A Review of Grayling Ecology, Status and Management Practice

Recommendations for Future Management in England and Wales

Technical Report
W245

Centre for Ecology & Hydrology

A Review of Grayling Ecology, Status and Management Practice
Recommendations for Future Management in England and Wales

R&D Technical Report W245

A T Ibbotson, R J Cove*, A Ingraham, M Gallagher, D D Hornby, M Furse, C Williams*

Research Contractor:
*Environment Agency & Centre for Ecology and Hydrology

Publishing Organisation
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury,
BRISTOL, BS32 4UD.

Tel: 01454 624400 Fax: 01454 624409
Website:www.environment-agency.gov.uk

ISBN: 1 85705 370 2

The work is the result of a collaborative study jointly funded by the Agency and the Natural Environment Research Council.

Dissemination Status
Internal: Released to Regions
External: Released to Public Domain

Statement of Use
This report reviews the state of knowledge on the ecology and distribution of grayling in England and Wales and examines current management practices. It also makes recommendations for future management of the species and identifies areas for further research. It will be of use to Agency Fisheries staff, external fishery managers and any other individuals with an interest in grayling and grayling fisheries.

Research Contractor
This document was produced under R&D Project W2-042 by:
Centre for Ecology & Hydrology, Winfrith Technology Centre, Winfrith Newburgh, Dorchester, Dorset DT2 8ZD

Tel: 01305 2135000 Fax: 01305 213600

Environment Agency's Project Manager
The Environment Agency's Project Manager for Project W2-042 was:
Richard Cove, Environment Agency - Wales

Further copies of this report are available from:
Environment Agency R&D Dissemination Centre, c/o
WRc, Frankland Road, Swindon, Wilts SN5 8YF

tel: 01793-865138 fax: 01793-514562 e-mail: publications@wrcplc.co.uk

CONTENTS

List of Tables

List of Figures

EXECUTIVE SUMMARY

- In 1999 the Environment Agency and the Centre for Ecology and Hydrology commenced a collaborative project with the objectives to review European grayling ecology, current population status in England and Wales and associated management practices. From this appraisal, the key aims were to make recommendations for future management of the species and identify future research and development needs to aid the sustainable management of the grayling and its fisheries.

- Historically, grayling have not had as high a fishery resource value in England and Wales as in continental Europe. The classification of grayling for regulatory purposes has been confused and in some cases, fishery regulations were the same as for coarse fish. Recently however, attitudes towards grayling in England and Wales have changed, one manifestation being the formation of a specialist group - the 'Grayling Society' who aim to protect and preserve the grayling and its habitat as well as angling for the species.

- The review of grayling ecology, status and current management practice was undertaken through the acquisition of published scientific literature, unpublished data from a variety of sources, and by communication with selected Environment Agency fishery managers and scientists in all Agency regions.

- A questionnaire was posted to relevant Agency fishery officers and members of the Grayling Society resident in England and Wales requesting them to list issues they felt affected grayling populations and to prioritise areas where management guidance was needed. Both sources identified habitat degradation as the most important issue affecting grayling.

- The distribution of grayling in each of the Agency regions of England and Wales is described. The occurrence of grayling within salmonid and coarse fisheries is identified, and introductions and extinctions are also discussed.

- Reviews of the biology and ecology of grayling identified much useful information however, there are notable gaps in knowledge particularly of habitat requirements, migratory behaviour and barriers to migration.

- The management of grayling was found to be inconsistent between Agency regions, particularly in the areas of removal policy, stocking and transfer of fish, and exploitation and regulation. There was a lack of management guidance on aspects of habitat requirements, socio-economic value, monitoring and conservation.

- There was a particular failure to include grayling in any operational impact assessments, which generally targeted trout even where grayling were the dominant species.

- Research is required into the habitat requirements, migratory behaviour and impact of barriers to grayling migration and distribution, and this should be given high priority by the Agency.

- Twenty-one recommendations for the future management of grayling are made. These include a recommendation to develop and agree through consultation, a strategy for the management of grayling in England and Wales. Suggested objectives of this strategy are to plan and carry through the recommendations of this report, raising both management standards and the quality and quantity of strategic science underpinning that management, to a similar level to salmon and trout.

ACKNOWLEDGEMENTS

The production of this report is the result of collaboration between the Environment Agency and the Centre for Ecology and Hydrology. The Grayling Research Trust provided funding to complete the questionnaire survey of Grayling Society members. The report is multi-authored, but additional individual thanks go to Mark Atherton, Henry Brown, Nicole Caetano, Grant McMellin, Nigel Milner, Dave Willis, John Woolland and Willie Yeomans from the Agency and Alan Ayre, Roger Cullum-Kenyon, Ross Gardiner, Robin Mulholland and Anthony Wilson from the Grayling Society/Grayling Research Trust, who all offered helpful guidance and input on draft reports. Thanks also go to the Agency area fishery staff who responded to the questionnaire and provided data for this report.

1. INTRODUCTION

1.1 General Description

The name grayling is at least five centuries old (Magee, 1993). The Latin name, *Thymallus thymallus* (L.) originates from the faint smell of the herb thyme, which emanates from the flesh, scales and skin. Although grayling were considered for a time by some taxonomists to constitute a separate family (Thymallidae; Wheeler, 1969), the presence of the adipose fin groups the grayling taxonomically within the family Salmonidae as a sub-family Thymallinae (Bagliniere, 1999) with only one genus, *Thymallus*.

The morphology of the grayling is well described by Northcote (1995). It is slightly flat-sided with a relatively small mouth (Figure 1.1). The upper jaw projects slightly beyond the lower jaw. Juvenile grayling are silvery/light green with bluish parr marks along the flanks. Adults however, have a grey/green back, green sides and a white under-body. A distinguishing feature of the grayling is its large dorsal fin, which has four to five rows of red and black spots (Wheeler, 1969; Cihar, 1998). The dorsal fin of the grayling is larger in males than females, producing notable sexual dimorphism (Witkowski, Kowalewski & Korkurewicz, 1984).

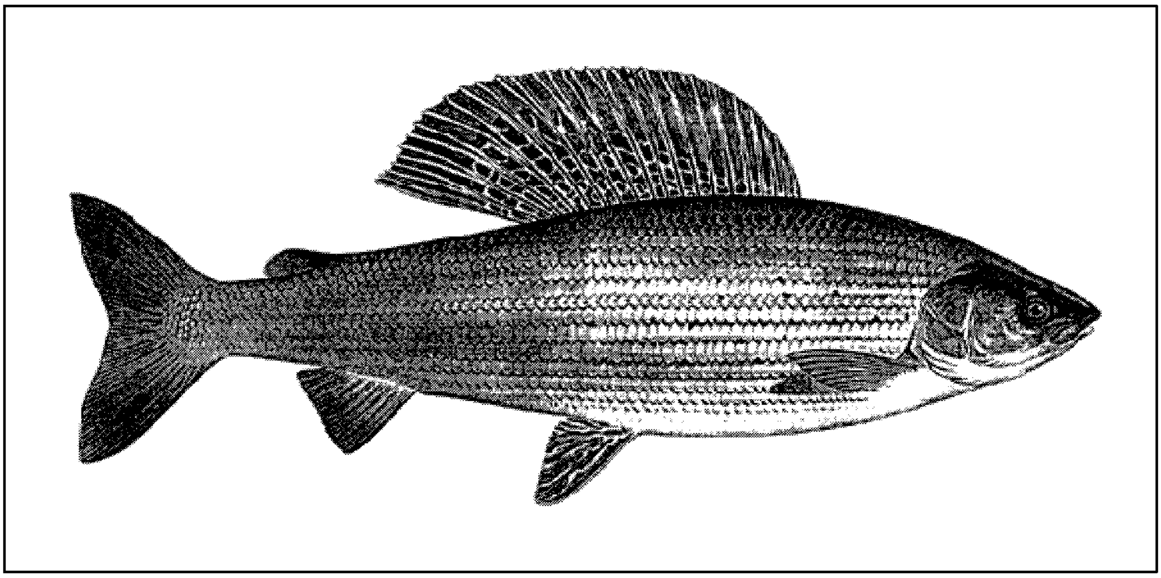

Figure 1.1 An Adult Male *T.thymallus* Copyright: R.A. Ade

1.2 Attitudes to Grayling in the United Kingdom

Historically, the grayling has been under-rated by UK anglers and was rarely regarded as a game fish, particularly in southern trout streams. Fly-fishermen considered grayling as an unwanted intruder, 'never thought fit to be included in the same breath as trout or salmon' (Broughton, 1989). One hundred years ago, Halford (reported by Wilson, 1989) noted a conversation between two trout fishermen which included their hope that they should observe 'the last remaining pike choking on the last grayling' in the River Test. Similarly, Grimble (1913) said regarding the Eden; 'these upper reaches are famous for their trouting and, though of late years grayling have increased so much as to become detrimental to the well-being of the trout….'.

Recently more anglers and fishery managers have begun to recognise the fishery potential of grayling both in salmonid depauparate rivers (Hellawell, 1969) and as a means of extending the fishing season where salmonids are the principle target species. In 1989 'Grayling: the Fourth Game Fish' by Ronald Broughton was published indicating an improvement in the general attitude towards grayling. This increasing interest in the grayling has gathered momentum with the formation of 'The Grayling Society' in 1977 whose stated aims include 'the protection and preservation of the grayling and its habitat'. In 1997 'The Grayling Society' reported a worldwide membership of over 1200.

1.3 Attitudes to Grayling in Mainland Europe

By comparison, grayling have been held in high regard in continental Europe, as has its relative the Arctic grayling (Thymallus arcticus (Pallas) in the United States. For example in the 1930's, Ritz (1959) a famous angler, commented on the importance of grayling and that L. de Boisset, considered to be the greatest French fly-fishing writer of his time, rated grayling as the best sport fish.

Scientists and governmental bodies in most European countries supporting grayling populations were polled for their attitudes to grayling. In all cases, grayling were highly thought of and in most instances were regarded as an important fishery resource.

1.4 Scientific Coverage of Grayling

The lower fishery status of grayling has meant it has received less attention scientifically in the UK than the other abundant salmonid species, salmon (*Salmo salar* L.) and brown trout (*Salmo trutta* L.). In recent years there has been a rise in the number of scientific papers and reports produced on grayling in Europe and Arctic grayling in North America (Figure 1.2).

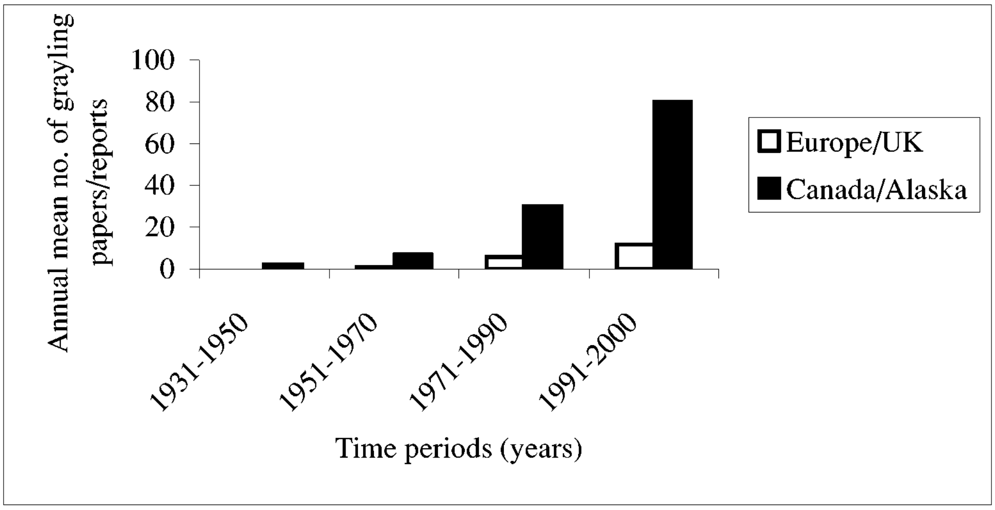

Figure 1.2 The mean number of grayling papers/reports produced each year between 1931 and 2000, in Europe/UK (*T. thymallus*) and Canada/Alaska (*T. arcticus*) (from Northcote, 2000)

1.5 Objectives of this Report

Until recently, the grayling was regarded as a coarse fish. As far back as 1969, Hellawell stated that 'the unique position of the grayling as the 'coarse' fish member of the Salmonidae may explain the neglect of this species by fishery biologists'. This lack of clear classification had contributed to the grayling's low fishery status as well as an inappropriate management and regulation strategy, e.g. adopting the national coarse fish closed season. In 1997, the Environment Agency formed two national Fisheries Centres, one for salmonids and the other for coarse fish. Jurisdiction for the grayling came under the control of the salmonid centre and a review of its regulation and management was instigated.

The objectives of this report are:

- To review available information on the biology, ecology and current management of the grayling.

- To use the current knowledge on grayling to make recommendations for its future management in England and Wales

- and, where these recommendations cannot be made because of a lack of information, to identify and prioritise future research which will provide the necessary strategic knowledge.

2. METHODS

2.1 Literature Review

Literature searches of Aquatic and Sciences Fisheries Abstracts (ASFA) for the period 1979-2000 and the Freshwater Biological Association (FBA)/Institute of Freshwater Ecology (IFE) current awareness database were conducted. Scientists, both in the UK and abroad, were contacted and asked to provide information on work completed by themselves and others known to them. This raised over 400 references concerned with grayling and Arctic grayling. Titles and abstracts of these were read and from these, a bibliography containing approximately 200 records was compiled primarily concerning the biology, ecology and management of grayling. Inter-library loans were obtained for the references not held by the FBA's library at Ferry House. Examination of the references indicated that some items were irrelevant but identified further references of relevance. These latter references were also acquired and included in the bibliography.

The literature review concerns the biology and ecology of grayling under the headings of habitat, reproduction, feeding, age and growth, migration, interactions with other species and disease. In some instances where information on European grayling was deficient, comparable research on Arctic grayling is quoted instead. It is made clear in the text where this occurs.

2.2 Agency Data

Initial contact with Agency fishery officers, scientists and team leaders was made by telephone during the summer of 1999 to establish the quantity of data and reports on grayling held at each area office. Based on these initial approaches, written requests were made on 13 September 1999 for:

- Data on the distribution of grayling, which were later converted to digital maps using the GIS software ArcView version 3.1.
- A copy of local fisheries byelaws.
- Other data and reports identified, to be of sufficient high quality for inclusion in this report.

Personal visits were made to Calverton Fish Farm and the Upper Severn, South Wessex and Dales area offices of the Agency where large volumes of data were held.

2.3 Questionnaire

To place the objectives of this report into the context of the needs of both Agency fishery managers and interested parties (such as anglers), Agency and Grayling Society members were sent a questionnaire (see Project Record). This requested them to list issues they felt affected grayling populations in their area and to prioritise subjects on which they required management guidance.

2.4 Strengths and Weaknesses of Collated Data

The thorough search of both scientific and grey literature through databases, known contacts and Agency offices indicates this report contains all readily available information relevant to the ecology, current status and management of grayling.

Although most of the data used represent peer reviewed scientific work, a large proportion of it comes from unpublished grey literature including theses, Agency internal reports and in some cases raw data. With non-peer reviewed literature, attempts were made to distinguish between anecdotal comment and that which was supported by technical data. Where information only related to opinion, this is specified in the report.

Searches of Agency offices for information highlighted both a lack of depth of data on grayling and where potentially useful data were available, it was frequently fragmented or held in a non-standard form, making it difficult and labour intensive to collate and assess its quality and value. Often Agency officers had formed opinions on factors affecting grayling populations from years of experience but were unable to substantiate them with supporting data.

3. DISTRIBUTION

3.1 Worldwide Distribution

The grayling is distributed from west Wales, throughout Europe to the White Sea at latitudes of 40° - 70°N (Jankovic, 1964) (Figure 3.1). It is found at altitudes of up to 500 m in the Alps and 1000 m in the Carpathians (Northcote, 1995).

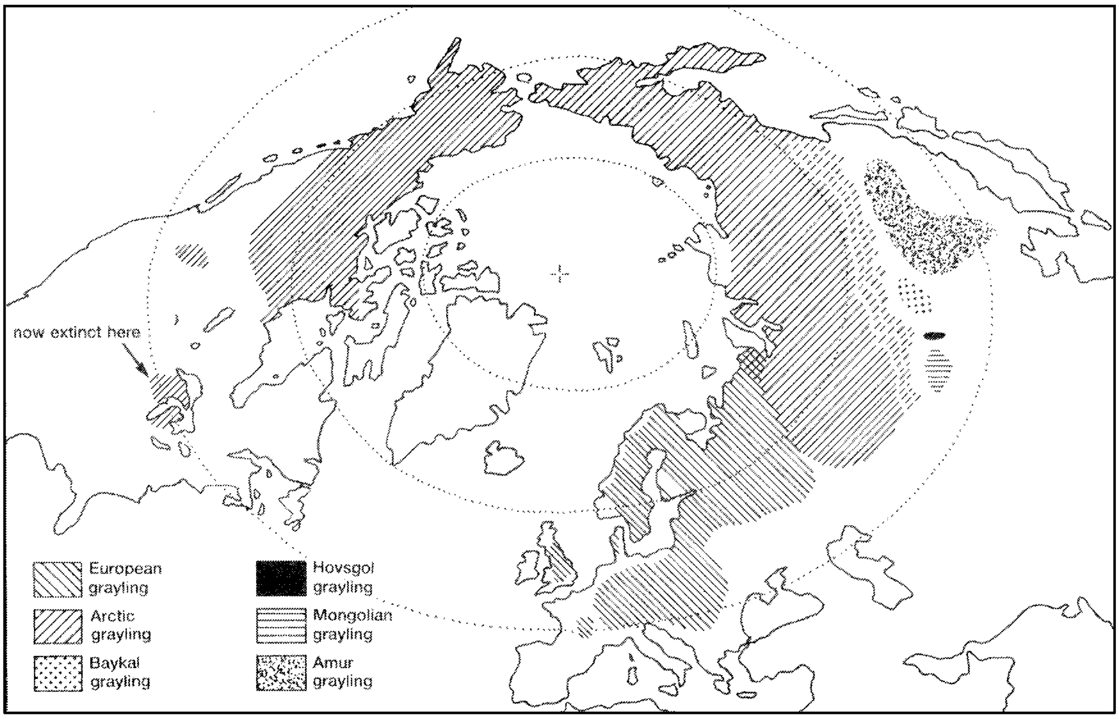

Figure 3.1 The Worldwide Distribution of Grayling (from Broughton, 1989)

The grayling is thought to have reached British rivers via the North Sea River before Britain became isolated from continental Europe (Woolland, 1986a). The distribution pattern over much of Europe is consistent with dispersal from a single refuge in the Danube basin after the last glacial period, when Britain was still joined to the continent and the rivers of the East Coast of England flowed into the Rhine. Gardiner (1989) states that the grayling's natural distribution was limited to the Rivers Ouse, Trent, Hampshire Avon and their tributaries; and possibly the Rivers Severn, Wye, Thames, Ribble and Welsh Dee. The grayling is absent in southern Europe and Ireland.

The grayling has been found in archaeological deposits in York, dating from the first to the twelfth century (Gardiner, 1989). It is therefore likely, that it is indigenous in the Yorkshire Ouse system. Its original distribution before man's influence is not clear. They have been transferred from East Yorkshire to tributaries of the Ouse to replace populations made extinct by pollution (Magee, 1993). The grayling was introduced to Scotland in the 1800s (Gardiner, 1994). It is a freshwater fish in the UK but also lives in brackish waters at the north of its range, outside of the United Kingdom (Gardiner, 1989).

The majority of grayling populations present in the UK are thought to originate from stocking conducted over the past 200 hundred years. All of these have been made from British origin; there is no evidence of stocks being introduced from overseas (Gardiner, pers. comm.).

3.2 Distribution in England and Wales and Current Population Status

To determine the distribution of grayling in England and Wales, fishery personnel in each of the 26 Agency areas were asked to provide maps or National Grid References (NGRs) detailing presence or absence. Locations were requested for where grayling are:

- Present
- Extinct (i.e. grayling now absent from surveys where they were previously recorded)
- Introduced
- Present within a coarse fishery
- Present within a salmonid fishery (trout or salmon)
- Present within a mixed fishery (salmonid and coarse fish present)

All map data were converted into NGRs and the data were finally represented by region in a Geographical Information System (GIS). Agency regions did not correspond with hydrometric regions used as the basis for the GIS. Distribution points and lines were entered for each region and superimposed onto the hydrometric regions.

