of fish in the main river was also due to lack of suitable habitats, e.g. the River Rother at Birdholme (site 2) and Slittingmill (site 6) (Figs 5.22, 5.23 & 5.24).

Little or no improvement in the fish status was observed in 1988. By 1994 improvements to sewage and industrial discharges had been made but this did not lead to improvements in the status of fish stocks in the main river. However, some considerable improvements in the fish stocks were made in the River Doe Lea, a tributary of the Rother. These improvements were linked to increased dilution to colliery discharges to the tributary from Markham and Bolsover Mines. Other tributaries which held considerable densities of fish (brown trout) were the River Hipper at Somersall Lane (site 24) and at Holymoorside (site 25) and Brookside Beck (site 26) Brookside (Fig. 5.24). Limited numbers of brown trout and coarse fish were captured in the tributaries from Birdholme Brook (site 35) to the Moss (site 38) (Fig. 5.24). Most of the brown trout were thought to have originated from previous stocking. Between Pigeon Brook at Aston (site 39) and Whiston Brook (site 46) no fish were found (Fig. 5.24), and sewage litter was observed at this location. Poor water quality due to sewage impacts appear to be the main cause in the lack of fish at these locations.

In 1995 a survey to assess the survival of stocked coarse fish indicated that the stocking was unsuccessful due mainly to habitat and water quality problems (Fig. 5.25). The Moss Brook (site 48) (Fig. 5.25) suffers intermittent pollution discharges (EA, 1997) and therefore the lack of fish would be expected. At Rother Valley Country Park a mixed cyprinid assemblage was found. Fish density and diversity was higher below the weir (site 50) than above the weir (sites 49) (Fig. 5.25), due possibly to enhanced oxygenation below the weir.

6.1.4. Stocking programmes

Stocking programmes in the catchment appear so far to have been unsuccessful due mainly to the impacts of sewage and industrial effluents on the water quality and the degraded state of fish habitats.

The results of the 1988 fisheries survey of the River Dearne were poor despite a major re-stocking programme which was undertaken in the previous three years. More than 10000 mixed coarse fish were released (Firth, 1997) by Yorkshire Water and angling interests groups in an attempt to assist in this enhancement. Yet in the 1988 survey only a few of the small numbers of fish caught could be traced to the re-stocking work. Over the following three years, the middle Dearne suffered more acute pollution incidents (Table 5.1). which were compounded by the chronic effects of poorly treated sewage. The causes of these incidents were traced to the two sewage treatment works serving Barnsley at Darton and Lundwood.

In response to the improving conditions of the Dearne between Darton and the centre of Barnsley (resulting from work at Darton STW), Yorkshire Water and the EA have carried out extensive stocking in recent times. The general conclusion about this stocking is that this form of enhancement is largely ineffective because of absence of good habitats and continued water quality problems. All efforts should concentrate on reduction of the water quality problem to enhance the fish stocks and remove this bottleneck to survival of the fish populations.

6.1.5. Fish Pathology

Considerable numbers of fish that were caught in the surveys of 1981 and 1984 in the River Don were found to have various pathological symptoms. The majority of fish examined revealed the presence of parasites normally associated with lentic water conditions, such as eye fluke, *Diplostomum,* infestations. Many fish also had gill damage, burst lenses, fin erosion and fungal infestations (Yorkshire Water, 1982). Other pathological manifestations were abnormal ovaries in some stoneloach and nodular testes in some minnows.

Digenean eyeflukes of the genus *Diplostomum* and related genera are widespread and common parasites of freshwater fish (Kennedy, 1974; Chappel *et al.*, 1994)). Cercariae emerging from the molluscan first intermediate hosts, *Lymnaea* spp. penetrate the skin and gills of the fish host and migrate to the eye. The metacercariae of certain species including *Diplostomum spathaceum* (L) lodge in the lens of the eye where they may cause serious pathological effects (Shariff *et. al.*, 1980). Infection can reduce host vision and hence impede feeding (Owen *et al.*, 1993), increase susceptibility to predation and cause direct mortality among infected fish (Brassard *et al.*, 1982a, b). In this study, many gudgeon with burst lenses were reported. This was related to heavy *Diplostomum* infestations.

The aquatic environment places many demands on fish and other organisms. Stress responses in fish to a variety of environmental changes, including pollution have been documented widely (Laitinen *et al.*, 1996), but one source of stress rarely considered is that imposed by parasites. Freshwater fish under natural conditions are exposed to free-swimming larval stages of a variety of parasite species. The penetration mechanisms of fish parasites and their pathological effects on hosts tissues have been described extensively (Williams & Jones, 1994). However, few studies have considered the behavioural responses of fish to larval parasites or the physiological responses following infection (Laitinen *et al.*, 1996).

The abundance and diversity of parasite infestation have been linked to various effects of pollution and habitat degradation with higher levels in stressed environments (Valtonen *et al.*, 1997). Pollution and habitat degradation problems in the catchment therefore represent important factors contributing to the incidence of fish parasitic diseases in the rivers.

The fish pathological conditions observed in the study are particularly relevant. Parasites are known to reduce growth and recruitment (Hine & Kennedy, 1974, Kennedy, 1974).

Further research to update knowledge on the status of fish diseases in the catchment would be worthwhile. The control of parasites or pathogens in the rivers through pollution control appears to be important in reducing parasite numbers (Valtonen *et. al.,* 1997). This would enhance fish health, survival, growth and recruitment.

6.1.6. Recent changes in fish status in the Don, Rother and Dearne catchment.

River Don at Penistone

In the River Don at Penistone, brown trout and grayling were the only fish of recreational importance that were caught. Brown trout numbers remained fairly steady but there were considerable fluctuations in the number of grayling present (Fig. 5.27). The reasons for the changes in fish numbers have been presented in Section 5.2.1 and relate to river conditions and water quality problems. Abandoned mine discharges impact on the water quality of the River Don at Penistone and this possibly restricts the fish populations at this site. The declining numbers of grayling appear to be linked to the intermittent discharge of mine waters to the river at this site (Section 5.2.1). Declines in fish populations that are caused by discharges of mine effluents often result from failure to recruit young age classes (Nelson, 1982). Studies have shown that early developmental stages of fish are more sensitive than later stages to low pH (McKim, 1977; Brungs *et al.,* 1978). Several studies have documented considerable susceptibility to low pH during the alevin stage (Kwain, 1975; Menendez, 1976; Daye and Garside, 1980). The low fish numbers of brown trout and grayling might be attributed to poor recruitment of the species.

The River Don at Beeley Woods

Beeley Woods is located downstream of the River Don at Penistone. Fish numbers and species diversity was higher in the River Don at Beeley Woods than was observed upstream in the River Don at Penistone. This might be related to abundance of food and suitable holding places for fish.

Coarse fish were caught in all the surveys but brown trout were captured only occasionally (Fig. 5.28). Grayling disappeared from the catch after February 1996 and by May 1997 no brown trout was found. A deterioration in water quality associated with the drought possibly caused the disappearance of the species as they are intolerant to pollution.

A generally downward trend in species diversity characterised the River Don at Beeley Woods. The decline was probably due to low flows and poor water quality which possibly caused fish to disperse to other parts of the catchment. There is also a weir upstream of Beeley Woods which restricts fish movements. These factors affect fish abundance and species diversity of the River Don at Beeley Woods.

Fish abundance and diversity in the River Don at Penistone & Beeley Woods.

No significant difference was found between fish densities in the River Don at Penistone and downstream at Beeley Woods (Levene's Test For Equality of Variances, $P > 0.05$) (Appendix 1.5). On the contrary, there were significant differences ($P < 0.05$) between species diversity and species richness at the two sites. An increasing trend in species diversity downstream was evident from the study. This trend is in accordance with the findings of Vannote *et al.* (1980) and Zalewski *et al.* (1990), in that species diversity tends to increase downstream. The higher species diversity at Beeley Woods might be the result of more suitable holding places for the various species, and of abundant food sources. The abundant woody debris (snags), mud, silt and decomposing leaves from bankside vegetation provide a more diverse habitat for the macrobenthic invertebrates. These habitats often serve as feeding areas for fish species that feed on benthic macroinvertebrates (Brownlow and Bowlen, 1994; Meffe & Sheldon, 1988). This might partly account for the higher fish species diversity at Beeley Woods. These features were not evident in the river at Penistone.

River Dearne at Cudworth Common

With the exception of 3 gudgeon and a yearling roach no fish were caught in the River Dearne at Cudworth Common between 1995 and 1997. Earlier surveys by the EA (formerly NRA) and Yorkshire Water yielded no fish. Water quality problems due to sewage, industrial, and mine water effluents are implicated in the lack of fish in the river

(Section 5.2.3). The habitat is characterised by massive growth of *Ranunculus* species suggesting considerable organic enrichment at this site. Olfactory evidence of decomposing sewage was noted during the study, suggesting the presence of sewage effluents from the Lundwood STW located upstream of this site.

The River Dearne at Pastures Bridge

Roach and gudgeon were captured in all the surveys, with roach dominating the catch at all times (Fig. 5.29). In 1995 the River Dearne at Pastures Bridge was re-engineered to include meanders in an otherwise straight trapezoidal channel (Firth, 1997). In subsequent surveys the majority of fish were captured in the meandering sections of the river. However, this re-engineering work of the channel has not improved the general status of the fish stocks at this location (Fig. 5.29), and fish populations and species diversity remain poor. It is unclear why fish populations have not consistently improved but this might be related to occasional low flows which results in migration of fish to other habitats, or perhaps due to natural shifts in fish abundance.

The results of the survey carried out before the re-engineering of the channel in 1994 indicate that fish population densities improved only marginally in 1995. Species diversity was, however, lower in 1995, i.e. after the re-engineering works (Fig. 5.29). The higher diversity found in 1994 (Fig. 5.21) has not been attained since. It is probable that movement of some species to other parts of the catchment took place during or after the re-engineering exercise.

The low fish numbers found in March 1997 was probably due to a dispersion of fish to other parts of the catchment in response to the low flows at that time. Surveys carried out by the EA in March 1997 elsewhere in the Don catchment also found greater reductions in fish numbers, and a lack of recruitment was found in at least two sites (EA, 1997).

There is little or no riparian vegetation in this stretch of the River Dearne. Protected and controlled riparian vegetation at the stream edges plays a major role in increasing fish stocks (White and Brynildson, 1967; Garcia de Jalon, 1995). It provides fish with cover, bank stability, terrestrial food supply, cool summer water temperatures and overwinter protection (Garcia de Jalon, 1995). It also controls cross-sectional shape, favouring deeper stream channels that have higher refuge capacities (Platts, 1991). Although including meanders appeared to have provided some refuge for fish, the lack of riparian vegetation is an important omission and it is recommended that riparian and in-stream vegetation is provided to enhance fish status in the river.

The River Dearne at Pastures Bridge is located in a predominantly rural and agricultural area and is impacted by run-off from various agricultural activities. The river at Pastures Bridge also receives discharges from Harlington STW located upstream (Appendix 1.3). It remains unclear whether discharges from these sources impacted on the water quality at this time to result in the poor fish abundance and diversity.

The River Rother at Birdholme Bridge

The River Rother at Birdholme (Chesterfield) remained fishless during the study. A combination of factors are implicated in the absence of fish in the river at this location and these have been described in Section 5.2.5. The river flow was generally poor and the habitat was contaminated with various domestic wastes. Riparian and instream vegetation was very much restricted and the river bank was littered with various human wastes that eventually found their way into the river. The river lacked suitable holding places for fish. Discarded motor oils in bottom sediments of a river, as was observed in the River Rother at Birdholme, do not enhance water or habitat quality. Consequently, the improvement of water quality and the restoration of degraded habitats in the River Rother are crucial and should be addressed prior to any fish stocking exercises being undertaken. Fish stocking exercises carried out in the past in the Rother have been of little or no value due to the prevailing water quality problems and the degraded habitats.

The River Rother still suffers from serious pollution problems for most of its length. The upper reaches of the River Rother have few or no fish due to poor water quality and lack of suitable habitats. Despite closure, the coking works at Wingerworth has left a legacy of tar pollution (Firth, 1997) that still devastates aquatic life. The river quality can only be described as poor. Through Chesterfield effluents from Old Whittington STW impact on the water quality of the Rother. The water quality has been poor since 1970 (Firth, 1997). The works now operate under stricter consent conditions in an attempt to improve the quality of effluent discharged to the Rother. Partly due to the improvements at the Old Whittington STW, the River Rother is now able to support limited coarse fish stocks downstream of the Chesterfield conurbation; the first time in almost 100 years that fish have been present (Firth, 1997).

6.1.7. Fish growth in the Rivers Don and Dearne

Growth is an important aspect of the ecology and life history strategy of fish, and quantification of growth is frequently a crucial part of fisheries research and management (Summerfelt & Hall, 1987; Weatherley and Gill, 1987). Back-calculation of fish lengths from scales is a widely used approach for estimating the growth history of individual fish and for characterising the growth of fish populations (Jearld, 1983; Carlander, 1987; Busacker *et al.*, 1990).

The growth rates of roach in the River Don at Beeley Wood and in the River Dearne at Pastures Bridge did not differ appreciably in the first 4-5 years of growth. Thereafter the roach at Pastures showed a slight increase in growth which was marginally above the standard growth curve (Fig. 5.30), possibly due to diet change or the abundance of a good food base (Cowx, 1989). However, dace in the two rivers showed a faster growth rate than the standard growth rate (Fig. 5.31). It is probable that the observed growth rates were related to the relative abundance of preferred food resources of the various species (Cowx, 1989). The preferred food of dace in the two rivers was, possibly, more abundant than those for roach, therefore enhancing its fast growth. This aspect, however, was beyond the scope and vision of this study. The two rivers appear to be in an intermediate state of pollution with considerable organic enrichment enhancing availability of various food sources for fish, thus possibly resulting in the observed growth rates.

The growth curves of perch in both the River Don at Beeley Woods and the River Dearne at Pastures Bridge were above the standard or average growth curve (Fig. 5.32), suggesting faster growth rates for the species at these sites. There was little or no difference in the growth pattern of the species in the two rivers. In the River Don at Beeley Woods, perch were often captured among macrophyte cover where large numbers of minnows were also found. Minnows provide a source of food for perch therefore enhancing their growth rates.

Chub were only captured in the River Dearne at Pastures Bridge. The growth rates were faster than the standard growth rates (Fig. 5.33). Coarse fish, including chub, have been stocked into the middle and lower reaches of the River Dearne prior to the surveys and most of the chub captured possibly originated from previous stocking.

Growth rate of brown trout in the River Don at Penistone was better than has been observed in the upper River Tees in Yorkshire and only marginally better than the River Don at Beeley Woods (Fig. 5.34). It would appear that the preferred food resources of the species was relatively more abundant in the River Don at Penistone and this possibly enhanced growth rates. Food preferences of the species were, however, not investigated as this was beyond the scope and vision of this study. There were no apparent differences in the growth rates of grayling in the same river at Penistone and Beeley Woods (Fig. 5.35). The reason for this observation is unclear, but this might be related to the exploitation of similar food bases by the species at the two sites. The growth of grayling at the two sites was lower than that determined by Woolland and Jones (1975) for the same species in the upper River Dee in North Wales (Fig. 5.35). This might also suggest a relatively good food base, and perhaps more suitable habitat conditions, for the species in the upper River Dee.

The fast growth of all species suggests that all rivers have the capacity to support larger fish populations. However, this will not be possible until the bottlenecks restricting the survival and recruitment are removed.

6.2. Macroinvertebrate abundance and diversity

The use of aquatic macroinvertebrates to assess the biotic integrity of rivers has been extensively reviewed (Miller *et al.*, 1988; Gerritsen, 1995; Paller *et. al.*, 1996). The usefulness of macroinvertebrates as indicators of biological water quality has been reviewed in Chapter 2. This section discusses the abundance, diversity, species richness and evenness of macrobenthic fauna in the River Don at Penistone and Beeley Woods, the River Dearne at Cudworth Common and Pastures Bridge and in the River Rother at Birdholme Bridge.

6.2.1. The River Don at Penistone

The macrobenthic fauna of the River Don at Penistone was characterised by pollution-tolerant species with Chironomidae and Asellidae dominating the fauna (Fig. 4.31a & 4.31b). Species diversity, species richness and evenness were low (Fig. 4.31b). Heterogeneity of substratum particle size is considered to be of critical importance in providing varied microhabitats which are able to support an abundant and diverse fauna (Scullion *et al.*, 1982). The river bed at Penistone was generally characterised by different sizes of rocks, stones and boulders, perhaps providing heterogeneity of habitat for the fauna. The low species diversity might partly be attributed to water quality problems as pollution-sensitive organisms were absent.

In this study, macroinvertebrate diversity was low. Morse *et. al.,* (1980) collected large numbers of macroinvertebrates in Georgia (USA), and concluded that their abundance and diversity seemed associated with the heterogeneous environment produced by macrophyte growth. Macrophyte abundance in the River Don at Penistone was sparse and restricted. Hence, this condition limited the diversity of niches for several types of macroinvertebrates possibly resulting in the observed low diversity of the macroinvertebrates. The ASPT scores were low and remained fairly stable throughout the study (Fig. 4.31b), but there were considerable fluctuations in the BMWP scores.

The major controlling factor in the distribution of invertebrates is the nature of the river bed (Hynes, 1978). The river bed may be the "eroding" type which is often characterised by rocks, stones, gravel and boulders. It may also be a "depositing" type characterised by silt or mud (Hynes, 1978). The intermediate condition, sand, forms a convenient dividing line as it is a particularly unsuitable habitat for animal life, and is often almost barren. Superimposed on any of these types of substratum may be found weed beds which provide a third type of substratum. The river bed at Penistone is mainly the "eroding" type with stones, gravel, boulders and rocks although patches of mud occur in places. This partly explains the occurrence of the various macrobenthos found at this site.

The generally low diversity of the macroinvertebrate fauna in the river at Penistone might also be linked to water quality problems resulting in the elimination of species that are intolerant of the prevailing pollution status. The *Gammarus* found in the samples occurred only in February and June 1996, and was not found in subsequent surveys. The relatively low frequency of occurrence of *Gammarus* was possibly a result of declining or poor water quality.

Many workers have investigated the effects of flow perturbations on stream macroinvertebrates. Evidence suggests that changes in flow resulting from natural or artificial causes substantially modify the abundance of invertebrates in rivers (Brooker & Hemsworth, 1978; Evans, 1979; Irvine, 1985). High flows have been associated with general increases as invertebrates are flushed out, and low flows with reductions (Brooker & Hemsworth, 1978). The reduced flows between December 1996 and May 1997, possibly, contributed to the low macroinvertebrate abundance and diversity (Figs 4.31a & 4.31b) observed.

6.2.2. The River Don at Beeley Woods

As in the River Don at Penistone, the macrobenthos was dominated by pollution-tolerant forms with Asellidae, Chironomidae, and Erpobdellidae occurring in all samples (Fig. 4.32a & 4.32b). The results of the macrobenthic surveys on the River Don at Beeley Woods reveal low values for Shannon-Weiner, Margalef and Pielou indices (Fig. 4.32b) suggesting low degrees of diversity, species richness and species equitability respectively. The BMWP and ASPT scores were low (Fig. 4.32b), suggesting poor water quality. The river at Beeley Woods appeared to provide a more diverse habitat than at Penistone due to the presence of snags, debris and decomposing macrophytes on a predominantly rocky and stony substratum (Section 4.10). This might partly account for the relatively higher species diversity in the River Don at Beeley Woods.

Macroinvertebrate abundance and diversity in the River Don at Penistone & Beeley Woods.

There were no significant differences between the BMWP and ASPT scores in the River Don at Penistone and those of Beeley Woods (Levene's Test For Equality of Variances, $P>0.05$) (Appendix 1.6). There were, however, significant differences in the species diversity of the macrobenthos (Levene's Test For Equality of Variances, P= 0.05) at the two sites. As with the fish diversity, macroinvertebrate diversity was higher downstream supporting the river continuum concept. No significant differences in evenness and species richness (P> 0.05) were found for the two sites and it appears that the higher species diversity at Beeley Woods was due to species numbers. The Shannon-Weiner function increases as both the number of species and the equitability of species distribution increase.

6.2.3. The River Dearne at Cudworth Common

The macrobenthic fauna of the River Dearne at Cudworth Common was dominated by characteristic taxa found in polluted waters; Asellidae, Chironomidae and Erpobdellidae. The domination of the macrobenthic fauna by pollution-tolerant species, with Asellidae being the most abundant on all occasions (Fig. 4.33a & 4.33b), indicates the river probably suffers gross organic pollution or simple eutrophication The strong repellent smell of the waters appears to lend credence to this observation. The river receives domestic, sewage and industrial wastes from the Barnsley area. Species diversity, richness and evenness were low (Fig. 4.33b) as a consequence and no pollution-sensitive taxa were found. The poor assemblage of the macrobenthic community appears to be related principally to organic enrichment (Pinder & Farr, 1987; Whitehurst & Lindsey, 1990) with sewage effluents being implicated most. The observed low BMWP and ASPT scores (Fig. 4.33b) reflect the poor water quality of the river at this site.

6.2.4. The River Dearne at Pastures Bridge

Unlike the River Dearne at Cudworth Common the macrobenthic invertebrate fauna at Pastures Bridge was generally dominated by Gammaridae (Fig. 4.34a & 4.34b), suggesting a relatively clean water. The Gammaridae are freshwater crustaceans and are frequently associated with clean running waters and often found in great abundance (Fitter & Manuel, 1986). Apart from Gammaridae, the remaining fauna consisted of pollution-tolerant taxa with Asellidae, Chironomidae and Sphaeriidae, (Fig. 4.34b) suggesting some degree of organic enrichment (Section 4.12). Species diversity, richness and evenness were low (Fig. 4.34b) indicating a poor macroinvertebrate community. The substratum of the River Dearne at Pastures Bridge consists mainly of muddy sediments and some riffle areas with stones and gravel providing suitable habitat for the Gammaridae. This diversity of habitat was, however, restricted. Heterogeneity provided by the substratum and habitat was therefore limited and, possibly, restricted the diversity of the macrobenthic fauna (Scullion *et al.*, 1982). Improvements to discharges from Harlington STW located upstream might have enhanced water quality at Pastures Bridge, hence the dominance of the macrobenthic community by Gammaridae. However, the BMWP and ASPT scores show that water quality is still poor (Fig. 4.34b), and would require further improvements.

6.2.5. The River Rother at Birdholme Bridge

Macrobenthic invertebrates in the River Rother at Birdholme (Chesterfield) were characterised by pollution-tolerant forms only, with Chironomidae representing the dominant group (Fig. 4.35a & 4.35b). Asellidae constituted the next dominant group in the fauna. Motor fuels and oil spillage from the main arterial road were observed in the surface waters and in the bottom sediments as they were agitated (Section 5.2.5). This could affect the level of dissolved oxygen in the water. In their studies on the effects of motorway run-off on freshwater ecosystems, Maltby *et al.*, (1995) reported an increase in sediment concentration of total hydrocarbons, aromatic hydrocarbons, heavy metals and some anions. It is probable that the run-off from the main arterial road created a similar condition at this stretch of the river. This affects water quality and, possibly, the abundance and diversity of the macrobenthic community.

Species diversity, richness and evenness were low although the number of individuals represented by only pollution-tolerant taxa were high for most species. Similarly, BMWP and ASPT scores were low, reflecting the poor water quality of the river.