Grayling are present in all regions although they inhabit few rivers in Anglian Region (Liversedge, 1982 and 1992). In southern England, grayling are most densely populated in the chalk streams, particularly the Rivers Test and Avon. In the north, the largest populations exist in the Rivers Trent, Severn, Ouse, Wharfe and Ribble. In Wales, grayling are confined largely to the eastern rivers; the Dee, Severn and Wye. A small isolated population exists in the Teifi (Woolland, 1986a). The grayling is found in two lakes in England and Wales; the Gouthwaite Reservoir in Yorkshire and Llyn Tegid (or Bala Lake) in North Wales (Duigan, Millband & Gritten, 1998).

Few extinct populations were identified although there are undoubtedly many rivers such as the River Don in Yorkshire where industrial pollution has caused the extinction of an historical grayling population (Environment Agency, 1997a). Similarly, few rivers were separately identified as stocked even though it is thought that most populations were introduced.

In all Agency regions, with the exception of South West and Southern, grayling distribution coincides with both salmonid and coarse fisheries. In South West and Southern regions, grayling are predominantly found in trout and salmon fisheries.

The densities and biomass of grayling in Agency regions is highly variable. In Anglian Region densities never reach very high levels, unlike those that are occasionally obtained in South West and North East regions (Table 3.1).

Table 3.1 Examples of the range and mean densities and biomass of grayling observed in some Environment Agency regions (Thames (various Environment Agency fishery survey reports of River Dun 1995; Kennet and tributaries 1988/89-1994). Anglian (Environment Agency, 1993; 1996a). Midlands (Environment Agency, 1982; 1992d; Jacklin, 1998). North East (Environment Agency, 1984; 1990; 1994a; 1994b; 1994c; 1995a; 1996b). South West (Environment Agency, 1992b). Wales (Woolland, 1972))

Region	Density (n 100 m^{-2})		Biomass (g 100 m^{-2})	
	Range	Mean	Range	Mean
Thames	0 - 6	2	0 - 2870	359
South West	0 - 25	1	2 - 728	208
Anglian	0 - 3	0	0 - 340	50
Midlands	1 - 2	2	/	/
North East <1 year old	0 - 96	10	/	/
North East >1 year old	0 - 69	9	/	/
Wales	2 - 36	16	259 - 1542	788

3.2.1 North East Region (Figure 3.2)

The grayling is highly regarded in the Dales area of North East Region, however it is of a lower fishery resource value in the Northumbrian area due to more limited distribution.

River Wharfe and tributaries

Grayling were introduced into the Wharfe around 100 years ago. Angling pre-1980s indicated that reasonable numbers of grayling were present (Axford, pers. comm.) and in fact, this species was considered the second most important fishery in the Wharfe. Since the 1980s grayling numbers have reportedly been in decline (Axford, pers. comm; Yorkshire Water Authority, 1982a; Yorkshire Water Authority, 1984a; Environment Agency, 1994a). Evidence of successful recruitment in the years 1995, 1996 and 1997 was observed from surveys (Environment Agency, 1997b) but catches and recruitment appeared to be poorer in 1998 (Axford, pers. comm.). Grayling currently exist in the Wharfe in a mixed fishery.

Between Linton falls and the River Dibb (10 km), in the upper reaches of the Wharfe, grayling stocks were boosted in the 1970s by fish stocked from the West Beck. Stocks now appear to have fallen to a low level (Axford, pers. comm.). Downstream of the Dibb to Lobwood weir, a small population of large grayling exists (Hopkins, pers. comm.) within a salmonid fishery. Below this point the population becomes larger and more balanced in terms of structure.

River Hull and tributaries

Considerable information about grayling has been collected from the West Beck, a tributary of the upper reaches of the River Hull. Large numbers of grayling were formerly removed on a regular basis in order to promote the introduced trout fishery. These fish were widely stocked across the Yorkshire Region (Axford, pers. comm.).

Between 1979 and 1984 an intensive series of electric fishing surveys provided data on the grayling population of the West Beck. Grayling was the most abundant species in every year

(Yorkshire Water Authority, 1980; 1982a; 1982b; 1984a; 1984b) and there was evidence of an annual alternation in year class strengths during most of this period.

River Ure

Anglers have perceived a decline in the grayling population of the upper reaches of the Ure where they are present within a mixed stock fishery. Subsequent requests for re-stocking to supplement the fishery have ensued, however, the Agency have resisted this (Hopkins, pers. comm.). The mid-reaches support considerable stocks by comparison (Hopkins, pers. comm.) and the lower reaches support a population together within a salmonid fishery.

River Don

In 1982, grayling were entirely absent from the River Don (Crofts, pers. comm.) and had been so for at least the previous 100 years. One of the earliest records of the presence of grayling was in 1843, however by 1850, records showed they had disappeared. Reports from 1894 (Bradley, 1894) indicated that trout dominated the river. However, since a restocking programme was initiated in the early 1980s, a spawning population of grayling is now present in the River Don.

The River Dearne, a tributary of the Don, used to support grayling but they have not been recorded recently. Grayling were almost completely absent from the system until the 1980s due to an industrial pollution event (Firth, pers. comm.). Current population numbers are unknown, however, a programme of reintroduction is intended (Firth, pers. comm.).

River Nidd

Axford (pers. comm.) commented that in 1979 the Nidd was the only major Yorkshire Dales river to hold grayling throughout its entire length. In the lower reaches, they are less abundant than the upper reaches. Grayling currently exist within the River Nidd's salmonid fishery.

River Tyne and tributaries

Grayling are generally absent from the River Tyne, however the River Derwent (a sub-catchment of the Tyne joining the main river in the upper estuary) supports a small population which is thought to be in decline in recent years according to anecdotal evidence (Rippon, pers. comm.). A recent survey by the Agency has recorded grayling at Allensford in the upper reaches of the River Derwent (Shelley, pers. comm.). It is thought grayling were introduced into the River Derwent during the 19th century from which time they have persisted. Grayling currently exist within an introduced trout fishery (Shelley, pers. comm.) on the River Derwent.

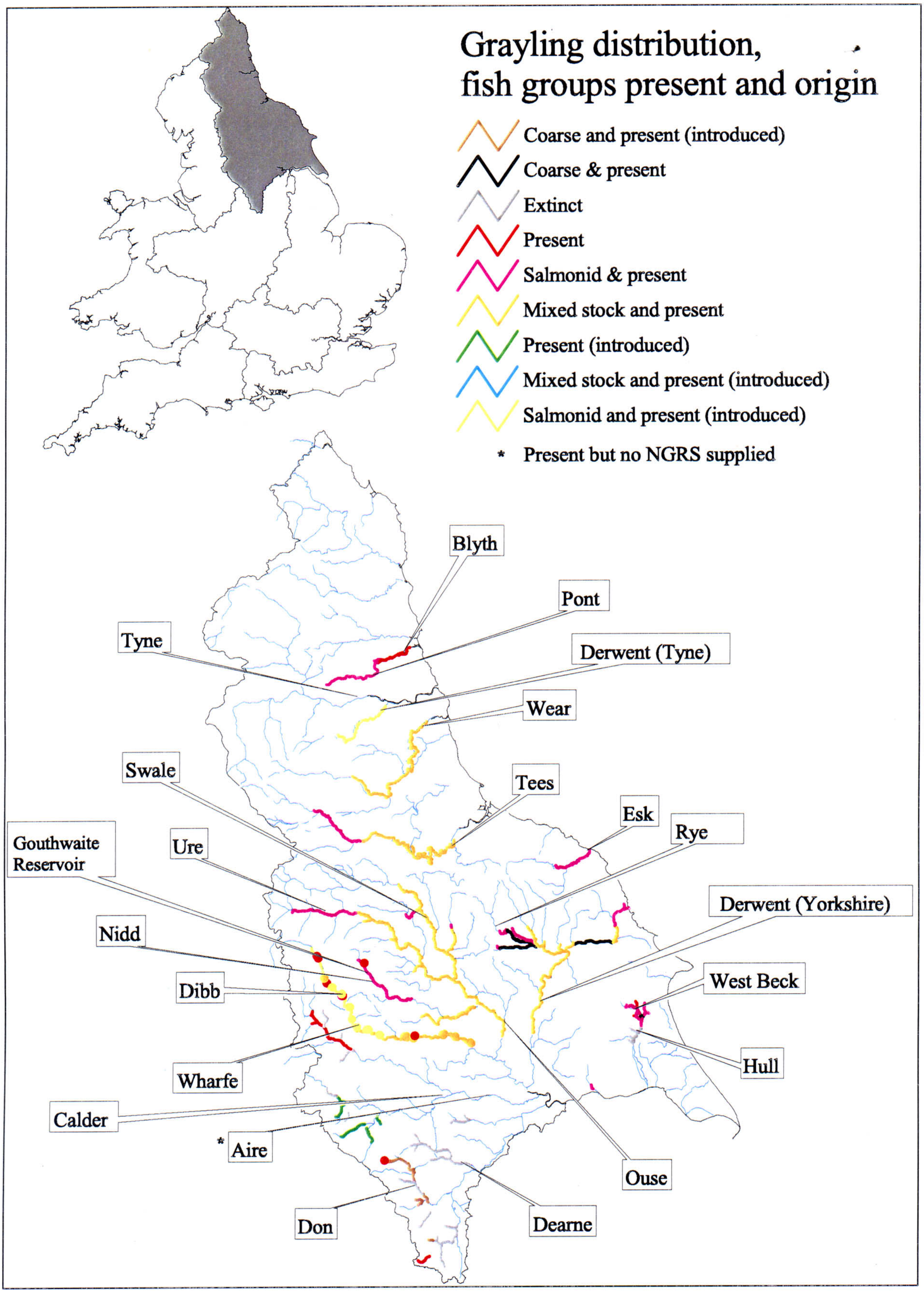

Figure 3.2 Grayling distribution, the origin of populations and fishery types present in the North East Region of the Environment Agency

The Yorkshire Derwent, Ouse and Esk are known to have limited stocks within coarse, mixed and salmonid fisheries, respectively. However, several of the larger tributaries of the Derwent, including the River Rye and the Costa Beck (not shown due to the scale of the map) have considerable stocks. In the Lower Holbeck (not shown as before), grayling were recorded as a major species in 1995 and were found co-existing with dace (Environment Agency, 1996c).

Little information is available regarding the stocks of grayling in the River Blyth (Environment Agency, 1996d). However good populations are known to exist in the middle and lower reaches and in the River Pont (the main tributary of the Blyth) within a trout fishery (Shelley, pers. comm.). The mid-reaches of the Tees (Hopkins, pers. comm.) and Swale (Environment Agency, 1998a) both support important stocks within a mixed fishery.

The River Calder is known to have an introduced population (Firth, pers. comm.). This re-introduction took place in 1985 and appeared initially to have failed, however around 10 years later anglers reported catching small grayling, in spite of a pollution event in 1991 (Firth, pers. comm.).

Significant numbers of grayling are known to exist in the River Wear between Chester Le Street in the lower part of the catchment and Wolsingham in the upper reaches (Shelley, pers. comm.). A survey recently conducted by the Agency has shown grayling to be on the Bedburn Beck (not shown), a couple of kilometres downstream of Wolsingham, and in the main River Wear at Durham City (Shelley, pers. comm.).

The River Aire supports limited grayling stocks (Firth, pers. comm.).

3.2.2 Anglian Region (Figure 3.3)

Grayling have in general a low value as a fishery resource in the Anglian Region, which is a reflection of the relatively small populations. Low abundance is due to the predominance of lowland rivers and fen drains in this region. Only two major populations exist in Lincolnshire, in the Rivers Witham and the Great Eau near Alford.

It would appear that all major and remaining grayling populations have been introduced in Anglian rivers periodically, historically and in response to angling club requests (Randall, pers. comm.). The success of such introductions in producing a sustainable population has been variable. The Rivers Chater (Environment Agency, 1996a), Ise (Environment Agency, 1995b; 1999a) and Little Ouse (Atkinson, pers. comm.) have in recent surveys demonstrated unsuccessful stocking programmes. However, the Gwash (Environment Agency, 1996e), Great Eau (Environment Agency, 1992a; 1995c) and Witham (Environment Agency, 1991) all have healthy populations of grayling.

The development of the Great Eau population has been slow. In a 1982/83 survey, grayling predominated over the coarse fish and trout populations at Withern Bridge and again in 1986. However, between 1989 and 1992 (Environment Agency, 1992a) a serious decline was observed at all survey sites.

Data are not available to show the current status of the introduced grayling in the River Great Ouse.

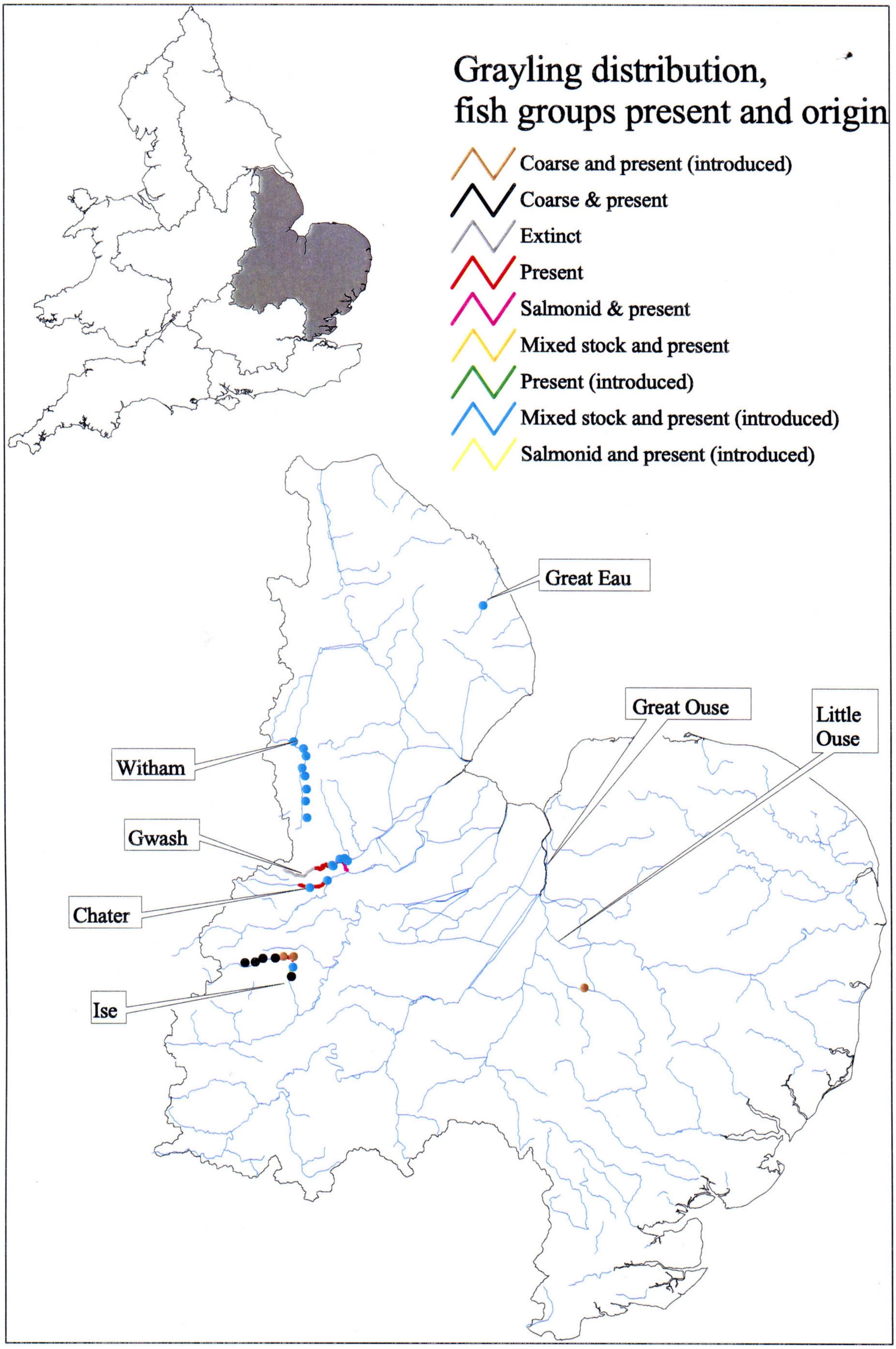

Figure 3.3 Grayling distribution, the origin of populations and fishery types present in the Anglian Region of the Environment Agency

3.2.3 Thames Region (Figure 3.4)

In areas where grayling are abundant, they are a highly valued fishery resource.

The largest population of grayling in Thames Region exists in the River Kennet and one of its tributaries, the River Lambourn (Lidgett, pers. comm.), the latter within a trout fishery. Grayling are absent from the lower Kennet downstream of Newbury. The expansion of Newbury and Thatcham in the late 1970's exceeded the capacity of Newbury sewage treatment works to maintain water quality sufficiently to allow grayling to persist (Stone, pers. comm.).

The upper Kennet (upstream of Hungerford) supports a grayling population within a trout fishery and between Hungerford and Newbury, grayling exist within a mixed fishery (Stone, pers. comm.). They are also present in varying numbers on the Rivers Dun and Enborne, tributaries of the Kennet (Stone, pers. comm.) within a mixed and coarse fishery, respectively.

The Rivers Pang and Coln, support grayling populations in a mixed fishery with a recruiting population found during routine fisheries surveys in the last seven years (Stone, pers. comm.). A small isolated population is also found in the Sor Brook (not shown), a tributary of the Cherwell with a small number over a range of sizes found in recent surveys (Stone, pers. comm.).

Grayling are not indigenous to the River Wey catchment and were introduced between the World Wars (Thomas, pers. comm.). In the early 1980s further introductions were made from the Kennet and the Pang, however, these fish disappeared and further stockings were not conducted following a change in fishery policy. The population is restricted to the area around the confluence of the northern and southern sections of the river. The greatest densities are located in the lower most reaches of the northern stretch.

Grayling were historically introduced into the River Mimram (Exeter, pers. comm.) and have recently been observed during electrofishing surveys in 1993 and 1999. They are thought to be present around Tewin (not shown) but may be elsewhere although there is no supporting evidence for this. Grayling were also observed in the River Chess (no dates given (Exeter, pers. comm.)), however, there was no data indicating their presence in the later part of 1998 (Exeter, pers. comm.). Little information is available on the populations in the Rivers Windrush and Lee although they exist within mixed fisheries (Lidgett, pers. comm.).

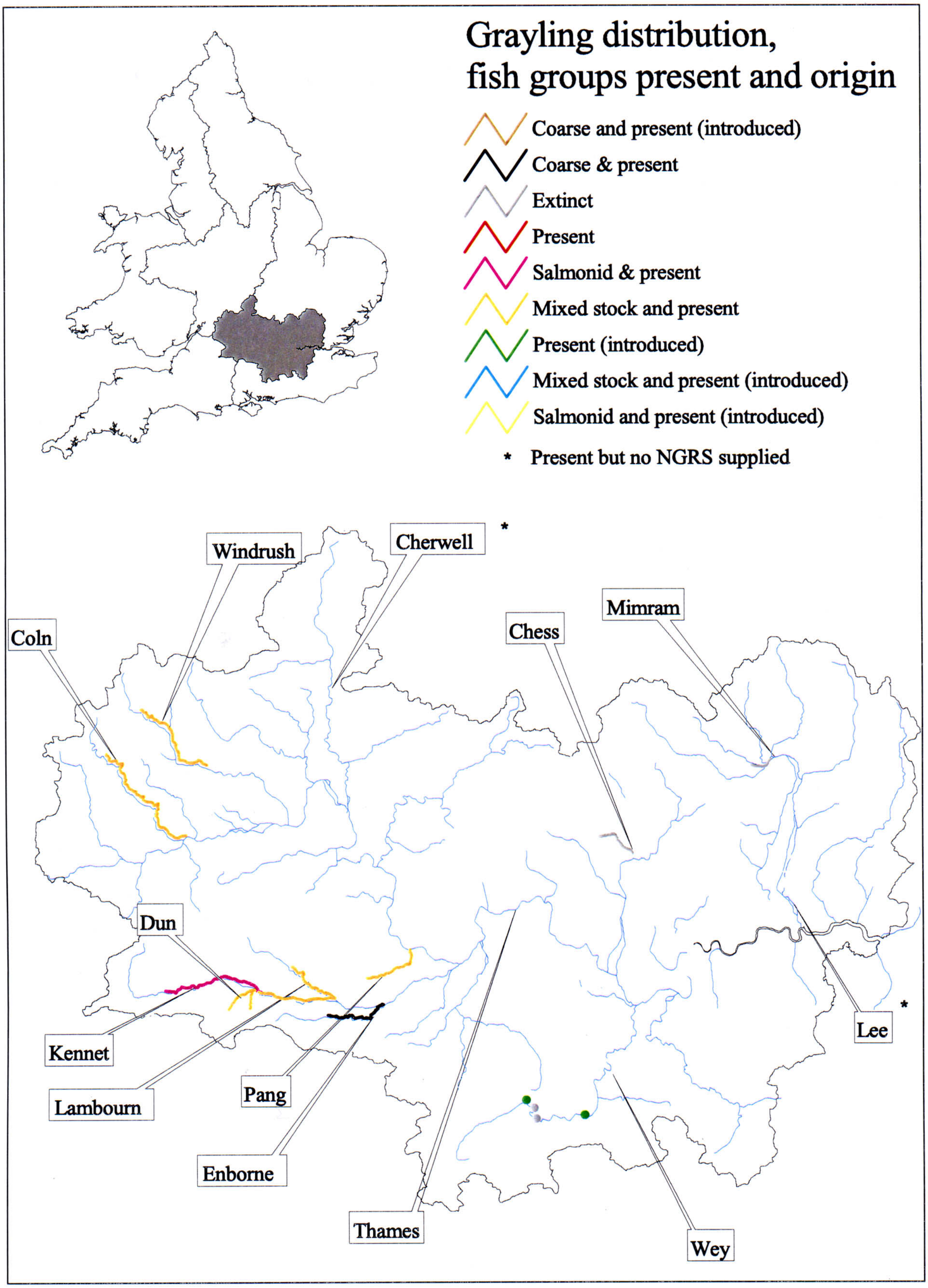

Figure 3.4 Grayling distribution, the origin of populations and fishery types present in the Thames Region of the Environment Agency

3.2.4 Southern Region (Figure 3.5)

In general there has been a history of grayling removal from the chalk streams of Hampshire. Despite the abundance of this species in those rivers, they have been largely ignored as a fishery resource and little monitoring has taken place.