The river was in a poor condition as domestic wastes, including empty cans, old prams, polythene wrappers, concrete bricks, faecal matter and concrete washings from a building construction site, were observed at this site. This is perhaps one of the major problems accounting for the poor state of the river. Whilst these human wastes might be providing a more varied habitat they also block the channel and impede flow and thereby limiting the habitat suitability to some aquatic biota. The potential for flooding may be enhanced and this could also pose a threat to life and property in the area. The wastes may also smother spawning substrate of fish. The condition in the River Rother at Birdholme lends evidence to the fact that the river is seen as a dumping ground for unwanted domestic wastes. Consequently the river is unsightly and unattractive. The poor macroinvertebrate diversity (Fig. 4.35b) and the absence of fish in the river over the last decade calls for an urgent need to address the water quality problems facing the Rother sub-catchment as a whole. Rehabilitating the fish stocks of the Rother catchment can only be an appropriate exercise if the water quality problems are addressed first.

In general, the BMWP and ASPT scores for the sites were low. Samples sizes, which were frequently small, might have affected the biotic scores observed. River conditions, e.g. low river flows due to drought conditions, possibly, affected the number and species of macroinvertebrates present (Brooker & Hemsworth, 1978; Evans, 1979), leading to the low scores.

The ASPT scores were found to be more stable with changes in macroinvertebrate types whilst the BMWP was more sensitive. These findings agree with those of Pinder & Farr (1987) who found that the BMWP scores were most sensitive to slight changes in pollution status. The ASPT score represents an average and are much less affected by sample size, season and habitat (Calow & Petts, 1994).

6.3. Water quality of the Don, Rother & Dearne catchment

The Don, Rother and Dearne catchment has water quality problems which have impacted on the fisheries of the catchment for many years. Although various major improvements have been undertaken in the last seven years, much work remains to be done particularly in the Rivers Dearne and Rother, and their tributaries. The impacts of sewage works, combined sewer overflows, industrial discharges, contaminated land, mine effluents and pollution incidents continue to threaten the recovery of fish stocks in the catchment. Water quality problems in the catchment have frequently resulted from high ammonia and BOD levels and man-made contributions of heavy metals to river sediments over the past years.

Ammonia is a common pollutant of fresh waters originating from sources which include sewage effluent, industrial discharges, agricultural wastes, and as a natural end product of protein catabolism through intensive fish culture (Twitchen & Eddy, 1994). It is highly poisonous to salmonids and symptoms of acute toxicity include hyperventilation, hyper-excitability, convulsions, loss of equilibrium, coma and death (Twitchen & Eddy, 1994).

This section discusses the temporal and spatial trends in water quality in the Don, Rother and Dearne catchment and the improvements that have taken place over the last decade. The water quality of the sub-catchments are discussed below.

6.3.1. The upper Don

Ammonia and BOD levels

Between 1988 and 1991, the level of ammonium nitrogen in the upper Don was low and within the EQS limits (EC, 1978) (Fig. 4.1). The building and commissioning of the Cheesebottom STW in 1977 and the shutting down of other small sewage discharges upstream in 1978 (Firth, 1997) possibly contributed to the observed compliance of ammonia levels with the EQS standards during this period. This scenario altered in 1991, due possibly to the inadequacies of the sewage treatment system, resulting in the EQS limits being exceeded. Improvements to the sewage treatment works at Blackburn Meadows in 1992 and 1994 have resulted in considerable reductions of ammonia and BOD levels (Figs 4.1 and 4.2).

Trace metals

The upper Don sub-catchment, particularly in the Sheffield area, experiences considerable industrial activity with steel manufacture being of great importance. The sub-catchment also drains old mining areas which release various metals into the rivers. The metal content of river waters and sediments is normally controlled by the abundance of metals in the rocks and soils of the river's catchment area, and by their geochemical mobility (Vivian and Massie, 1977; Dixit & Witcomb, 1983). Thus, a catchment area containing mineralised rocks will usually have elevated metal levels in the waters and sediments of the rivers draining it (Elderfield *et al.*, 1971; Abdullah & Royle, 1972;

Aston *et al.*, 1974). However, very high metal levels in rivers are normally associated with polluting discharges and/or metalliferous mining and smelting activities (Vivian & Massie, 1977; Dixit & Witcomb, 1983). Due to run-off over waste tips and through mines, the pollution may continue for many years after the mining and/or smelting activities have ceased (Dixit & Witcomb, 1983).

Nickel and iron

The potential detrimental effects of iron on the fish populations in streams were recognised in the 1930s (Geertz-Hansen & Rasmussen, 1994). The combination of acid waters and iron on the development of fish eggs and larvae might have the following effects. Soluble iron (Fe^{2+}) might be precipitated as Fe^{3+} on and between the stones or gravel (Scullion and Edwards, 1980), and/or upon the low alkaline surface of fish eggs (Geertz-Hansen & Rasmussen, 1994), and the gill epithelium of sac-fry larvae. There may also be a direct effect of iron on the eggs and larvae (Geertz-Hansen & Rasmussen, 1994) as result of this process. Larsen & Olsen (1950) have also reported gill damage due to precipitation of ochre produced by a lignite mine in Denmark. Where pH falls below 3 or 4 due to sulphuric acid and ferric sulphate, fish will be rapidly killed due to the acidity alone (Alabaster & Lloyd, 1980). However, under conditions where hydrolysis of the soluble iron (Fe^{2+}) is initiated, possibly catalysed by bacteria, the fish may be killed by the precipitation of ochre (Geertz-Hansen & Rasmussen, 1994).

In the upper Don, the decline in steel industry resulted in generally low levels of nickel and iron (Figs 4.11 & 4.12). The toxicity of iron to fishes increases significantly as the pH decreases (Decker & Menendez, 1974; Nelson *et al.*, 1991). Iron concentrations of 2.0 mg l^{-1} have been described as indicators of acid pollution, but the toxic effects of iron on aquatic organisms are not well understood (Nelson *et al.*, 1991). Thus, toxicity due to lowering of pH is enhanced at this concentration. Iron concentrations in the upper Don were generally well below 2 mg l^{-1} (Figs 4.11 & 4.12). It would appear from this observation that acid pollution of the waters was not an issue of concern. However, there were occasional bouts of high iron levels of between 4000 $\mu g\ l^{-1}$ (4 mg l^{-1}) and 10000 $\mu g\ l^{-1}$ (10 mg l^{-1}) which might be related to flushing out of the element during wet weather conditions, or due to discharges from abandoned mines (Fig 4.12), or from leachates from spoil heaps. Nickel is one of the chief metals released by mining operations into rivers or streams (Nelson *et al.,* 1991). It may produce toxic effects alone or synergistically with other metals, but this is less clearly understood (Nelson *et al.,* 1991). The EC (1978) limit for nickel in freshwater bodies is 50-200 $\mu g\ l^{-1}$ (Miller, 1991; Dobbs & Zabel, 1994). Nickel levels in the upper Don were within the acceptable range (Fig. 4.11).

Zinc and copper levels

Although zinc is a constituent of many enzymes and is essential to all organisms, high levels are very toxic to fish (Dixit and Witcomb, 1983). Copper toxicity in water ameliorates in the presence of calcium, magnesium, strontium and barium (Mathis & Cummings, 1973).

Zinc is usually found in nature as a sulphide, often associated with sulphides of copper, lead, cadmium and iron (Hale, 1977). The toxicity of zinc to aquatic animals, like the other metals, is modified by environmental variables such as water hardness, dissolved oxygen, pH and temperature (Holcombe *et al.*, 1979; Nelson *et al.,* 1991). Zinc concentrations apparently have to be high to significantly affect aquatic biota (Nelson *et al.*, 1991). Holcombe *et al.*, (1979) found that exposure of three generations of brook trout to zinc concentrations of 2.6 to 534 $\mu g\ l^{-1}$ had no effect on survival, growth and reproductive success. For salmonids the allowable total zinc concentrations in fresh water ranges between 0.03 and 0.50 mg l^{-1} (EC, 1978). For cyprinids, however, the range is between 0.3 and 2.0 mg l^{-1}. The zinc concentrations of the upper Don (Fig. 4.13) were within the limits defined by the EC Directive and would therefore appear to be satisfactory. The highest concentration of zinc was about 300 $\mu g\ l^{-1}$ (0.3 mg l^{-1}).

Copper is relatively insoluble in natural waters but becomes more soluble as pH declines due to acid hydrolysis of the ion, so it may be introduced into streams via acid mine drainage (Nelson *et al.,* 1991). Copper levels that should be achieved for both salmonids and cyprinids range between 0.005 mg l^{-1} and 0.112 mg l^{-1} (EC, 1978). McKee and Wolf (1971) recommended an allowable maximum copper concentration of 0.02 mg l^{-1} (20 $\mu g\ l^{-1}$) in waters inhabited by fish, but this concentration is often exceeded. The copper levels of the upper Don were generally low and within the EC limits. They were also within the allowable maximum concentrations of McKee and Wolf (1971) (Fig. 4.14).

Copper-induced mortality of fishes occurs when insoluble copper-protein compounds form on gill surfaces; these cause sloughing of gill epithelia, and the fish eventually suffocate (Wilson *et al.*, 1981).

Lead concentrations

Lead is relatively unimportant for aquatic life due to its low solubility (Lloyd, 1992) despite its importance in human toxicology. This property of low solubility limits the occurrence of lead in significant concentrations in most waters. Lead occurs naturally as the mineral galena and its solubility in water decreases with increasing water hardness (Davies *et al.*, 1976). Hale (1977) reported that the solubility of lead in water ranges from 500 $\mu g\ l^{-1}$ in soft water (< 100 mg l^{-1} $CaCO_3$) to 3.0 $\mu g\ l^{-1}$ in hard water. It therefore precipitates in hard waters but solubilises in relatively soft waters. The reasons for this observation are less clearly understood (Hale, 1977) but this might be related to acid hydrolysis of the Pb^{2+} ion to form soluble compounds of lead such as lead sulphate ($PbSO_4$). Lead is toxic to aquatic organisms and fish can be eliminated from waters containing 0.3 mg l^{-1} (Dixit & Witcomb, 1983; Balasubramanian *et al.*, 1995), however, at this level the invertebrates are rarely affected (Dixit & Witcomb, 1983). Lead induced mortality of fishes is similar to that of iron (Nelson *et al.*, 1991). In water containing lead salts, a suffocating film of mucus forms over the body and gills leading to death (Nelson *et al.*, 1991).

The EC limit for total lead in freshwater is 4-20 $\mu g\ l^{-1}$ (Miller, 1991; Dobbs & Zabel, 1994). Between 1990 and 1997, lead concentrations in the upper Don were generally low and within the acceptable EC limits (Fig. 4.15). There were, however, sporadic peak increases exceeding the EC limits (Fig. 4.15), which might be related to overflow from mine tailings and spoil heaps. Lead concentrations were generally below 0.3 mg l^{-1} which has been described as the concentration at which fish can be eliminated from the water (Dixit & Witcomb, 1983; Balasubramanian et *al.*, 1995). Lead mining was an important activity in the catchment in the past (Firth, 1997). The decline in this activity in the catchment might also explain the low levels of the element.

6.3.2. The lower Don

Ammonia and BOD levels

Water quality changes in the lower Don are dictated largely by events in the Rother, upper Don and the Dearne as these eventually combine to form the lower Don. The ammonia and BOD levels of the lower Don showed remarkable reductions after improvements to discharges from STWs in the upper Don (Figs 4.1 & 4.2)) and Darton STW in the Dearne (Fig. 4.6). Improvements to discharges from industrial sources in Doncaster in 1992 and 1994 (Section 4.2.1) contributed to considerable reductions in ammonia and BOD levels. Prior to this period (1988-1992) the ammonia and BOD levels were high and well above the EQS limits (Figs 4.3 & 4.4). This was due to inadequacies in the sewage treatment facilities.

Nickel and iron

Nickel and iron in the lower Don derives from mining activities and from steel industries in the upper Don, particularly around Sheffield. The decline in the steel industry associated with the upper reaches resulted in lower levels of the metals reaching the lower Don, hence the observed low concentrations after 1993 (Figs 4.16 & 4.17). In general the levels of the metals were low. Nickel levels (Fig. 4.16) were within the acceptable standard set by the EC, i.e. 50-200 $\mu g\ l^{-1}$ (Miller, 1991, Dobbs & Zabel, 1994).

Zinc and copper

Zinc and copper concentrations in the lower Don were generally low and stable, as observed in the upper Don (Figs 4.18 & 4.19). Once again the concentrations of the individual metals do not appear to present any serious threats, although periodic peak increases of the metals need to be investigated in detail. The legacy of colliery spoil heaps and contaminated land appear to be the most plausible explanation for the peak increases. The low levels of the metals relate, possibly, to the decline in steel and galvanising activities in the catchment which are important sources of these elements.

Lead concentrations

Lead concentrations in the lower Don in 1990-1997 (Fig. 4.20), were substantially lower than 3 mg l^{-1}, the concentration at which fish can be eliminated from waters (Dixit and Witcomb, 1983; Balasubramanian *et al.*, 1995). They were also within the acceptable EC limits of 4-20 $\mu g\ l^{-1}$. As with other metals, the peak increases observed were possibly related to leachates from lead contaminated sites or metal spoil heaps.

6.3.3. The Dearne catchment

Ammonia and BOD levels

Sewage effluents and pollution incidents are major contributors to the level of ammonia and BOD in the Dearne sub-catchment. The concentration of ammonia has consistently exceeded the recommended EQS (Fig. 4.6) with BOD levels also being high (Fig. 4.7). Some limited reductions in ammonia and BOD concentrations were achieved with improvement schemes at Darton and Lundwood sewage treatment works. Water quality of the River Dearne constitute an important issue and remains a major set-back in the development of fisheries in the catchment.

Trace metals

The River Dearne flows through the Barnsley Coalfield where mining of coal and discharges of mine waters from the collieries and pumping stations take place. Mining may cause concentrations of dissolved metals to exceed background levels, particularly in situations involving acid mine discharge (Finlayson & Ashuckian, 1979; Nelson *et al.*, 1991). Mining may introduce toxic metals into streams through acid-stimulated mobilisation of metal ions from metalliferous minerals (Nelson *et al.*, 1991), particularly if discharge occurs through waste piles.

Nickel and iron

Nickel and iron levels have remained low in recent years (Figs 4.21 and 4.22), as in the other sub-catchments. This has been a result of pit closures and mine water treatment plants being constructed to cut down pollution from this source (Section 4.6).

Zinc and copper

Fluctuation in zinc levels of the Dearne might be attributed to periodic releases from spoil heaps during wet weather conditions. Unlike zinc, copper levels remained low and stable which might be related to the geochemistry of the area. In general the level of both metals were low and will not be expected to adversely affect aquatic biota (Nelson *et al.,* 1991).

Lead concentrations

Lead concentrations were within the acceptable EC limits of 4-20 $\mu g\ l^{-1}$ (Fig. 4.25). Reduction in mining activity in the Dearne catchment has resulted in lower concentrations of lead being introduced into the river (Fig. 4.25). In addition, improvements in pumping of mine waters in the catchment is a contributory factor in the observed low levels of lead.

6.3.4. The Rother catchment

Ammonia and BOD

Ammonia and BOD levels of the Rother catchment were generally high between 1988 and 1992 (Figs 4.9 & 4.10) due to inadequate sewage treatment facilities (Section 4.4.1). However, the closure of coking works in 1992, improvements to the Old Whittington STW in 1993 and the enforcement of discharge consents in 1994 led to a considerable fall in the ammonia and BOD levels to the catchment (Figs 4.9 & 4.10).

In 1988, the tributaries of the Rother were also characterised by high ammonia levels (Fig. 4.8), e.g. the River Doe Lea at Doe Lea Bridge & Netherthorpe (sites 14 & 15). Sewage discharges from Bolsover STW are implicated in the high levels of ammoniacal-nitrogen in the River Doe Lea. On the other hand the River Hipper at Somersall Lane, Trough Brook at Brimington (site 32) and Shire Brook at Beighton (site 43) had satisfactory ammoniacal-nitrogen levels (Fig. 4.8) which were below the recommended EQS (EC, 1978) limit.

Nickel and iron

A legacy of contaminated land from mining and industry characterises the Rother catchment. The extent of contamination appears to be considerably high, hence the shutting down of three of the four existing coking works in 1991-92 and further improvements to STW (Figs 4.9 & 4.10) did not appear to affect the levels of nickel and iron in the river (Figs 4.26 & 4.27). Peak concentrations of the metals were occasionally observed (Figs 4.26 & 4.27). These were possibly related to releases from leachates and waste containment sites in the catchment. In general, however, the iron levels were below the level considered to be indicative of acid pollution (Nelson *et al.*, 1991), thus iron concentrations were less than 2 mg l^{-1}. Nickel levels were below the EC limits of 50-200 $\mu g\ l^{-1}$ (Fig. 4.26) and would be considered satisfactory.

Zinc and copper

The zinc and copper load of the Rother catchment remained stable through 1990-1997. The occasional peak release is explained by drainage from spoil and waste containment sites. Zinc and copper toxicity are related to various environmental variables (Mathis & Cummings, 1973; Nelson *et al.*, 1991), hence no inferences can be made at this stage on the potential adverse effect of the two metals in the catchment.

Lead

Historic lead mining activities in the hills of Chesterfield (Firth, 1997) and the fast development of the coal industry contributed to the level of lead in the Rother catchment. However, lead concentrations since 1990 have been generally low and stable, with occasional peak increases of the metal to the catchment (Fig. 4.30). As with other metals these peak increases were possibly a result of releases from despoiled mine sites or waste containment sites. In general, lead levels were low and within the EC limits (4-20 $\mu g\ l^{-1}$). They were also less than 0.3 mg l^{-1}, the lead-induced mortality level for fishes. The low and steady level of lead might possibly be related also to the lead content in the underlying rock and the geochemical mobility of the metal (Vivian & Massie, 1979; Dixit & Witcomb, 1983).

6.4. Summary

To sum up, this study has highlighted key issues that impact on the fish stocks of the Don Rother and Dearne catchment. Many attempts have been made to restock the catchment with fish to enhance the fish population, but these have generally been ineffective or have only resulted in modest localised improvements. The main reasons for the poor fish population densities are poor water quality and unsuitable or degraded habitats. The poor water quality and degraded habitats have resulted from a legacy of previous industrial and mining activities (NRA, 1994b; EA, 1997; Firth 1997). However, urban development and population increases have also placed further demands on sewage works resulting in some sewage works becoming severely overloaded and becoming less efficient. Improvements to sewage treatment works have been carried out and these have resulted in considerable localised improvements to water quality. Periodic incidents of pollution from sewage, industry and agriculture have often reversed the progress in water quality improvements and usually culminating in the death of many fish. Apart from discharge of ochre from abandoned mines to some sites in the catchment, metal pollution levels were generally within the acceptable EC limits (EC, 1978).

Fish population densities in the Rivers Don, Rother and Dearne remain low with many stretches of the Rother being fishless. Water quality improvements have been localised and often not sustained due to setbacks from pollution incidents in the catchment. Much work is required at many locations to improve water and habitat quality to enhance the fish stocks. It is therefore not out of place to survey the issues impacting on the fisheries of the catchment and to explore the options available for the resolution of the problems. The subsequent chapter addresses these issues and the options for development of the Don, Rother and Dearne catchment for rehabilitation of the fisheries.

CHAPTER SEVEN

CONCLUSIONS

7.1. General

There are many anthropogenic activities which impact on the water quality and fisheries of the Don, Rother and Dearne catchment (Section 2.5). There is also increasing attention to protect, enhance and conserve the fish stocks of the catchment but there is still much scope for effective management of the water quality and fish stocks of the catchment.

The historical and recent surveys of the Rivers Don, Rother & Dearne identified numerous impacts of changes in water quality and habitat degradation on the fisheries of the catchment. Polluting discharges from industry, sewage and mine waters continue to be of major concern in the catchment. The legacy of contaminated land, illegal tipping of industrial and domestic waste compounded by pollution incidents from farmyard manure and silage liquors, animal slurries, sewage, industry and other unknown sources impact on the water and habitat quality resulting in the poor state of the fish stocks.

Remarkable progress has been made to reduce ammonia and BOD levels and improve water quality generally in the rivers through improvements to sewage treatment works. Further improvements are desired to enhance the water quality and fish stocks of the catchment.

Water quality still impacts on fish populations to the extent that they are periodically depleted by *ad hoc* pollution events of known and unknown origins (Tables 5.1 & 5.2). The catchment, particularly the River Dearne, continues to be threatened by pollution incidents from industry, sewage and agriculture. These incidents represent major bottlenecks to improving the fish stocks of the catchment. Much work remains to be done to improve the water quality, rehabilitate the degraded habitats and enhance fish stocks of the catchment.

Whilst the EA and its predecessors have made considerable progress in rehabilitating the fisheries of several stretches of the catchment, there have been various setbacks due, mainly, to water quality problems and pollution incidents which have devastated the fish stocks. The fisheries have, in general, only improved marginally. Indeed, in many cases little or no improvement to the status of fisheries has been achieved and many sites remain fishless. The River Dearne at Cudworth Common, the River Rother at Birdholme (Chesterfield) are typical examples. Fish stocking programmes in the catchment have proved to be ineffective due to water quality problems and unsuitable habitats. It remains crucial that the water quality and habitat degradation problems are addressed before any large scale or localised rehabilitation schemes are embarked upon in the catchment.

Enhancement measures have been limited because they have not been carried out in a thorough fashion including provision of riparian cover or bankside vegetation. The benefits of riparian and bankside vegetation are well documented (White & Brynildson, 1965; Platts, 1991; Garcia de Jalon, 1995) and have been presented in Section 6.1.6. The River Dearne at Pastures Bridge (Plate 6) is an example of a habitat enhancement measure. It is recommended that trees are provided on the river banks to provide cover.

Weirs and other flow control structures in the catchment restrict longitudinal connectivity (Lucas & Frear, 1997; Cowx & Welcomme, 1998), hence limiting free movement or migration of fish to perhaps more suitable areas for feeding and reproduction.

Trace or heavy metal pollution of the rivers does not constitute an issue of great concern because most of these are within acceptable limits (EC, 1978) as revealed in this study. The heavy metal concentrations were generally low. The closure of the steel and coking industries has resulted in reduced levels of the metals reaching the watercourses. However, there are still localised impacts of abandoned mining discharges in certain parts of the catchment that continue to receive the attention of the EA.

Ammonium-nitrogen levels of the Dearne and Rother (Figs 4.6 & 4.7), remain high and above the EQS limits (EC, 1978) of 1.0 mg l^{-1}. Further work needs to be done to achieve this standard.

The degraded habitats and poor water quality of the catchment need to be rehabilitated and the fisheries managed on a sustainable basis to enhance the recreational, conservation and aesthetic value of the rivers.

Discharges from both active and abandoned coal mines remain important causes of poor water quality of the catchment. Some parts of the catchment have been impacted by mine waters for many years. This is evident from the presence of ochre in some rivers, e.g. the River Don at Penistone, the River Little Don and Dalton Brook. There is no legislation regarding discharges from long abandoned mines and former mine owners cannot be held responsible for effluents from their long abandoned mines. This represents a setback in the objective of improving water quality and rehabilitating the fisheries of the catchment.

Recently, European funding has been obtained for a joint project between the Environment Agency, Barnsley Metropolitan District Council, the Local Authority and Hepworth Building Products to treat mine waters from the abandoned Bullhouse mine which have severe impact on the River Don at Penistone. Recent fish surveys (November 1995 - July 1997) revealed declining populations of grayling and brown trout in the river Don at Penistone. It was noted that the ochre from abandoned mines transformed the water to an orange-to-rust-coloured appearance that further converted to a dark, chocolate colour after receiving run-off from rain. On a brighter note, a programme of fishery restoration on some River Don tributaries continues with grayling introductions to the Barlow Brook and River Loxley (EA, 1997). The value of this restoration work is, however, yet to be realised.