The River Rother holds the best grayling population known in the Sussex area (Horsfield, pers. comm.). Fish were originally stocked in the late 1970s through to the 1980s using fish from the Rivers Meon and Anton, despite the fact that grayling have never thrived in the Meon due to the lack of suitable habitat (Horsfield, pers. comm.). The healthy population of grayling in the River Ouse also originated from stock transferred from the Meon and Anton in the late 1970s and through the 1980s (Horsfield, pers. comm.). All of these rivers support grayling within mixed fisheries.

There are known to be significant, thriving populations of grayling that were introduced into the Rivers Test (including the tributaries Anton, Dever and Dun) and Itchen (Leman, pers. comm.), all within mixed fisheries.

There is some evidence to suggest that grayling exist downstream of Ashurst on the River Medway (Cave, pers. comm.; Environment Agency, 1992c). The population is thought to be self-sustaining at a low level within a mixed fishery. There is also known to be a small self-sustaining population on the River Teise (a tributary of the Medway). Grayling were re-introduced from the River Anton into the mixed fishery there (Cave, pers. comm.).

In the 1980s and 1990s grayling were introduced into the River Great Stour at Canterbury (Cave, pers. comm.) from Hampshire rivers. A few are thought to have survived between Fordwich and Chartham in a mixed fishery (Cave, pers. comm.). A grayling was also recovered from the River Darent of the Darenth Complex (Cave, pers. comm.) during the early 1990s, however there have been no recent observations.

An additional, little known, small population also exists on the River Hamble (not shown) (Leman, pers. comm.).

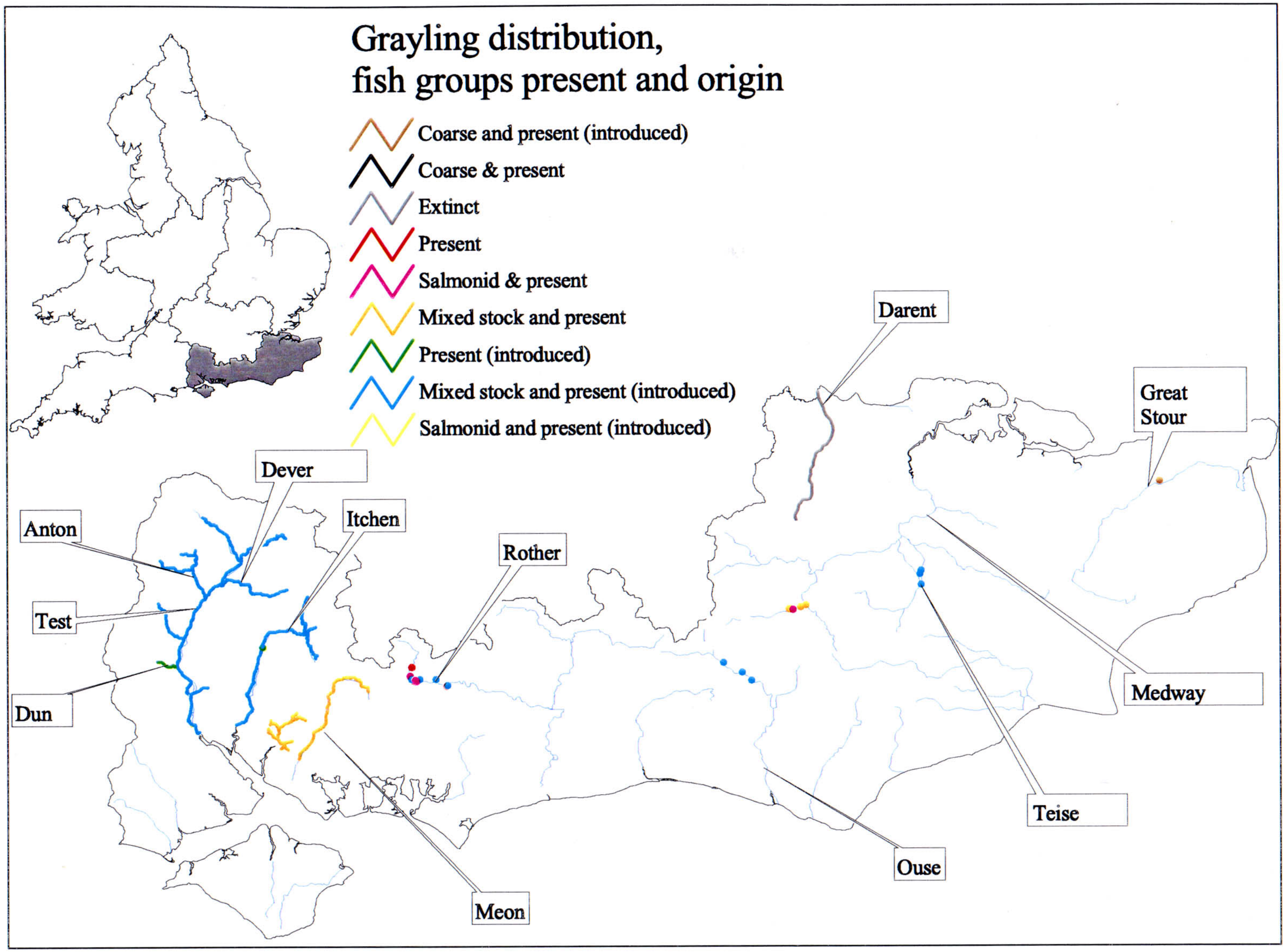

Figure 3.5 Grayling distribution, the origin of populations and fishery types present in the Southern Region of the Environment Agency

3.2.5 South West Region (Figure 3.6)

Grayling are present only in a few catchments in the South West Region (Jervis & Hirst, 1997, 1998). Their fishery resource value is high in the North Wessex Area, however in Devon, Cornwall and South Wessex Areas, grayling are largely ignored, making their fishery value low.

There is little information available regarding the populations in Cornwall, however the River Tamar supports stock introduced around 1900 (Wood, pers. comm.). Currently grayling exist within a salmon and trout fishery.

The River Exe is the only catchment in Devon to support a grayling population (Steel, pers. comm.). They are found in the mid reaches, around Tiverton and in the Little Exe upstream of the Exe/Barle confluence. It is not known whether grayling exist in the lower reaches of the Exe around Exeter as this area is not surveyed by the Agency (Steel, pers. comm.). The lower reaches of the Culm and Creedy (both Exe tributaries) also support small populations within salmonid fisheries.

The River Tone supports a breeding population above Taunton and at Lower Halse water and Hillfarrance Brook (Thomas, pers. comm.) both of which are within mixed fisheries.

In the North Wessex area, introductions were made into the Somerset Frome as far back as the early 1930s. Prior to this time, grayling were absent due to industrial pollution (Thomas, pers. comm.). Grayling were transferred from the Hampshire Avon into the lower reaches of the Somerset Frome in 1987.

Grayling exist at generally low densities in the main Bristol Avon between Malmesbury and Dauntsey as well as parts of the River Chew and Semington Brook (Thomas, pers. comm.).

In South Wessex Area the Hampshire Avon and its tributaries, contain a very important grayling population. Above Salisbury the population mainly coincides with trout fisheries (in the Rivers Nadder, Ebble (not shown) and Wylye) and has historically suffered determined efforts to control the population by removal. In the 1970s most fisheries operated rules requiring anglers to remove all grayling captured (Ibbotson, pers. comm.). Below Salisbury its distribution coincides with coarse fisheries and here the grayling provide a well-regarded additional fisheries resource. Today all of the grayling removed from upstream of Salisbury are reintroduced below Salisbury.

Occasionally grayling are found in the lower sections of the River Stour. There are grayling in the lower half of the River Allen, a chalk stream tributary of the Stour, where they are regularly fished for outside the brown trout season. This population was also subject to removal in the past. Here, their distribution coincides with mixed fisheries.

There is a small population confined to the middle chalk stream section of the River Crane, another Stour tributary.

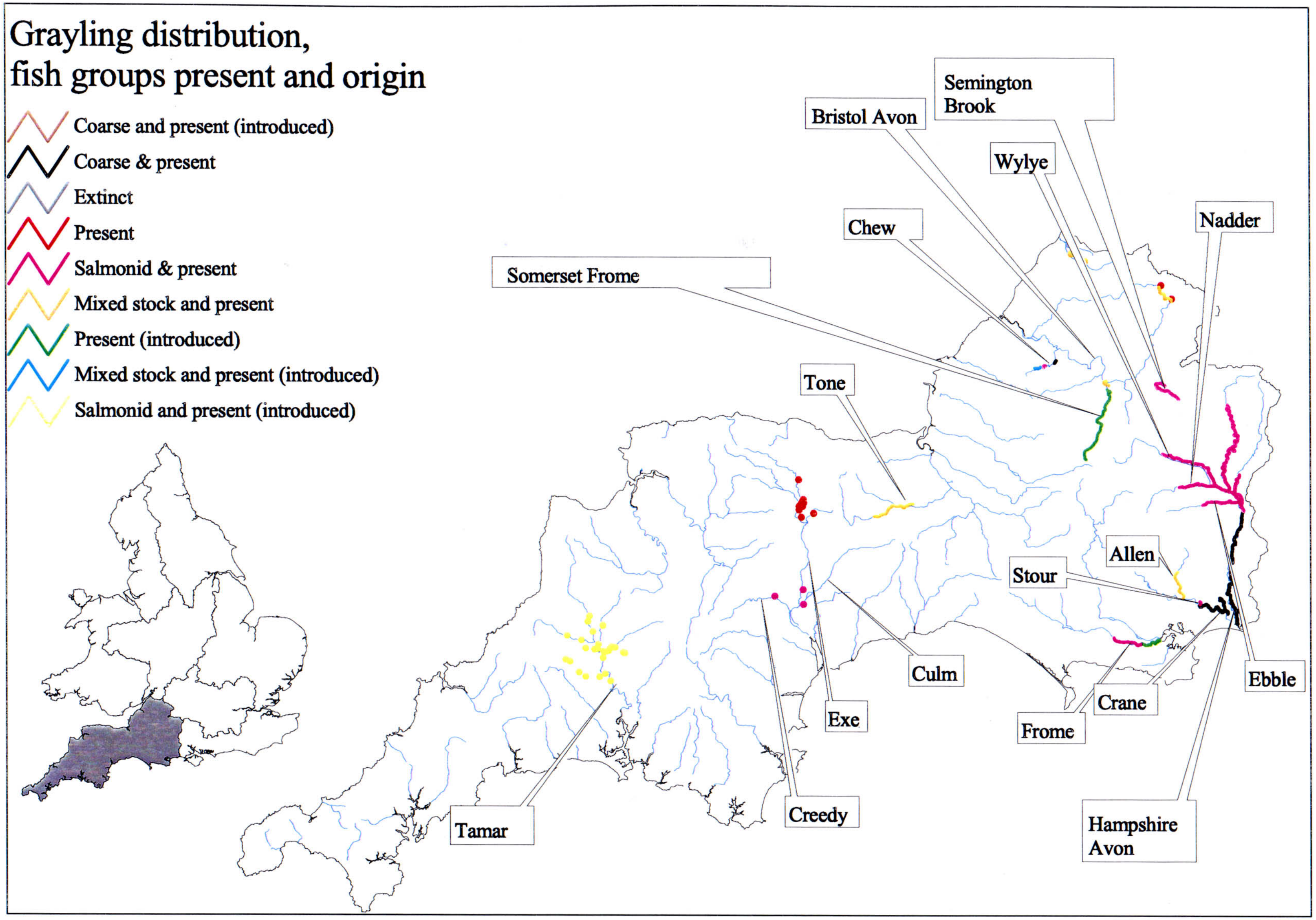

Figure 3.6 Grayling distribution, the origin of populations and fishery types present in the South West Region of the Environment Agency

In the past, surplus grayling, particularly from the River Avon, were used to introduce the species to a number of other UK rivers such as the River Rother (Johnson, pers. comm.) Many populations in southern English rivers probably originated from the Hampshire Avon. In recent years the level of removal activity in this catchment has declined. There has been a significant change in anglers attitudes towards grayling and they are now regarded as an additional fisheries resource which can be exploited outside the trout angling season.

Most of the populations in the Hampshire Avon catchment have abundant grayling. This is certainly the case in the River Wylye (Ibbotson, unpublished). However, there have been some recent concerns about some populations e.g. the River Nadder, where anglers have reported declines in the fishery (Lightfoot, pers. comm.).

The Dorset Frome population is also thought to be abundant up to Dorchester Weir (Ibbotson, pers. comm.).

3.2.6 Environment Agency Wales (Figure 3.7)

Grayling are regarded as a high value fishery resource in the large eastern rivers of Wales (Dee and Wye) but this is currently not the case in the south of the country. Interest in the species appears to be increasing with the Agency receiving applications for stocking consent from angling clubs in South Wales.

The River Dee is the only catchment in North Wales to support a grayling population (Cove, pers. comm.) - excluding the upper Severn and tributaries, which come under Midlands region. Woolland (1972) made some tentative estimates of the grayling abundance on the upper River Dee and Llyn Tegid (Bala Lake) based on the limited number of grayling he was able to tag. The estimated population densities were between 2.4 and 14.3 fish 100 m^{-2} and 24.4 and 35.8 fish 100 m^{-2}, in the River Dee and Llyn Tegid, respectively (Woolland, 1987). The upper Dee and Llyn Tegid (Bala Lake) populations are thought to be indigenous (Woolland, 1972) and their dispersal downstream through the Dee catchment has been documented in Dee and Clwyd River Authority annual reports.

Dutton (unpublished) conducted an angling study of grayling in the upper Dee over a period of 10 years. His rod catch-effort and age composition data implied declining grayling populations around Llandrillo (upper Dee) between 1986 and 1996, particularly for younger fish. Dutton attributed this decline to increased predation by cormorant and goosander, although no evidence for this was presented.

A recent study by the Agency (Environment Agency, 1997c) looked at the opinions of anglers on the Dee, angling catch-rates and fish age structure in order to clarify the current status of the grayling stock. This followed reports of poor grayling catches in the upper Dee in 1996 and the general downward trend in Dutton's angling catch rate. The results of the study were inconclusive and angler opinion was divided as to whether the population was in decline. Catches returned to more normal levels in subsequent years and the likely cause of the 'decline' was attributed to in-river migration from the Dee around Llyn Tegid (Cove, pers. comm.). The grayling fishing on the Dee draws anglers from throughout the UK and hosted the World Flyfishing Championship in 1990 where grayling were the main target species. A recent major fish kill in the lower river below Bangor-is-y-Coed (July 2000) included grayling in the casualties.

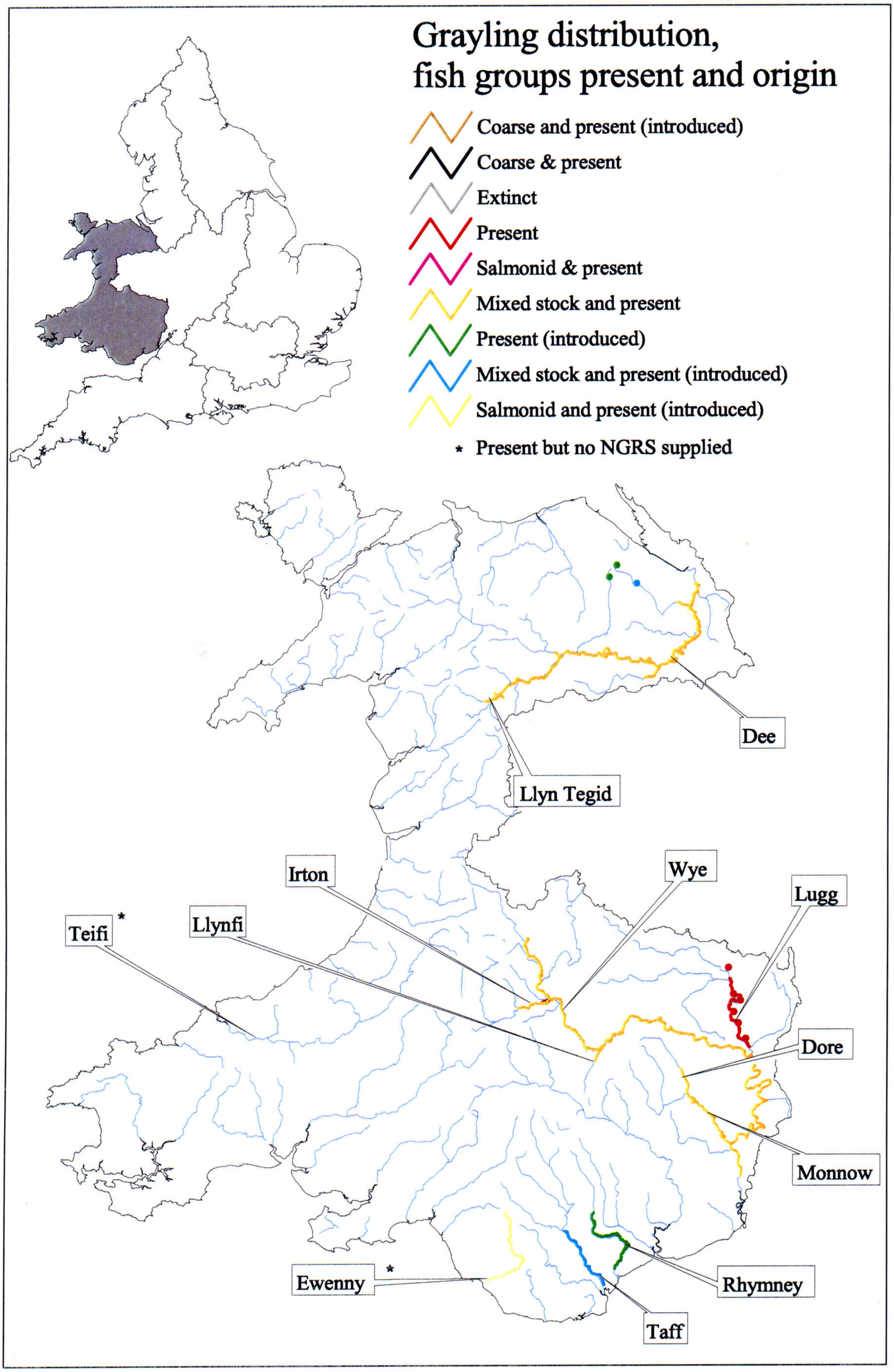

Figure 3.7 Grayling distribution, the origin of populations and fishery types present in Environment Agency Wales

In South Wales, grayling were recorded in the Ewenny prior to a fish kill but it was not established how many grayling were casualties of this pollution event. Four hundred grayling (10-15 cm) were reintroduced in 1994 (thought to originate from Cumbria). A further pollution incident took place (1996) during which juvenile grayling were killed, indicating that successful spawning had occurred (Mee, pers. comm.). Anglers report that grayling are currently thriving in the Ewenny and two unconfirmed reports suggest that they are now resident in the River Ogmore (shared estuary with Ewenny). Grayling were introduced into the River Teifi but is not known whether there is an extant population (Mee, pers. comm.).