Improved water quality through increased dilution can only take place when a new source of water has been found to provide the dilution. Alternatively, improved water quality may be achieved through reductions in polluting quantities from sewage treatment works and industry. Habitats will be enhanced through water quality improvements. Whilst Blackburn Meadows Sewage Treatment Works has been permitted to discharge limited amounts of certain metals to the River Don, construction work has also begun at Thorne sewage works to provide a further stage of treatment (EA, 1997). Inadequate treatment of industrial effluents degrades river quality. The existing systems of treatment on the River Rother at Staveley, River Doe Lea at Bolsover and the River Don at Doncaster and Goole have been found inadequate (NRA, 1994b).

The contamination of the River Doe Lea by dioxins and furans continues to receive the attention of the Environment Agency which has been monitoring the levels of these substances since its discovery in 1991. Meanwhile, improvements to the operation of Beighton waste disposal site have been agreed with Sheffield City Council and hopefully this will improve the quality of the leachate prior to their discharge.

Abstraction for agricultural and spray irrigation and the potential for further abstractions continues to threaten the existing low water flows at several sites in the catchment. The management of water resources needs to be optimised through further regulation of abstractions and releases from reservoirs.

Accumulation of litter and domestic wastes can be observed at many sites along the rivers. The River Don through Sheffield, the River Dearne through Barnsley and Cudworth Common, and the River Rother through Chesterfield present examples of habitats degraded by this practice. The conservation value of the catchment has been diminished by poor water quality, low flows, and a loss of natural in-stream and bankside habitat. Lack of access and the low aesthetic value of the river amenity combine to produce a low level of public interest for leisure pursuits.

Maintaining and improving recreational fisheries in the catchment is restricted by poor water quality and quantity, lack of facilities and access, conflicts with other users, and public attitude of treating the catchment as dumping grounds for their unwanted wastes. Fish stocks in the catchment have been affected by various anthropogenic activities such as sewage and industrial pollution. There is a growing need to rehabilitate the fish stocks.

This chapter presents the main issues impacting on the fish stocks of the Don, Rother and Dearne catchment and establishes a rational plan for improvement of the fisheries on a long term basis. These issues constitute the main problems or bottlenecks to the improvement of the fish stocks in the catchment. In the Don, Rother and Dearne catchment addressing the issue of water quality is crucial for the rehabilitation of fish stocks. The Aquatic Resources Management Planning (ARMPs) technique will be used to establish the way forward on a rational basis. ARMPs are descriptive tools that provide a proper context, help to set priorities and enable policy and legislation to be implemented through the project cycle. The methodology enables the needs and aspirations of all water users to be accommodated where possible and provide a sound planning base for the development of river catchments. The ARMPs enable an assessment of the current status and comparison with the objectives set. Where objectives are not met, the options to resolve the problems can be considered. ARMPs also attempt to resolve conflicts over resource use through aggregating the relevant aspects of the area into a multi-functional and multi-use plan. Project concept notes and Logical Project Frameworks will be developed to address the water quality and habitat degradation problems. These projects will attempt to explore ways in which the regulatory body, in collaboration with other user groups and institutions, could improve this role through the restoration of fisheries in degraded sections of the Don, Rother and Dearne catchment.

In relation to the issues that have been identified a number of options available for the resolution of the issues have been generated to try and improve the fish stocks of the catchment. The advantages and disadvantages of pursuing the various options are summarised, and these could form the basis for consultations among user groups. The options generated represent a range of alternative courses of action which are not necessarily mutually exclusive. Some options might be more appropriate in certain parts of the catchment than others and some options may be pursued together. The issues and options generated provide an integrated approach to set priorities and plan for the future of the catchment, and in particular to rehabilitate the fish stocks. They could also provide an opportunity to meet set objectives for fisheries in an integrated manner through a consistent planning framework for identifying and resolving any conflicts and maximising collaboration to enhance the fish stocks.

7.2. Aquatic Resource Management Plan (ARMP) for the rehabilitation of fisheries in degraded habitats of the Don, Rother and Dearne catchment.

Background

In many areas of the United Kingdom, there is continued concern about the impacts of environmental and water pollution on fisheries within major river systems. In many instances human populations have become established in close proximity to, or within the catchment area of major rivers.

Over the last century there has been an increase in the use of rivers and their adjacent lands for waste disposal, navigation, recreation, industry, agriculture and the development of flood defences and land drainage. In many cases this has led to water pollution and degradation of the riverine habitat. As a result, the fish populations have declined at the affected sites. Although natural factors may account for some of the variability in fish populations, riverine fisheries are under sustained pressure from a range of factors. The human manipulation of the river environment through river engineering, stream regulation, and also pollution from domestic, sewage, industrial and agricultural effluents, have all impacted on the fisheries of the rivers.

Riverine fisheries constitute an important resource in the economic development of the UK (Atkinson, 1994). The Environment Agency (renamed as such in April 1996), established under the Water Act 1989 as National Rivers Authority, was given the mandate to maintain, improve and develop riverine fisheries in the UK. To achieve this task it is important that the riverine habitat is rehabilitated to support a diverse fish population with good biomass. It is important that user groups such as river engineers, farmers and industrialists are made more aware of the importance of fisheries and the need to maintain both species and habitat diversities. Their collaboration and involvement in the management of fisheries in the catchment remain crucial to the success of the rehabilitation.

Water quality improvement and the restoration of degraded habitats in the Don, Rother and Dearne catchment continue to be a major concern of the Environment Agency as indicated in the Local Environment Agency Plan (LEAP) for South Yorkshire and North-East Derbyshire. One of the key management objectives of the catchment is to monitor and improve fish stocks. In doing so attempts are being made to develop and monitor fish populations in areas recovering from the effects of habitat degradation from sewage, mining and industrial sources. A programme of fishery restoration is continuing, and grayling have been re-introduced to the Rivers Rivelin and Loxley, and to the Barlow Brook after a hundred years of absence (EA, 1997).

7.2.1. Catchment uses and impacts

The catchment has a great diversity of uses and these have been described in detail in Section 2.4. Previous uses of the catchment have not altered very much from their current uses. Recreational activity is generally low and consists of sporadic low intensity catch-and-release recreational fisheries for non-salmonid species close to urban areas. The catchment is impacted by diverse anthropogenic activities. These include mine water discharges, sewage effluents, industrial and agricultural discharges, river engineering, and the dumping of rubbish, solid and other domestic wastes on adjacent lands or in water courses.

7.2.2. Status of the catchment

Water quality and habitat degradation

The main features of the river quality of the Don, Rother and Dearne have been described in Section 2.3. For each river, significant stretches have poor water quality resulting mainly from sewage effluents, mining and industrial discharges. Consequently habitats have been degraded in step with deteriorating water quality. Fish populations and diversities therefore remain restricted.

Macroinvertebrate abundance and diversity at several sites remain restricted by poor water quality. Pollution-tolerant macrobenthos constitute the dominant fauna whilst the pollution-sensitive ones are either absent or present in relatively small numbers at most survey sites.

Water quantity

Water quantity in the rivers is limited by the diverse uses to which water is put in the region (Section 2.4). In addition to 4 compensation reservoirs, the upper reaches of the catchment are impounded with 19 reservoirs for potable water (Section 2.4.1). The catchment was hit by a drought in 1995-96 that lasted 20 months (EA, 1997). Low flows characterised several stretches within the catchment with loss or degradation of fisheries habitats.

Fisheries

The details of the main fish stocks of the catchment have been presented in Chapter 5. At several sites in the Rivers Rother and Dearne, the fish populations and diversity remain restricted or absent. The abundance and type of fish communities present has not promoted the development of sustainable high value game fisheries. Salmonids are rare and very sporadic in their occurrence and coarse fish populations remain precariously low in the catchment.

Poor water quality and habitat degradation have been the main causes of the poor state of the fisheries in the rivers. Sections of the major rivers have been subjected to major engineering works for drainage purposes, resulting in loss of physical habitat. Whilst the proximity of urban areas (e.g. Sheffield, Barnsley, Rotherham, & Chesterfield) is beneficial to the development of sport fisheries, fish population densities are too low or fish are absent at some of these sites, thus making angling at such sites less attractive.

Recreation

The recreational uses of the catchment have been described in Sections 2.4.6, 2.4.7 and 2.4.8. Recreational fishing is an important sport in the catchment. The Don and its tributaries are used for angling. It is envisaged that as habitats become enhanced in step with water quality improvements, the demand for use of the catchment for recreational activities will increase as well. Maintaining and improving water-based recreation in the catchment is restricted by poor water quality, lack of facilities and access.

Conservation

The catchment has Sites of Special Scientific Interests (Section 2.4.5). The conservation value of the catchment has been impacted by poor water quality, low flows and loss of in-stream and bankside habitat at several sites. Water flows and quality need to be maintained or improved to protect fish and wildlife. Lack of access and low aesthetic value combine to produce a low level of public interest.

7.2.3 Issues and options

The issues identified have been categorised as follows:

- ❑ water quality;
- ❑ habitat degradation;
- ❑ abstraction for drinking water supply;
- ❑ industrial and agricultural abstraction;
- ❑ low recreational value of the catchment;
- ❑ poor status of the fisheries;
- ❑ data collection for fisheries management in the catchment.

❑ Water Quality

The issue of water quality in relation to fisheries is extremely complex; and the effect of pollution on fish life may take many forms. It may act directly on fish as in chemical toxicity (Axford, 1994) or indirectly by changing water quality parameters and consequently the suitability of the habitat for fish (Alabaster & Lloyd, 1982; Vostradovsky, 1993; Axford, 1994). The impacts of pollution should be exemplified by the fish community structure; and this is often the case (Vostradovsky, 1993). In most cases the fish community structure changes to one dominated by pollution-tolerant species, such as roach and bream, often at the expense of the less tolerant species, e.g. grayling, brown trout, or barbel. Where effluents have been discharged into rivers, catastrophic consequences, resulting in the deaths of many fish, have occurred. Several examples of such catastrophic events have been encountered at various locations in the Don, Rother and Dearne catchment (Tables 5.1 & 5.2).

Treated sewage is the most common effluent discharged into rivers, both in terms of number of outfalls and volume of effluent (Cowx & Welcomme, 1998). The main impacts on fisheries are related to increases in biological oxygen demand, and the nutrient and ammonia levels caused by the effluent. The impact of the discharge on the fish community is related to the volume and concentration of the water quality parameters, the quality and volume of the receiving water and the physical environment downstream of the discharge point (Cowx & Welcomme, 1998). Chronic exposure to sewage effluents and high BODs may affect population parameters such as fecundity and recruitment, age at maturity and mortality (Cowx & Welcomme 1998).

The Don, Rother and Dearne catchment receives sewage effluents from many sewage treatment plants located within the catchment area (Fig. 2.3). Sewage effluent disposal therefore constitutes an important issue impacting on fisheries in the rivers.

Issue 1. Impacts of sewage effluent disposal in the catchment on water quality and fisheries.

Nature of the problem

The deterioration in water quality of the River Don below Sheffield results mainly from the discharges of treated sewage effluent from Blackburn Meadows sewage treatment works (NRA, 1994b) into the catchment.

The Rother sub-catchment has 30 sewage treatment works (NRA, 1994b; EA, 1997) all of which impact on the water quality. Water quality deterioration have, particularly, been considerable at stretches impacted by Danesmoor (Clay Cross), Old Whittington (Chesterfield), Staveley, Woodhouse Mill and Dronfield STWs (NRA, 1994b).

The water quality of the upper reaches of the River Dearne is impacted by effluents from Clayton West sewage treatment works. Over the years, sewage systems have become overloaded due to human population increases, urbanisation, industrial development and the lack of investment to improve the treatment facilities. Combined Sewer Overflows (CSOs), which were originally meant to operate in periods of heavy rainfall, remain functional under dry weather conditions (NRA, 1994b). The recipient rivers have become polluted as a result. Examples can be found in some tributaries, e.g. River Sheaf, River Hipper and the main River Don at Conisborough.

Options for the resolution of the issue and the advantages and disadvantages of pursuing the options have been identified and include:

Options	Advantages	Disadvantages
a. Enforcing existing discharge consents rigorously through increased monitoring, and taking legal action when required.	Improved water quality in the catchment. Rivers protected from unacceptable deterioration or pollution.	Possibility of non-compliance by some companies. Cost to dischargers.
b. Partially treating sewage at CSO sites.	Reduction in pollution by CSO.	Cost of treatment.
c. Diverting discharges to rivers with higher flows.	Localised improvements to river stretches.	Not applicable at all sites. Problem moved but not solved. Cost.
d. Improving sewage treatment facilities over a 5-year period.	Improved water quality over longer time scale.	Slower improvement in water quality. Cost of improvement. Disruption of some installation.
e. Do nothing.	No direct costs.	Water quality and fish stocks continue to deteriorate.

Favoured options

The rigorous enforcement of existing discharge consents through increased monitoring and improving the sewage treatment facilities should be the favoured options; i.e. (a) and (d). Enforcement and deterrent penalties would help reduce any further additions of polluting discharges and also improve water quality. Improvements in sewage treatment facilities would enhance water quality through improved quality of sewage effluents. These options are preferred over (b) and (c) which only partially treat the problem or shift it elsewhere. Doing nothing (e) would leave the problem unresolved and with the potential to deteriorate further. The favoured options would facilitate the achievement of the desired water quality objective in the short and long term. This would, however, come with some considerable costs as described above.

Issue 2. Industrial and chemical effluent disposal in the catchment degrade water quality and impact on the fisheries.

Nature of the problem

The catchment has received chemical and industrial inputs for many decades. Inadequate treatment and emissions from chemical substances degrade water quality and adversely impact on the aquatic biota. Several sites in the catchment such as the River Rother at Birdholme Bridge (Chesterfield) and at Staveley, the River Dearne at Cudworth Common, the River Don at Doncaster and Goole have been impacted by various industrial discharges. The contamination of the River Doe Lea in the Bolsover area (Derbyshire) in 1991 by dioxins and furans is a typical example.

The regulation and control of chemical and industrial discharges to the watercourses are important to improve water quality. Existing standards need to be enforced more rigorously to improve water quality and to keep the momentum of improvement. Options to resolve the problem have been identified and presented below:

Options	Advantages	Disadvantages
a. More rigorous enforcement of existing consents with periodic reviews to improve quality of chemical effluent.	Improved quality of chemical effluents to the rivers.	May not be practicable for all industries. Cost to industry.
b. Clean up sites contaminated by chemicals,. e.g. dioxins and furans.	Improved water quality.	Cost of cleaning up.
c. Divert discharge to sewer.	Reduction in chemical inputs to the rivers.	Cost of diversion, Overloading of sewers and sewage treatment works.
d. Do nothing.	No direct costs.	Continuing pollution.

Favoured options

Enforcement of existing consents and periodic reviews of water quality standards (option a) would enable appropriate recommendations to be made for improvements in treatment facilities to meet the discharge limits. Remedial action (option b) would tackle the problem and facilitate a more rapid action. Options (a) and (b) are the favoured options. Option (c) would tend to shift the problem elsewhere but not solve it and would possibly increase the chemical loading of the sewers. Doing nothing (d) leaves the problem unsolved as nothing is done about the issue.

Issue 3. Solid waste disposal in the catchment poses a threat to river quality and fisheries.

Nature of the problem

The catchment has waste disposal sites (NRA, 1994b) that impact on water quality. Some sites that have been shut down remain potential sources of pollution to both surface and groundwater due to leachates from the affected sites. Leachates impoverish downstream water quality with disastrous consequences to aquatic life and fisheries. Examples can be found in the Cudworth Dyke, River Doe Lea at Glapwell and the Shire Brook at Beighton. Various options to help resolve the issue are summarised below.

Options	**Advantages**	**Disadvantages**
a. Assess the extent of leachate contamination at various landfill sites and their impact on water quality.	Enhance knowledge on the gravity of the problem at affected sites leading to appropriate action to improve water quality downstream of the landfills..	Cost of investigating impacts of leachates.
b. Remedial work at problem sites. Use of enhanced protection systems.	More efficient use of land, less land needed for landfills. May reduce overall costs.	Cost of remedial work. Requirement to dispose of leachate.
c. Recycle and re-use of wastes and waste minimisation.	Risk of water pollution reduced.	Cost of recycling processes.
d. Do nothing.	No direct costs.	Risk of solid waste pollution.

Favoured options

The favoured options would be to carry out remedial work at the affected sites and also consider the possibility of recycling the wastes, where appropriate. These options have the advantage of tackling the problem straightaway and with regard also for environmental safety. This would reduce the pollution risk to the watercourses and the environment. Options (a) would involve considerable loss of time while the problem carries on and option (d) provides no opportunity for solving the problem.

Issue 4. Industrial activity on estates poses a threat to water quality and fisheries of the catchment.

Nature of the problem

Invariably industrial activity involves handling, storage, use and disposal of chemicals. Without adequate measures to prevent pollution, contamination of surface and groundwaters due to spillage or wrong connection of trade effluents would occur. Increased run-off could increase the risk of flooding. Through Doncaster, the Don suffers from problems related to the discharge of contaminated surface waters from industrial estates. Some of the issues are related to oil, others with incorrect drainage or process operation (NRA, 1994b). Pollution of shallow groundwater by pentachlorophenol and other wood preservatives was reported at a Doncaster timber yard (NRA, 1994b). Remedial action was embarked on by the company concerned. It is important that similar incidents do not occur in future. The options available to forestall future occurrences are described below:

Options	**Advantages**	**Disadvantages**
a. Industries should provide a clear assessment of possible impacts of their effluents on the water environment to the Environment Authorities.	To allow an assessment of potential pollution to the environment.	Costs to the industries concerned. Would require some research. Costs to developers.
b. New developments should include pollution prevention schemes during the planning process.	Prevent any further incidences of pollution.	This option cannot remedy already polluted sites.
c. Industries should treat their effluents to acceptable standards before discharge.	Risk of pollution to rivers reduced	Treatment costs to industry.
d. Increased monitoring, investigate and prosecute polluters with deterrent fines, and/or offending industry cleans up.	Reduction in number of pollution incidents.	Cost of investigations and prosecution. Deterrent fines may not be applicable as fines are set by the courts and not the EA.
e. Diversion of contaminated surface waters to sewage systems.	Improved surface water quality. Risk of flooding reduced. Improved surface water quality and reduction in pollution incidents. Less risk of flooding.	Increased hydraulic load on sewerage system and sewage treatment works. Cost of diversion and treatment.
f. Do nothing.	No costs incurred.	Threats to water quality remain unchanged.

Favoured options
The prevention of pollution at the initial planning phase (option b), treating industrial effluents to acceptable standards before discharge (option c), and (d) monitoring with severe deterrent penalties for offending industries would be favoured options. Option (e) shifts the problem but increases the hydraulic load on the sewage systems whilst option (a) may be difficult to predict and may over or under-estimate the effects of their effluents on the watercourses and the biota. Option (f) leaves the problem unsolved.

Issue 5. Abandoned coal mine waters are potential pollutants to the rivers in the catchment.

Nature of the problem

The effects of mining on aquatic resources do not necessarily end when the operations discontinue. Many old and abandoned mines continue to release pollutants into nearby streams and many dredged areas continue to provide poor aquatic and riparian habitats for fish (Nelson *et al.*, 1991). The pumping of mine waters usually ceases as the coal mines close. If the cessation persists over a long period, water builds up in the abandoned mine and becomes heavily impregnated with red iron oxides, chlorides and ammonia. The termination of the pumping process leads to a loss of dilution of mine waters reaching the water courses. The consequent increase in salinity or ionic concentration in the rivers receiving such mine waters could cause considerable osmotic stress to aquatic life and also lead to changes in the ecosystem. Water pumped from mines to keep them workable often provides vital dilution for downstream effluent discharges.

It is also known that long abandoned mine waters cause shortfalls in water quality by blanketing the river bed with rust-coloured deposits which can be lethal to aquatic biota. The recent closure of some mines in the catchment area will result in pollution when the mine waters surface unless some action is taken to mitigate the problem. The quality of some rivers has deteriorated already where this situation exists and pumping has ceased, e.g. the River Don below Penistone. The long history of mining in the catchment has not only left a legacy of large areas of contaminated and despoiled land but also polluted mine waters. A total length of 30 km is affected (EA, 1997) and particularly bad examples are found on the River Don at Bullhouse (Penistone) and the Little Don at Sheephouse Wood (Stocksbridge). Other examples can be found in the River Dove at Worsborough Reservoir and in the River Hipper. The following options may be pursued to address the issue.

Options	Advantages	Disadvantages
a. Investigate problem and take remedial action.	Will enable the rapid implementation to remedy the problem	Cost of investigation. Funding and legislative powers may not be made available.
b. Pump mine waters and treat to required standards before discharge..	Improvement in quality of discharge. Dilution for effluents.	Cost of pumping and treatment. Responsibilities not clearly defined. Legislation not in place.
c. Abandoned mine sites could be developed further.	Leachate reduction in the long term, hence reduction in pollutants reaching water courses. Possibility of utilising of residual coal/fuel left. at the sites.	Cost of development. Risk of pollution and health threats during development.
d. Seek Government or EC funding for remediation of pollution from abandoned mines, e.g. Sheephouse Wood & Bullhouse mine waters.	Reduce pollution from abandoned mines and rehabilitation of habitats. Reduce financial burden on any one organisation.	Cost of remediation and rehabilitation.
e. Do nothing.	No direct costs incurred.	Lack of dilution for effluents. Continued pollution from mines.

Favoured options

The remediation of affected sites as in (d) above would offer a long term solution despite the considerable funding involved. Re-developing abandoned colliery sites (c) would also result in a long term reduction of mine effluents to the rivers. Options (c) and (d) are therefore the preferred options. Whilst pumping of mine waters (b) has been the practice over many years, it requires sustained funding to keep the pumps working all the time and provides little or no long term solution to the problem. Option (a) may take a long time to achieve and may not have the legal backing in place. Doing nothing (option e) would leave the problem unattended.

Issue 6. The disposal of rubbish and domestic wastes in watercourses contaminates the water and threatens aquatic biota.

Nature of the problem.

In many locations unwanted household, domestic and builders' wastes, and other litter have been dumped in the rivers. These have often included packaging and waste from bankside industries, food wrappers, cans, old prams, used car tyres and bicycles. These, combined with debris left in streams and sewer overflows, can impact on the water quality and harm fish and other aquatic biota. Apart from reducing the aesthetic value of the river, the garbage can also block channels and increase the risk of flooding. Illegal tipping of rubbish detracts from the amenity of the river environment and may also cause land and water pollution.

The condition described above can be found in several places, including the River Don through Sheffield and Penistone, the River Dearne through Barnsley and Cudworth Common, and the River Rother at Birdholme Bridge and Chesterfield.

The perception of some people that watercourses are dumping grounds for their unwanted domestic wastes should be discouraged through a more radical approach. Dumping litter or waste attracts more dumping and that could exacerbate the problem. A number of options to resolve the issue are stated below.

Options	**Advantages**	**Disadvantages**
a. Initiate public education programmes to create some awareness of the litter and domestic waste problem.	Could lead to changes in waste disposal attitudes for the benefit of the community. Reduce littering and river contamination.	Cost of public education on the subject. Public willingness to co-operate not guaranteed.
b. Collaborate with local authorities to clean up affected stretches of rivers.	Improve the aesthetic value of the watercourses. Reduce risk of flooding. Reduce water contamination.	Cost of organising cleaning. This option does not necessarily remove the problem.
c. Do nothing.	No costs incurred.	Continued dumping of rubbish in water courses. Risk of flooding increased. Maintenance costs of watercourses will remain high.

Favoured options
The removal and cleaning up of domestic wastes through collaboration with the local authorities would enhance water flow and reduce blockage of the river channel at the affected sites. The risk of flooding will also be reduced, and life and property would be protected. Initiation of public awareness programmes may take a longer time to achieve the desired objective. At the same time, public education and awareness programmes should be stepped up to change waste disposal attitudes of people who live in the vicinities, and to make them custodians and watchdogs for offenders. Doing nothing (option c) would leave the problem to, possibly, escalate.