Grayling are also present in the Rivers Rhymney and Taff (Clyde, pers. comm.), originating from fish transferred from the Lambourn and Kennet (Thames Region) during the mid-1980s. Despite a large fish kill on the Rhymney, anglers report that the population is currently thriving (Gough, pers. comm.).

The River Wye in southeast Wales supports a good, stable population within salmonid and coarse fisheries (Clyde, pers. comm.) but little has been reported recently of the population in its largest tributary, the River Lugg.

3.2.7 Midlands Region (Figure 3.8)

The importance of grayling varies within Midlands Region. For example, where grayling are abundant in the upper reaches of the River Severn, they are an important fishery resource, whereas in the River Trent, they are too scarce to form a significant fishery.

River Trent and tributaries

Grayling populations in this area have been historically widespread but occur at low densities. Records show their existence in 1622 (Anon, 1622), 1751 (Deering, 1751) and 1890 (Jacklin, pers. comm.) when they were considered to be scarce. However, gross water pollution from industrial and domestic effluents and the construction of navigation weirs in the early 20th century have eliminated these populations. Agency survey data from 1997 (Jacklin, pers. comm.) indicated that grayling were present although in low numbers within a trout and coarse fishery.

Anglers consider that grayling stocks in the River Dove on the upper reaches of the River Trent are declining (Jacklin, pers. comm.). The Agency has concluded that the perceived decline is due to events such as removals altering the population structure (Jacklin, pers. comm.). There is currently a good, self-sustaining population within a mixed fishery (Jacklin, pers. comm; Sedgewick, pers. comm.).

Grayling are also present in the Rivers Wye and Derwent (Easton, pers. comm.). In each case, the upper part of their distribution is combined with trout fisheries and in the lower part, the population is within a coarse fishery. The origin of these populations is unknown and there has been no recent stocking (Easton, pers. comm.). The population is currently self-sustaining (Jacklin, pers. comm.).

The Tean also supports a population of grayling within a mixed fishery.

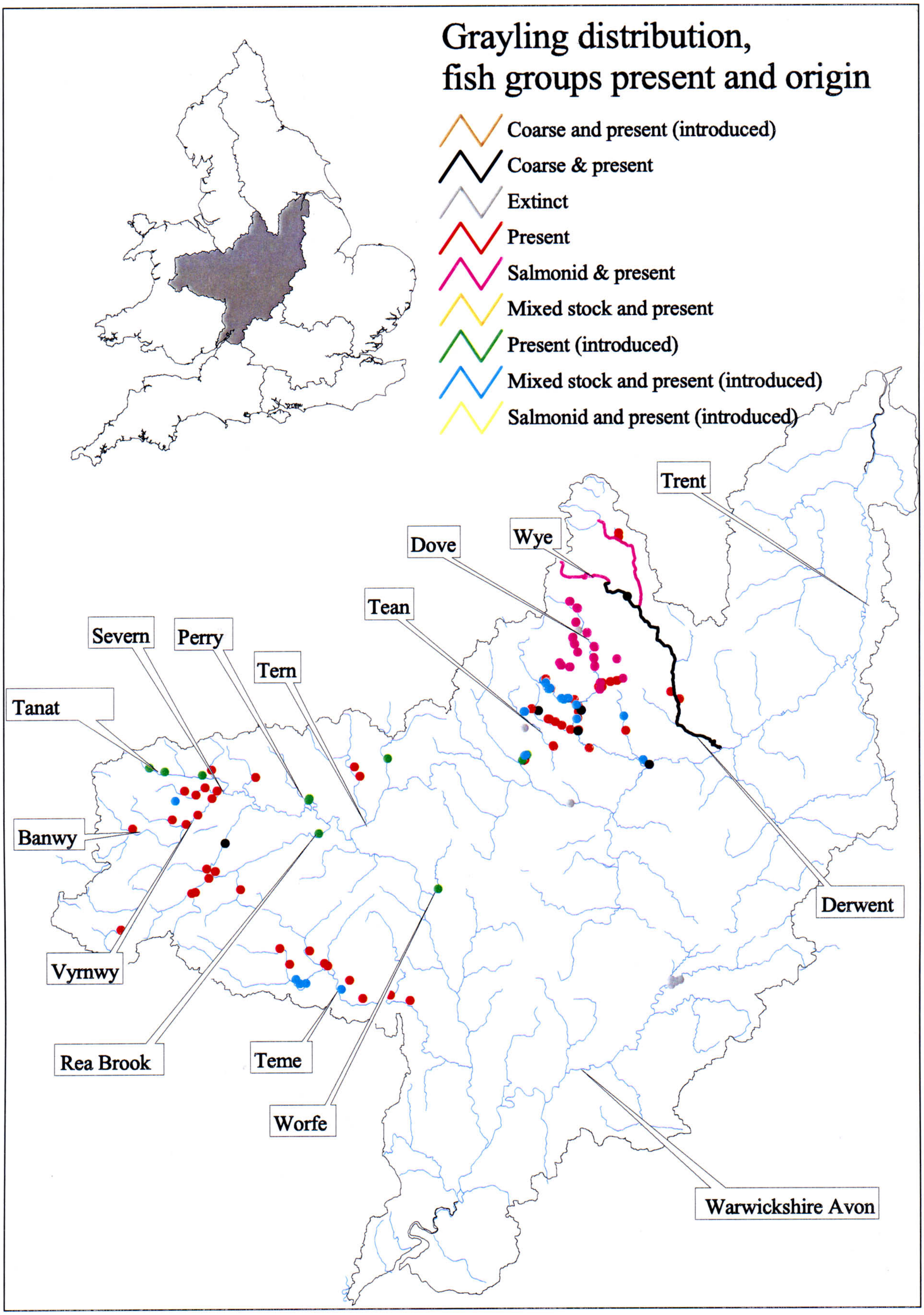

Figure 3.8 Grayling distribution, the origin of populations and fishery types present in the Midlands Region of the Environment Agency

River Severn and tributaries

The grayling stocks of the upper and mid-reaches of the River Severn have historically been highly variable (Severn Fishery Board, 1931; 1932; 1934; 1940; 1941; 1944; 1945; Woolland, pers. comm.).

Grayling are indigenous in much of the Severn catchment, and are particularly abundant in the upper reaches of the River Severn above Welshpool. Good numbers are also present in the Rivers Vyrnwy and Banwy (Woolland, pers. comm.). Populations in some tributaries (e.g. the Rivers Tern, Perry, Worfe and Rea Brook) have been established through stocking programmes and the Tern, in particular, now supports a thriving population (Woolland, pers. comm.).

Historically, the Rivers Tanat and Teme also supported abundant populations, but severe declines occurred in both rivers in the mid 1970s, possibly as a consequence of exceptionally high temperatures at that time (Woolland, pers. comm.).

In the Lower Severn, grayling are thought to be present only in the upper reaches of the Warwickshire Avon and in the river Little Avon (not shown). Both rivers support low density populations, possibly due to pressure from competing species (Britton, pers. comm.).

3.2.9 North West Region (Figure 3.9)

Grayling populations in this region are of relatively low fishery value due to their scarcity. However, grayling are considered to be valuable by several angling clubs on the Ribble (Atherton, pers. comm.).

The River Calder, a tributary of the Ribble, suffered a severe pollution event in 1995 during which several adult grayling were killed. More recent records found grayling present in the Calder in 1998 for the first time since angling surveys began in 1971. There is little information regarding the current population status in the Hodder, another Ribble tributary, however they are known to exist within a salmonid fishery (Atherton, pers. comm.).

The River Eden suffered two significant pollution events in 1987 and 1993, during which there were major fish kills. Grayling were restocked only after the latter kill and numbers have steadily increased since the 1990s (Atkins, pers. comm.). It is believed that grayling were introduced to the upper reaches of the Eden around the end of the 19th century. The population co-exists within a mixed fishery throughout the course of the Eden (Atkins, pers. comm.).

There are limited grayling stocks in the Rivers Dean and Goyt (neither shown), where distribution is restricted to certain points (Chappel, pers. comm.), and the River Dane. These fish are thought to have been illegally introduced as their origin is uncertain (Chappel, pers. comm.). All of these rivers support mixed fisheries.

The Rivers Peover Eye, Wincham Brook and Ane (not shown), all tributaries of the River Weaver, support low numbers of grayling in mixed fisheries. The origins of the former population are thought to be an illegal stocking (Chappel, pers. comm.).

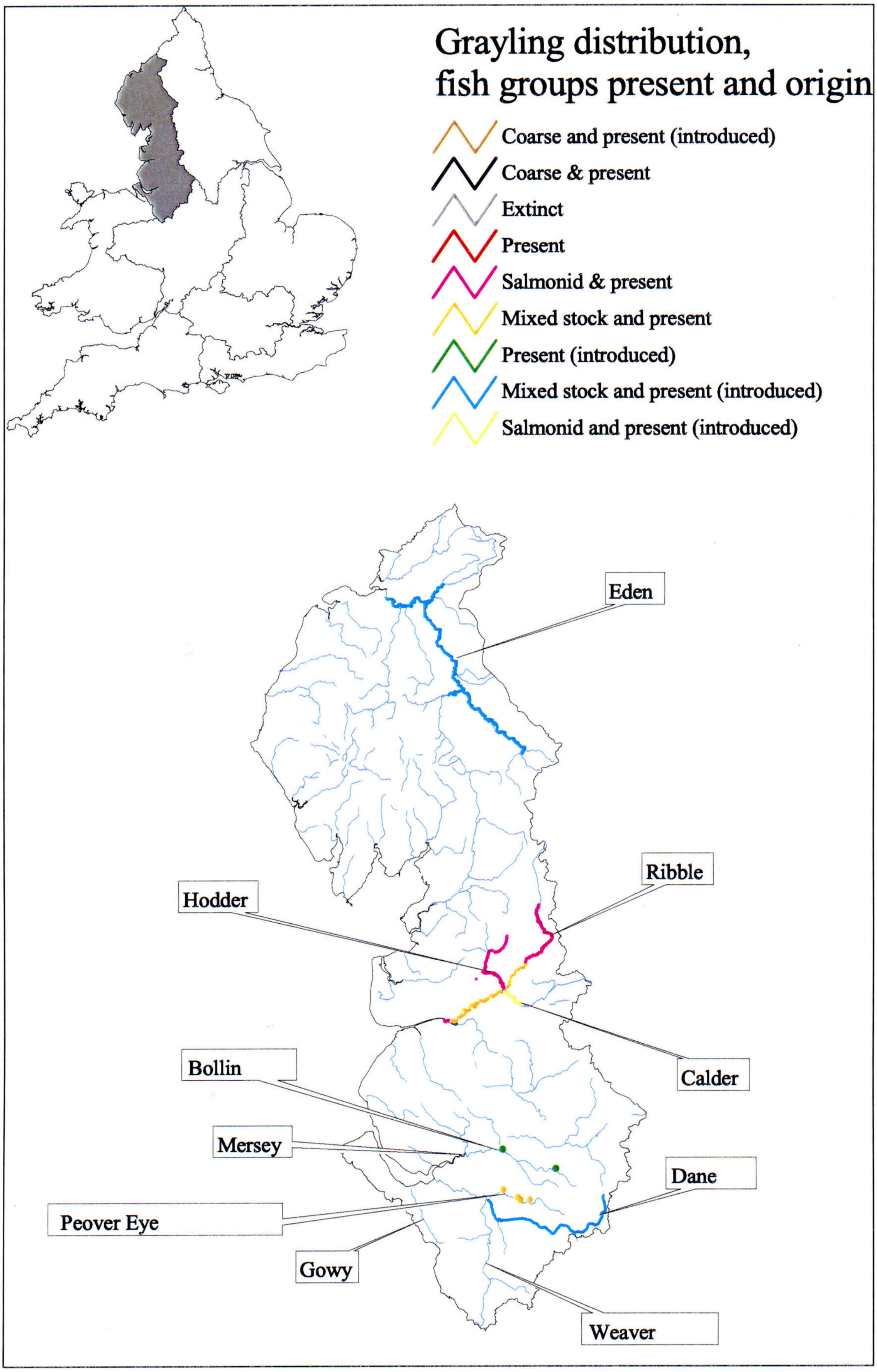

Figure 3.9 Grayling distribution, the origin of populations and fishery types present in the North West Region of the Environment Agency

A small population originating from Calverton fish farm and the River Test exists in the River Gowy, near Chester within a mixed fishery (Cove, pers. comm.).

Finally, a small population exists on the River Bollin, a tributary of the Mersey, where they were introduced (no dates given) (Hately, pers. comm.).

4. THE BIOLOGY AND ECOLOGY OF GRAYLING

4.1 Age and Growth

4.1.1 Ageing of fish

Fish ageing can be conducted by destructive or non-destructive methods. Destructive methods of ageing include the use of bone material: otoliths, cleithra and gill opercula. Non-destructive ageing involves examination of the number of annuli formed on the scales, signalling the end of each year's growth (Wootton, 1990). Grayling can be aged by this method as they have relatively clear annuli (Figure 4.1). Scale formation takes place when grayling have attained a length of 33.5-37 mm (Wootton, 1990), with the first scales laid down along the lateral line (Brown, 1943; Gustafson, 1948; Peterson, 1968).

Woolland (1972) gives the most comprehensive review of scale formation in grayling, in addition to the results of his own age study on the River Dee. Jones (1953) categorised the concentric scale rings on scales originating from Llyn Tegid, North Wales, into three types according to their shape and clarity:

- Wide summer rings
- Narrow summer rings
- Winter rings

In some cases, grayling annuli have been observed to exhibit breaks in growth (Hutton, 1923; Woolland, 1972). These were only found in 2+ and 3+ fish and were therefore thought to be 'spawning marks'.

The ease of reading grayling scales decreases with age and beyond the age of five, it is reported to be difficult to read grayling annuli as the growth rate slows and the annuli become very densely packed (Gardiner, pers comm; Ibbotson pers. comm.). A comparison of the use of otoliths and scales as ageing tools for Arctic grayling showed that interpretations of both give similar estimations for fish aged seven and eight (Craig and Poulin, 1975). However, scales underestimated the ages of older Arctic grayling (McCart Craig & Bain, 1972; de Bruyn and McCart, 1974; Craig and Poulin, 1975). This is because otoliths constantly lay down clear annuli during the life of the fish, whereas scale annuli become denser with age (Nordeng, 1961). Data involving older fish, which have been aged using scales, must therefore be interpreted with caution.

Grayling have a relatively short life span in the UK (Table 4.1), with mortality often attributed to post-spawning stress, predation and angling pressure however, longer-lived populations are found at higher latitudes and altitudes (Cihar, 1998) with associated lower water temperatures.

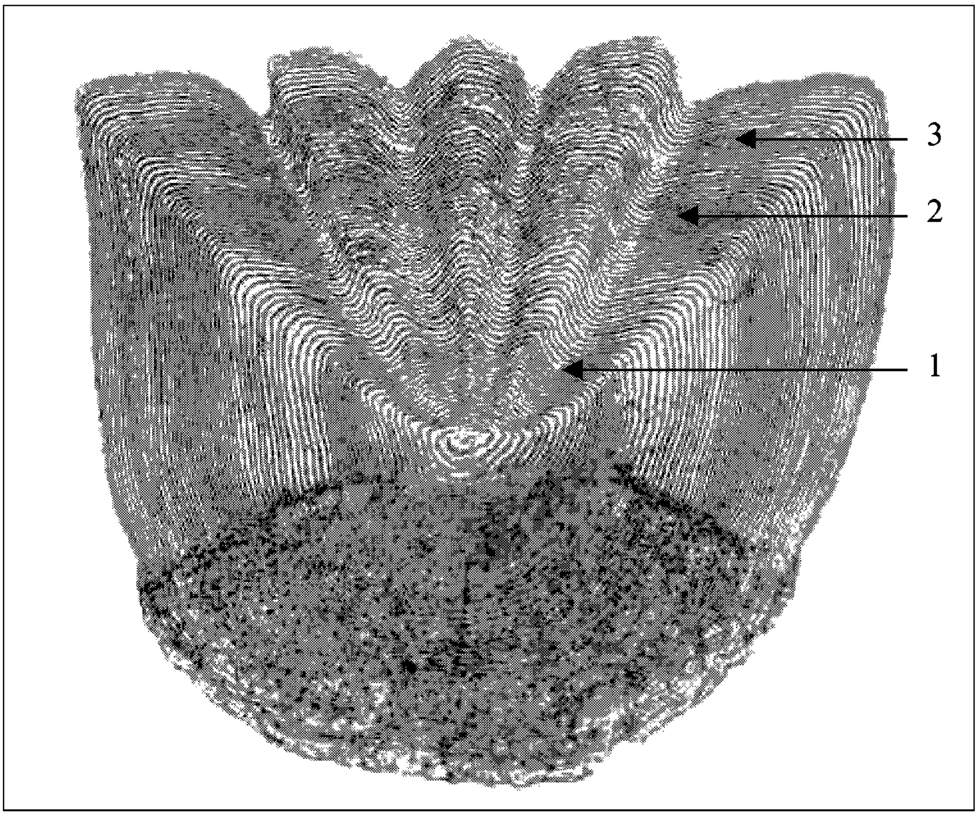

Figure 4.1 A scale taken from a three year old River Wylye October grayling at 32 cm (Cove, unpublished). Arrows indicate each year's growth annulus

Table 4.1 Geographical variation in maximum age (years) of *T.thymallus*

Age/years	Location	Reference
2 / 3	Bela (former Czech Republic)	Nagy, 1984
3 / 4	Medway	Cave, personal communication
>4	Nidd	Environment Agency, 1995a
5	Dove	Jacklin, 1998
5	Test	Crundwell, 1991
5 / 6	Teise, Wylye	Ibbotson, unpublished
6+ and 7+	Dee and Llyn Tegid	Woolland 1987
9	Britain	Maitland and Campbell, 1992
10	Scandinavia	Sømme, 1935
13	Former Yugoslavia	Woolland, 1987

4.1.2 Age structure

The age structure of grayling populations can be highly variable (Ibbotson, 1999). For example, on the River Wylye the number of grayling does not always decline with age and in some years there were more two year old fish than one year olds in the electric fished sample, indicating that there may be annual fluctuations in recruitment. The causes of these are unclear at present, mark-recapture techniques have been adopted subsequently to verify these recruitment fluctuations.

4.1.3 Growth rate

The application of scale ageing data in determining the growth rate of a fish, is reliant upon a constant frequency of annulus formation (Wootton, 1990). If the distance between each annulus is related to growth rate, the growth pattern of the fish can be calculated by a process called 'back-calculation'. This is achieved by establishing the relationship between the length of the fish and the size of the scale over a wide range of lengths (Wootton, 1990). In some cases this is proportional but in most it is not and a more complex formula is used (see Woolland, 1972 for Llyn Tegid and River Dee grayling formulae). This method requires validation however (due to the presence of, in some cases, false annuli), which is achieved by observing the same population over a period of years, examining scales of known aged fish or by other methods (Wootton, 1990). Growth can also be estimated for an entire population using scale ageing.

Growth rate is most rapid in the first year (Hellawell, 1969; 1971; Woolland, 1972) (Figure 4.2). Growth is reduced to a much lower, stable rate at around three to five years, which coincides with the attainment of sexual maturity (Hellawell, 1969; Witkowski *et al.*, 1989; Ellison, 1992).

Male grayling grow faster than females (Huitfeldt-Kaas, 1927; Sømme, 1935; Haugen and Rygg, 1996). Woolland (1972) observed that male and female grayling grew at the same rate for the first two years of their life, however, males grew significantly faster from this point onwards. This divergence correlated with the onset of sexual maturity.

Grayling growth rates depend on the interactions between their physiological ability to grow and the influence of their environment (Witkowski *et al.*, 1989). Water temperature, river size and length of plant growing season are the most influential abiotic parameters (Persat and Patee, 1981; Witkowski *et al.*, 1984). The importance of temperature in determining growth rates has been demonstrated by Mallet *et al.* (1999) who modelled growth rate seasonally in grayling and found that the best model incorporated seasonal changes in water temperature. Generally, at higher latitudes with lower ambient temperatures, fish grow more slowly. Hence, in central and Western Europe, growth rates are very high whilst in the Urals on the eastern edge of Europe, growth is slow (Witkowski *et al.*, 1989). When all other factors are constant, growth increases with increasing temperature up to a certain threshold value depending on the river system, after which, growth decreases (Persat and Patee, 1981).

River size is a determining factor of growth rates (Persat and Pattee, 1981). Growth is observed to be faster in larger rivers although the processes behind this observation are not fully understood.