❒ Habitat Degradation

Loss and degradation of suitable habitat conditions constitute one of the principal issues affecting the status of freshwater fisheries. The loss or degradation is often associated with water and land resource development. Mining and industrial activities in the Don, Rother and Dearne catchment have had a toll on the fisheries in the catchment. River engineering and management practices are important perturbations associated with the decline of river fisheries (Mann, 1988). River channelisation may lead to the loss of certain habitat features, e.g. the pool-riffle pattern and channel meandering (McCarthy, 1985). A typical example is the River Dearne at Pastures Bridge before 1995. The river was engineered to give a straight trapezoidal channel (Plate 5). A section of this channel was re-engineered in 1995 (Firth, 1997) to create a series of meanders (Plate 6). The effect of the action has resulted in considerable increase in habitat diversity although in-stream and bankside vegetation remain restricted. However, recent fish surveys have observed high fish numbers in the meandering sections.

The disposal of domestic wastes into watercourses does not only impact on the water quality but also degrade the physical habitat of fish making it virtually impossible for fish to survive. This condition has been described for the River Rother at Birdholme and for several other sites in the catchment.

The most successful method of habitat rehabilitation has been watershed protection. Hynes (1975) effectively made the case that a stream and its valley are an inseparable ecological unit. Protection of habitat is by far the most effective stream rehabilitation and enhancement technique. The goal of the resource managers should be to maintain the integrity of a stream and its streamside zones (Everest *et al.*, 1987). A number of issues and options have been described below to try and rehabilitate the habitat to enhance fish survival and recruitment.

Issue 1. Contaminated land degrades fish habitats and water quality.

❑ *Nature of the problem*

Previous industrial activity such as coal, coking and steel production has left a legacy of land contaminated with various chemicals which find their way to surface and ground waters. The risk of pollution is always enhanced when the land is disturbed again for re-development. The River Rother at Wingerworth, Rotherham and Birdholme (Chesterfield), and the River Dearne at Wath/Manvers present examples of contaminated land already causing pollution to aquatic biota, and degrading their habitats. Below are options to mitigate the problem.

Options	**Advantages**	**Disadvantages**
a. Investigate and get land cleaned up by offending industry and/or pay fines as well.	Consistent with "polluter pays" principle. Serve as deterrent to potential polluters. Improved habitat quality.	Cost of investigation. Polluter difficult to trace or no longer around. Complex legal situation.
b. Re-develop land to required standards appropriate to use.	Utilisation of poor quality land. The threat of contaminated land impacting on river quality reduced.	Cost of development and remediation. Clean-up targets uncertain.
c. Do nothing.	No direct costs incurred.	Problem persists with no improvements to fish habitats and water quality.

Favoured options

Investigating and getting the offending industry to clean up or being fined in a court of law and, re-developing already affected public lands for which the polluter cannot be traced or legally be made to clean would be the favoured options. It is becoming increasingly accepted that those who pollute should clean up or receive the appropriate punishment. Re-developing land would, however, require enormous spending and could take a long time to accomplish. If the affected land or site is privately-owned redevelopment would also present further legal difficulties.

Issue 2. Human manipulation of the river environment through engineering works degrades the habitats and water quality.

Nature of the problem.

Many of the principal factors affecting the status of freshwater fisheries are directly related to the loss of suitable habitat conditions through anthropogenic activities associated with land and water resource development (Hellawell, 1988). River engineering and management practices associated with land development, agriculture and forestry are the main perturbations associated with the loss of habitat and decline in river fisheries (Mann, 1988). River channel works, such as channelisation (Cowx *et al.*, 1986), can also damage fish habitat conditions. In the Don, Rother and Dearne catchment, channelisation and flood prevention work has been carried out at several locations. The works usually involve embanking the river, increasing channel capacity and providing flood corridors. These impact on fish habitats and on water quality.

River engineering works have been carried out in some parts of the catchment. Where river channels have been modified by construction of levees for flood defence purposes, or constrained by urbanisation and culverting, the physical habitat utilised by fish, especially for alimental and reproductive purposes, can be seriously degraded. The overall effect of such works on the river environment is to cause major reductions in habitat diversity, loss of suitable substrate and reduction in food resources. The River Don through Rotherham, Sheffield, and its tidal reaches are extensively degraded habitats due to channelisation and river engineering works. Other examples are the River Dearne through Barnsley and the River Rother through Birdholme (Chesterfield).

Most of the flood defence structures of the catchment were built many years ago when the rivers were unable to support fish life and therefore were constructed without consideration of the development of fisheries and their supportive natural habitat (EA, 1997). The need to review these structures to enhance the habitats and the fisheries cannot be over-emphasised. A number of options to resolve the issue have been presented below.

Options	Advantages	Disadvantages
a. Locate and document degraded habitats to provide for future habitat enhancements.	Identification of main problem areas. Future restoration of degraded habitats enhanced.	Cost of restoration. Long term solution which depends on opportunities.
b. Initiate joint or collaborative projects to rehabilitate degraded habitats.	Restoration of degraded habitats, and enhancement of fisheries. Benefits to wildlife.	Possible increased costs to developers.
c. Prevent further culverting and alteration of river channel.	Retention of natural river corridors to benefit aquatic ecosystem.	Loss of land to other users.
d. Review and improve existing flood defence structures such as floodbanks, floodwalls and regulators with a view to enhancing fisheries.	Enhanced opportunity for the restoration of fisheries.	Cost of reviewing and improving the existing structures.
e. Do nothing.	No costs incurred.	Habitats remain degraded and. condition may deteriorate.

Favoured options

Identification of main problem areas (a), initiating joint or collaborative projects to rehabilitate degraded habitats (b) and preventing culverting (c) would be the favoured options to enhance the fisheries. Funding would be required for options (a) and (b) and would need to be actively pursued. Preventing culverting (option c) would require little or no expenditure of money as planning permissions are usually required before culverting takes place. Reviewing and improving flood defence structures (d) could be incorporated as part of options (a) and (b). The costs and benefits of pursuing these options have been presented above.

Issue 3. Physical obstructions within the catchment restrict the free movement of fish.

Nature of the problem.

Weirs and dams, unless covered by sufficient depth of water at a relatively low velocity at intervals throughout the year, provide barriers to fish migration (Cowx & Welcomme, 1998). Physical obstructions to the passage of fish, e.g. weirs and flow control structures prevent the free movement of fish within the catchment (NRA, 1994b). The restriction of free movement can have significant implications for fish distribution, recruitment and development of fish populations (Lucas & Frear, 1997). Areas of the catchment that become suitable and available for re-colonisation will remain inaccessible to migrating or relatively sedentary fish unless passage facilities are made available (Lucas & Frear, 1997).

Regulators on the River Rother at Woodhouse Mill, Canklow and Rother Valley Country Park are typical examples of physical obstructions to the free passage of fish in the catchment. Other examples include the weirs on the River Don at Sprotborough, Beeley Woods and Aldwarke. Some options to address the issue are summarised below.

Options	Advantages	Disadvantages
a. Provide fish passage by removing all obstructions where practicable.	Improved passage for all fish species in the catchment. Improved access to feeding and reproductive habitats for both coarse fish and salmonid fishery.	May take a long time to implement. Development of migratory salmonid fishery may not necessarily be desirable for anglers.
b. Maintain physical barriers but provide passage of fish around the obstructions.	Improved access for both coarse and salmonid fish species to feeding and reproductive areas.	Limited development of migratory fish stocks. Full fishery potential not realised. Some costs will be incurred in providing access around physical barriers.
c. Prevent construction of further physical barriers to fish passage.	Unlimited access to various habitats by both coarse and salmonid fish.	May not be in the interest of all catchment users.
d. Provide passage for fish whilst carrying out restoration or repair works on weirs and other obstructions.	Improved passage for fish within the catchment. Enhance restoration of a salmonid fishery. Conserve time.	May take a long time to accomplish.
e. Do nothing.	No costs incurred.	Existing restrictions to fish movements prevail.

Favoured options

Preventing the construction of further barriers to fish passage and the provision of passage around existing obstructions (options b, c & d) would enhance fish movements at minimum cost. Construction of fish by-pass channels and stepped fish passes around weirs and dams (Cowx & Welcomme, 1998), would be useful in enhancing fish movements. The use of technical devices such as a Denil fishway positioned across weirs (Cowx & Welcomme, 1998), has been demonstrated to enhance fish movements elsewhere in Europe and North America and this could also be used. Removing all obstructions, including flood control gates (option a), would not only involve a relatively high expenditure of money but could also cause possible flooding problems and threaten human life and property. Doing nothing would only leave the existing barriers to restrict fish movements.

❑ Abstraction for drinking water supply

Issue 1. Water abstraction for drinking reduces flow in the watercourses.

Nature of the problem.

The headwaters of the catchment are impounded by 19 reservoirs (Section 2.4.1) for the supply of potable water. Reservoirs used for public water supply have been empowered to receive flows but release no compensation water (NRA, 1994b). There are only 4 compensation reservoirs which are used to supplement flows in the catchment (NRA, 1994b). Some watercourses are affected by low flows as exemplified by the River Little Don below Langsett Reservoir.

It is expected that as water quality improves in the years ahead further abstractions might take place in the catchment. Considerable amounts of water are imported into the catchment for public supply from Ladybower Reservoir on the Derbyshire River Derwent to the west and from the Yorkshire River Derwent to the north (NRA, 1994b). Ground water is also imported from the Sherwood sandstones of neighbouring catchments.

Water abstractions create a lack or reduction of flow downstream for further abstraction. The condition can lead to a loss or reduction in suitable habitats for the fisheries within the catchment. Other aquatic biota can also be adversely affected due to low flows as they become exposed, especially the sedentary fauna.

The reduction in flow also implies some loss of dilution for effluents and an enhancement of pollution. Some options that may be pursued to mitigate the problem are summarised and presented below:

Options	Advantages	Disadvantages
a. More rigorous enforcement of acceptable minimum flow for maintaining water quality and fisheries.	Ensures flow requirements are met throughout the year to sustain fauna	May present problems for industries that abstract water from the catchment.
b. Release optimum compensation water to the catchment.	Improved river habitat to enhance fisheries. Increased dilution for effluents.	Reduction in water stored in existing reservoirs. Possibility of building new reservoirs if water demands remained unchanged.
c. Reduce demand for water by public and industry.	Existing resources go further.	May not be practicable for some industries or public.
d. Provision of alternative storage facilities.	Compensation flows can be increased to enhance flows in the catchment. Reduced costs to public and industry. Provision of improved river flows in the summer.	Cost of providing storage facilities.
d. Do nothing.	No costs incurred.	The already low flows in some watercourses may be worsened during dry summers.

Favoured options

More rigorous enforcement of an acceptable minimum flow would ensure that flow requirements for the fish stocks are satisfied during each season. This would involve releasing water from compensation reservoirs into the catchment when flow falls below the minimum acceptable limit. However, legislative requirements regarding compensation flows have to be met before this option can be pursued. The public and industry should be encouraged to reduce water usage where practicable, but this appears possible under emergency situations when water levels are precariously low as happened in the drought of 1995/96. The use of hose pipes for watering was banned during this time. Providing alternative storage facilities (option d) would require space and considerable funding to sustain it. Doing nothing leaves the problem unresolved and may be exacerbated during the hot, dry months.

❑ Industrial and agricultural abstraction

Issue 1. Industrial and agricultural abstractions reduce flow in the watercourses.

Nature of the problem.

Industrial and agricultural abstraction of water constitutes an important use of the catchment. Much of the industry has located in the catchment due to the need for water in their industrial processes.

There are 125 licensed industrial abstractions in the catchment which utilise both surface and ground water (NRA, 1994b). Water is used in many areas of the catchment for agricultural activities including irrigation of crops and watering of livestock. There are also 44 licensed abstractions for spray irrigation in the catchment with a further 177 licenses for other agricultural or domestic uses (NRA, 1994b). The aggregate effect of this situation is reduced flows to the rivers with its consequent effect on the resident flora and fauna. Abstraction of water results in loss of discharge and current velocity, and this has profound impacts on the river (Cowx & Welcomme, 1998) and the fisheries regardless of the destination of the abstracted water. A major problem of pollution may occur if insufficient volume of water remains to effectively dilute effluents to the river. The following options may be pursued to try to resolve the conflict.

Options	**Advantages**	**Disadvantages**
a. New applications for abstraction should ensure that river flows are protected and be submitted with potential impacts on water quantity and quality.	Ensure maintenance of river flows in future and protect fish and other wildlife habitats. Provide baseline information for decision making.	The current situation remains unchanged. Expected impacts may not be known or may be under-estimated.
b. Set minimum flow requirements at specified sites.	Maintenance of wet areas and habitats for fish and wildlife.	Limits on how much water can be abstracted.
c.. Rigorous enforcement of current abstraction limits.	Enhancement of flows and wetland areas for wildlife.	Restricted access to abstractions. Could adversely affect crop irrigation and livestock watering.
d. Do nothing.	No direct costs.	Problem remains. Fish and wildlife habitats might be endangered.

Favoured options

Enforcing current abstraction limits more rigorously and reducing abstractions through a rigorous review of new abstractions should be the favoured options (option a & c). This would enhance flow in the rivers. Crop irrigation and livestock watering are, however, likely to be affected by pursuing these options as less water might become available for these activities. Setting minimum flow for specified sites (option b) might require legal backing which might not be in place at the time, and could take a long time to be achieved. Reviews of water licenses/consents are part of recent issues being addressed by the EA (EA, 1998b) and this could be incorporated as part of the process to expedite action. Similarly, reductions in abstraction licences might also require bye-laws or legal backing and it is important that these issues are also addressed before the options are pursued. Option (d) leaves the problem unresolved.

❑ **Low recreational value of the catchment.**

Issue 1. The recreational value of the catchment could be increased through further development.

Nature of the problem

The urban communities in the catchment area are increasingly using the rivers for recreational purposes. Further demand for the recreational use of the catchment might take place as the water quality, habitats and wildlife improve. It is important that the catchment's potential for satisfying the community's recreational is realised. This calls for the involvement of local authorities to develop the catchment to boost its recreational or amenity value. Some areas are already being developed for this purpose (NRA, 1994b). The Rivers Don and Dearne at Denaby and the River Rother at Orgreave are examples of such areas that could be developed further (NRA, 1994b). Also, the lower reaches of the River Doe Lea have been suggested. The following options might be pursued in an attempt to resolve the issue above.

Options	Advantages	Disadvantages
a. Carry out collaborative projects with local authorities and industry to promote the recreational value of the catchment.	Would enhance the recreational values with limited costs.	Some limited costs involved in provision of amenities.
b. Provide improved access to watercourses	More sites available for recreational use. Pressure reduced on present accessible sites.	Costs involved in provision of access and management of sites as people start using them. e.g. rubbish collection.
c. Do nothing	No costs incurred.	No enhancement of facilities.

Favoured options

Collaborating with local authorities to promote recreational activities and improving access to the waterside would enhance recreational fisheries in the catchment and should be the favoured options. The local authorities could assist in providing limited funding for the required improvement. Local authorities facing budget cuts from Government might not be in a position to fund the improvement but it would be possible to approach some donor institutions, or other grant awarding bodies such as the Lottery Fund for assistance. Doing nothing (option c) leaves the problem unresolved.

❑ Poor status of the fisheries

Issue 1. Fish stocks and fisheries of the catchment need further improvement.

Nature of the problem.

In many parts of the catchment fish populations remain precariously low. Fisheries survey data collected by Yorkshire Water and the EA (formerly NRA) over the last 14 years have revealed either very low fish populations or the complete absence of fish at many locations. Examples of poor fish stocks are numerous on many sites on the Rivers Don, Rother and Dearne, as revealed in the historical surveys.

Some tributaries of these rivers have similar problems. The situation has mainly been the result of a complex array of various anthropogenic factors impacting on the water quality and the fisheries of the catchment. Disposal of industrial and domestic effluents in the catchment area has been one of the factors responsible for deteriorating water quality, habitat losses and the deteriorating fish populations over the last decade. Unfortunately, many industrial developments have been associated with the lower reaches of the rivers. As a consequence, coarse fish populations have suffered, and in many cases the rivers have become fishless.

Evidence of similar situations suggests that improvements in water quality have alleviated this problem in recent years as shown in studies on the Rivers Trent, Thames, and Willow Brook (Banks 1979; Harper *et al.*, 1979; Cowx & Broughton, 1986; Mann, 1990).

A number of options that may be pursued to improve fish populations of the catchment are described below:

Options	Advantages	Disadvantages
a. Collaborate with public and industry to ensure improvements in water quality.	Enhancement of fish survival and recruitment with improved water quality.	Difficult to achieve. Cost of educating public on issue. Problem remains unsolved in the short term.
b. Re-stocking of the rivers with fish as water quality improves.	Enhancement of fish stocks and fish populations. Attract more anglers, hence more revenue.	Cost of fingerlings, labour and other miscellaneous costs.
c. Re-stocking of the rivers with pollution-tolerant angling fishes,. e.g. tench, bream and roach.	Improved fish populations at affected sites. Fish able to cope with pollution stress.	Some fishes may not survive. Restricted fish numbers and low diversity.
d. Restrict access to sites during spawning seasons of most valuable species.	Will enhance recruitment of valuable fish stocks.	Denied access may upset anglers and other users.
e. Do nothing.	No direct costs.	Problem remains unresolved.

Favoured options

Re-stocking of the rivers with relatively pollution-tolerant angling fishes, e.g. roach and bream following water quality improvements would be the preferred options, i.e. options (b) (c) & (a). Collaborating with industry would enhance co-operation and facilitate improvement in water quality. Water quality data/information (physical, biological and chemical) for the sites should be consulted prior to the re-stocking activities to assess the water quality improvements, suitability and the potential success or otherwise of the stocking exercise. The need to stock fish in the rivers following water quality improvements overrides access restrictions (option d), since many sites are fishless or have low population densities with poor recruitment due mainly to poor water quality and habitat problems. Option (e) leaves the problem unresolved.

The issue of improving water quality of the catchment, with respect to sewage and industrial effluents, must receive greater priority. It is important that the issue of water quality is addressed before mass stocking of the rivers with fish is undertaken. In this connection some sites would need to be cleaned up, and steps also taken to upgrade some of sewage treatment works to improve the quality of effluents discharged into the catchment. Discharges from industry need to reach acceptable standards through improved treatment facilities. Recent developments have shown that Yorkshire Water has put in place various strategies to upgrade sewage treatment works in the region. It is expected that some improvements to the quality of effluents discharged will be made.

Issue 2. Threats of catastrophic pollution incidents from industry, agriculture and mining, and sewage works in the catchment remain.

Nature of the problem

Many fish kills resulting from various pollution incidents have been reported in the catchment (Tables 5.1 & 5.2). The catchment is threatened by pollution incidents from industry, agriculture, mining, and sewage works. In some cases, the cause of the pollution incident remains unknown (Table 5.1) and this means it could occur again without any precautions being taken to avert the catastrophe. Until this is sorted out large scale enhancement measures are meaningless in the long term because they are lost at a stroke. Below are some of options that may be pursued to curtail the pollution incidents.

Options	Advantages	Disadvantages
a. Promote greater awareness in industry, agriculture, and community of the impacts of their effluents on fish.	Enhanced knowledge leading to better control of pollution incidents.	Cost of campaigns and education targeted at the relevant organisations and individuals.
b. Increase monitoring, inspection and enforcement action to safeguard water quality and enhance the fisheries.	Maintenance of suitable water quality and improved fisheries.	Cost of monitoring and inspection.
c.. Prosecute offenders with deterrent penalties.	Serve as a deterrent to others. Covers some costs of losses.	Costs to offenders and humiliation.
d. Do nothing	No costs incured.	Problem remains unresolved.

Favoured options

Increased monitoring, inspections and enforcement action by the statutory body in charge to safeguard water quality and the prosecution of offenders with deterrent penalties would help reduce pollution incidents, i.e. options (b) & (c). Community education on the subject (option a) is laudable but may not be cost-effective and would, possibly, take a longer time to achieve the desired objective. Option (d) leaves the problem unsolved.

Issue 3. Progress of re-stocked fish should be routinely monitored.

Nature of the problem

The Environment Agency (formerly the NRA) of North East Region embarked on a fish re-stocking programme at various sites in the catchment between 1988 and 1995 (C. Firth, pers. comm.). Roach, perch, bream, gudgeon, chub, dace and barbel have been stocked into all three rivers. Indications are that the first evidence of successful reproduction of roach, bream and perch in the River Don occurred in 1989 (C. Firth, pers. comm.). In the River Dearne it occurred 2-3 years earlier. In the Rother evidence of recruitment was found in a recent survey in 1998 by the Environment Agency (EA, 1998a) but this appears restricted to only a few sites. Fish stocked into the catchment have either been purchased from fish farms or from routine fisheries management operations, e.g. destocking and fish rescues. All of the fish released were from still water sources and were not acclimatised before being released into the rivers (C. Firth, pers. comm.). Conditioning of fish to running water has been shown to influence their growth and swimming performance (Johnston & Goldspink, 1973; Broughton, 1977). The red muscle development in fish found in running waters have been found to be more well developed in terms of the number and diameter of the muscle fibres than those found in lentic waters. It has been demonstrated that a 15% increase took place in the diameter of the red muscle fibres of Coalfish *Gardus virens* (L.) exercised at varying speeds for 42 days (Broughton, 1977; Johnston *et al.*, 1977). Further experiments at reduced speeds led to hypertrophy of the red and white muscle fibres of the fish (Broughton, 1977; Johnston *et al.*, 1977). It is probable that the lack of acclimation to flowing water affected the swimming, survival and therefore the stocking success of fish in the catchment. Survival and retention rates of these fish, post stocking, were therefore likely to be low.

Information on the ages of fish stocked was only reliable for chub, dace, and barbel as these were obtained from fish farms. With the exception of 20% of the dace which were 1+ years old, the remaining farmed stock were all 2 year olds. No long term stock improvement with evidence of recruitment appears to have taken place with stocked fish. The following may be pursued as an option to mitigate the above problem.

Option	**Advantages**	**Disadvantage**
a. Review stocking strategies and acclimatise fish taken from lentic waters to flowing water conditions, e.g. for one week before -stocking to enhance stocking success..	Will allow improvements in stocking strategies to be made and enhance stocking success.	Cost of review.
b. Monitor progress of re-stocked fish for evidence of recruitment and stock improvement	Will enhance better estimates of survival and growth and allow weaknesses to be identified at an early stage.	Cost of monitoring.
c. Do nothing.	No costs incurred.	Weaknesses remain unidentified and situation remains unchanged.

Favoured options
Reviewing stocking strategies, e.g. for lentic water fishes acclimation to flowing water before stocking, and monitoring or carrying out post-stocking appraisal to assess the progress of stocked fish, e.g. survival, growth and retention rates, would enable the effectiveness of the stocking exercise to be assessed. The "do nothing" option would not help to remedy the weaknesses in the re-stocking exercise and the problem remains unsolved.

❒ Data collection for fisheries management in the catchment

Issue 1. For the purposes of managing fisheries in the catchment, water quality, fisheries and other biological data for the same location should be collected at short time intervals, e.g. one week when recruitment and mortality are assumed to be negligible.

Nature of the problem
The fisheries survey data collected by Yorkshire Water, and the EA (formerly NRA) over the last decade have provided useful evidence of some impacts on fisheries in the catchment. However, in most cases, the fisheries data and other biological or chemical data were collected at long time intervals and in different seasons. In other cases, the locations for collection of water quality and fisheries data have been different. This situation makes it quite difficult to relate the prevailing water quality to the scenario on fish abundance and species diversity at the time. The biological and chemical processes taking place in the river situation coupled with various anthropogenic activities in the catchment would necessitate that fisheries surveys, water quality measurements and other biological data are taken at shorter time intervals of, e.g. up to one week when recruitment and mortality are assumed to be negligible. Such a sampling strategy would provide vital information on the effects of any localised impacts on the fish stocks and, perhaps, on other aquatic biota. In addition no data on habitat modifications and channel morphometrics are available to facilitate habitat modelling and rehabilitation work.