In the River Lambourn at Bagnor, growth of grayling was negatively correlated with the mean summer (April–October) level of discharge (Berrie, unpublished). The instantaneous growth rates of 0+ and 2+ fish were found to decrease with increasing discharges. However, the growth rates of 3+ fish were unaffected by discharge levels. It was concluded that grayling growth was indirectly affected by the level of discharge in the River Lambourn by some other environmental parameter associated with this, probably temperature (Berrie, unpublished).

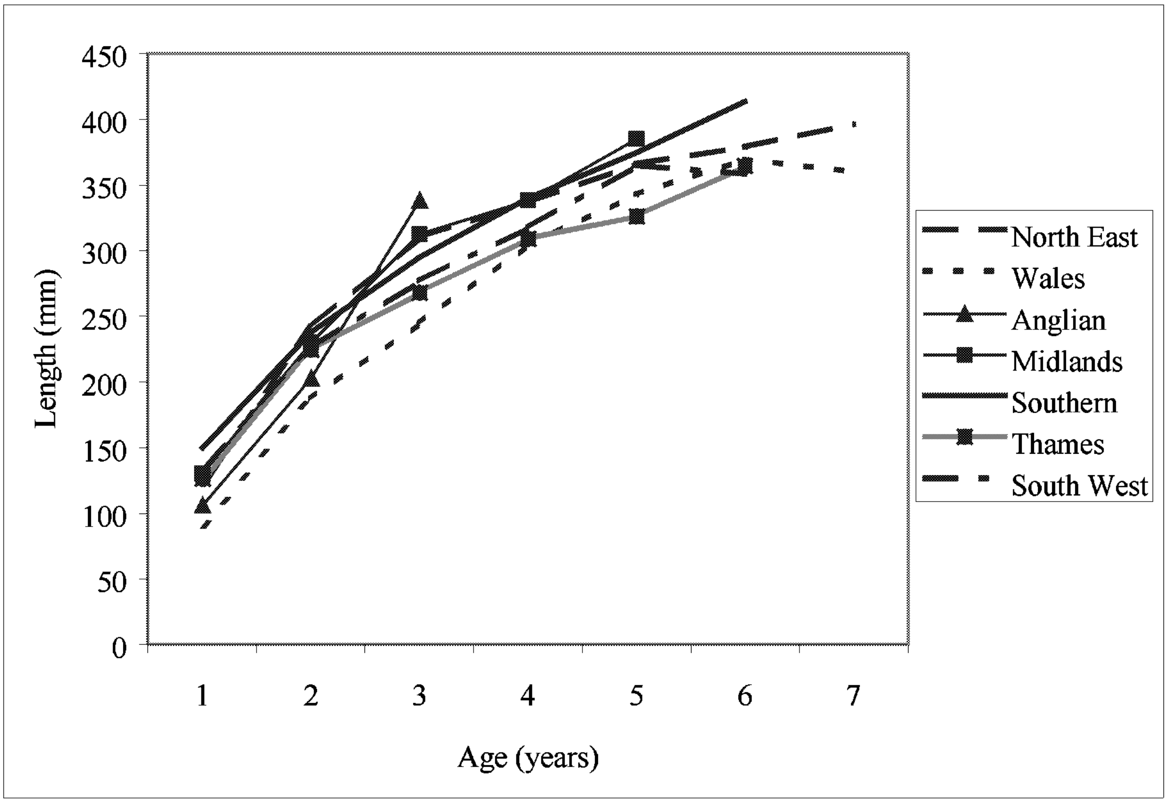

Figure 4.2 Examples of mean length (mm) at age (years) of grayling in Environment Agency regions of England and Wales (sources Woolland, 1972; Yorkshire Water Authority 1980, 1982a, 1982b, 1984a, 1984b; Environment Agency 1984, 1990, 1994c, 1995a; Jacklin, 1998; Ibbotson, unpublished; Mann, unpublished)

Temperature indirectly determines the growth rate of Arctic grayling by affecting the duration of the potential growing season (Armstrong, 1986) and by determining the availability of food in the locations used by hatchlings (Armstrong, 1986). The majority of Arctic grayling growth studies have focused on post first-year growth. Again this varies according to the river system studied, although variation between rivers in a similar geographical location is less (Armstrong, 1986). Growth rates are slowest, longevity is greatest, and individuals are generally smaller for northern Alaskan Arctic grayling. The opposite is true of southern Alaska (Kruse, 1959; Craig and Poulin, 1974; Armstrong, 1986). Growth takes place predominantly during the summer months and is one tenth of this for the rest of the year (Armstrong, 1986).

4.1.4 Sexual maturity

Maturation of grayling occurs at different ages depending on geographical location (Table 4.2) and maturation rates differ between sexes (Jankovic, 1964), with males maturing at a lower mean age than females.

Table 4.2 The age at which sexual maturity is attained in grayling at different locations

Age of maturity (years)	Location	Reference
1 – 2	Former Yugoslavia	(Jankovic, 1964)
2 – 4	Southern England	(Crundwell, 1991)
		(Ibbotson, unpublished)
2 – 5	Dee	(Woolland, 1972)

4.2 Foraging Behaviour and Diet

Food availability and the capacity to obtain it efficiently are vital if a species is to survive in a particular habitat (providing that all other parameters are suitable). These two factors change as a species develops, producing a shift in habitat and foraging strategies.

4.2.1 Feeding habitat

As grayling mature, the station in the water column they occupy changes. Initially, larvae forage pelagically and feed on drift in the upper layers of the river. As juveniles, they migrate away from the river margins, into the main channel where they hold a benthic feeding station within 5 cm of the substratum (Scott, 1985) and catch drifting invertebrates (Sempeski *et al.*, 1995). Grayling remain feeding in the upper layers until they attain a length of 15 cm (Haugen and Rygg, 1996). It is in the older stages that the grayling begin bottom feeding on prey such as Ceratopogonidae (biting midge larvae) and *Sialis* (alderfly) larvae (Furse, unpublished), although they still frequently rise to the surface to intercept drifting prey such as *Elmis* (aquatic beetle) larvae (Peterson, 1968).

4.2.2 Prey composition

The type of prey consumed by grayling varies with age (Table 4.3). The larvae of grayling have been found to feed mainly on chironomid larvae (non-biting midge) irrespective of the diversity of invertebrates available. Juveniles exhibited greater diversity in their feeding, although copepods and oligochaetes, chironomid larvae and pupae still constituted more than 90% of prey ingested (Carmie and Cuinat, 1984; Witkowski *et al.*, 1984; Scott, 1985; Woolland, 1987; Sempeski *et al.*, 1995). These prey were also observed in grayling under one year old from the Lambourn, together with *Simulium* (blackfly) and *Ithytrichia lamellaris* (caddis fly larvae) (Furse, unpublished). Older, 1+ grayling consumed mostly *Gammarus* (freshwater shrimp) in addition to prey eaten by 0+ fish (Furse, unpublished).

Generally adult grayling become predominantly bottom feeding with increasing age and the contribution of aerial prey to their diet falls correspondingly (Dahl, 1962; Jankovic, 1964; Peterson, 1968; Woolland, 1972) (Table 4.3).

The predominant prey of 2+ and 3+ grayling in the River Lambourn was *Gammarus pulex* (43.8%), together with *Simulium* (blackfly), chironomid and *Ithytrichia lamellaris* larvae (caddis fly) (Furse, unpublished). Terrestrial invertebrates did not form an important component of the diet on the River Frome (4.3% in 0+ and 0-0.1% in 1+ and older fish) (Keay, 1990). An increase in terrestrial intake may occur when aquatic prey are scarce (Dahl, 1962). Fish eggs are consumed opportunistically (Hellawell, 1971), although no evidence of egg predation was found in the Rivers Test and Itchen (Leman, 1994). However, 0+ roach scales (Crundwell, 1991) and minnows (Ibbotson, unpublished) have been found in stomach contents in southern English chalk streams indicating that grayling will predate other small fish. Gravel has also been found in stomach contents, which may be a deliberate act to help with food mastication, mistaken identification or a by-product of the consumption of caddis cases (Keay, 1990). Generally, prey consumed by 2+, 3+ and 4+ grayling in the River Test did not differ significantly (Crundwell, 1991).

Table 4.3 Food ingested by *T.thymallus* (* : juvenile food, ** : adult food, *** both juvenile and adult food)

Prey item	Reference	
Adult aquatic insects (caddis fly, mayfly, dipteran, *Gammarus*, *Asellus,* Hirudinea)	***	(Keay, 1990; Scott, 1985; Furse, unpublished)
Larval aquatic insects (dipteran, caddis fly, mayfly)	***	(Scott, 1985; Furse, unpublished)
Zooplankton	*	(Scott, 1985)
Gastropods	**	(Furse, unpublished)
Terrestrial invertebrates, Oligochaeta	***	(Furse, unpublished)
Salmon eggs	***	(Hellawell, 1971)
Trout eggs	***	(Mills, 1971; Gerrish, 1934a)
Cyprinid eggs	***	(Hellawell, 1971)
Roach fry and minnows	***	(Crundwell, 1991) (Ibbotson, unpublished)

The size of prey items generally increases with fish size as would be expected with the growth of the mouth and stomach, allowing the accommodation of larger items. Young grayling were shown to have consumed mostly dipteran (true fly) larvae and aerial insects, whilst adults took large trichopteran (caddis fly) larvae and crustacea (Woolland, 1972). Larger fish also consume larger numbers of prey items (Dahl, 1962; Hellawell, 1971; Woolland, 1972; Sempeski and Gaudin, 1996).

4.2.3 Foraging strategy

The shift in habitat with life-stage is closely related to changes in foraging strategy. Feeding usually begins on first emergence to surface waters (Penaz, 1975). As the fish grows, the mouth-gape diameter enlarges enabling the grayling to consume a greater variety of larger prey items (Sempeski and Gaudin, 1996).

4.2.4 Seasonal changes

Seasonal variation in environmental conditions, such as temperature and light intensity, affect feeding intensity and prey type. Ambient temperatures directly influence feeding intensity by causing water temperatures to fall or rise and periods of the lowest (2°C) and some of the highest water temperatures (24°C) have been found to be associated with low feeding intensity (Woolland, 1972). The reasons for such behaviour are thought to be attributed to fish reducing feeding activity in an attempt to conserve heat energy and as a result of lower oxygen tensions in the water, respectively (Ball, 1961). Feeding rate was maximal during periods of intermediate temperature (16-18°C) between October and November (Hellawell, 1971; Woolland, 1972).

Seasonal variations in the composition of available food also directly affect the diet (Woolland, 1972). In the River Dee during the winter, the most common foods consumed were caddis larvae, crustacea, true fly larvae and plecopteran (stone fly) nymphs (Woolland, 1972). By comparison, the summer stomach contents consisted mostly of caddis larvae, aerial insects and ephemeropteran (mayfly) nymphs, in addition to blackfly larvae which were washed out when increased water levels followed high rainfall (Hellawell, 1971; Woolland, 1972; Crundwell, 1991; Leman, 1994). This would indicate that grayling are opportunist feeders exploiting seasonally available prey.

4.2.5 Diurnal changes

Although grayling feed continuously throughout the day, maximum activity occurs at dawn and dusk, with no feeding at all during the night (Scott, 1985). Olifan (1956) attributed such behaviour to the fact that grayling fed on drift and hence their diurnal rhythm was co-ordinated with peaks in drift density.

Grayling have also been observed to feed in the water column and less frequently on the bottom during the day, whilst at night, they tend to rest on the bottom (Sempeski and Gaudin, 1995a).

4.2.6 Feeding hierarchies within populations

The feeding position occupied by individual Arctic grayling is related to a dominance hierarchy (Hughes, 1992). It has been demonstrated that in a habitat where there was a difference in the desirability of feeding stations, the resident grayling population would compete and configure according to rank into such stations with the most dominant fish inhabiting the 'best' location.

The presence and manifestation of hierarchies in the feeding behaviour of other salmonids is generally well documented but there is no published information for grayling.

4.3 Reproduction

4.3.1 Fecundity

The fecundity of grayling varies with geographical location (and therefore stocks) and size of females (Table 4.4). However, in the River Test Crundwell (1991) found no variation in fecundity at different locations.

Table 4.4 The variation in grayling fecundity with geographical location

Mean no. of eggs/kg female	Location	Reference
10,000 - 31,000	Yugoslavia	(Jankovic, 1964)
10,500	Augerolles, France	(Carmie *et al.*, 1985)
8,700	Dee and Llyn Tegid	(Woolland, 1972)
4,000 - 5,000	Wylye	(Ibbotson, unpublished)
3,350 - 6,005	Test	(Crundwell, 1991)

Fecundity and egg size increase as female grayling grow. The proportion of gonads to total body weight increases with size. Gonad weight increased as a proportion of body weight at higher body lengths until at 35 cm, a female was 15% gonad mass two weeks before spawning (Ibbotson, observation).

The eggs of grayling are smaller than those of salmon and trout and are approximately 3-5 mm in diameter (Ibbotson, observation). They are yellow in colour and normally located in pockets on the surface of gravel substratum (Ibbotson, observation), although the activity of spawning can result in the burial of some eggs up to depths of about 5 cm.

4.3.2 Spawning precursors and timing

Grayling spawn in spring. In northern European countries, spawning occurs from the end of March (Parkinson, Philippart & Baras, 1999) to the first half of June, (Eloranta, 1985; Scott, 1985; Gonczi, 1989; Clark, 1992; Linloekken, 1993; Kristiansen and Døving, 1996) or just after snowmelt (Peterson, 1968; Witkowski and Kowalewski, 1988). In the UK, grayling are thought to spawn in the upper River Dee during late April and mid-May (Woolland, 1972) or as early as late February in southern England (Ibbotson, observation).

The onset of spawning in grayling and Arctic grayling correlates significantly with climatic conditions, which influence water temperature (Witkowski and Kowalewski, 1988). Grayling are stimulated to spawn by temperatures ranging from 3-11°C, although spawning at temperatures as high as 14°C has been recorded in the Frome, Southwest England (Scott, 1985).

4.3.3 Behaviour

Males arrive on the spawning grounds several days before the females (Fabricius and Gustafson, 1955). In the case of Arctic grayling, males are present weeks before the females to secure a favourable territory (Beauchamp, 1990). There is a trade off between early arrival to secure a good spawning habitat and the increased risk of egg disturbance by later spawners.

European grayling males adopt and defend their territories, courting females approaching from downstream (Persat and Zakharia, 1993; Poncin, 1994; Parkinson *et al.*, 1999). Males exhibit aggressiveness throughout the whole year, however, such behaviour becomes more pronounced during the spawning season when they begin to defend their territories (Fabricius and Gustafson, 1955). Females are only tolerated in male territories at the moment of spawning. Outside this period, they hide under overhanging vegetation, banks and behind stones, or sit in pools downstream of the male territories (Ibbotson, observation). The oldest and largest grayling spawn first (Witkowski and Kowalewski, 1988).

The sex ratio has been found to change over the spawning season at the spawning sites. During the first three days, males dominate females by 3:1, decreasing mid-spawning to 1.5:1 (Witkowski and Kowalewski, 1988). Towards the end, the ratio equals out as fewer males ascend the river, until eventually the females are dominant (Witkowski and Kowalewski, 1988). An unequal ratio of 6:1 (males:females) has been reported in some grayling populations (Libovársky, 1967) and it has been inferred that sex ratio is strongly influenced by angling pressure on females during the summer (Libovársky, 1967).

4.3.4 Courting display and spawning act

Grayling spawning is initiated by the males vibrating display (Fabricius and Gustafson, 1955) which attracts females. The mechanism behind a female's choice of male is unclear, however, in addition to visual cues olfactory stimuli are also thought to be important (Fabricius and Gustafson, 1955). Streambed stability in the spawning territory, is a final consideration of the female, because spawning does not take place in a redd (Beauchamp, 1990).

The male hovers in the water, bending the caudal part of his body upwards so that the tail is lifted, he erects the dorsal and pelvic fins fully (in spasmodic and an almost twisted manner) and continues to perform vigorous and very rapid trembling body movements (Fabricius and Gustafson, 1955). When females are almost ready to spawn they become aggressive, attacking other individuals of both sexes and move several times towards the male that is usually situated on a gravel bank. This resident male often reacts aggressively. As the female ripens, she becomes less aggressive and approaches the male with her back arched and the dorsal fin pressed down, which suppresses male aggression. (In contrast, female Arctic grayling erect their dorsal fin (Tack, 1971)). The male grayling approaches her and trembles. He does not erect his fins or bite in this courting act. Initially, the female flees but returns to complete the act. The male's trembling intensifies to a very quick vibration. He erects his fins to their fullest extent and tilts over on his side so that the female's back is covered with his large dorsal fin and part of his back. The caudal area is bent laterally, crossing over the tail of the female, pressing it down against the bottom. The bodies of the two fish form a cross shape. Vigorous flapping movements of the tail fin follow (more or less horizontally and close to the ground). The female begins trembling, supporting herself on her pelvic fins and bending the caudal part of her body very sharply and dorsoventrally, so that the anal fin is pressed against the ground whilst the tail and fore-part of her body are lifted. Very intense trembling movements occur at the caudal end of her body, to the extent that the adipose fin is buried beneath the gravel. Once this has reached a crescendo, the female opens her mouth wide for several seconds. This is the stimulus for male orgasm. The male gapes and a joint orgasm follows. A sharp flick of the caudal fin pushes the genital openings down deep where the eggs and milt are released over a period of approximately 14 seconds (Fabricius and Gustafson, 1955). At the moment the female releases her eggs other males suddenly enter the spawning territory and attempt to release their milt in the vicinity of the female (Ibbotson, observation). Immediately after this, the male attacks the female who retaliates or flees. Grayling spawning acts usually occur in the afternoon or evening coinciding with the warmest water temperature (Fabricius and Gustafson, 1955).

4.3.5 Unusual courting/spawning observations

Visual, as well as acoustic and vibrational cues, are important in fish spawning behaviour (Satou *et al.* 1987; Persat and Zakharia, 1993). An example of the strength of the role visual and acoustic cues play, was shown in the River Ourthe (Belgium) where a grayling was observed trying to spawn with a barbel (Poncin, 1994). The barbel was motionless, quite like the submissive female grayling and produced a gravel noise, both of which may have attracted the male grayling. Intraspecific, homosexual spawning attempts have also been reported (Fabricius and Gustafson, 1955).

Hermaphroditism is rarely reported in Salmonidae, and until 1991, had never been documented in grayling. However, an hermaphrodite grayling was discovered in the River Nysa Klodzka, Lower Silesia, Poland (Blachuta, Witkowski & Kokurewicz, 1991), displaying both male and female gonads which were smaller than those of the true sex, and a unique dorsal fin.

4.3.6 Hybridisation between grayling species

Shubin and Zakharov (1984) documented the presence of hybrids in some rivers of the polar and sub-polar Ural, which had developed between grayling and Arctic grayling in their secondary contact zone (Mayr, 1968). These hybrids were verified as being such by identification of the fractional composition of serum proteins in most cases but also on the basis of visual examination (Shubin and Zakharov, 1984).

4.3.7 Emergence

After spawning, the fertilised eggs of grayling remain in the gravel for approximately 177 degree-days after which they hatch (d'Hulstere and Philippart, 1982). The optimal temperature for hatching lies between 7 and 11°C (d'Hulstere and Philippart, 1982). Hatching time decreases with increasing temperature (Humpesch, 1985) up to a temperature of approximately 15°C where further increases have little effect (Elliott, Humpesch & Hurley, 1987). Mortality at hatching is highly site specific and varies from year to year depending on both biotic and abiotic factors. Examples of biotic factors include; predation, disease or genetic fitness of the embryo. Abiotic factors include flooding or drought.

After 4-5 days in the gravel, feeding on their yolk sac, grayling fry emerge (Bardonnet *et al.*, 1993). The fry begin feeding near the water surface before the yolk sac has been fully absorbed (Scott, 1985) and complete re-absorption of the yolk sac occurs after 12 days (156 degree-days) (Scott, 1985). Bardonnet and Gaudin (1991) give an approximate time for emergence of 10 days post-hatching.

When the hatchlings first emerge, their fork length ranges between 1-1.2 cm (Maitland and Campbell, 1992) and 1.5-1.9 cm or less depending on egg size (Scott, 1985; Sempeski and Gaudin, 1995a). Emergence differs from other salmonids in that it is diurnal rather than nocturnal (Elliott, 1986; Brannan, 1987). Grayling fry emergence peaks at dawn (Gaudin and Persat, 1985; Bardonnet and Gaudin, 1990) but downstream displacement does not commence until nightfall (Bardonnet and Gaudin, 1990). Such nocturnal movement may be a predator-avoidance strategy (Godin, 1982; Gustafson-Marjanen and Dowse, 1983) or alternatively, prolonged presence in daylight may facilitate the familiarisation of the fry with their surroundings (Bardonnet and Gaudin, 1990).