The Environment Agency has different sections responsible for monitoring different aspects of the water environment. Fisheries, water quality and other biological data of the catchment are not necessarily collected by the same section of the Agency. This has often resulted in collection of water quality and fisheries data independently of each section at different times. It is important that improved co-ordination is put in place to make it possible for fish surveys and other biological data to be collected and collated at the same time of sampling. The options below may be pursued to try and resolve the issue on data collection, collaboration among data collectors and enhance fisheries management.

Options	Advantages	Disadvantages
a. Review existing data collection objectives for fisheries and water quality.	Provide baseline information for decision-making and improved utilisation of resources. Improved knowledge of impacts on fisheries in the catchment.	Cost of review.
b. Improve co-ordination and collaboration between fisheries and other biological data collectors in the catchment.	Will enhance information on impacts on fisheries in the catchment to facilitate appropriate decision-making for fisheries and catchment management.	Cost of collaborating.
c. Do nothing.	Data collection and collaboration remain unchanged and no additional costs incurred.	No improvements in data collection, collaboration, and fisheries management.

Favoured option

Options (a) and (b) would be the preferred options whilst option (c) provides no solution to the problem. Reviewing the data collection objectives (a) would enhance better focus on fisheries and streamline data collection for the purpose of fisheries management. Improving co-ordination and collaboration between water quality, fisheries and other biological data collectors would facilitate the collection of data to be harmonised, and enhance information on impacts on fisheries at various times and locations in the catchment.

Issue 2. Fish stocking strategies within the catchment could be improved further.

Nature of the problem

Stocking refers to the repeated injection of fish into an aquatic ecosystem from a source external to it (Cowx, 1994; Cowx and Welcomme, 1998). Stocked species may either be already native to the recipient water body or may be exotic to it. Fish have been stocked into the Rivers Don, Rother and Dearne and some tributaries at various sites for many years in an effort to restore the fish stocks of the affected sites. The fish stocked were either weighed and recorded in pound weight (lb.) or counted and recorded numerically. Information on survival and retention rates of stocked fish remain fragmentary. Restocking of the rivers continue to play a significant role in trying to enhance fish populations in the catchment. Stocking is often embarked on for mitigation, enhancement or restoration purposes in conditions where naturally sustainable populations are restricted or absent.

In the Don, Rother and Dearne catchment, stock depletion is due mainly to water quality problems, habitat modification and degradation. Stocking for restoration has been embarked upon in the catchment for years to re-establish the fisheries which have been eliminated due to poor water quality and habitat degradation. The following options are suggested for stock improvement which may be pursued as part of the fish re-stocking strategy in the catchment:

Options	Advantages	Disadvantages
a. Restoration of habitats and resolution of water quality problems before stocking fish like dace, brown trout and barbel.	Survival of fish is enhanced, and naturally sustainable populations can be achieved. Underlying pollution problem removed.	Cost of restoration of habitats.
b. Production of hatchery fish based on stock that are desired by anglers and would be expected to be found, e.g. roach, dace, chub.	Would ensure that desired fish are produced to satisfy anglers and with minimum environmental stress for the fish. Maintain biodiversity.	Production costs for hatchery-reared fish.
c. Timing of stocking should coincide with abundance of food, e.g. in spring or summer.	Maximum chances of survival through the first winter.	Cost and manpower requirements could be high.
d. Trickle stock fish at several sites along a section of the river.	Reduces the risk of density dependent mortality and intraspecific competition.	No improvement to fish stocking strategies.
Do nothing	No direct costs incurred	

Favoured options

Fish should be trickle stocked at several sites along a section of the river over a period of days or weeks (option d) following water quality improvements (option a). Stocking should coincide with times when there will be abundance of food for the stocked fish, i.e. options (c). The costs and benefits of pursuing these options have been presented above.

Water quality improvements can be assessed from current water quality information prior to stocking. The costs of producing, maintaining and managing fish fingerlings in the hatchery (option b), and the time involved in achieving the desired sizes makes it less attractive and could possibly be pursued in the long term with adequate funding.

In this study several anthropogenic impacts have been identified as causing shortfalls in water quality and impoverishing the fish stocks of the catchment. Among these are the effects of sewage, industrial, agricultural, and mine effluents. They also include leachates from landfill or waste containment sites, wastes from domestic sources and other unknown sources. The resolution of some or all of these problems requires financial, capital and human resources. Poor water quality represents the main constraint to the establishment of fisheries in the catchment. It therefore falls in place to prioritise the resolution of water quality and habitat degradation problems and establish a rational approach to rehabilitate and enhance the fisheries in the catchment.

7.2.4. Priorities for rehabilitation

Water quality shortfalls pose a major challenge to the restoration of the Don, Rother & Dearne catchment as a viable fishery. There is a growing need to resolve the water quality and habitat degradation problems in the catchment to enhance the recovery of the fishery. There is considerable evidence that poor water quality in the catchment has constrained the development of fish stocks in the catchment and therefore should receive great priority. In particular, pollution from sewage sources should receive much attention as it continues to threaten the survival of fish in the catchment.

Sewage pollution occurs in all three sub-catchments and constitutes the main cause of fish mortality in terms of the magnitude of deaths caused by known pollution incidents (Tables 5.1 & 5.2). Tackling the issue of water quality through the resolution of sewage pollution problems constitutes a major step towards the rehabilitation of fisheries in the catchment and should be given priority.

A deterioration of fish stocks occurs on the River Little Don below Stocksbridge STW where effluents from the works impact on the water quality (Section 5.1.4) and results in the denuded fish fauna. A number of the lower Don tributaries, especially the EA Beck and the Little Went, have so far failed to meet the EC Fisheries water quality standards due to discharges from sewage works, viz. the South Elmsall and Carleton STWs (EA, 1997). Kearsley Brook, also in the lower Don catchment, has also been impacted by combined sewer overflows (EA, 1997). The Dearne catchment, in general, has ammonia levels over and above the EC limits (Fig. 4.6). Fish numbers in the Dearne catchment are also low (Figs 5.15-5.18) due mainly to sewage problems (Table 5.1). The River Dearne at Cudworth Common is fishless due to the impacts of sewage discharges from Lundwood STW. The Rother catchment with its 30 STW (NRA, 1994b; EA, 1997) continues to have ammonia levels in excess of the recommended EC limits (Fig. 4.9). Many stretches of the River Rother are fishless due to water quality and habitat degradation problems (Figs 5.22-5.24).

Despite considerable efforts to improve the fish populations of the catchment through stocking and some habitat improvement measures, the general status of the fish stocks remains poor. Angling in the catchment therefore faces a precarious existence, although some reaches hold reasonable stocks of coarse fish (NRA, 1994b). Shortfalls in water quality and habitat degradation problems have been blamed for the limited improvements in fish stocks.

There is a complex interaction of factors influencing water quality in fresh waters and insufficient is known about the role of each or their synergistic or antagonistic relationships (Axford, 1994). Consequently, rehabilitation methods targeted at water quality are often difficult to achieve (Axford, 1994). Nonetheless, some success has been achieved elsewhere in recent years, and improvements in the status of fisheries are being achieved with respect to water quality (Axford, 1994).

Cowx (1994) stated that a holistic approach to fisheries management is necessary and this should incorporate habitat restoration, pollution control, management of flow regime, stocking and introductions and the do nothing strategy. Individual remedial measures may result in adverse impacts in a different aquatic component so all the impacts of any proposed management scheme should be considered. Effective water quality, habitat and fisheries management in the Don, Rother and Dearne catchment should prevent or reduce further deterioration of the fisheries.

Stocking as a tool for enhancement of the fisheries would remain ineffective unless the water and habitat quality problems are addressed. Limited resources for the resolution of water quality and habitat problems to rehabilitate the fisheries calls for prioritisation of the various activities. These are described in the subsequent paragraphs.

Prioritisation of work

Priority 1. Enforcement of water quality standards

The sustained maintenance of water quality standards is crucial for the future rehabilitation of fisheries in the Don, Rother and Dearne catchment. Enforcement and compliance with water quality standards should therefore be upheld. Despite the extensive stocking of the River Dearne with brown trout and coarse fish, pollution problems have rendered the exercises ineffective (NRA, 1993a). The survey of the river in 1991 recommended the review of the current discharge consents and introduction of more stringent consents for sewage and industry (NRA, 1993a).

Following the decline in the coal industry in the Rother catchment and tough new legislation rigorously enforced by the EA against water companies and industry, the water quality of the river has improved remarkably. Recently seven sites on the Rother located between the confluence of the River Whiting and Chesterfield were sampled. For the first time in 100 years, fish were captured and their size suggests recruitment may have occurred (EA, 1998a). These were mainly cyprinids but limited numbers of brown trout and one grayling were also captured. Most of the fish were stocked earlier in 1994, 1995 & 1996 (EA, 1998a) but it is thought that there was also an ingress of fish from some tributaries and adjacent still waters due to water quality improvements (EA, 1998a). It is quite obvious that the tough enforcement action played a significant role in the maintenance of suitable water quality and, hence, the improvement in the fish .

The rigorous enforcement of existing discharge consents and compliance with water quality standards for sewage and industry will protect, enhance, conserve and improve fish stocks in the catchment. This will ensure that the water quality standards in the watercourses are not exceeded. This can be achieved through a more effective monitoring of water quality standards. Compliance with the standards would lead to improvements in water quality and prepare the grounds upon which rehabilitation of the fisheries can progress. The drawback to this line of action is that it will require putting more resources to monitor the water quality stations. Both alternatives would require considerable funding. External funding may be sought if local authorities or public funding are unable to meet increased monitoring costs. The co-operation of riparian owners will be required to maintain standards. Failure to comply with the standards set should result in imposition of heavy, deterrent penalties and, where possible, the legislation should be reviewed to permit severer penalties to be brought to offenders. This might include paying fines in addition to cleaning up the affected watercourse or bearing the cost of cleaning up. Effective monitoring and enforcement action, including prosecuting offenders to safeguard water quality, would also help keep pollution incidents to a minimum and facilitate the long term, sustainable improvement in the fisheries.

The setting and enforcement of effluent standards should be based on the performance of the best treatment plant available. This should take into account the cost implication, benefits and feasibility of such processes. This will ensure that the best possible standards and improvements can be made to improve water quality. It will also facilitate or complement the enforcement of existing standards for discharge of effluents. It is probable that the enforcement of this action would present some difficulties as additional costs would be incurred by industries which do not meet the required effluent quality standards and would lead to non-compliance. More resources will be required to cover increased monitoring and some financial aid may be required from local authorities, internal and external sources. These possibilities will need to be explored.

Priority 2. Cleaning up pollutants in watercourses, sediments and contaminated land and river rehabilitation

Some locations in the catchment have been impacted by industrial and mining wastes, some of which are buried in the river sediments. They have persisted for quite some time and would not necessarily clean up if left unattended. Some lands adjacent to the rivers have also been contaminated. Globules of tar have been reported to leak from Avenue Coking works into the River Rother at Chesterfield (EA, 1998a). These wastes have to be cleaned up to enhance the water and habitat quality for restoration of the fishery.
Cleaning up contaminated land and waste disposal sites adjacent to rivers will reduce

leachates reaching the rivers, e.g. the banks of River Don at Penistone, the Rother at Birdholme Bridge & Rotherham, and the Dearne colliery sites. Cleaning up contaminated sediments at various locations of the catchment would improve water and habitat quality to enhance the fish stocks, e.g. industrial oils, tar globules and concrete washings in the River Rother and ochre in the River Don at Penistone and Beeley Woods.

In 1989, a cleaning up programme was carried out in the Rother catchment (EA, 1998a), and the recent catch of several coarse fish species, brown trout and grayling has been attributed mainly to the cleaning up exercise (EA, 1998a). This success highlights the efficacy of cleaning up contaminated stretches of the river to enhance water quality and the fish stocks. The cleaning up exercise should also include the removal of blockages in watercourses caused by dumping of domestic and unwanted waste to enhance flow at affected sites, e.g. the River Don through Sheffield, the River Dearne through Barnsley and the River Rother through Chesterfield. The cleaning up of contaminated stretches of the river will require substantial funding and it will be necessary to seek funding from both internal and external sources that have an interest on environmental issues and restoration of fisheries in the catchment. In this regard appeals can also be made to industry, water companies as well as existing mining companies in the catchment to assist in providing financial or logistic support.

Provision of free passage for fish around obstructions such as weirs and regulators (Northcote, 1998; Prignon *et al.*, 1998), should also be undertaken. The obstructions created by dams, sluices and weirs may be bypassed by the provision of fish passes. The maintenance of longitudinal connectivity is essential for the free movement of all fish species (Section 6.1.1), within the maximum range (Cowx & Welcomme, 1998;). Fish commonly require different habitat conditions for the completion of their life stages. The maintenance of longitudinal connectivity would facilitate upstream and downstream movements to suitable habitats for alimental and reproductive purposes, thus enhancing survival and recruitment of fish. Interactions between riparian vegetation and river channel provide suitable habitats, e.g. connected backwaters and inshore zones (Scheimer & Zalewski, 1992; Mann *et al.*, 1997). Riparian vegetation, where lacking, should be provided to enhance survival of stocked fish, particularly fish fry. Fish larvae generally tend to inhabit banks and live at stream edges and lateral habitats (Tales, *et al.*, 1996; Jurajda *et al.*, 1997).

The recent capture of salmon in the River Don may be the beginning of a recolonisation process by the species, and provision of passage facilities would enhance the migratory life of the species.

Priority 3. Enforcement of existing consents for water abstractions to maximise flow.

Enforcing existing minimum flow requirements or setting new flow requirements, if desirable, to provide effective dilution for potential pollutants and enhance habitat suitability for fish should be undertaken during this stage. Water quantity is important and plays a vital role in providing vital dilution for pollutants and also enhance the suitability of habitat for fish (Burton & Wesche, 1974). The River Little Don below Langsett Reservoir is known to be affected by low flows and does not meet the minimum flow requirements (NRA, 1994b). High flows are required in headwater catchments to flush channels of fine sediment and to rejuvenate in-stream habitats (Cowx & Welcomme, 1998). Water companies, industry and agriculture impact on the water quantities through abstractions, import of water and subsequent discharge into the catchment. The maintenance of minimum flows would require the close collaboration of all concerned to improve water quantity, quality and the fish stocks. There might be legislative problems with compensation flow changes to suit prevailing river conditions and this could be an important constraint in the maintenance of the minimum flow. This aspect will need to be addressed if required.

Priority 4. Reduction of pollution from abandoned mines

Measures to prevent further pollution of the rivers from abandoned mines should be undertaken as in the Sheephouse Wood & Bullhouse mine waters project where mine waters are treated to precipitate the ochre in reedbed ponds before the supernatant is discharged into the river. Alternatively, active pumping of mine waters, as already happens, can be intensified and more closely monitored to prevent incidents where pump or power failures have resulted in pollution of the rivers by the mine waters. Both alternatives would require substantial funding and would necessitate internal and external funding with the collaboration of local authorities and industry.

Priority 5. Fish stocking programmes and management

Stocking has been recognised as an effective tool for enhancing fish status (Cowx, 1998). Whilst this is true, stocking success impinges on a wide array of factors of which water quality plays an important role. The ineffectiveness of fish stocking programmes in the Don, Rother and Dearne catchment has been attributed mainly to problems with water quality and lack of suitable holding places for fish. Efforts should therefore be made to address water quality problems prior to stocking.

Steps should also be taken to maximise the environmental fitness and survival of the stocked fish. Fish stocking programmes should coincide with periods of food abundance to maximise chances of survival. For fish bred under artificial conditions this would also reduce competition with wild stocks for food and territories (Hendry, 1998). Wild stocks compete better for food and territories (Hendry, 1998), and artificially-reared salmonids can be out-competed for space and invariably drift downstream where they are preyed upon by larger predators or birds.

Stocking fish from lentic waters into flowing waters would require an acclimation period to enhance their swimming or red muscle development (Broughton, 1977) and subsequent adaptation to their new environment. Fish reared in lentic waters are generally not environmentally well adapted to life in flowing water and many are washed out of the system during high flows or floods (Hendry, 1998). Post-stocking appraisals to assess survival rates and hence stocking success should be undertaken.

To facilitate the execution of the above priorities for addressing the water and habitat quality problems of the Don, Rother and Dearne catchment the following approach could be embarked upon.

1. Stepping up community education and involvement in addressing the water quality problems. The EA produces diverse information and educational leaflets and these could be an important forum to educate and remind both public and industry on the problem. The use of local television and media could assist in creating greater awareness on the subject and encourage both industry and the public to co-operate.
2. Introducing popular, enforceable legislation (Axford, 1994) where the existing

standards could be improved, as has taken place in the Rother catchment (EA, 1998a), to enhance water quality and quantity. The introduction of a new, tough legislation against industry and water companies which was enforced by the EA (EA, 1998a; C. Firth, pers. comm.), has led to localised but considerable improvements in water quality of the Rother and fish have recently been found alongside evidence of recruitment. The legislation involved tightening of existing discharge consents and reduction of discharges from industry and water companies. The tough legislation was introduced in 1989 when the NRA took over the management of the catchment from Yorkshire Water Plc (C. Firth, pers. comm.).

3. Enforcing the desired water quality targets that will enhance the fish stocks. These would involve more rigorous and/or increased monitoring and ensure compliance with the set water quality standards. This would come with some costs, and funding from both internal and external sources should be explored.

4. Active participation of companies in meeting the targets set for improvement. The co-operation and collaboration of industry is crucial for improvement in water quality and the fish stocks. Liaison between the enforcing statutory body and industry would be required. Industries could assist in providing some limited funding or logistic support such as machinery for some activities, e.g. dredging or cleaning up some habitats. Catchment liaison with local authorities and angling groups would be worthwhile.

5. Seeking EU funding or actively seeking funding from various agencies, e.g. MAFF and the UK Lottery Fund, to resolve problems with mine effluents from abandoned sites. In seeking funding from these agencies the rules and conditions for securing funding should be explored to ensure that projects can meet the requirements for funding. A joint collaborative funding by EU, industry and local authorities has been used at some locations in the River Don to address mine water pollution problems, and this could be expanded to other areas in the catchment with similar problems.

A number of projects have been formulated to improve water quality to enhance the long term improvement of the fisheries in the catchment. These are presented in the subsequent chapter.

CHAPTER EIGHT

RECOMMENDATIONS FOR FUTURE ACTION AND DEVELOPMENT OF FISHERIES IN THE DON, ROTHER & DEARNE CATCHMENT

8.1. Introduction

Water quality and habitat degradation problems have been identified as the main bottlenecks to the improvement of fish stocks in the Don, Rother and Dearne catchment. Although industrial, agricultural and mine effluents constitute important causes of the poor water quality of the catchment, sewage pollution remains a central problem to all the sub-catchments. Pollution incidents from sewage sources have so far caused more fish deaths in the catchment than any other known cause (Tables 5.1 & 5.2).

This section addresses the problem of water quality and habitat improvements to rehabilitate the fish stocks of the catchment. The section also presents a number of projects that could be pursued to enhance the water quality and habitats to improve the fish stocks. The proposals of the projects have been presented in the Project Concept Notes, and further details of each project are described in the Logical Project Frameworks. These are draft proposals and additional information including funding, costs and suitable personnel would be required before execution of the projects.

8.2. Objectives

Against the background of the prevailing conditions in the catchment the overall objective of the project is to enhance the fish stocks in the Rivers Don, Rother, and Dearne through improved aquatic resources management and action, e.g. rehabilitation of watercourses and active water quality improvements. The specific objectives are to:

1. identify the catchment and habitat features that structure fish populations in the rivers;
2. assess the impacts of water and land use activities on fish habitats and fish stocks;
3. improve water quality, fish abundance and species diversity in degraded habitats of the catchment through;

- physical rehabilitation and/or re-engineering of degraded sections of the catchment;

- more rigorous enforcement of effluents/discharges limits and consents to the catchment;
- improved fish stocking methods;
- improved catchment management.

The present study identified impacts from landuse practices such as agriculture, industry, mining, construction, sewage and landfills on river habitats, fish abundance and diversity. Objectives 1 and 2 above have therefore been covered as part of this study. Project concept notes and logical project frameworks for this aspect have been included in this chapter (Section 8.4 & 8.4.1) for completeness. These are intended to provide baseline information leading to the formulation and development of project concept notes and logical project frameworks for subsequent projects (Sections 8.5.1 - 8.7.1).

The present study also provides baseline information on water quality shortfalls and habitat degradation in the catchment and status of the fisheries. However, the enforcement of, and compliance with water quality standards to improve water quality and fisheries in the rivers would require further action and should be investigated.

8.3. Projects

Rehabilitation of fisheries and degraded river sections

The rehabilitation of fisheries and degraded sections of the rivers will be undertaken following an evaluation of feasibility, costs and benefits. The Environment Agency should co-ordinate the work in collaboration with land and riparian owners, local angling clubs, voluntary organisations and other interest groups within the catchment area. The project will be advanced through a series of phases as described below. At each phase one or two projects will be undertaken and these are described in the relevant phases. Project concept notes and logical project framework for each of the projects are also provided.

Phase 1: Compliance with water quality standards and consents for discharge.

This phase would ensure that existing water quality standards are more rigorously enforced in line with the EC standards so that they can support the required fisheries. At present ammonia discharge levels in the Dearne (Fig. 4.6) and Rother (Fig 4.9) catchment are well above the recommended EC standards of 1.0 mg l^{-1}. The River Ea Beck and Kearsley Brook, which are both tributaries of the Lower Don, still have sewage pollution problems due to discharges from Elmsall, Wrangbrook, Adwick and Carcroft STWs (EA, 1997). Local Environment Action Plans would need to enforce more rigorously quality of effluent discharges, and also regulate water quantity through periodic reviews and stricter enforcement of abstraction limits. In addition, a seasonal minimum flow regime should be set and enforced to protect the rivers and the fish habitats. These will call for consultations between the EA, Water Companies, agriculture, industry, angling interest groups and other user groups in the catchment area.

During this phase, biological, physical and chemical water quality and fish should be continually monitored, and this should include the levels of pesticides and oestrogenic or endocrine disrupting substance (Logical Project Framework Objective 2).

Phase 2: Physical rehabilitation of watercourses

Some water courses may require dredging or re-engineering to remove toxic materials that have been buried in the bottom sediments in the rivers, e.g. motor oils and lubricants in the River Rother at Birdholme Bridge and ochre in the River Don at Penistone. Dioxins have also been found in the River Doe Lea, a tributary of the River Rother. Other activities during this phase will include

- rehabilitation of in-stream and bankside physical habitat. Several sites in the rivers are choked with domestic wastes and the bankside physical habitat has been contaminated by various wastes. The physical removal of these wastes from the river and bankside should be embarked upon to try and clean up the river;
- diversion of abandoned mine effluents into specially constructed lagoons to eliminate pollution of the recipient waters;

- re-engineering to include putting in meanders in place of straight trapezoidal stretches and provision of bankside vegetation where necessary;
- removal of obstacles to fish movement to enhance fish migrations (Cowx & Welcomme, 1998; Prignon *et al.*, 1998; Northcote, 1998).

Measures to improve the water and habitat quality of the catchment would be investigated under Logical Project Framework Objective 4.

Phase 3. Fish stocking programmes

Existing fish stocking programmes should be formulated to establish required stocking densities following water quality and habitat restoration. Fish from similar habitats that are desired by anglers should be stocked to enhance chances of survival (Cowx, 1998b). Stocking success may be enhanced by stocking fish species already present (Hickley, 1994) in the river or that would be expected to be present; especially if the sites to be stocked are fishless. In addition, stocking of relatively pollution-tolerant species (Davies, 1977), such as roach, tench and bream should be undertaken to enhance stocking success. Precautionary measures should be taken to minimise the possibility of disease transfer. This could be achieved by avoiding stocking fish of unknown origin that are not certified as disease-free (Cowx, 1994; Cowx & Welcomme, 1998).

Constant monitoring of restoration and progress of fish stocks and habitat improvements should be maintained over the duration of the project. During this phase, a review of the management activities for rehabilitating the fisheries of the catchment should be undertaken (Logical Project Framework Objective 3).

Duration

During Phase 1 the rigorous enforcement of water quality standards and compliance with water abstractions in the catchment should involve additional monitoring. The more rigorous enforcement of the required water quality standards through severer and deterrent penalties to offenders may require the backing or enactment of bye-laws or a legislative instrument and should be addressed. This phase may require between 2-3 years to permit data on pesticides and oestrogenic substances to be collected, analysed and reports made. It would also allow possible legislative issues on consents and discharge reviews to be addressed. Periodic monitoring and site inspections have to be undertaken by the statutory authority to ensure that water quality standards set are maintained.

During Phase 2, the physical rehabilitation of degraded sections of the catchment may require a 2-3-year period. This phase will be carried out as a trial project pending its incorporation into management of the aquatic resources of the catchment.

Phase 3, which will involve fish stocking programmes and the review of fisheries management activities in the catchment, may require up to 2 years to complete. Whilst the physical rehabilitation of the catchment is taking place the necessary preliminary preparations can be made towards obtaining broodstock for stocking. Broodstock might be obtained from the Ouse system due to the absence or low fish numbers in the catchment. This will possibly cut down the total project duration to last between 5 and 6 years.

Institutional Support

The project would be managed or overseen by the statutory body or any appropriate body responsible for the catchment. Institutional support for the project will be provided by organisations such as the EA and Yorkshire Water Services. British Waterways would provide support for the navigable stretches. Institutional support will also be provided by Barnsley, Doncaster, Rotherham and Sheffield Councils. The Environment Agency would provide the technical team for field surveys. However, other private institutions or agencies could be also be utilised to carry out the work. Similar exercises carried out by the EA have utilised other institutions and this could be done in this case. Angling clubs, conservation bodies and riparian owners would also provide vital support for the project.

Costs

The process of implementing measures for the rehabilitation of degraded habitats and for the restoration of fisheries in the catchment will come with some considerable costs, and indeed include identifying and securing funding for the required work. Whilst it is not possible at this stage to provide detailed costing for all aspects of this project it would be possible after all the necessary consultations and financial estimates have been made. The initial costs associated with the fisheries survey, water quality and macroinvertebrate surveys should not be too much in excess of those already incurred by the EA for its rolling programme of surveys. On the contrary, the management options and trials at the degraded sites throughout the catchment could require an expenditure running into several millions of pounds. It is suggested that some funding agencies are approached to assist in the implementation of the project. The European Community, MAFF, and the National Lottery Organisers of the UK are potential sources of funding for the project. Prior investigation must, however, be made to ensure that the rules and conditions for obtaining funding from these agencies can be met by the projects.

The potential beneficiaries of the rehabilitation scheme should play a part in funding it. This has the advantage of giving local interests and communities a commitment to the success of the scheme and the right to have a say in the projects. It is therefore essential that those managing the project produce realistic costings before seeking public and private funds for the projects. Other possible sources of funding that should be considered are:

- local businesses and industry, e.g. sponsorship of dredging or removal of toxic sediments from sites near their locality;
- government grant-in-aid, emphasising on the conservation values of sites of scientific interests within the catchment and the need to maintain and improve them;
- riparian owners;
- education and research grants, e.g. some parts of the project that have appropriate research and educational components can be funded through this means;
- major national or international bodies with interest in environmental issues, e.g. Global 2000;
- setting up a Don, Rother & Dearne charitable trust to bring in funds;
- the Heritage Fund;
- the Millennium fund;
- Yorkshire Water Services;
- the Councils-Yorkshire and Derbyshire,
- Landfill tax

Funding agencies operate different rules and criteria for providing financial support and it is important that these are contacted prior to progressing with formal applications for funding.

Evaluation

It is important to constantly evaluate the project output after each phase in relation to the defined objectives. This feedback will permit an assessment of the methods and strategies and how they can be improved. Successes and failures, problems encountered and how problems were solved should be reported. This will serve as a guide for the future so that past mistakes can be avoided. The project approach should be viewed as a long term system to assist the development of fisheries in the catchment. It therefore deserves careful evaluation by those who implement or manage the project.

8.3.1. Justification

Poor water quality and degraded habitats represent the main bottlenecks to the development of fisheries in the catchment. The need to address the water quality and habitat degradation problems of the catchment cannot be over-emphasised.

Fish populations of the catchment have, generally, been restricted due to poor water quality mainly as a result of the discharge of sewage effluents, and habitat degradation problems. A deterioration of fish stocks occurs on the River Little Don below Stocksbridge STW where effluents from the works impact on the water quality (Section 5.1.4). The Dearne catchment, in general, has ammonia levels over and above the EC limits (Fig. 4.6). Fish numbers in the catchment are also low (Figs 5.15-5.18). The River Dearne at Cudworth Common is fishless due to the impacts of sewage discharges from Lundwood STW. The Rother catchment with its 30 STW (NRA, 1994b; EA, 1997) continues to have ammonia levels in excess of the recommended EC limits (Fig. 4.9). Many stretches of the River Rother are fishless due to water quality and habitat degradation problems (Figs 5.22-5.24). Previous mining and industrial activity in the catchments have caused considerable degradation of habitats which affect the fish stocks. Sewage pollution occurs in all the three sub-catchments and accounts for the highest number of fish deaths by known pollution incidents. Tackling the issue of water quality through the resolution of sewage pollution problems constitutes an important step towards the rehabilitation of fisheries in the catchment.

The European Commission (EC) Freshwater Fisheries Directives on water quality (78/659/EEC) and habitats have been adopted by the UK (NRA, 1994b; EA, 1997) and these have been applied in the Don, Rother and Dearne catchment. There is evidence that the water quality of the catchment has not met the requirements of the EC Directives. Fish populations have been poor mainly due to water quality problems. The projects will seek to address the issues to create suitable water quality and habitat conditions for rehabilitation of the fish stocks. The project will also generate vital information which will improve knowledge on the dynamics of fish abundance and diversity in degraded habitats of the catchment.

The Don and its tributaries and reservoirs have, in the past, been used by anglers for both trout and coarse fishing. The long history of poor water quality problems and habitat degradation has constrained demand for use of the catchment for recreational activity, particularly angling. In general, the angling industry provides income through license fees and the tackle industry. The angling industry also provides fisheries-related jobs such as bailiffs and wardens. The poor status of fisheries in the Don, Rother and Dearne catchment therefore means the contributions to income and employment are non-existent. As water quality improves it is anticipated that demand for use of the catchment for angling and other leisure pursuits will increase, thus increasing the amenity value of the catchment. Addressing the water quality and habitat issues of the catchment to enhance the fish stocks is, thus, justified.

The contribution of revenue from the angling industry to the local and national economies of the UK is significant enough to warrant the preservation and development of the fishery resource upon which the angling industry is based. There can be no angling if there is no fish to be caught and considerable revenue will be lost to the state and local authorities.

There is considerable evidence that the riverine habitats of the catchment have undergone significant degradation following many years of pollution from mine wastes, sewage and industrial effluents, and also of agricultural and domestic wastes. The emphases of these projects are to create suitable and improved habitat conditions and suitable water quality for naturally sustainable fish populations. This approach should reduce management costs in the long term and maximise economic benefits.

Stocking and re-stocking programmes within the catchment have so far proved ineffective in resolving the declining stock numbers and low species diversity. It appears that until the water quality problems are addressed stocking exercises make no economic sense. The need to address the problem can therefore not be over-emphasised.

The projects will provide information that will enhance the development and improvement of catchment management and conservation. The project will also facilitate or complement the efforts of the EA, land-owners and angling clubs in the area in making future decisions on the management of the fisheries of the catchment.

8.3.2. Project concept notes and logical project frameworks

The study has identified key issues impacting on the fisheries of the Don, Rother & Dearne catchment (Section 7.2.3) with the issues of water quality and degraded habitats being common to all 3 sub-catchments. The project cycle approach has been used in this study to formulate projects with the overall objective of rehabilitating fisheries in the catchment. The project approach establishes a framework for collection and analysis of data whilst addressing the socio-economic environmental and policy issues (Section 3.8). Project concept notes have been developed for each of the projects. To facilitate a systematic progression, a logical project framework has been designed for each project. The advantages of employing these tools to progress the projects have been presented (Section 3.8).

It would be reiterated here that the project concept notes and logical project frameworks which are presented in the subsequent pages represent draft proposals but not the final project. The final progression or execution of the project would require additional information of which funding, costs, suitable personnel and perhaps legislation might be important.

PROJECT CONCEPT NOTE 1

8.4 ASSESSING THE IMPACT OF LAND USE PRACTICES ON RIVER HABITATS, FISH ABUNDANCE AND DIVERSITY.

Project summary

The project objective is to assess the impact of land use practices on river habitats, fish abundance and species diversity over the past decade. Land use practices have important influence on adjacent aquatic habitats and biota. The project would establish past and present land use activities in the catchment area of the Rivers Don, Rother and Dearne through examination of relevant literature, database search, field observations and interviews. The impacts of the various land use practices on the aquatic environment, particularly on fish abundance and diversity, will be elucidated from the data obtained from the study. The findings will be useful in updating knowledge on land use practices in the catchment and provide valuable suggestions, where appropriate, to improve river habitats for fish. The project will be managed by a consortium of people with interest in the catchment who would also liaise with local authority planners and MAFF. The EA has, in the past, utilised consultants to undertake research on its behalf and this could be done in a similar way. Funding for the project would be sought from external sources.

This project was undertaken as part of this study. This project concept note provides a basis upon which the development of concept notes and project frameworks can be formulated to advance subsequent projects.

Background

Riverine areas have always been ideal locations for the settlement and consequent expansion of human populations. However, these attractions have conspired to cause problems that impact on the aquatic habitat often resulting in a denuded fish fauna. Past industrial activity in the Don, Rother & Dearne catchment, particularly coal mining and steel production, attracted human populations to the area. As time progressed, human activities became intense in the catchment, putting pressure on the terrestrial and aquatic resources. The industrial activities also left a legacy of contaminated land which leach pollutants into the adjacent waters. Leaching of chemicals from landfill sites poses a real threat to water quality of the rivers. Agricultural practices result in the leaching of fertilisers, pesticides and silage liquor into the aquatic environment. Conflicts often arise with land and water uses, particularly those who wish to abstract water for agricultural, domestic or industrial use and those who want to use the aquatic medium as a conduit to dispose of waste products generated on land (Haywood & Crean, 1998). Consequently, the aquatic habitats have been degraded and fish populations and species diversity have been restricted, as in the Don, Rother and Dearne catchment.

Relevance to national economy

The Don, Rother & Dearne catchment has served as an important focus of economic activity in the past and still remains important for its coal mining and steel industry. This project is a local one and is not expected to have any impact on the national economy. It will serve to document the land use practices in the catchment area and also provide options for managing the catchment to improve fish habitats to enhance the fisheries.

Project description

In addition to data and/or information on land use practices, the project will involve considerable travels to various parts of the catchment. Interviews and/or questionnaires of land and riparian owners to update knowledge on the prevailing land use practices will be required. The project will identify the various land, land/water use practices that impact on the waters of the Don, Rother and Dearne catchment over the last decade to elucidate changes in habitat, fish abundance and species diversity. This project was undertaken during this study and forms the thrust of this thesis. This concept note and its logical project framework are intended to provide a baseline leading to the subsequent projects, i.e. Project concept notes 2, 3 & 4 and associated logical project frameworks

Inputs

As detailed in Logical Project Framework (LPF) (Objective 1). Inputs include personnel for data collection, transport, finance, computers, printers and stationery, and office space and furniture.

Economic, social and environmental considerations

The project is expected to have some environmental benefits in the long term as land use practices and their impacts on the aquatic environment are assessed. This will permit reviews of the various uses to improve the fish stocks of the catchment. Some socio-economic benefits may accrue in the long term as the fisheries recover but for the present this remains far-fetched.

Budget summary

No details of budget can be made at this stage. Issues relating to funding, costs and employment of personnel to carry out research would need to be addressed before budgets can be made for progressing the project. However the budget will include all the costs described for "Inputs" and for the entire costs of running the project.

Arrangement for project implementation

The project will be executed by the consortium appointed to carry out the project. The project would be overseen and co-ordinated by the statutory body appointed to manage the catchment or any similar body responsible for the catchment. The project leader would be a member of the consortium and would be responsible for planning the day to day activities of the project.

Monitoring and evaluation

The project will be monitored half yearly by the project team of consultants and the statutory body responsible for the catchment. Status reports will be presented to show progress and constraints. Activities monitored will include data collection and analysis, interpretation of data and status reports. Project accounts will also be monitored by the project management team and subjected to auditing.

Major risks and assumptions

The assumptions and risks are described in LPF Objective 1. The project assumes that historical data for land use practices in the catchment do exist and are accessible. As already identified during the execution of this study, historical information/data for the landuse practices do exist and are accessible.

The project also assumes that individuals and institutions are willing and able to co-operate fully with information on how their land or land/water use practices impact on the rivers and the fish stocks of the catchment.

Logical Project Framework 1 **Project Life:** 1 Year

8.4.1. Project objective 1: To assess the impact of land-use practices on river habitats, fish abundance and diversity.

SUMMARY A	**INDICATORS B**	**VERIFICATION C**	**ASSUMPTIONS AND RISKS**
CATCHMENT OBJECTIVES	CATCHMENT INDICATORS	CATCHMENT STATISTICS	WIDER ASSUMPTIONS AND RISKS
1. To monitor, protect, conserve and enhance fish stocks in the Don, Rother and Dearne catchment.	Changes in land-use practices and effects on habitat, water quality and fish stocks.	Data on fisheries and land use impacts collected by the EA and Water Authorities. over the last decade.	-Data on fish and land-use practices are available. -Land-use practices affect fish in the rivers -There is a need to protect, conserve and enhance fish stocks in the catchment.
PROJECT OBJECTIVE	INDICATORS RELATING TO PROJECT ACHIEVEMENT	PROJECT RECORDS	PROJECT ASSUMPTIONS AND RISKS
Assess impact of land-use practices on habitat quality and fish abundance and diversity.	Identification of land-use practices which directly or indirectly affect watercourses and fisheries in the catchment. This will include data on location and impacts from agriculture, industry, mining, construction, sewage and other human wastes in water courses in the catchment.	Examination of historical data and impact assessment records on agricultural, industrial, mining, chemical and sewerage, and construction activities in the catchment area.	-Land-use practices do impact on water quality, fish abundance and diversity -Data is available, reliable and accessible. -Changes in fish abundance due to land-use practices can be differentiated from natural changes in communities.
OUTPUTS	MAGNITUDE OF OUTPUTS	PROJECT RECORDS	OUTPUT ASSUMPTIONS & RISKS
Establish the main land-use practices that impact on fisheries habitats and fisheries in the catchment and recommendations to enhance fisheries and catchment management.	-Document land use practices, including changes, in the catchment and their impacts on riverine habitats, water quality and fish abundance and diversity. -Results of detailed analysis of species abundance and diversity, mortalities, growth rates and biomass. -Document recommendations to improve catchment management and planning.	-Environment Agency data on fisheries and water quality and physicochemical factors stored on databases. -Land-use data from riparian owners and local authorities, landowners, planners and MAFF. Results of project data analysis generated during project.	-Data on fish and land-use practices are available and accessible.

SUMMARY A	INDICATORS B	VERIFICATION C	ASSUMPTIONS AND RISKS D
INPUTS	IMPLEMENTATION TARGETS, TYPE AND QUANTITY OF RESOURCE	DISBURSEMENT AND COMMISSIONING OF REPORTS	INPUT ASSUMPTIONS AND RISKS
1. Personnel to collect data on various land-use practices in the catchment.	-Suitable personnel to undertake fieldwork, analyse, and transfer data to spreadsheets and databases. -Computer database for information storage -Adequate storage space or filing cabinets for historic documents and secondary data.	-Project database -Verifications on qualifications and experience of personnel -Labour cost of personnel -Receipts for all expenses incurred	-Suitable personnel and financial resources are available for the project -A complete data set is available -Records or secondary data on land-use are available at no cost to project.
2. Transport	Suitable vehicles to carry personnel to field for data collection exercises. Vehicles may be purchased or hired.	-Proofs of purchase or hiring of vehicles for use by personnel. e.g. receipts. -Proof of Guarantees for use of vehicles for the whole project period.	-Project budget permits the purchasing, hiring and running of vehicles.
3. Finance	Money required for running cost of project, payment of wages, and purchases.	-Project Accounts	Funding is available for execution of the project.
4. Computers, printers and relevant software	Availability of computing facilities for analysis of data and preparation of reports.	-Receipts for purchases of computers and software-Guarantees for use of computers for duration of project. -Production of half-yearly reports.	-Resources are available for acquiring computers, computer software, and running them.
5. Office Space and Facilities	Adequate office space and furniture for work by project personnel.	Letting agreement or housing contracts	Location of offices will be within reasonable distance from project area and affordable by the project.
6. Sundry items	Supplies of stationery, calculators, telephones and facsimile.	-Cost of stationery, -Installation and running costs of telephones and fax. -Receipts for all purchases and expenditure.	Resources are available to procure sundry items.

PROJECT CONCEPT NOTE 2

8.5. MONITORING AND ASSESSING SOME ASPECTS OF CHEMICAL WATER QUALITY

Project summary

The project objective is to monitor and assess the levels of pesticides and oestrogenic substances in the Rivers Don, Rother and Dearne. The project will provide and update knowledge on the levels of these substances in the catchment. The project will also investigate the impacts of these substances on fish abundance and recruitment. The project will be executed by a consortium of people with suitable qualifications and an interest in the catchment, and managed by the statutory body or similar organisation empowered to manage the catchment. Pesticides are expensive to monitor, and the project may be expected to cost more than the usual routine monitoring of biological and chemical water quality by the EA. Some aspects of chemical water quality (ammonia, BOD and metal levels) have been covered during this study but need to be expanded to include levels of pesticides and oestrogenic substances.

Background

The Don, Rother & Dearne catchment is impacted by a diverse array of pollutants which include sewage effluents (Fig. 2.3), discharges from abandoned mines (Fig. 2.4) and also agricultural and industrial effluents. Discharges from industry and sewage may contain complex organic chemicals (NRA, 1994b; Section 1.4), and this might include pesticides, dioxins and oestrogenic substances. Agriculture, including livestock rearing, is an important activity in the catchment and farmers invariable apply pesticides in their operations. Hamilton (1985) reported high levels of aldrin, dieldrin and lindane in the Rivers Mole and Taw and at a hatchery on Exmoor, Devon. These substances caused paralysis and high mortality of rainbow trout fry and brown trout. The source of the substances was traced to a disused sheep dip (Hamilton, 1985). Pesticides are present in the Don, Rother and Dearne catchment (J. Hancox, pers. comm.) and would be interesting to investigate. Investigations into endocrine disrupting effects in animals have been carried out *in vivo* or *in vitro* in laboratories and the results have served as basis for predicting potential effects of the substances under field conditions. In recent times, the EA funded a research to identify oestrogenic substances in domestic sewage effluents (EA, 1998b). The results have enhanced the understanding of the role of these substances in observed abnormalities in some wild fish populations. Most studies on the subject have been confined to laboratory tests and relatively few studies have focused on effects of oestrogenic substances on fish and the aquatic environment. On the River Lea in North London, ferminising male roach were found and further investigations revealed that a third of the males had signs of ferminisation (EA, 1998b). These showed production of oocytes in the male testis and increased levels of vitellogenins in the blood stream. Vitellogenins are proteins associated with egg production in female fish. The studies also identified sewage effluents discharged by STWs as the source for the endocrine disrupting substances.

Oestrogenic substances have been found in the River Aire (NRA, 1995b). This caused salmonid fish to change sex. Detailed investigations of the substances in the River Aire catchment have also indicated that ferminisation of male fish were significantly higher downstream of the sewage discharges that contained detergents namely, alkylphenol ethoxylates from the textile industry. The use the oral contraceptive pill containing oestrogens and oral progestagens, and also oestrogen creams and hormonal preparations have been blamed for the changes in fish (Pearce, 1996; Hylland & Haux, 1997). Oestrogenic substances occur in the Don, Rother & Dearne catchment (J. Hancox, pers. comm.), and therefore worth investigating. There is a wide range of substances with endocrine disrupting effects. These include organochlorine pesticides such as DDT, lindane, aldrin & dieldrin. Others include polychlorinated biphenyls, steroids and many synthetic chemicals. These chemical pollutants could directly or indirectly affect fish (Axford, 1994) resulting in low fish numbers and poor species diversity. Changes in sex, as a result of oestrogenic substances, would obviously affect fish reproduction and recruitment. Much work remains to be done on the impacts of pesticides and oestrogenic substances on the fisheries of the Don, Rother and Dearne catchment.

Dioxins have also been found in river sediments in the Rother catchment and the problem is being addressed by the EA. The NRA (now EA) initiated investigations into the occurrence of dioxins and furans in the Rivers Doe Lea and Rother, and also funded the Water Research Centre to investigate their effects on fish. The study could, possibly, be expanded to include other sites in the catchment with additional funding.

Relevance to the national economy

The project is not expected to relate to the national economy and therefore has no direct relevance to the national economy. The project will, however, document the levels of the named substances in the catchment and how they affect water quality, fish abundance, species diversity and recruitment.

Project description

The project will entail a detailed study and biochemical analysis of water samples, sediments and macrobenthic fauna to determine the levels of the chemical substances present. It would also investigate and monitor residues in fish flesh and internal tissues to verify and assess the level of contamination to elucidate effects on growth and recruitment. Data would be collected over a 2-3-year period at quarterly intervals from selected sites in the catchment to ascertain the levels of the substances. Further work and monitoring frequency would depend on the levels of the substances found and their effects on the fish fauna.

Inputs

Inputs are as detailed in LPF Objective 2. They include electric fishing equipment, laboratory facilities with appropriate biochemical analysis equipment, macroinvertebrate sampling kits, computers, printers, stationery supplies, transport and personnel.

Economic, social and environmental considerations

The project is expected to have considerable environmental benefits to the catchment in the medium to long term as the chemical pollutants and their sources are identified and steps taken to improve water quality. In the long term the fish stocks might improve in step with improving water quality and fish stocking programmes, resulting in some social and economic benefits to the catchment area.

Budget summary

The actual budgetary costs cannot be given at this stage. Additional information relating to costs of equipment, funding and hiring of personnel to carry out projects would need to be collected. Listing and prioritising of pesticides and oestrogenic substances in terms of their actual or potential impacts on fisheries would also need to be done to assist budgeting. On the other hand the budget will include all the inputs described earlier. Due to the high costs often involved in such studies, it is expected that the budget might exceed what the EA in the region spends in their routine biological and chemical surveys and analysis.

Arrangement for project implementation

The project will be executed by a consortium of people with relevant expertise in the subject matter and an interest in the catchment. The project would be managed by the statutory organisation or similar body empowered to manage the affairs of the catchment. The project leader would be a member of the consortium and would be responsible for the day to day running of the project.

Monitoring and evaluation

The monitoring and evaluation of project will be undertaken by the consortium appointed to carry out the project and by the statutory body at half yearly intervals. They consortium will report on both achievements and constraints of the project. The consultants would monitor field surveys, laboratory analysis, data analysis and reports writing. Project accounts will also be monitored by the consortium and the management body and subjected to auditing.

Phases of activities

- Phase 1.