4.4 Interactions with Other Species

4.4.1 Competition

Grayling are salmonids but have historically been regarded as coarse fish. As a result some salmon and trout anglers considered grayling to be vermin and tried to eradicate them. This opinion is based predominantly upon the perception that grayling actively compete with trout and juvenile salmon for food and habitat space.

Although one species would probably benefit in the absence of the other, mixed fish populations allows much more efficient utilisation of all the resources available, ultimately resulting in enhanced productivity of a particular stream (Woolland, 1988).

In the presence of trout, grayling occupied deeper, slower flowing areas of Swedish rivers with a finer substrate. In the absence of trout they moved to areas with a coarser substrate (Greenberg, 1999; Degerman Naslund & Sers, in press), indicating segregation at the micro-habitat level. As both species grow, competition decreases and segregation increases. Degerman *et al.* (in press) speculated that introducing grayling to brown trout streams could restrict habitat use by trout, (particularly in deeper waters) and indirectly affect the life history and biomass of the trout.

A number of studies exist which indicate food resource overlap between trout and grayling. The population of grayling on the River Dee has been extending downstream since 1945 according to local fishery annual reports (Environment Agency, 1998b) and as a result, concern was expressed with respect to the effect this downstream expansion had on other species present in the Dee, particularly trout. Llyn Tegid has also seen a population increase due to regulation producing enhanced summer water levels aiding early stage survival. The diets of salmon, trout and grayling parr in the River Dee exhibited some overlap (Woolland, 1972) although this is not uncommon in a shared habitat where a particular food item is abundant. Observation of dietary overlap does not necessarily infer competition.

Resource partitioning and differences in feeding behaviour was hypothesised as the mechanism allowing trout and grayling to co-exist in the River Lambourn (Furse, unpublished). In the first instance, grayling feed on invertebrates predominantly from the streambed in direct current, whereas trout feed on invertebrates typically associated with plant communities such as *Ranunculus* which are present in areas of turbulence. Muller (1954) and Solewski (1963) also observed this. Grayling differ in their feeding behaviour as they are gregarious and tend to feed in shoals, foraging widely (Furse, unpublished). Trout feed in territories and therefore forage less. Morphologically, grayling have small mouths, which are ventrally positioned with tiny teeth. By comparison, trout have relatively larger terminal mouths and larger teeth. Both arrangements are well suited to the feeding habits of each species. All of these factors would indicate that interspecific competition should not occur given sufficient habitat diversity. Even if the two species are feeding in the same location, they have been observed to ingest different prey (Gerrish, 1934a; 1934b) and therefore utilise available resources efficiently. In summary, diet itself is not a conclusive indicator of interspecific competition between trout and grayling where food is super-abundant (Sale, 1979).

The evidence for competition is limited. There have been few investigations into competition between trout and grayling that provide good evidence either supporting or refuting its occurence (Fausch, 1984). Undoubtedly competition between grayling and some other fish species, including trout, does occur (Jagsch *et al.*, in press), but its quantification and consequences are very hard to determine and no study has achieved this to date.

Since grayling and trout have different distributions each occupying a separate zone but with some overlap at the edge of these distributions, it is likely that within each of their zones one species will dominate. That is, grayling will dominate in the grayling zone and trout will dominate in the trout zone. Many trout fisheries are supported within the grayling zone by artificial stocking. This is a cultural practice, brought about by angler demand, that is likely to continue, but it will not change the physical and chemical characteristics of the zone. In these situations it would be advisable to utilise the grayling population as a fishery resource.

4.4.2 Predation

Predation is an effective natural mechanism of population control. Sempeski and Gaudin (1995b) have stated that 'Predation risk has been recognised as the main factor influencing size-dependent segregation of individuals'.

The grayling has a number of natural predators, which vary geographically. Otters, other fish and piscivorous birds such as the heron, kingfisher, cormorant and goosander commonly predate upon grayling. Pike and perch predate on smaller fish living in shallow habitats (Sempeski and Gaudin, 1995b). Stocked grayling have been found in 18% of pike stomachs in a first release experiment in Scandinavia (Carlstein and Eriksson, 1996). Grayling that migrate from lakes to rivers are more susceptible to predation than those that migrate within rivers as the former prefer the slow moving waters where predatory fish reside (Henriksson and Muller, 1979).

The appearance of cormorants during the winter 1995/1996, resulted in a decline of the grayling population of a 15 km stretch of the River Lenne, N. Rhine Westphalia (Frenz, Klinga & Schumacher, 1997; Staub *et al.*, 1998). On the Dove in the mid-1990s, predation by cormorants was considered a serious problem (Jacklin, pers. comm.). The birds preyed selectively on the smaller fish, affecting the stability of the grayling population. In addition, herons, mink and otters also predate grayling on the Dove (Jacklin, 1998). There have also been angler concerns about cormorant predation and alleged grayling declines in the Dee (Environment Agency, 1997c). Uiblein *et al.* (2000) also comment on the high predation pressure exerted by cormorants in the Fuschler Ache in Austria.

Cormorant predation is perceived as a serious problem by many anglers. A recent study on the impacts of fish eating birds (MAFF, 1999) did not consider grayling directly but concluded that serious damage to fisheries from fish eating birds was not a general problem but was a problem for some specific fisheries.

A severe reduction in the number of grayling in the upper Danube was found following the intensive stocking of eels (Hoffmann *et al.*, 1995).

There is some evidence that grayling are piscivorous. They have been observed consuming salmonid eggs, especially those of trout (Mills, 1971). Gerrish (1934a) observed that during a five-year period, 40-50% of chalk stream grayling contained trout ova in the spawning season. The impact of such predation is not known. Grayling are also known to predate trout (Furse, unpublished), roach fry (Crundwell, 1991) and minnows (Ibbotson, unpublished). Some evidence of trout predating grayling and grayling fry is also available (Mills, 1971).

4.5 Migration

There is very little information on the migratory behaviour of grayling generally and that available suggests that the extent of migrations is highly variable. In southern English chalk streams the habitats required to complete whole life cycles lie within close proximity to each other. In some cases grayling may exist quite adequately within a 100 m stretch of river

(Ibbotson, observation). In contrast, Linloekken (1993) reported grayling of the Glomma River system, Southeast Norway travelling 120 km to reach feeding grounds.

Grayling display various forms of movement and migration. These range from local movements such as foraging within a home range or shifts in habitat with age or season, to long distance migrations such as spawning migrations from river to tributary, lake to tributary, sea to river and diel migrations. In each instance a degree of homing behaviour is displayed.

4.5.1 Home ranges

Grayling often make short-term foraging trips and return to a specific 'spot' in their own territory, occupying what is known as a 'home range' or the 'area over which an animal normally travels' as defined by Hayne (1949). Woolland (1972) identified this restricted movement pattern in the River Dee. He established by recapturing tagged grayling, that 76% of all movement was within a 1 km radius of the 'home area'. However, this distance did increase to a maximum of 10 km in one case. He suggested that grayling fall into two groups in respect to movement:

- A large static group which occupy a home range and hold a specific station in their territory, occasionally conducting foraging trips within a specified area around it.
- A smaller group which forage widely and do not appear to hold any particular territory.

In the River Dee, fish have been found to move very little and occupy a home range (Woolland, 1986b). In Llyn Tegid home ranges were absent or they occupied non-specific areas, swimming randomly in a particular habitat which suited their requirements (Woolland, 1986b).

Those fish in the second category may have been weaker and were subsequently forced to move away by competing resident fish and establish a territory elsewhere (Woolland, 1972). This seems likely in view of Woolland's (1972) study of the homing tendencies of grayling transferred from their home range to another site 250 m away. He found that fish tended to return to their original station.

4.5.2 Seasonal movements

Local movements can also be seasonal (Table 4.5). Woolland (1986b) observed that Dee grayling showed seasonal shifts in the depth and position occupied. In Llyn Tegid migration from the lake to the feeder streams and the main river (Dee) took place between June and September (Woolland, 1972). The reasons for this were not clear, however, the rise in temperature and lower oxygen concentrations of the lake (as an enclosed body with no temperature regulating flow regime as found in a river system) could be the cause (Hellawell, 1969). When conditions in the lake approximated those in the stream or river in October, the grayling returned to the lake.

Table 4.5 Seasonal shifts in habitat (depth and position) of adult grayling (Woolland, 1986b)

Parameter	Winter	Spring	Summer	Autumn
Depth (m)	1 - 2 m	Shallows	Shallows	
Position	Shelter from currents e.g. depressions		More scattered All over especially midstream	Back to lake, stream etc.
	Congregate in one spot	Spawning migration	Most in/near spawning grounds	

In the autumn, in sub-arctic Finnish rivers, at temperatures between 1.7-6.7°C, grayling migrate to potential over-wintering sites 1-14 km up or downstream (Nykanen, Husko & Maki-Petays, 2001). The mean daily movement rate and the total range covered by the fish in autumn were 1053 ± 1636 m and 3135 ± 1850 m, respectively (Nykanen *et al.*, 2001). The over-wintering sites were characterised by deeper water (1.5-4 m), lower velocities (0.2-0.8 m s^{-1}) and finer bottom substrates (mainly sand) than in the late summer (1-3.1 m, 0.3-1.1 m s^{-1} and cobble-boulder, respectively).

4.5.3 Feeding

The feeding migrations of grayling are inferred from information regarding spawning migrations. It is assumed that grayling return to the original grounds post-spawning to feed.

Arctic grayling have been recorded migrating from spawning to feeding grounds for the summer months (Craig and Poulin, 1975). Feeding fidelity has been demonstrated in tagged Arctic grayling, in tributaries of the Tanana River in Alaska, where 99% of recaptures were made in the same river (Tack, 1980). Such migrations vary according to age, the type of overwintering system and the type of spawning system (Armstrong, 1986). However, for the first year, Arctic grayling are thought to remain in their natal area to feed.

Migrating Arctic grayling travelling to unsilted rivers to feed, vary in their exact destination within the system according to age. For example, juveniles (1, 2 and 3 year olds) tend to reside in the lower regions of rivers; pre-adult (4, 5 and 6 years) occupy the mid-regions and the adults (7 years and over) the uppermost regions (Armstrong, 1986). It is not known whether these migration patterns are repeated in European grayling.

4.5.4 Spawning

The most notable migration is that of the adult male and female grayling, ascending the rivers to spawn. Homing in this case is the ability of a fish to return to its natal river and is one method of ensuring reproductive isolation (Pavlov *et al.*, 1998) and a return to a river system with the environmental requirements suitable or optimal for that particular organism. Little research has been conducted on the spawning migrations of grayling, however Woolland (1972) reported that grayling from Llyn Tegid and the upper Dee migrated into the feeder tributaries to spawn (including Afon Llafar and Lliw). During the migration, they ascended a few small gauging weirs (Woolland, 1972) but the actual spawning event was never observed.

Radio tracking has been used to study the spawning migration of grayling in the Aisne River, Belgium (Parkinson *et al.*, 1999). Six fish were tagged and found to migrate distances of between 230 and 4980 m upstream. This movement took place under decreasing floods, increasing temperature and low turbidity. Males arrived several days earlier at the spawning grounds than the females and remained there longer (2-3 days). Males occupied one homing area whereas females moved between areas. Amongst the small number of fish studied grayling displayed high fidelity, returning to the precise pool-riffle sequence in which they were originally tagged, during the late winter and spring (Parkinson *et al.*, 1999). The mechanism controlling such homing behaviour is unknown but the use of chemical cues as guidance has been suggested (Døving, Selset & Thomnesen, 1980).

Migration distance has been shown to be dependent on temperature and the numbers of fish migrating are greatest at the time of a full moon (Witkowski and Kowalewski, 1988). Pavlov *et al.,* (1998) conducted tagging mark-recapture surveys on grayling and found that only 18.7% went back to spawn in their home stream. Homing success over a one-year period was highly variable with 17% being detected in other streams (Table 4.6).

Table 4.6 The homing success (% returns) of different aged *T.thymallus* over a one-year period (Pavlov *et al.*, 1998)

Age of fish	% Homing success
0+	2.5% returned
2+	92.3% returned
2+ - 5+	57.7% returned
	17% overall strayed

4.6 Barriers to Migration

The inhibition of grayling migration is of concern where habitats required for different life-stages are separated by impassable barriers or where local extinction has occurred in areas that cannot be recolonised for the same reason. Where the former applies, the population becomes extinct and in the second case, distribution becomes patchy and demonstrates high local fluctuations in population size.

4.6.1 Physical Barriers

It is difficult to identify any examples of catchments where grayling populations in the United Kingdom have become extinct as a direct result of the interference of migration between essential habitats, but this does not mean they have not occurred.

It is easier to identify patchy distribution of grayling as a result of barriers in many river systems. In many cases what seem quite minor barriers appear to inhibit grayling mobility and the ability to colonise particular areas (Ibbotson, observation). This is particularly obvious where the distribution comes to an abrupt halt at a weir. For example, at Dorchester Weir on the Dorset Frome, grayling are present immediately below the weir but absent above it (Ibbotson, observation). This phenomenon also occurs on the River Alwen (a tributary of the Dee) (Dutton, pers. comm.). Even minor hatches appear to have a significant impact on the movement of grayling on chalk streams (Ibbotson, observation).

In a habitat assessment of the River Ise (Environment Agency, 1999a), grayling were found at a site where they were thought to have been washed downstream during flooding and were unable to regain their upstream position due to the presence of a sluice at Boughton House. Within the Great and Long Eau system (Environment Agency, 1995c) grayling are affected by barriers.

The weirs at Lobwood and Addingham Low Mills on the River Wharfe are thought to be barriers to upstream migration. These are implicated by the presence of sparse populations with unbalanced age structures upstream where the population is affected by downstream displacement during floods. By comparison, stocks immediately below the weirs are larger and more balanced (Hopkins, pers. comm.).

In North America, culverts at road crossings are considered potential barriers to juvenile Arctic grayling, depending on the current velocity in the culvert (Northcote, 1995).

4.6.2 Fish-pass design

There is very little information available to aid fish pass design specifically for grayling. Jungwirth (1996) investigated the impact of pass design on grayling in the River Mur, Austria. He found that fish passes which resemble the morphology and hydraulics of natural tributaries, are most effective at allowing grayling to migrate over weirs.

Barriers negotiable by other salmonids may restrict grayling migration. There is currently not enough information on grayling swimming capabilities or migratory behaviour to design fish passes specifically for grayling. Grayling swimming capability will be investigated in Phase II of R&D project 708/CDV/MS, which will go ahead in 2001.

The problem of negotiating apparently minor barriers may also suggest a behavioural reluctance to migrate past them. The characteristics of river structures that act as barriers need to be identified.

A recommendation has been made in Chapter 11 that the migratory behaviour of grayling in UK rivers is researched. Defining the characteristics of river structures that act as barriers to grayling could be included as part of that study.

4.7 Habitat Requirements

Grayling are frequently ignored in habitat improvement programmes. It is a common misconception that they have the same habitat requirements as other non-migratory salmonids such as trout (Environment Agency, 1992a) and although grayling may benefit from some of the habitat improvements designed for trout, this may not always be the case.

Milner, Hemsworth and Jones (1985) name three areas of fisheries management where it is important to have information on the habitat requirements of fish. These are:

- enhancement, where fisheries improvement schemes such as stocking or habitat improvement require information on the suitability of habitat for the target species;

- conservation, where the value of sites can be graded or classified, and;
- impact assessment, where the consequences of past or future decisions on fish abundance can be measured against a previously determined baseline.

4.7.1 The variation in habitat requirements by life-stage

Different life-stages require specific habitat types in order to survive and three main in-stream habitat divisions have been identified for grayling (Sempeski, Gaudin & Herouin, 1998) (Figure 4.3):

- The main channel; generally the middle of the stream with the fastest flow rate.
- The dead zone; marginal areas with the slowest flow rate.
- The transition zone; between the dead zone and main channel with an intermediate flow rate.

Local habitat use is limited by the ability of the grayling to hold station against the velocity of the water.

The hydrodynamic potential of a fish (or potential for a fish to move through water as determined, for example, by shape) is very important for the colonisation of new habitats. A shift from the dead zone, to the transition, and then to the main channel corresponds to an increase in the current velocity and potentially an increase in drag on the body of a fish (Sagnes, Gaudin & Statzner, 1997). During the development of juvenile grayling, changes occur in the shape of the fish and these are reflected in the position the fish occupies in a riverine habitat. That is, development produces a body shape which reduces drag and allows the fish to move into areas of higher exposure and velocity (Sagnes *et al.*, 1997).

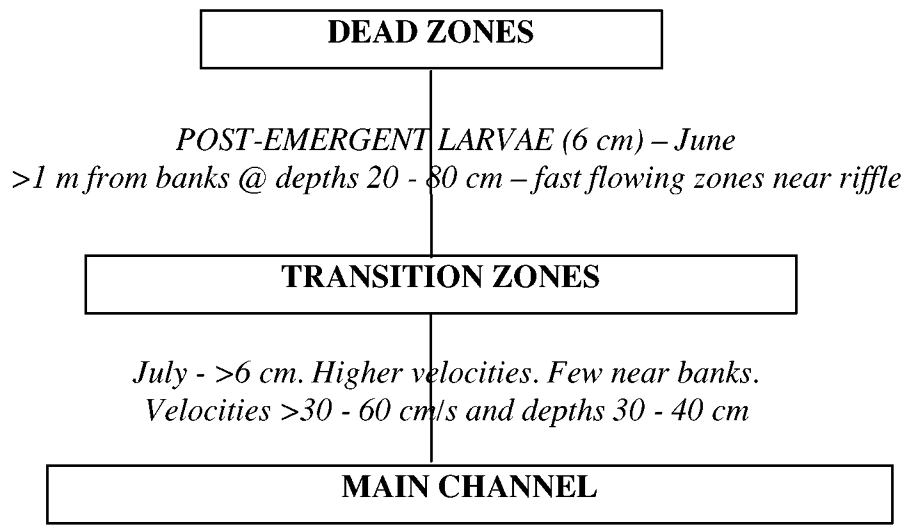

Figure 4.3 Shift in Habitat Type with Different Life-Stages of grayling (Bardonnet, Gaudin & Persat, 1991)

4.7.2 Habitat use at a geographical scale

Features associated with the geological scale include catchment-wide variables such as geology, altitude, topography and climate. In general, these are beyond direct management by man.

Huet (1959) described rivers according to the type of physical, chemical and biological qualities associated with suitable habitat conditions for different adult fish species as shown in Table 4.7.

Table 4.7 The species zonation of rivers according to habitat type (Huet, 1959)

Zone	Definition
Trout	Steep, upland streams; water cool and well oxygenated; riverbed of rock, boulder or pebbles.
Grayling	Further downstream, river wider, water cool and well oxygenated gentle slope. Riffles and rapids separated by pools and runs.
Barbel	Further downstream, river wider, slight incline, riverbed is sandy/muddy silt. Water warmer and less well oxygenated.
Bream	Most downstream species, river widest, slight incline, riverbed is fine silt. Water warmer and less well oxygenated.

The grayling zone is characterised by rivers and larger, more rapidly flowing streams. The gradient is usually less than that of trout waters with riffles and rapids being separated by pools. Trout and grayling inhabit the more rapid stretches whereas the lentic waters in between are occupied by cyprinids such as barbel and chub. The gradient in the grayling zone is 5.7 m km^{-1} (Huet, 1959).

Longitudinal age segregation has been noted in Arctic grayling, with adults dominating the upper reaches of rivers and juveniles the lower reaches (Hughes, 1992). He found that annual emigration between different aged areas was up to 24% for downstream reaches and conversely 51% immigration was observed to upstream reaches; reinforcing the idea that fish move upstream as they mature (Hughes, 1998). It is not known whether this pattern occurs in European grayling populations.

4.7.3 Habitat use at the macro-habitat scale

The macro-habitat scale is associated with characteristics of individual sites or reaches along the length of the river, such as channel shape and the riparian zone. This is the scale at which most habitat management takes place. Unfortunately, it is also the area where the least amount of information is available, much of which is contradictory.

Spawning

Some authors (Hobbs, 1937; Stuart, 1953) state that site selection for spawning differs from trout and salmon, which often locate redds towards the downstream end of pools whereas in grayling, spawning often takes place at the upstream end of a pool (Fabricius and Gustafson, 1955). Others, Ibbotson (observation) found grayling in English chalk streams also preferred the downstream end of pools as sites for depositing eggs.

Larvae

When larvae first emerge, they are relatively weak swimmers and tend to avoid habitats with steep banks or great depths (Bardonnet *et al.*, 1991). They must learn quickly to locate food as the yolk sac is almost consumed and the oesophageal plug may not yet be removed, inhibiting feeding particularly if they are unable to fill their swim bladder (Bardonnet *et al.*, 1993). The larvae are also in a comparatively exposed habitat. It is, thus, the dead zones which provide a vital nursery habitat for fry in the first few weeks post-emergence as they reduce energy costs by minimising swimming activity and favouring the capture of suspended food particles (Sempeski and Gaudin, 1995b; Sempeski *et al.*, 1998). Such zones often contain high levels of vegetation that aids predator avoidance (Sempeski *et al.*, 1998). In addition, areas of high flow could flush larval stages into areas where food is sparse, or off-line pools which are only accessible during floods (Clark, 1992). Finally the dead zone, being an area of low flow, reduces turbidity increasing larval development by improving feeding efficiency (Clark, 1992).

Sempeski *et al.* (1998) have shown that larval grayling are sensitive to the three-dimensional shape of the dead zone and that this influences their choice of such habitats. During the day, larvae preferred zones with the greatest depth (displaying the maximum density of prey), whilst during the night they preferred zones with the flattest bottom (and therefore low bottom velocity).

Adults

In the River Dee grayling are generally found in areas with a good sequence of pool, riffle, glide and run (Woolland, 1986a). However, they are also extremely abundant in channels that have been heavily managed for flood relief. Examples of this include the River Tern (Midlands Region) where fifty fish introduced in 1979, have resulted in a large population (Woolland, pers. comm.). Ibbotson (1993) found the highest densities of grayling in chalk streams occurred in wide, rectangular, straight channels.

In an attempt to produce a Habitat Quality Index for grayling in chalk streams, Ibbotson (1993) found a negative correlation between grayling density and percentage ‘in-stream’ macrophyte cover at 67 chalk stream sites. Half the variation in grayling density could be explained by the standing crop of weed during the summer ($R^2 = 54.7\%$, $p < 0.001$). It was not clear why grayling should apparently avoid areas with large amounts of 'in-stream' cover. Hellawell (1971), established that grayling obtained food predominantly from the river bed, including insect larvae, crustacea, and molluscs and Ibbotson (observation) found that substrate material up to gravel size was ingested by grayling. Hellawell (1971) suggested that the grayling's ventrally situated mouth appears to be an adaptation to feeding on the substrate. Dense growths of rooted vegetation may interfere with this feeding behaviour, thus reducing the available feeding area (Ibbotson, 1993).

In some rivers, riparian as well as in-channel habitat plays an important role in determining the abundance of grayling (Environment Agency, 1995b). Where land is improved for pasture and is grazed, livestock can increase erosion of the riverbank if unfenced and limit the growth of marginal aquatic habitats essential to juvenile grayling and their invertebrate prey (Environment Agency, 1995b).

4.7.4 Habitat use at the micro-habitat scale

The micro-habitat scale relates to measuring the attributes of the so called 'focal point' or observed position of the fish. These are the type of data that are used in the Physical Habitat Simulation model (PHABSIM), but are not generally used in habitat management. PHABSIM quantifies the amount of potential habitat available for target organisms, in a given stream reach, for a variety of discharges (Bovee, 1982). Large amounts of data describing the focal point have been collected for Arctic grayling (Hubert *et al.*, 1985). However, these data have not been collected for grayling in the UK and only infrequently throughout Europe. Where grayling have been the target species of a PHABSIM study on the River Wharfe (Environment Agency, 1999b), Habitat Suitability Indices had to be developed from expert opinion rather than empirical data. Even these were difficult to develop because there was so little information on habitat use by grayling (Maddock, pers. comm.).

Spawning

Ibbotson (unpublished) found that grayling preferred to spawn in substrates with diameters ranging from 2 to 8 cm (Figure 4.4), such as coarse gravel.

This is generally in agreement with data from the River Indalsalven in Sweden, where grayling eggs were found in substrate which consisted predominantly of gravel (Gonczi, 1989) (Table 4.8).

Sempeski and Gaudin (1995c) have suggested a predominance of fine and coarse gravel with fine pebble and fine gravel adjacent to the spawning site of grayling, very similar to that also described by Darchambeau and Poncin (1997).

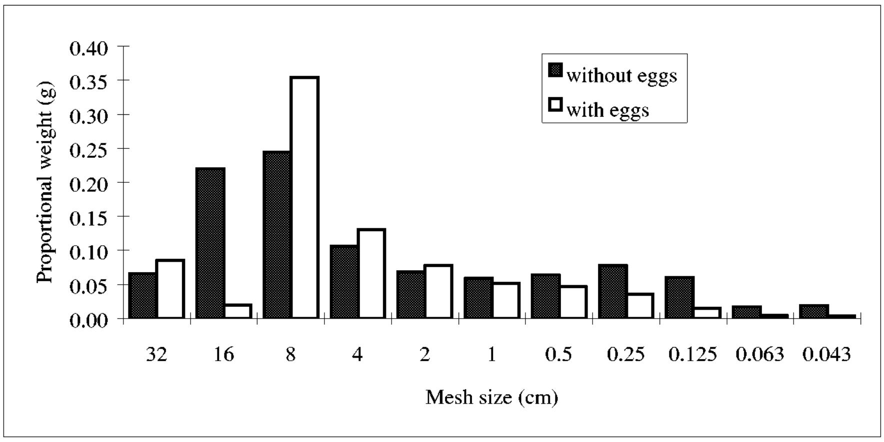

Figure 4.4 The proportional weight of different substrate diameters with and without eggs of grayling recorded from the Wylye at Knook in March 1992 (Ibbotson, unpublished)

Table 4.8 The size (cm) and percentage (%) composition of bottom substrate on the spawning ground of *T.thymallus* in the River Indalsalven, Sweden (Gonczi, 1989)

Substrate	Substrate size (cm)	Percentage (%)
Sand	No figures given	5 - 15
Gravel	<2	40 - 70
Small stones	2 - 10	20 - 30
Bigger stones	>10	Few

Ibbotson (unpublished) observed grayling at two southern English chalk stream sites and found they spawned at mean column velocities between 0.25 and 0.82 m s^{-1}, with a modal mean column velocity of 0.4–0.5 m s^{-1}. Other authors found spawning at velocities, ranging from 0.2-0.9 m s^{-1} (Gonczi, 1989). Sempeski and Gaudin (1995c) (Table 4.9) identified velocities between 0.3 and 0.5 m s^{-1}. Resting pools are also essential at any site and the mean current velocity was found to be much lower (0.14 m s^{-1}) in these pools (Sempeski and Gaudin, 1995c).

Table 4.9 Velocities (m s^{-1}) measured at spawning sites at the Rivers Pollon and Suran, France (Sempeski and Gaudin, 1995c)

Position	Pollon (m s^{-1})	Suran (m s^{-1})
Mean velocity	0.478	0.477
Mean bottom velocity	0.372	0.337

Depth is an important consideration during spawning. The water must be deep enough to reduce the chance of the eggs being de-watered and exposed to lethally high temperatures (Beauchamp, 1990). Spawning occurred at depths ranging from 15 to 74 cm, with a modal depth of 30-40 cm in two southern English chalk streams (Ibbotson, unpublished). Similar depths (20-55 cm) were measured at spawning sites in Belgium (Darchambeau and Poncin, 1997) and Sweden (36 cm) (Gonczi, 1989). Although, water depth at spawning sites may vary from year to year and from site to site (Sempeski and Gaudin, 1995c) (Table 4.10).

Table 4.10 The depths (cm) selected by *T.thymallus* as spawning sites on the Rivers Pollon and the Suran, France (Sempeski and Gaudin, 1995c)

Selection	Depth (cm)	
	Pollon	Suran
Strongly selected	10 - 40	20 - 30
Avoided	<10 or >60	<10 or >40

Larvae

The mean current channel velocity inhabited by larval stages is 0.1 m s^{-1} and the bottom velocity preferred is approximately 0.05 m s^{-1}, above fine substrates of silt and sand (Table 4.11) (Sempeski and Gaudin, 1995c; Greenberg, 1999). The preferred water velocity of post-emergents is between three and nine body lengths s^{-1} (Scott, 1985).

Table 4.11 The river bed substrate type favoured by different sized grayling (Greenberg, Svendsen & Harby, 1996)

Fish size (cm)	Substrate type
2 – 8	Sand/silt/gravel
9 – 18	Neutral
19 – 50	Preference for cobbles and boulders

The preferred depth for larval grayling has been found to range from 105-180 cm (Table 4.12) (Sempeski and Gaudin, 1995b; Greenberg *et al.*, 1996).

Table 4.12 The water depth (cm) favoured by different sizes of grayling (cm) (Greenberg *et al.*, 1996)

Fish size (cm)	Depth (cm)
2 – 8	105 - 180
9 – 18	45 - 90
19 - 50	75 - 165

Juveniles

As the post-emergent grayling fry grow (2-2.8 cm) (Scott, 1985) they move one metre or more away from the bank and to depths of between 0.2 and 0.8 m. Sempeski and Gaudin (1995b) state a preferred depth of 55 cm.

These zones have a higher velocity, tending to be riffle and mid-channel areas (Bardonnet *et al.*, 1991). Larger fry will move to the transition zone, allowing the fish to observe and catch drifting prey in both the dead zone and main channel whilst remaining protected from strong currents, minimising energy consumption (Bardonnet *et al.*, 1991; Sempeski *et al.*, 1998). Sempeski and Gaudin (1995a) quote a preferred mean water velocity (0.25-0.55 m s^{-1}) and bottom water velocity (0.25-0.35 m s^{-1}) for juvenile grayling in the Pollon, France.

The preferred substrate size of juveniles ranges from sand to pebble (Sempeski and Gaudin, 1995a; Mallet *et al.*, 2000).

Adults

Adult grayling prefer water velocities of 0.2-0.5 m s^{-1} (Greenberg *et al.*, 1996), in the deepest water (Crofts, 1994) and above substrates ranging from sand to pebble (Mallet *et al.*, 2000).

There is a trend toward a preference for deep water with increasing age in the River Ain, France (Mallet *et al.*, 2000). Optimal ranges were; 50-60 cm, 80-120 cm and 100-140 cm for 0+, 1+ and adult grayling (>2+) respectively. Fish of similar ages have been observed shoaling together and feeding in their 'typical' habitats (i.e. older fish in the deeper, slow regions; younger fish in shallow areas) (Dahl, 1962).

4.7.5 Diel shifts in habitat use

The distribution of grayling varies between night and day. As juveniles develop, they migrate during the day from the dead zone to the main channel. Once the grayling have attained 6 cm or more in length, they leave the marginal habitats (Bardonnet and Gaudin, 1991).

At night, all size classes of grayling were observed in the dead zone (Bardonnet and Gaudin, 1991). This change in habitat is characterised by a shift in depth from deep to shallow water at night for all size classes (Figs. 4.5 -4.7) (Bardonnet and Gaudin, 1991).

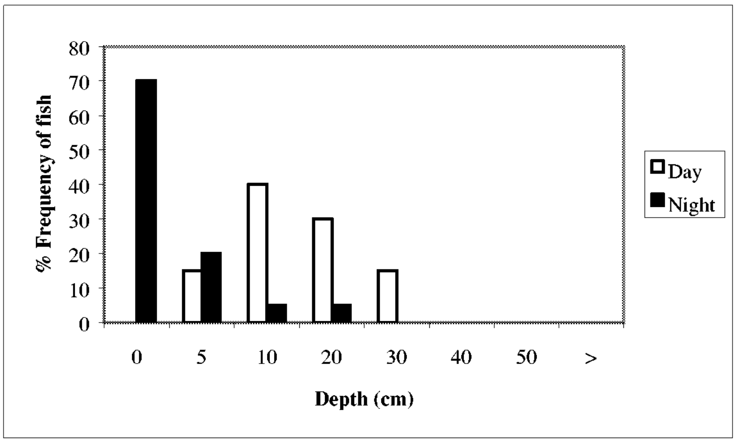

Figure 4.5 Day/night water depth use by grayling in Group 1 (1.5-2 cm) (N_{day}: 291, N_{night}: 182) (From Bardonnet and Gaudin, 1991)

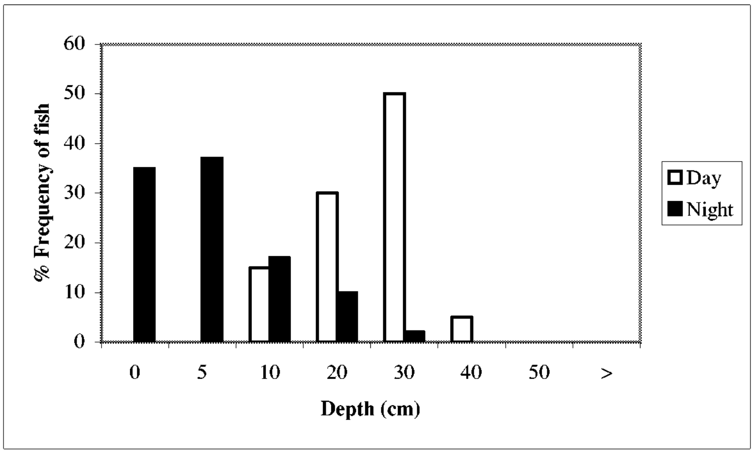

Figure 4.6 Day/night water depth use by grayling in Group 2 (2-4 cm) (N_{day}: 305, N_{night}: 225) (From Bardonnet and Gaudin, 1991)

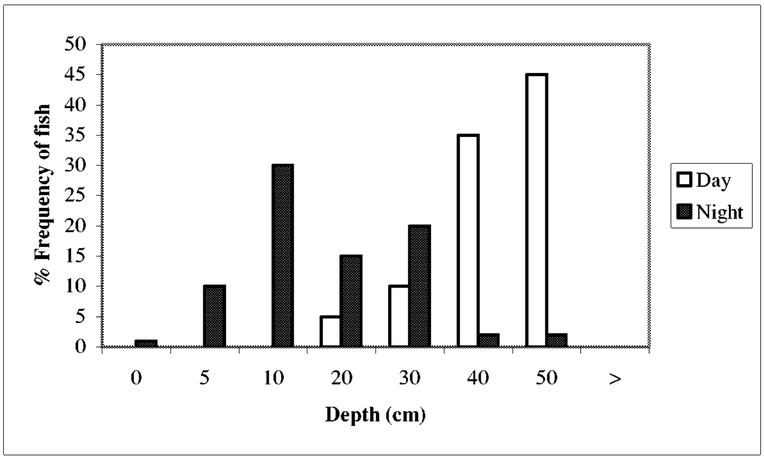

Figure 4.7 Day/night water depth use by grayling in Group 3 (>4 cm) (N_{day}: 127, N_{night}: 100) (From Bardonnet and Gaudin, 1991)

4.7.6 Habitat degradation

Channelisation

Both trout and grayling utilised higher water velocity microhabitats in channelised streams than in restored ones (Maki-Petays, Vehanen & Muotka, in press). Grayling were less susceptible to downstream displacement in channelised streams during both summer and winter than trout. Grayling were displaced during winter only. Both species became more aggregated during the winter. The spatial pattern of grayling was unaffected by channelisation, however they were more contiguously distributed in high flows. The habitat preference curves indicated that habitat requirements were narrowest in winter and the most important habitat factor for grayling was availability of flow refuges, although this should not be surprising in a hydro-peaking channel.

In a large Finnish river suffering from hydro-peaking radio-tagged grayling preferentially used an area of channel restored with small islands, reefs and cobble and boulder structures (Vehanen *et al.*, in press).

Drainage and dredging

Habitats are constantly lost from small tributaries by drainage works. Dredging removes substrate essential for young fry and juveniles as well as invertebrate prey. This leads to destabilisation of bottom substrate, possibly dislodging very fine particulate matter, which subsequently smothers the gravel beds of spawning grayling (Persat, 1996).

An example of the impact drainage has on grayling can be seen in the tributaries of the Arve River in France. Grayling formerly used these areas as spawning grounds as they were protected from snowmelt floods (Persat, 1996). However, the main river was dredged to build a highway and exploit gravel, producing huge erosional impacts. In addition, now only impassable waterfalls connect the original river with its tributaries, impeding the passage of grayling spawners (Persat, 1996).

An example of drainage impacts in the UK can be taken from Yorkshire, where from the 1980s onwards, the grayling population in the River Wharfe above Linton falls has declined and recently none have been recorded (Axford, pers. comm.). It is thought that this could be due to the increased magnitude of spates resulting from an increase in moorland gripping. This process involves digging drainage channels and produces increased run-off from the moor directly into the rivers (Axford, pers. comm.).

4.7.7 Temperature

The lower critical temperature of grayling is 4°C and the upper critical temperature ranges between 18 and 25°C (Table 4.13) (LaPerriere and Carlson, 1973; Woolland, 1986a, Crisp, 1996; Baars, 1999). After 10 days acclimation to 20°C, the 24 hour lethal temperature was 26.2°C (Kraiem and Pattee, 1980). Lethal temperatures were directly related to the acclimation temperature (Kraiem and Duvernay, 1981).

Table 4.13 The suggested optimum, upper and lower critical temperatures (°C) for grayling in Europe (Crisp, 1996)

Range	Temperature (°C)
Lower critical	0 - 4
Upper critical	>18
Optimum	18

Several Agency reports cite instances where high temperatures, usually occurring during periods of drought, have resulted in declines of grayling populations. These include the River Chater (Environment Agency, 1996a), River Ise (Environment Agency, 1995b), River Witham (Environment Agency, 1991) in Anglian Region and River Hull in North East Region. In Midlands Region annual catches of grayling on the Upper Teme declined from 700 in the mid 1970s, to 50 in the mid 1980s for the same reason (Woolland, unpublished).

4.7.8 Chemical conditions

Land-use and its associated organic inputs to rivers and streams, is critical in determining the physicochemical parameters and biota of a system. The water chemistry and its quality are of prime importance for biodiversity in aquatic ecosystems. Failure to meet the sometimes quite restricted chemical requirements of a species results in decline or even complete eradication. Such problems have become very common in recent years with increased industrialisation, agriculture and changing land-use.

Generally, water quality requirements of grayling are similar to brown trout; cool, well oxygenated waters (Woolland, 1986a). Grayling can be found in waters ranging from very low productivity (e.g. the Bayern Forest, Germany) to high productivity such as the Alps (Baars, 1999).

The optimum pH of water containing grayling is around pH 7 (Baars, 1999) with a pH of 6.5-9.0 being the optimal range for fish generally. Outside this range fish, including grayling, become highly susceptible to the toxic effects of poisons (Alabaster and Lloyd, 1982). In

aluminium-poor water at pH 5.0, aluminium is not acutely toxic to grayling although they are more sensitive to aluminium toxicity and acidity than trout (Poleo *et al*., 1997).
Grayling have a minimum oxygen requirement of 5-7 mg l^{-1} (Duvernay, 1975) at temperatures of 18-20°C. Below 4 mg l^{-1} oxygen at temperatures above 25°C all grayling die (Duvernay, 1975). Kraiem and Pattee (1980) found that the 24-hour lower lethal oxygen requirement was 3.6 mg l^{-1}. Larval grayling are recorded as being able to tolerate concentrations ranging between 1.4 mg l^{-1} at 8°C and 1.8 mg l^{-1} at 20°C (Feldmuth and Eriksen, 1978). Successful embryonic and larval development can occur when interstitial oxygen concentrations are at 10 mg l^{-1} (Zeh and Donni, 1994).

4.7.9 Pollution

Although the environmental requirements are broader for grayling than brown trout, Woolland (1986a) has stated that grayling 'succumb' to pollution and higher temperatures more rapidly than trout. Jervis (1999) suggests from provisional results that grayling are less able to detoxify organic pyrethroids (a constituent of sheep-dip) than trout, for two reasons. Firstly the organ of detoxification, the liver, is smaller in grayling as a percentage of the total body weight, than that of trout or coarse fish. Secondly some detoxifying enzymes are less concentrated in grayling than trout and coarse fish (Jervis, 1999). Hence grayling are far less tolerant of high levels of organic pollutants than trout.

Although it has been documented that water pollution by organochlorines, organomercury, acidification, PCBs, DDEs, has resulted in the decline of grayling populations in Europe (Mackay, 1970; Poleo *et al*., 1997), there are not many case studies of pollution events involving grayling. The Douglas Water in Scotland was polluted with industrial detergent in 1968, resulting in a large fish kill including grayling. This was also the case on the nearby River Gryfe, adjacent to the outflow (Mackay, 1970). Tannery wastes selectively eliminated juvenile grayling before adults, by increasing suspended solids, free sulphides and the BOD (Mackay, 1970). Rivers in Serbia suffered severe pollution in the late 1960s from industrial and domestic wastes, erosion, dam construction and intensive over-fishing which resulted in the decline or disappearance of grayling (Jankovic, 1978).