Collection of baseline information and/or historical data on chemical substances present in the catchment; study and analysis of historical water quality data. These would relate to pesticides and oestrogenic substances.

- Phase 2.

This phase will involve field surveys and laboratory studies. Biochemical analysis of water samples, sediments, benthic macroinvertebrates and fish would be undertaken to establish presence and concentrations of the chemicals. Surveys would be done at quarterly frequency. Electric fishing surveys would also be undertaken to collect fish samples for analysis.

Major risks and assumptions

The project assumes that adequate funding can be found to carry out the study. It also assumes that suitable personnel with the requisite qualifications and expertise would be available to carry out the study.

Logical Project Framework 2

8.5.1. Project objective 2:. To monitor and assess levels of oestrogenic substances and pesticides in the Don, Rother & Dearne catchment.

Project Life 4 years

SUMMARY A	**INDICATORS B**	**VERIFICATION C**	**ASSUMPTIONS AND RISKS D**
CATCHMENT OBJECTIVES	CATCHMENT INDICATORS	CATCHMENT STATISTICS	WIDER ASSUMPTIONS AND RISKS
To monitor, protect, enhance and improve water quality in the Don, Rother and Dearne catchment.	Changes in levels of pesticides and oestrogenic substances in water, sediments and fish. Physiological/endocrine changes in sex of fish, recruitment and fish abundance.	-Chemical water quality data collected by Water Authorities and EA. -Fisheries data in relation to chemical water quality collected by the EA and Water Authorities.	-There is a need to monitor, protect, enhance and improve water quality of the catchment.
PROJECT OBJECTIVE	INDICATORS RELATING TO PROJECT ACHIEVEMENT	PROJECT RECORDS	PROJECT ASSUMPTIONS AND RISKS
1. To assess the levels of oestrogenic substances and pesticides in the Don, Rother & Dearne catchment.	-Baseline information on the occurrence of pesticides and oestrogenic substances in the catchment. -Biochemical examination of water and sediments for substances. -Examination of benthic macroinvertebrates for pesticide residues and oestrogenic substances. -Examination of fish for pesticide residues and evidence of endocrine-disrupting substances. -Identification of possible sources of chemical substances. -Half-yearly status reports on project.	-Chemical water quality data/information held in the databases of the EA and Yorkshire Water Authorities. -Examination of past and present chemical data/information on effluents from agricultural, industrial, chemical, and sewerage activities in the catchment area.	-Baseline data and/or information are available and accessible.

SUMMARY A	INDICATORS B	VERIFICATION C	ASSUMPTIONS AND RISKS
OUTPUTS	MAGNITUDE OF OUTPUTS	PROJECT RECORDS	OUTPUT ASSUMPTIONS AND RISKS
-Enhance knowledge on the levels of oestrogenic substances and pesticides in the catchment -Enhance knowledge on the incidence of endocrine disrupting substances in fish and effects on recruitment. -Recommendations to improve chemical water quality and fisheries.	-Fish abundance and recruitment in relation to the levels of the chemical substances. -Spatial and temporal extent of water contamination by the chemical substances -Documentation of recommendations to improve water quality and fisheries.	Analysis on past chemical data held by the EA and current data on the substances. Analysis of past and present data on water quality and fish status in the catchment.	Historical chemical data on the substances are available and accessible. Suitable personnel are available to collect and carry out data analysis. Laboratory facilities are available for analysis. Improvement in water quality and fisheries habitats are required.
INPUTS	IMPLEMENTATION TARGETS, TYPE AND QUANTITY OF RESOURCE	DISBURSEMENT AND COMMISSIONING OF REPORTS	INPUT ASSUMPTIONS AND RISKS
1. Personnel to collect and carry out biochemical analysis on levels of pesticide and oestrogenic substances in water, sediments, fish and benthic macro invertebrates.	-Suitable personnel to undertake data collection and analysis. -Storage space for historic documents and secondary data.	Verification on qualifications, expertise and experience of project personnel Receipts for purchases related to the project.	-Suitable personnel and financial resources are available. -All equipment are available and can be obtained as and when required. Secondary or historic data is available.
2. Transport	Delivery vehicles for hiring or purchasing to transport equipment and personnel for field surveys.	Receipts of purchases or hire of vehicles Guarantees for the use of project vehicles throughout project life.	Project budget can accommodate the purchase or hire of vehicles and for their day to day running.
Finance	Funds for running costs of project, wages of personnel and purchases.	Project Accounts	Money is available for the execution of the project.
Computers, printers, and software	Computing facilities for processing and storage of data and for presentation of reports.	Receipts for purchase of computers, printers and relevant software.	Financial resources are available for purchasing computers, printers and software.
Electric fishing gear, laboratory space and equipment, chemicals and other expendables, and macroinvertebrate sampling equipment.	-Adequate laboratory space and facilities -Adequate macroinvertebrate sampling kits -Electric fishing gear.	Expenditure receipts on chemicals, reagents and other expendables and for all laboratory equipment.	-Laboratory facilities are available. -Financial and human resources are available for the work.
Office/Laboratory space	Adequate working space and furniture for project personnel.	Letting agreement or housing contract.	Offices/laboratory will be within suitable location and are affordable by the project.
Sundries	Stationery supplies, telephones, calculators	Receipts covering costs for all purchases	Resources are available to purchase sundries

PROJECT CONCEPT NOTE 3

8.6. REVIEW OF MANAGEMENT ACTIVITIES FOR REHABILITATION OF FISHERIES IN THE DON, ROTHER & DEARNE CATCHMENT

Project summary

The project objective is to review fisheries management activities in the Don, Rother and Dearne catchment during the past decade. The project would document the fisheries management activities in the catchment for the past and present and make recommendations for improvement where necessary to rehabilitate the fish stocks. The project would establish any flaws, set-backs or omissions in the management of the fish stocks that restrict the establishment of a viable fishery in the catchment. The project would be managed by the statutory body or similar organisation responsible for catchment. The project will basically be a desk study one lasting up to 1 year.

Background

The Environment Agency and its predecessors (the NRA and Yorkshire Water) have made considerable progress in trying to manage the fish stocks of the Don, Rother and Dearne catchment. Despite these efforts the status of fisheries in the catchment remains rather poor at many locations. Such management activities have included river engineering and channel modification (Plates 5 & 6), habitat improvement schemes, water pollution control and fish stocking programmes. Stocking programmes have so far been ineffective with only localised improvements in recent times (EA, 1998a). The project would be expected to identify options for improvement in the management of fish stocks in the catchment.

Relevance to the national economy

No direct relevance can be made to the national economy with the execution of the project although it is anticipated that the project would lead to identification of options for facilitating the management of fish stocks in the catchment to enhance the fisheries.

Project description

The project would entail documenting the fisheries management activities in the catchment during the past 10 years to the present day and an evaluation of the success of failure of the objectives of the activities. The project would involve accessing the databases of the EA for details on fish stocking and introductions, river engineering and channel modification, habitat improvement and restoration schemes, water pollution control and fish disease control measures. Fish statistics data for the period will also be studied in relation to the management activities.

Inputs

The inputs are described in LPF Objective 3 and include personnel, transport, finance, computers and printers, office space and stationery supplies.

Economic, social and environmental considerations

The project will generate information that would be useful for the future management of fisheries and the aquatic environment. Socio-economic and environmental considerations might be made where there is a need to review management activities, e.g. re-engineering of a stretch of a river.

Budget summary

The budget will include cost of the inputs outlined in LPF Objective 3 which also includes the running costs of the project.

Arrangement for project implementation

The project would be executed by a consortium of people appointed to carry out the project. The project would be managed and co-ordinated by the statutory body empowered to manage the catchment or by similar organisation with regulatory powers or duties for the catchment. The consortium would have a leader who will plan the day to day activities of the project in consultation with the project team.

Monitoring and evaluation

The consortium and management body of the project would monitor, evaluate and provide status reports on progress and constraints at 3-monthly intervals. Activities monitored will include data collection, analysis and interpretation and status reports. Project accounts will also be monitored by the consortium and management body, and accounts would be audited.

Major risks and assumptions

The main risks and assumptions are described in LPF Objective 3. The project assumes that there are data available on fisheries management activities for the catchment and that there are suitable personnel to analyse them through financial, environmental and socio-economic tests. The project further assumes that fisheries management efforts are not viable unless sustained improvements in water quality and fish populations and diversity have been attained.

Logical Project Framework 3

8.6.1. Project objective 3: To review management activities for the rehabilitation of fisheries in the Don, Rother and Dearne catchment.

Project Life: 1 Year

SUMMARY A	INDICATORS B	VERIFICATION C	ASSUMPTIONS AND RISKS
CATCHMENT OBJECTIVES	CATCHMENT INDICATORS	CATCHMENT STATISTICS	WIDER ASSUMPTIONS AND RISKS
To protect, conserve and enhance fish stocks in the Don, Rother and Dearne catchment.	-Changes in fish stock abundance and composition over the last 10 years. -Changes in demand for angling in the catchment.	-Data on fish population dynamics/fisheries statistics, and fisheries management activities over the last 10 years. Data on stocking and introductions, river engineering and channel modification, habitat improvement and restoration, water pollution control, & fish disease control measures.	-Data on fisheries statistics and fisheries management activities are available. -There is a need to protect, conserve and enhance fish stocks in the Don, Rother and Dearne catchment. -Management activities reflect the status of fish stocks in the catchment.
PROJECT OBJECTIVE	INDICATORS RELATING TO PROJECT ACHIEVEMENT	PROJECT RECORDS	PROJECT ASSUMPTIONS AND RISKS
To review management activities for the rehabilitation of fisheries in the Don, Rother and Dearne catchment.	-Analysis of fisheries statistics data, and examination of fisheries management activities. -Fish populations have declined and further decline must be avoided.	-Results of fish data held in the databases of the EA and Yorkshire Water Authority. -Records of management activities of the EA with costs of pursuing activities. -Fisheries data from local angling clubs.	-Review and improvement in fisheries management activities in the catchment is required. -Fisheries statistics data are available -Qualified personnel are available to carry out work.
OUTPUTS	MAGNITUDE OF OUTPUTS	PROJECT RECORDS	OUTPUT ASSUMPTIONS AND RISKS
1. Identification of fisheries management activities in the catchment.	Document all fisheries management activities for past and present.	-Data held in the databases of the EA, Yorkshire Water and local angling clubs.	Reliable data are available and accessible..
2. Recommendations for improved rehabilitation of fisheries and catchment management.	-Will depend on the magnitude and extent of habitat degradation and decline in fish populations and species diversity. -Identification of appropriate rehabilitation methods for implementation to improve catchment management through financial, environmental and socio-economic tests.	-Data obtained from the EA on fish population dynamics. -Records of fisheries management activities and costs. -Fish data from local angling clubs.	-There is a need to improve catchment management. -Suitable personnel are available to undertake financial, environmental, and socio-economic tests.

SUMMARY A	INDICATORS B	VERIFICATION C	ASSUMPTIONS AND RISKS
INPUTS	IMPLEMENTATION TARGETS, TYPE AND QUANTITY OF RESOURCE	DISBURSEMENT AND COMMISSIONING OF REPORTS	INPUT ASSUMPTIONS AND RISKS
1. Personnel to collect and review fisheries management activities records for the past and present.	-Suitable personnel to undertake data/records collection and analysis.	-Verifications on qualifications and experience of personnel.	-Suitable manpower and financial resources are available. -A complete data set is available. at no cost to project.
2. Transport	Vehicles for hiring or purchase to carry project personnel.	-Receipts for purchase or hire of vehicles. -Guarantees permitting the use of project vehicles during project life.	Budget permits the purchasing, hiring, and running of vehicles.
3. Finance	Money for running costs of project and wages.	Project Accounts.	Money is available for project.
4. Computers, printers and software	Access to computing facilities for analysis of data and preparation of reports.	Receipts of purchase of computers and software. Guarantees for use of computers for duration of project.	Funding is available for purchasing computers and running them.
5. Office space	Adequate office space and furniture for project personnel.	Letting agreement or housing contract.	Offices will be within a suitable location Running costs of office is affordable by project.
6. Sundry items	Stationery supplies, telephones, fax, calculators.	Receipts and invoices for all purchases.	Resources are available to purchase sundry items.

PROJECT CONCEPT NOTE 4

8.7. IMPROVING WATER AND HABITAT QUALITY OF THE DON, ROTHER & DEARNE CATCHMENT FOR FISHERIES REHABILITATION

Project summary

The project objective is to improve water quality and fish habitats of the Don, Rother & Dearne catchment for the rehabilitation of fisheries. Water quality has been identified as the main bottleneck to the establishment of fisheries in the catchment. The project would implement measures to improve water quality through various means such as improving the quality of sewage and industrial effluents discharged to the catchment and cleaning up grossly contaminated sites in the catchment. It would also involve the physical rehabilitation of degraded habitats prior to stocking of fish into the rivers. The project would be under the management of the statutory body empowered to manage the catchment. The project will be expected to cost considerable sums of money running into several millions of pounds and will require financial assistance from various donor organisations.

Background

The Don, Rother and Dearne catchment has serious water quality problems dating back many years. This has been attributed mainly to impacts from sewage, mining and industrial discharges, leachates from contaminated land and degraded habitats. As a consequence fish populations and species diversity have remained poor and most locations are fishless. Fish stocking programmes in the rivers have been ineffective for reasons that are mainly attributable to poor water quality and degraded habitats.

Relevance to national economy

The improvement of water quality and rehabilitation of fisheries in the Don catchment would not be expected to have any immediate relevance to the national economy and indeed would be a localised project. As the fisheries improve in response to improvements in water quality and habitat enhancement schemes, it is probable that a viable fishery might develop which could enhance recreational fisheries in the area. This might then impact on the local economy.

Project description

The project would seek to improve water quality through a more radical approach to improve the quality of sewage, mining and industrial effluents discharged to the catchment. This would involve a more rigorous enforcement of existing consents with severer penalties to offenders. A tough new legislation against industry and water companies which was enforced by the EA (EA, 1998a; C. Firth, pers. comm.) has resulted in considerable improvements to the fish stocks of the River Rother. The improvement is, however, localised and the exercise could be extended to other catchment areas. Where necessary legislative backing should be sought to improve fish stocks of the catchment as has happened in the Rother. The project would also involve the physical restoration of degraded sections of the river habitats. Grossly contaminated land adjacent to the rivers and contaminated bottom sediments will also be cleaned up through engineering works. Following the resolution of water quality problems, fish stocking exercises would be undertaken to re-establish the fisheries. The project would use data from Logical Project Frameworks 1-3 as basis for the rehabilitation and would be would be expected to last up to 5 years.

Inputs

As detailed in Logical Project Objective 4 and includes suitable personnel, equipment and traction vehicles, transport, computers, printers, netting equipment and sampling nets for stocking exercises, office equipment and stationery supplies.

Economic social and environmental considerations

The project would take due consideration of the environmental impacts of cleaning up adjacent contaminated land and removing bottom sediments and make proper arrangements for their disposal with minimum risk to the environment. River channel modification works would be done, where appropriate, with due consideration for the river environment, enhancement of habitats and the fish stocks. Improving quality of sewage and industrial effluents discharged to the river has obvious advantages to the river environment but might mean further financial or capital outlay by sewage and industry.

Budget summary

Whilst it is not possible to provide a detailed budget for the project at this stage, costs would be expected to include all the inputs described LPF Objective 4. These include costs of hiring and operation of traction vehicles for excavation, dredging and removal of contaminated sediments. Fish re-stocking programmes would also be covered by the budget. Funding should be sought from both internal and external sources.

Arrangement for project implementation

The project would be executed by a consortium of people with suitable qualifications and interest in the catchment. The project would be managed and co-ordinated by the statutory body with responsibilities for the catchment. The consortium would have a project leader who would be responsible for planning the day to day activities of the project. The management body would offer general supervisory roles for the project.

Monitoring and evaluation

The consortium and management body would undertake the monitoring and evaluation of project at half-yearly intervals over the five-year period. The consortium would report on the progress and constraints during the project. The activities monitored will include the physical rehabilitation exercises, quality of effluents discharged to the rivers from sewage and industry and also reports of project team. The consortium and management body would monitor project accounts and accounts would be audited.

Major risks and assumptions

The risks and assumptions are detailed in LPF Objective 4. The project assumes that there are reliable baseline data on water quality, habitat conditions that would form the basis for rehabilitation the fisheries. The project further assumes that financial and relevant expertise can be found to carry out the project.

Logical Project Framework 4: Phases 2 & 3 (Implementation of activities)

PROJECT TITLE: THE REHABILITATION OF FISHERIES IN DEGRADED HABITATS OF THE DON, ROTHER AND DEARNE CATCHMENT.

Duration 5 years

8.7.1. Project objective 4: To improve water quality and habitats of the Don, Rother and Dearne catchment for fisheries rehabilitation

SUMMARY A	**INDICATORS B**	**VERIFICATION C**	**ASSUMPTIONS AND RISKS D**
CATCHMENT OBJECTIVES	CATCHMENT INDICATORS	CATCHMENT STATISTICS	WIDER ASSUMPTIONS AND RISKS
1. To improve water quality of the Don, Rother and Dearne catchment through reduction of sewage and industrial effluents to the rivers.	Changes in water quality parameters. e.g. ammonia, DO, BOD, and heavy metals. Changes in fish numbers.	Water quality data collected by the Environment Agency (EA).	Water quality and related data are available. There is a need to improve water quality of the catchment.
2. To clean up grossly contaminated sections of the catchment and adjacent land through re-engineering works and bottom sediments removal.	Visual changes in water quality. Changes in level of contaminants in water and sediments.	Data from Phase 1 of study. EA data on contaminated waters and contaminated lands adjacent to rivers.	There is a need to clean up grossly contaminated sections of the catchment to enhance water quality and fisheries.
3. To restore and improve degraded habitats and rehabilitate fisheries of the Don, Rother and Dearne catchment. through re-stocking programmes.	Changes to habitats Physical changes and modifications to the river channel.. Changes in fish populations in the catchment.	EA data on degraded sections of the rivers. Data on degraded sections from Phase 1 of this study. Data on changes or modifications to riverine habitats and channels. Changes in fish populations.	Data on degraded habitats are available from the EA. There is a need to rehabilitate the habitats and fish stocks of the catchment.

SUMMARY A	**INDICATORS B**	**VERIFICATION C**	**ASSUMPTIONS AND RISKS D**
PROJECT OBJECTIVE	INDICATORS RELATING TO PROJECT ACHIEVEMENT	PROJECT RECORDS	PROJECT ASSUMPTIONS AND RISKS
To improve water quality, habitats and fish stocks in degraded sections of the Don, Rother and Dearne catchment.	Water quality improvements over time. Changes or improvements in fish populations.	Verification by analysis and comparison of the previous 10 years data and present water quality changes.	Financial resources and relevant expertise are available to carry out improvements to water quality and habitats..

OUTPUTS	MAGNITUDE OF OUTPUTS	PROJECT RECORDS	OUTPUT ASSUMPTIONS & RISKS
1. Improvements to water quality of the rivers. Re-colonisation of rivers by fish.	Significant improvements in water quality changes to meet required water quality targets for fisheries rehabilitation.	Data from Phase 1 of study. EA data on water quality over the last years.	Water quality improvements will take place.
2. Re-stocking and re-colonisation of rivers by fish following water quality improvements.	Changes in fish numbers following water quality improvements.	Fish data from Phase 1 of project. Fish data from EA databases.	Fish data are available from EA and Phase 1 of project.
3. Enhance aesthetic and amenity value of the rivers	Changes in leisure pursuits, e.g. bird watching, walking or picnicking along river banks.	EA records of changes in leisure pursuits.	Records of changes in leisure pursuits are kept by the EA and are available.
4. Restoration of physically-degraded riverine habitats including riparian and bankside vegetation.	-Removal of unwanted litter, waste and blockages, to enhance river flow. -Excavation of river beds to remove contaminated sediments e.g. industrial oils trapped in bottom sediments.	Records of physically degraded habitats from the databases of the EA. Data from Phase 1 of project.	Restoration of degraded habitats is required. Records on degraded habitats are available from the EA database and from phase 1 of study.
5. Re-channelisation of some blocked sections to include meanders to check flooding, enhance habitat diversity and create refugia for fish.	Re-channelisation of flood-prone sections. Re-engineering of blocked sections of rivers.	Records on re-channelised sections of the catchment from the EA databases. Records of sections requiring re channelisation from EA databases.	Records on channelised sections and sections requiring channelisation are available.

SUMMARY A	INDICATORS B	VERIFICATION C	ASSUMPTIONS AND RISKS D
INPUTS	IMPLEMENTATION TARGETS, TYPE AND QUANTITY OF RESOURCE	DISBURSEMENT AND COMMISSIONING OF REPORTS	INPUT ASSUMPTIONS AND RISKS
1. Personnel and to carry out water quality and habitat improvement works.	-Suitable personnel to undertake water quality and habitat improvement scheme .	-Verifications on qualifications and experience of personnel -Receipts for all purchases.	Manpower and financial resources are available for the rehabilitation exercise. .
2. Equipment and traction vehicles to carry out excavation and habitat enhancement works.	Suitable equipment and machinery to carry out habitat enhancement works.	Receipt for purchases or hiring of all machinery or equipment or for any contractual work	All machinery or equipment are available and can be purchased as and when required.
3. Transport	Vehicles for hiring or purchase to carry equipment and transport personnel.	-Receipts for purchases or hire of vehicles. -Guarantees permitting the use of the vehicles for entire project period	Budget permits the purchase, hiring and running of vehicles for the project.
4. Finance	Money for running costs of project, wages and purchases.	Project Accounts	Financial resources are available for execution of project.
5. Computers, printers and software	-Access to computing facilities for analysis of data and preparation of reports. -Computer database to store information and data.	-Receipts of purchase of computers and software -Guarantees for use of computers for duration of project.	Money is available for purchasing computers and running them.
6. Netting equipment and sampling nets for re-stocking of fish in improved habitats.	-Suitable netting and sampling equipment.	Receipts and invoices for all purchases.	Resources are available for purchase of netting and sampling equipment.
7. Office space	Adequate working space and furniture for personnel.	Letting agreement or housing contract.	Offices will be within a suitable location and are affordable by the project.
8. Sundry items	Stationery supplies, telephones, facsimile, electronic mail system, calculators.	Costs of sundry items listed. Receipts for all purchases.	Resources are available to purchase sundry items.

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Appendix 1.1. GQA chemical grading for rivers and canals

Water Quality	Grade	Dissolved Oxygen (% saturation) 10-percentile	Biochemical Oxygen Demand (BOD) mg/l) 90-percentile	Ammonia (mg/l) 90-percentile
GOOD	A	8.0	2.5	0.25
	B	7.0	4	0.6
FAIR	C	6.0	6	1.3
	D	5.0	8	2.5
POOR	E	2.0	1.5	9
BAD	F	Less than 2.0	More than 1.5	More than 9

The overall grade assigned to a river or canal reach is determined by the worst of the three grades for the individual determinands.

Source: The quality of Rivers and Canals in England and Wales (1990 to 1992). *Report of the National Rivers Authority,* May 1994, Water Quality Series **No. 19**

Appendix 1.2. Chemical classification of river water quality proposed by the NWC and adopted by the DoE

River Class	Quality Criteria	Remarks	Current and Potential Uses
1A VERY GOOD QUALITY	(i) DO saturation greater than 80% (ii) BOD not greater than 3 mg/l (iii) Ammonia not greater than 0.4 mg/l (iv) Where water is abstracted for drinking water, it complies with the requirements for A2* water. (v)Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available)	Mean BOD probably not greater than 1.5 mg/l No visible evidence of pollution	Water of high quality suitable for potable supply, and abstractions Game or other high class fisheries High amenity value
1B GOOD QUALITY	(i) DO saturation greater than 60% (ii) BOD not greater than 5 mg/l (iii) Ammonia not greater than 0.9 mg/l (iv) Where water is abstracted for drinking water it complies with the requirements for A2* water. (v) Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available)	Mean BOD probably not greater than 2 mg/l Mean Ammonia probably not greater than 0.5 mg/l No visible evidence of pollution. Water of high quality which cannot be placed in Class 1A due to high proportion of high quality effluent present, or due to the effect of physical factors such as canalisation, low gradient or eutrophication. Class 1A and 1B together are essentially the Class 1 of the River Pollution Survey (RPS).	Water of less quality than class 1A but usable for substantially the same purposes.

Appendix 1.2. continued

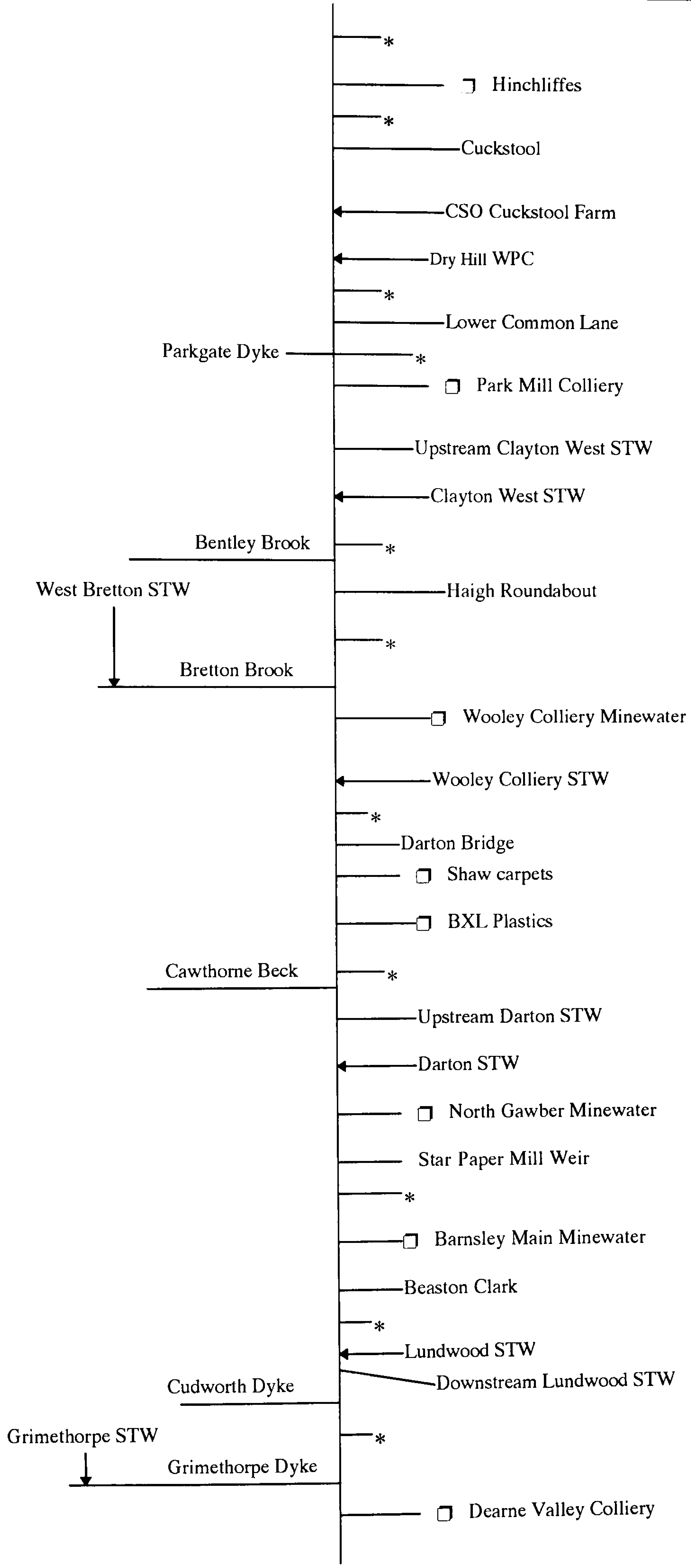
2 FAIR QUALITY	(i) DO saturation greater than 40% (ii) BOD not greater than 9 mg/l (iii) Where water is abstracted for drinking water, it complies with the requirements for A3* water. Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available) .	Mean BOD probably not than 5 mg/l Similar to Class 2 of RPS Water showing no signs of pollution other than humic coloration and a little foaming below weirs.	Water suitable for potable supply after advanced treatment Supporting reasonably good coarse fisheries Moderate amenity value.
3 POOR QUALITY	DO saturation greater than 10% Not likely to be anaerobic BOD not greater than 17 mg/l	Fish are absent or sporadically present. Similar to Class 3 of RPS	May be used for a low grade abstraction for industry. Considerable potential if cleaned up
4 BAD QUALITY	Water inferior to Class 3 in terms of DO. Likely to be anaerobic at times.	Similar to Class 4 of RPS.	Waters are grossly polluted and are likely to cause nuisance. Insignificant watercourses and ditches which are not usable. Objective is simply to prevent nuisance.
X	DO greater than 10% saturation		Insignificant watercourses and ditches not usable, where objective is simply to prevent nuisance developing.

Note (a) Under extreme weather conditions (e.g. flood, drought, freeze-up) or when dominated by plant growth, or by aquatic plant decay, rivers usually in Classes 1, 2 and 3 may have BODs and dissolved oxygen levels or ammonia content outside the stated levels for those Classes. When this occurs the cause is stated along with analytical results.

(b) The BOD determination refer to 5 day carbonaceous BOD (ATU). Ammonia figures are expressed NH_4.
This may not apply if there is a high degree of re-aeration.

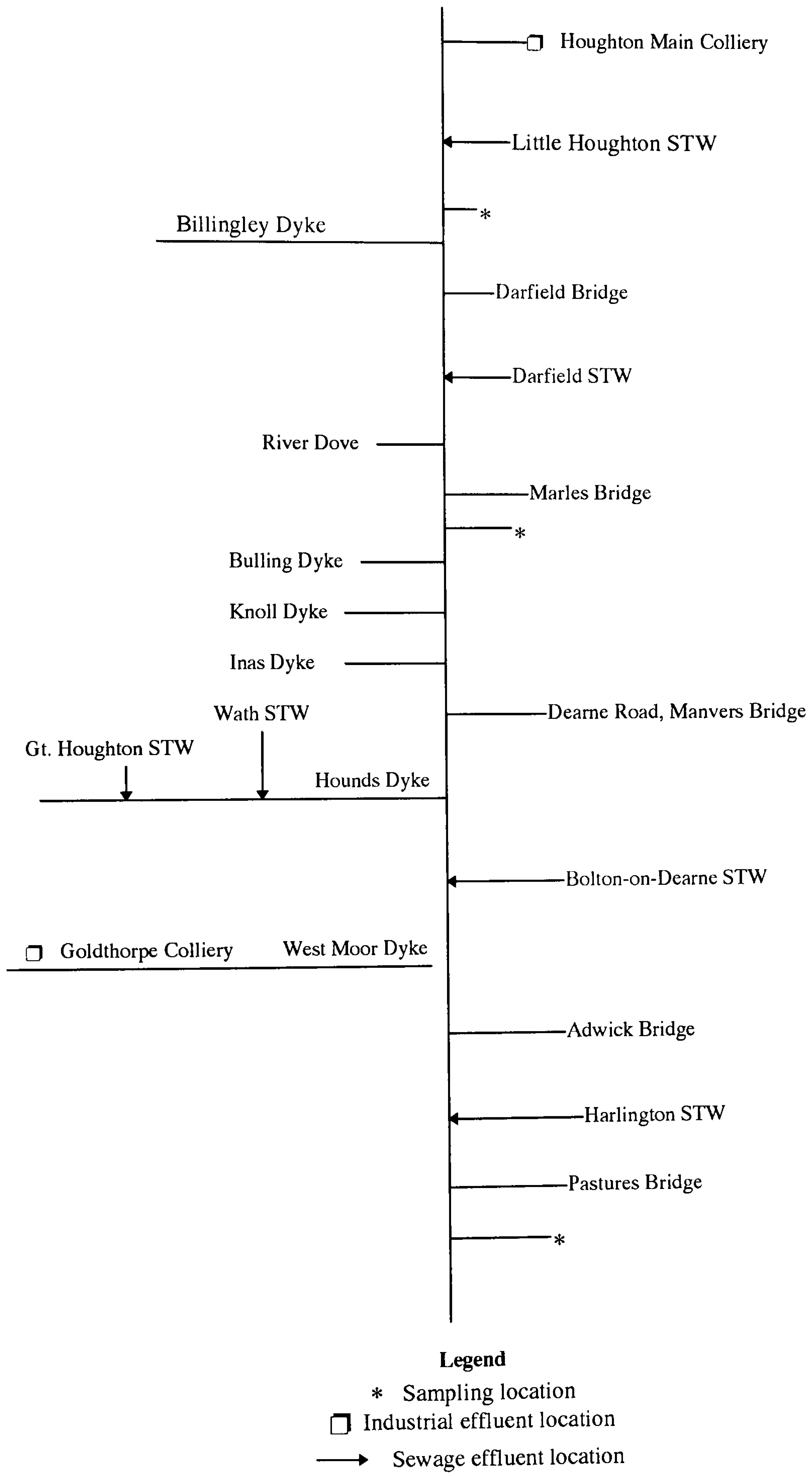
(c) In most instances the chemical classification given above will be suitable. However, the basis of the classification is restricted to a finite number of chemical determinands and there may be a few cases where the presence of a chemical substance other than those used in the classification markedly reduces the quality of the water. In such cases, the quality classification of the water should be down-graded on the basis of the biota actually present, and the reasons stated.

(d) EIFAC (European Inland Fisheries Advisory Commission) limits should be expressed as 95 percentile limits.
EEC category A2* and A3* are those specified in the EEC Council Directive of 16th June 1975 concerning the Quality of Surface Water intended for Abstraction of Drinking Water in the member States. (Bottomley *et al.*, 1985).



Appendix 1.3. Scheme of sampling points and effluent locations in the Dearne catchment.

Appendix 1.3 continued.



Source: Environment Agency (North-East Region)

Appendix 1.4. List of benthic macroinvertebrates at selected sites in the Rivers Don, Rother & Dearne (1995-1997).

The River Don

Penistone	Beeley Woods
Chironomus riparius	*Gammarus pulex*
Asellus aquaticus	*Chironomus riparius*
Gammarus pulex	*Sphaerium corneum*
Physa fontinalis	*Eiseniella tetraeda*
Lymnaea peregra	*Asellus aquaticus*
Simulium vittatum	*Erpobdella octoculata*
Erpobdella octoculata	*Physa fontinalis*
Helobdella stagnalis	*Gyrinus natator*
Eiseniella tetraeda	*Simulium vittatum*
Gyrinus natator	*Tipula paludosa*
Ancylus fluviatilis	

The River Dearne

Cudworth Common	Pastures Bridge
Asellus aquaticus	*Sphaerium corneum*
Chironomus riparius	*Chironomus riparius*
Sphaerium corneum	*Gammarus pulex*
Lymnaea peregra	*Asellus aquaticus*
Erpobdella octoculata	*Eiseniella tetraeda*
Eiseniella tetraeda	*Potamopyrgus jenkinsi*
Tipula paludosa	*Physa fontinalis*
Physa fontinalis	

The River Rother at Birdholme Bridge
Chironomus riparius
Sphaerium corneum
Asellus aquaticus
Eiseniella tetraeda
Physa fontinalis
Erpobdella octoculata
Tipula paludosa

Appendix 1.5. Fish density and diversity in the River Don at Penistone & Beeley Woods.

t-tests for independent samples of VAR00004 (Penistone(1) and Beeley Woods(2)

Variable	Number of Cases	Mean	SD	SE of Mean
VAR00001(Fish Density)				
VAR00004 1	7	2.8143	1.114	.421
VAR00004 2	7	1.9714	1.204	.455

Mean Difference = .8429

Levene's Test for Equality of Variances: F= .046 P= .834

t-test for Equality of Means

Variances	t-value	df	2-Tail Sig	SE of Diff	95% CI for Diff
Equal	1.36	12	.199	.620	(-.508, 2.194)
Unequal	1.36	11.93	.199	.620	(-.508, 2.194)

Variable	Number of Cases	Mean	SD	SE of Mean
VAR00002 (Shannon-Weiner index)				
VAR00004 1	7	.5016	.149	.056
VAR00004 2	7	1.2729	.302	.114

Mean Difference = -.7713

Levene's Test for Equality of Variances: F= 2.872 P= .116

t-test for Equality of Means

Variances	t-value	df	2-Tail Sig	SE of Diff	95% CI for Diff
Equal	- 6.05	12	.000	.127	(-1.049, -.494)
Unequal	-6.05	8.75	.000	.127	(-1.060, -.483)

Appendix 1.5. (continued).

-tests for independent samples of VAR00004 (Penistone & Beeley Woods).

Variable	Number of Cases	Mean	SD	SE of Mean
VAR00003 (Margalef's index)				
VAR00004 1	7	.3707	.052	.020
VAR00004 2	7	1.1951	.517	.195

Mean Difference = -.8244

Levene's Test for Equality of Variances: F= 16.387 P= .002

t-test for Equality of Means Variances	t-value	df	2-Tail Sig	SE of Diff	95% CI for Diff
Equal	-4.20	12	.001	.196	(-1.252, -.397)
Unequal	-4.20	6.12	.005	.196	(-1.305, -.344)

Appendix 1.6. Macroinvertebrate diversity in the River Don at Penistone & Beeley Woods.

t-tests for independent samples of VAR00006

Variable	Number of Cases	Mean	SD	SE of Mean
VAR00001 (BMWP Score)				
VAR00006 1	6	13.0000	4.427	1.807
VAR00006 2	6	16.5000	2.168	.885

Mean Difference = -3.5000

Levene's Test for Equality of Variances: F= 4.879 P= .052

t-test for Equality of Means

Variances	t-value	df	2-Tail Sig	SE of Diff	95% CI for Diff
Equal	-1.74	10	.113	2.012	(-7.985, .985)
Unequal	-1.74	7.27	.124	2.012	(-8.260, 1.260)

Variable	Number of Cases	Mean	SD	SE of Mean
VAR00002 (ASPT)				
VAR00006 1	6	2.9667	.650	.265
VAR00006 2	6	3.1000	.374	.153

Appendix 1.6. (continued)

Mean Difference = -.1333

Levene's Test for Equality of Variances: F= 1.555 P= .241

t-test for Equality of Means

Variances	t-value	df	2-Tail Sig	SE of Diff	95% CI for Diff
Equal	-.44	10	.673	.306	(-.816, .549)
Unequal	-.44	7.98	.675	.306	(-.840, .573)

t-tests for independent samples of VAR00006

Variable	Number of Cases	Mean	SD	SE of Mean
VAR00003 (Shannon-Weiner index)				
VAR00006 1	6	1.1272	.212	.087
VAR00006 2	6	1.3828	.185	.076

Mean Difference = -.2557

Levene's Test for Equality of Variances: F= .159 P= .698

t-test for Equality of Means

Variances	t-value	df	2-Tail Sig	SE of Diff	95% CI for Diff
Equal	-2.22	10	.050	.115	(-.512, .001)
Unequal	-2.22	9.82	.051	.115	(-.512, .001)

Variable	Number of Cases	Mean	SD	SE of Mean
VAR00004 (Margalef's index)				
VAR00006 1	6	1.0245	.166	.068
VAR00006 2	6	1.0608	.183	.075

Appendix 1.6. (continued)

Mean Difference = -.0363

Levene's Test for Equality of Variances: F= .016 P= .901

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	-.36	10	.726	.101	(-.261, .188)
Unequal	-.36	9.91	.726	.101	(-.261, .188)

t-tests for independent samples of VAR00006

Variable	Number of Cases	Mean	SD	SE of Mean
VAR00005 (Pielou's index)				
VAR00006 1	6	.7538	.092	.038
VAR00006 2	6	.7428	.224	.092

Mean Difference = .0110

Levene's Test for Equality of Variances: F= 2.671 P= .133

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	.11	10	.914	.099	(-.210, .232)
Unequal	.11	6.65	.915	.099	(-.223, .245)

Appendix 1.7. Age & growth of fish in the Rivers Don, Rother & Dearne (1995-1997).

Back-calculated growth history of grayling in the River Don at Penistone

				Mean length at age (mm)						
River	Site	Period	No. of fish	1	2	3	4	5	K	L∞ (mm)
Don	Penistone	Nov. 1995	9	88	110	173	200	-	0.05	548
Don	Penistone	Feb. 1996	3	85	122	159	186	217	0.09	540
Don	Penistone	June 1996	5	78	122	149	178	-	0.25	269
Don	Penistone	Sept. 1996	8	69	121	181	-	-	N/A	N/A
			Mean	80	119	166	188	217	0.13	452
Don	Beeley Woods	Nov. 1995	3	89	123	158	198		0.08	290

At Penistone, only 1 grayling each was captured in December 1996 and May 1997. They were aged 1+ and 2 + years and measured 100 mm and 131 mm in length respectively.. In July 1997, 5 grayling all aged 0+ with a mean length of 75 mm were captured in the same river.

Back-calculated growth history of brown trout in the River Don

				Mean length at age (mm)									
River	Site	Period	No. of fish	1	2	3	4	5	6	7	8	K	L∞ (mm)
Don	Penistone	Nov. 95	18	70	107	136	175	221				0.10	233
Don	Penistone	Feb. 96	10	77	128	165	199					0.22	331
Don	Penistone	June 96	10	84	142	176	218	258				0.11	557
Don	Penistone	Sept. 96	6	87	149	187	223	274				0.09	686
Don	Penistone	Dec. 96	9	86	148	186	223	270				0.12	583
Don	Penistone	May 97	7	97	155							N/A	N/A
Don	Penistone	July 97	14	88	147	188	219	268	304			0.09	666
			Mean	84	139	173	209	258	304			0.12	509
Don	Beeley Woods	Dec. 1996	4	89	126	163	193	218	245	287	314	0.10	499

Two brown trout each were captured at Beeley Woods in November 1995 and in February 1996, all of which were aged between 4+ and 6+ years old and measured between 250 and 338 mm long. Also, 2 rainbow trout aged 4+ & 6+ of 270 mm & 345 mm lengths respectively were captured.

Back-calculated growth history of roach in the Rivers Don and Dearne

				Mean length at age (mm)										
River	Site	Period	No. of fish	1	2	3	4	5	6	7	8	9	K	L∞
Don	Beeley Woods	Nov. 95	31	90	109	122	139	161	175	188	216		0.05	190
Don	Beeley Woods	Feb. 96	3	72	103	124	152	174	199				0.05	694
Don	Beeley Woods	June 96	5	86	106	122	140	159	166				0.13	256
Don	Beeley Woods	Sept. 96	5	76	111	167	183						0.23	289
		Mean		80	108	133	154	164	181	193	216		0.12	357
River	Site	Period	No. of fish	1	2	3	4	5	6	7	8	9	K	L∞
Dearne	Pastures Bridge	Nov. 95	39	65	90	122	152	180	208	227	246	268	0.05	650
Dearne	Pastures Bridge	July 96	39	67	93	124	153	182	211	239	277		0.04	641
Dearne	Pastures Bridge	Sept. 97	14	89	110	138							N/A	N/A
		Mean		74	98	128	153	181	210	233	262	268	0.05	646

Two roach, aged 5+ and 6 + and measuring 179 mm and 195 mm respectively, were captured at Beeley Woods in December 1996. An extra 8 roach aged 0+ year old were also captured at Pastures Bridge in September 1997..

Back-calculated growth history of gudgeon in the Rivers Don and Dearne

				Mean length at age (mm)					
River	Site	Period	No. of fish	1	2	3	4	K	L∞ (mm)
Don	Beeley Woods	Nov. 95	10	75	114	137		N/A	N/A
Don	Beeley Woods	June 96	15	58	94	120	138	0.34	183
Don	Beeley Woods	Sept. 96	14	52	84	112	135	0.16	270
Don	Beeley Woods	May 97	8	69	107	124		N/A	N/A
Don	Beeley Woods	July 97	32	54	80	102	133	0.25	227
		Mean		62	96	119	135	0.25	227
Dearne	Cudworth Common	Nov. 95	3	83	95			N/A	N/A
Dearne	Pastures Bridge	Nov. 95	5	75	95	110		N/A	N/A
Dearne	Pastures Bridge	July 96	24	58	84	108		N/A	N/A
		Mean		67	90	109		N/A	N/A

Only 1 gudgeon aged 3+ and measuring 126 mm in length was captured at Pastures Bridge in March 1997.. In Sept.. 1997 4 gudgeon all aged 1+ years old were also captured in the same river.

Appendix 1.7 (continued).

Back-calculated growth history of dace in the Rivers Don and Dearne

River	Site	Period	No. of fish	Mean length at age (mm) 1	2	3	4	5	6	K	L∞ (mm)
Don	Beeley Woods	Nov. 95	11	67	108	155	180	196	211	0.30	253
Don	Beeley Woods	June 96	4	88	135	163	183	204		0.33	245
Don	Beeley Woods	Sept. 96	8	56	101	138	175			0.1	499
Don	Beeley Woods	May 97	4	71	110	122				N/A	N/A
Don	Beeley Woods	July 97	17	89	109	132				N/A	N/A
		Mean		74	113	142	179	200	211	0.24	332
Dearne	Pastures Bridge	Nov. 95	3	84	122	177	201	230		0.15	409
Dearne	Pastures Bridge	July 96	4	72	126					N/A	N/A
		Mean		78	124	177	201	230		0.15	

Only 1 dace, 215 mm in length and aged 4+ ,was captured at Pastures Bridge in March 1997.

Back-calculated growth history of perch in the Rivers Don and Dearne

River	Site	Period	No. of fish	Mean length at age (mm) 1	2	3	4	5	6	7	K	L∞(mm)
Don	Beeley Woods	Nov. 95	4	87	117	147	162	194	209		0.10	393
Don	Beeley Woods	Feb. 96	6	86	117	167	200	228	251		0.10	497
Don	Beeley Woods	Sept. 96	4	88	128	170	190	220	250	300	0.02	1304
		Mean		87	121	161	184	214	237	300	0.07	731

River	Site	Period	No. of fish	Mean length at age (mm) 1	2	3	4	5	6	7	K	L∞(mm)
Dearne	Pastures Bridge	Nov. 95	7	86	125	161	181	193	228	251	0.09	516
Dearne	Pastures Bridge	July 96	6	110	141	189	221	258	298	-	0.02	1409
Dearne	Pastures Bridge	Mar. 97	8	87	132	171	215	256	294	328	0.04	1156
Dearne	Pastures Bridge	Sept. 97	4	68	112	158	192	229	288		0.05	640
		Mean		88	128	170	202	234	277	290	0.05	930

Only 1 perch aged 7+ and 312 mm long was caught at Beeley Woods in December 1996 whilst 2 were captured in July 1997. They were aged 6+ and 7+ and measured 295 and 316 respectively. One pike measuring 680 mm in length and aged 4+ years old was also captured at Pastures Bridge in Sept. 1997.

Appendix 1.7 (continued).

Back-calculated growth history of chub in the River Dearne at Pastures Bridge

		Mean length at age (mm)											
Period	No. of fish	1	2	3	4	5	6	7	8	9	10	K	L∞ (mm)
Nov. 95	3	81	119	166	197	258	314					0.11	232
March 97	8	89	135	180	208	270	296	333	383	407	443	0.05	1377
Mean		85	127	173	203	264	305	333	383	407	443	0.08	805

Two chub aged 1+ and each measuring 95 mm in length were captured in the River Don at Beeley Woods in July 1997.. In Sept. 1997 2 chub aged 6+ & 7+ years old were captured at Pastures Bridge. They measured 334 and 383 mm in length respectively.