4.8 Flow Requirements

Flow in rivers is the main control mechanism for all the physicochemical conditions experienced by the biota. The quantity of water determines the dilution factor for pollutants, the buffering capacity against ambient temperatures, the quantity of habitat and interacts with the structure of the channel to determine the physical forces experienced by the organisms (Gordon, McMahon and Finlayson, 1992).

River flows are measured on scales of timing, frequency, magnitude and duration. Any prescribed management of river flows must explicitly describe the River Flow Objectives (RFOs) in these terms.

This will be an important aspect of prescribing flows for grayling populations. Timing is crucial so that the flow conditions are appropriate for each of the grayling life stages (egg through to adult). Frequency is sometimes important to eliciting certain behaviours. For example, other adult migratory salmonids migrate upstream in response to freshets. Often, more than one freshet is required to move the adults all the way from the estuary to holding areas or spawning grounds. Magnitude has obvious effects close to its extremes, that is, from no flow to serious scouring floods. Abilities to survive conditions by any life stage are often a function of the conditions themselves and their duration. Temperature tolerance is a good example of this.

Unfortunately the information that enables good prediction of the impacts of flow regimes on grayling is not well known. Many UK regulated rivers contain grayling populations and often these rivers contain salmon and trout fisheries as well. General regulation rarely considers the impacts on the life history of grayling, and as with habitat management, there is sometimes a misconception that flow management for trout or salmon will be appropriate for grayling. This is unlikely to be the case particularly given their different spawning seasons and habits.

Grayling are rarely considered where minimum ecological flows are prescribed in spite of the significant number of cases where they dominate the affected fish communities. Trout or salmon are more frequently the target organisms for setting flow levels, even though they may be at the edge of their natural range.

4.8.1 Abstraction and low flows

Reducing natural flows is equivalent to reducing habitat quantity. Severe reduction in flows will also alter the habitat quality. Without the velocity capable of shifting fine sediments downstream, silt can permeate the gravels. This will affect the ability of grayling to reproduce successfully by reducing the oxygen concentration in the substrate where the eggs are laid. In summer months a decreased quantity of water in the channel reduces buffering ability against ambient temperatures. This can cause temperature stress, particularly where the proportion of flow consisting of cooler ground water falls through abstraction.

There are some examples where low flows have been cited as causing declines in grayling populations. In the River Ise the population first began to show signs of decline in the late 1980s. This was attributed to a combination of hot, dry summers and mild, dry winters producing a reduction in water flows (Environment Agency, 1995b). Catastrophic declines in the angling catches of grayling in upper reaches of the River Teme appeared to coincide with the drought of 1976. Continuing low numbers are thought to result from the inability of the population downstream to re-colonise these regions due to the presence of barriers to migration (Woolland pers comm). A similar situation has occurred in the River Wharfe in some reaches (Hopkins, pers. comm.). In this river, grayling have been seen making use of pools below weirs e.g. at Boston Spa as refuges from a lack of deep water in other reaches. This highlights the value of deep-water habitats for refuge during periods of drought.

By comparison, several years of reduced flows and drought in southern English chalk streams appeared to have little obvious effect on the survival and size of grayling populations (Ibbotson, observation). This may result from the presence of cool groundwater even at periods of low flows. Conversely, high flows produce a decrease in temperature which consequently, may reduce growth and survival of larvae (Walker, 1983). On the Lambourn at Bagnor, there was a negative correlation between summer discharge rates (April – October) and densities of 0+ grayling (Berrie, unpublished). High discharge favoured high densities of 1+ fish. It was suggested that this was due to the increased incidence of invertebrate prey. Discharges did not appear to have any effect on 2+ and 3+ individuals.

High flows during periods when grayling eggs are present could dislodge eggs which are usually only buried to a maximum depth of 5 cm (Fabricius and Gustafson, 1955). Ibbotson (unpublished) observed that the number of grayling eggs found in the gravel at one site on the River Wylye declined sharply following a minor freshet. In that case it is not known whether it had a serious impact at the population level. There is an ongoing study on the River Wylye where annual fluctuations in the grayling population are being monitored and related to river flow. The long-term nature of this project precludes the drawing of conclusions at this stage (Ibbotson, 1999).

The water abstraction process can have local impacts by drawing fish, particularly juveniles, into the pumps and destroying them (Magee, 1992). To mitigate this, legislation from the Environment Act (1995) regarding the screening of intakes has been enforced in 2000. Physical (visual, hydraulic or tactile cues) or behavioural screens (based on sensory cues using visual, hydraulic, acoustic or electrical cues) are recommended to divert fish from intake pipes. Recommendations on the type of screens are available but this is not thought to be a serious problem for grayling, although information on swimming ability of juvenile grayling may aid screen design.

4.8.2 Hydrological regime and regulation

Early water management regimes impacted upon grayling populations downstream of reservoirs (Environment Agency, 1997a). The minimum compensation flows for downstream users were timed to coincide with the requirements of industrialists, normally at the end of the day. Occasionally, the river below was allowed to run dry especially during periods of drought, however this was addressed by the middle of the 19th century.

There is evidence to suggest that regulation of water regimes can have beneficial effects on grayling. The susceptibility of the eggs to washout and the poor swimming ability of the juveniles means that grayling populations will not thrive under conditions of hydro-peaking (Valentin *et al.*, 1994). Water abstraction for nuclear reactors and hydro-electric power stations can also affect downstream flow by causing it to be more irregular (Northcote, 1995). On the River Wharfe, moorland gripping (increased drainage) has been implicated in changes to the hydrological regime and declining grayling populations. These fluctuating levels can increase the risk of fry becoming stranded and riverbed straightening can result in severe erosion of the bed, again limiting grayling habitat as well as invertebrate prey (Woolland, 1972). Juvenile grayling are susceptible to being washed downstream during spates. During periods of low flow (<0.3 m s^{-1}), fish remained at the outer margins of the main channel, however when the flow was increased (simulating spate conditions at <0.55 m s^{-1}) fish rapidly swam to the nearest refuge zone to avoid being swept downstream (Valentin *et al.*, 1994).

Regulation resulting from the construction of water storage reservoirs tends to remove the extremes of flow, creating a more stable environment. This reduces the effect of flooding, preventing the washing out of eggs and increasing the productivity of invertebrates. When droughts occur, water levels are stabilised by releases from the storage reservoirs aiding temperature regulation, maintaining the presence of marginal habitat for juveniles and reducing the chances of juvenile fish being trapped in pockets of water at the margins of channels. The quantity of habitat increases due to higher minimum flows (Woolland, 1986a).

A good example that highlights the benefit of regulation has occurred on the River Dee through regulated releases from Llyn Tegid (or Bala Lake), among others. Woolland (1972) studied the effects of regulation on grayling using data collected between 1950 and 1970. Over that period the density index (net catches) nearly quadrupled as the potential grayling habitat for the early life stages increased (Woolland, 1972, Environment Agency, 1998b).

4.8.3 Flow requirements for grayling

A general summary of what is known about the flow requirements of grayling is given in Table 4.14. There is evidence that stable conditions are advantageous, particularly during the early life-stages.

Table 4.14 Flows conditions required by grayling at different life stages

Life Stage	Time of year	Flow Conditions
Spawning Egg Alevin	February – May (depending on location)	Stable Medium to high
Juvenile	May – June	Stable Medium High enough to provide marginal habitat for juveniles
Adult	January – December	Medium High enough to ensure summer temperatures do not exceed 18°C for long periods

There is a clear need for strategic science to provide information, which will help develop greater guidance for setting River Flow Objectives. Currently there are a number of tools for doing this, including hydrological look up indices and models such as PHABSIM. None of these are predictive at the population level. There are more recent moves to develop models based on the ecological and biological requirements of fish, using energetic gain and individual based behavioural models. It will be several years before these are sufficiently developed to replace the current hydrological models.

The Kielder Water Transfer Scheme (KWTS) which has been operational since 1984 is key to water resource management in Northeast England. The reservoir regulates water in the North Tyne and Tyne rivers and supports abstractions for the transfer system conveying water to recipient locations in the Derwent, Wear and Tees catchments (Gibbins and Heslop, 1998). During particularly dry summers, water has been used to augment flows in the Derwent and Wear. Using PHABSIM simulations, the benefits of augmentation in avoiding the habitat loss of grayling and other salmonids in the upper regions of the Wear and of mine water releases in the lower reaches were highlighted. Gibbins and Heslop (1998) also comment that alternative methods of augmentation should be reviewed in order to alleviate further the effects of low summer flows and habitat loss.

4.9 Disease and Parasites

Disease-causing organisms and parasites are natural to the ecology and important to the management of any fish species in the wild. Although work on the diseases and parasites of grayling is increasing, information remains fragmented and reports of losses in the wild are scarce. Magee (1993) documented losses of grayling in Yorkshire due to a fungal disease in

1967. Most studies to date have been conducted in the Black Sea, White Sea and Barents Sea drainage basins (Mitenev and Shyl'man, 1985) with few references to grayling in the UK. Work here is limited and has only briefly detailed the parasite fauna of grayling in particular rivers or catchments, including the Lugg (Davies, 1967) the Dee (Chubb, 1977), and the Test and Itchen (Whitfield, 1999).

The grayling may act as a host to many species of parasite, bacteria, virus and fungi. However, the occurrence of clinical disease, and therefore mortality from these potential pathogens, is determined by a complex balance between the fish 'host' and its environment, and is not easily predicted. In view of limited records of problems in the wild, the potential impact of many disease-causing organisms on grayling remains speculative. However, it has been well documented that sub-optimal conditions such as poor water quality, high stock densities and inadequate nutrition, increase the vulnerability of fish to parasites and disease. Grayling may be particularly intolerant to such conditions, Laffineur, Delvingt & Lamotte (1992) describe them in aquaculture as having great sensitivity and fragility.

Grayling are known to be hosts to many parasite species (Table 4.15). A revised list of the parasites of freshwater fish in the UK, currently under preparation, recorded 27 species from *T.thymallus* (Kirk, pers. comm.). This is likely to be a modest estimate, increased significantly by parasites of low host specificity, but lacking specific references to grayling as a host. Mitenev and Shyl'man (1985) recorded 69 parasite species throughout the entire range of *T.thymallus*. The majority of these parasites occupy a wide range of fish hosts. However, the flukes *Gyrodactylus thymalli* (Mitenev and Shyl'man, 1985; Denham and Long, 1998), and *Tetraonchus borealis* (Davies, 1967), the crustacean *Salminicola thymalli* (Kabata, 1979; Mitenev and Shyl'man, 1985) and the tapeworm *Proteocephalus thymalli* (Mitenev and Shyl'man, 1985), appear to be specific to grayling. It should be noted that the acanthocephalan parasite *Pomphorhynchus laevis* is presently a Category 2 parasite (Environment Agency, 1999c), and its movement within the England and Wales is restricted under Section 30 of the Salmon and Freshwater Fisheries Act 1975.

Wild grayling will naturally harbour low level parasitic infections but their direct impact on the host is usually minimal. There are no records of the regulation of grayling populations in the wild by parasites (Northcote, 1995). Detailed reports of parasite-induced pathology are also scarce. However, a number of species that may infect grayling have been shown to cause significant pathology to other fish hosts. Perhaps the best documented of these include the freshwater fish louse *Argulus* sp. (Shimura and Inoue, 1984), the acanthocephalan *Pomphorhynchus laevis* (Wanstall, Robotham & Thomas, 1986), and larval tapeworms of the genus *Diphyllobothrium* (Henricson, 1980; Rahkonen *et al.*, 1996). In addition, Proliferative Kidney Disease (PKD), an important disease of farmed salmonids caused by the myxosporidian parasite *Tetracapsula bryosalmonae* (Canning *et al.*, 1999), has been recorded in both farmed and wild grayling (Bruno and Poppe, 1996).

Table 4.15 Checklist of parasites of *T. thymallus*. (*: Kirk, pers. comm.; ** Mitenev and Shyl'man, 1985; *** Moravec, 1994; **** Canning *et al.*, 1999)

Phylum/Class	Parasites
Phylum Protozoa	*Tetracapsula bryosalmonae***** *Chloromyxun thymalli* ** *Myxosoma cerebralis*** *Myxobolus neurobius*** *Myxobolus albovae*** *Myxobolus mulleri*** *Apiosoma spp.*** *Trichodina domerguei*** *Trichophrya piscium***
Class Digenea	*Allocreadium transversale** *Azygia lucii*** *Bunodera luciopercae** *Crepidostomum farionis** *Crepidostomum metoecus** *Crowcrocoecum proavitum*** *Crowcrocoecum testiobliquum*** *Crowcrocoecum wisniewski*** *Diplostomum spp*** *D.spathecium*** *D.indistinctum*** *D.commutatum*** *Ichthyocotylurus erraticus** *Phyllodistomum conostomum*** *Phyllodistomum folium** *Phyllodistomum simile*** *Phyllodistomum megalorchis*** *Phyllodistomum saviniengus*** *Pseudochaetosoma salmonicola*** *Tetracotyle intermedia*** *Tetracotyle variegata*** *Tylodelphys clavata***
Class Cestoda	*Cyathocephalus truncatus** *Diphyllobothrium dendriticum** *Diphyllobothrium ditremum** *Proteocephalus thymalli* ** *Triaenophorus nodulosus***
Class Acanthocephala	*Acanthocephalus anguillae** *Acanthocephalus clavula** *Acanthocephalus lucii** *Corynosoma strumosum*** *Corynosoma semerme*** *Echinorhynchus borealis*** *Echinorhynchus salmonis*** *Echinorhynchus truttae** *Neoechinorhynchus rutili** *Pomphorhynchus laevis**

Phylum/Class	Parasites
Class Nematoda	*Agamospirura sp*** *Camallanus lacustris*** *Contracaecum osculatum**** *Cottocomephoronema problematica*** *Cucullanus truttae** *Cystidicola farionis** *Cystidicoloides tenuissima*** *Cystidicoloides ephemeridarum**** *Pseudocapillaria salvelini**** *Raphidascaris acus*** *Rhabdochona denudata*** *Schulmanela petruschewskii****
Class Monogenea	*Discocotyle sagittata** *Gyrodactylus thymalii** *Gyrodactylus* sp.** *Tetraonchus borealis**
Class Hirudenea	*Piscicola geometra*** *Acanthobdella peledina***
Class Crustacea	*Argulus coregoni** *Salmincola thymalli**

Grayling may be susceptible to a number of bacterial pathogens and fungal infections. Perhaps the most important of these is the disease furunculosis, caused by the bacterium *Aeromonas salmonicida. A.salmonicida* has been isolated from grayling in many environments including the River Hull, Yorkshire in 1992 (Dolben, pers. comm.) and the River Test, 1999 (Scott, pers. comm.). Ocvirk (1992) described furunculosis as the most important disease to affect farmed grayling production. Carlstein *et al.* (1990) and Carlstein (1997) detailed losses of grayling in intensive culture due to an ulcerative syndrome (ASA) caused by an atypical strain of the bacterium, *Aeromonas salmonicida* var *achromogenes*.

Grayling are also vulnerable to secondary bacterial and fungal infections that usually occur as a result of a primary stressor, such as mechanical damage or poor environmental conditions. These infections are often caused by bacterium of the genera *Aeromonas* and *Pseudomonas*, or by members of the fungal family Saprolegniaceae, which are widespread in all aquatic environments.

Typical symptoms of secondary bacterial infection include haemorrhaging (particularly at the fin bases), lesions and loss of condition. Woolly growths or plaques on the skin of the fish are typical symptoms of fungal disease. Grayling damaged and exhausted from the act of spawning may die as a result of such infections (Scott pers. comm.).

A number of serious diseases exist, that although to date have not been responsible for specific losses in grayling, have been shown experimentally to be of potential importance. Examples of such pathogens include the diseases Viral Haemorrhagic Septicaemia (VHS), Bacterial Kidney Disease (BKD) and the monogenean parasite *Gyrodactylus salaris*, all Category 1 notifiable diseases in the UK under the Diseases of Fish Act 1937. It has been shown in laboratory studies that grayling may be susceptible to and killed by VHS (Wizigmann, Baath & Hoffman, 1980; Meier, Schmitt & Wahli, 1994) as well as acting as reservoir hosts, aiding dissemination of the disease. Grayling may also be susceptible to BKD, caused by the bacterium *Renibacterium salmoninarum* (Kettler, 1987) and act as a host to *Gyrodactylus salaris* (Bakke and Jansen, 1991). However, in absence of any documented records, the potential impact of these diseases on the grayling remains unknown.

Control of disease in the wild is difficult and seldom effective. Unlike under culture conditions, the treatment of infected grayling cannot rely on the use of chemical treatments, their use in the wild being generally considered ineffective, environmentally harmful and often illegal. In such circumstances, management strategies are the only real option. Reducing the movements and stocking of grayling reduces in turn the potential of introducing diseases.

Maintaining optimal conditions reduces the susceptibility of fish to secondary infections. Inadequate nutrition, poor water quality and unsuitable habitat are all parameters that hold the potential to weaken fish and reduce tolerance to disease. Maintaining such conditions for any fish species requires an understanding of specific requirements and balance of many biotic and abiotic factors. Unfavourable changes from the optimum, for example low flow rates, reduced oxygen availability or excessive temperature fluctuations may cause considerable disruption to sensitive fish species. Once ‘stressed’, grayling may become susceptible to pathogens that would otherwise not be a problem.

Parasites exhibiting complex life cycles may be controlled by the indirect manipulation of the intermediate hosts necessary for life cycle completion. This approach however, is seldom easily achieved due to the difficulty of controlling the balance of a wild and dynamic situation.

5. CURRENT AND FUTURE MANAGEMENT

5.1 Introduction

There is no national strategy for the management of grayling in England and Wales. Existing management practices vary widely between Agency regions and no formal guidance is available to Agency fishery managers and officers.

This section brings together, through the use of a questionnaire and visits to individual Agency offices, past and current management practices and makes a number of recommendations for future management.

5.2 Questionnaire

5.2.1 The Agency perception of the most important issues affecting grayling fisheries

Agency fishery officers identified habitat degradation, regulation of water including abstraction, barriers and pollution as the most important issues affecting grayling populations. Interestingly, mechanisms of direct impact on grayling populations, such as deliberate removal and angling pressure, were ranked low (Figure 5.1).

Individual regions ranked the issues affecting grayling populations differently. Water regulation including abstraction was most important in Anglian and Midland regions; barriers in North West Region; habitat degradation in Thames Region and Wales; and pollution in North East Region. Southern and South West regions both ranked transfers as the most important issue (see Project Record).

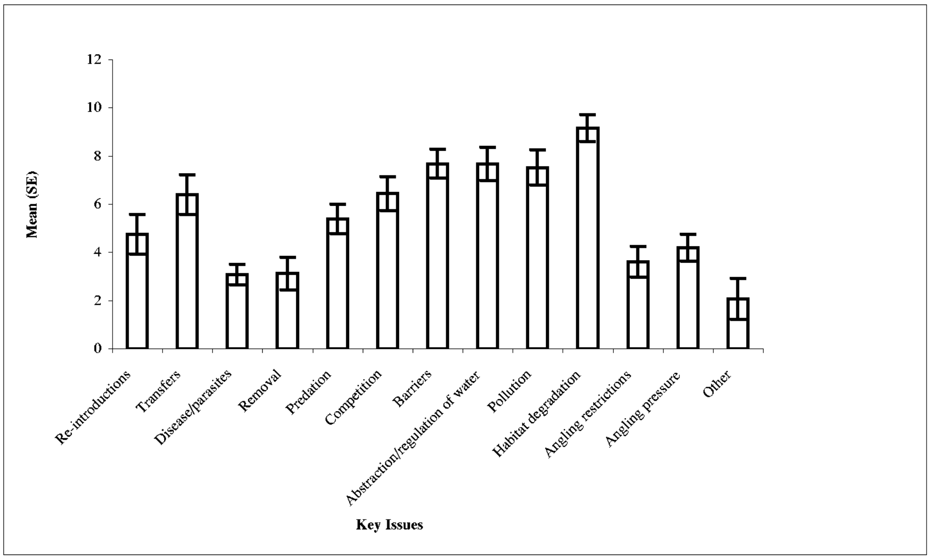

Figure 5.1 The most important issues (mean rank) affecting grayling fisheries as ranked by Agency Fisheries Team Leaders (n=26)

5.2.2 The Grayling Society members' perception of the most important issues affecting grayling fisheries

There were some similarities between the issues thought to affect grayling fisheries by Agency fishery officers and by Grayling Society members. Issues that ranked highly with both were pollution, habitat degradation and regulation of water including abstraction. Whereas Agency fishery officers considered barriers to be an important issue, Grayling Society members ranked this low. Another notable difference was that Grayling Society members considered predation to affect grayling fisheries, whereas this was not ranked very highly by Agency staff (Figure 5.2).

Individual areas ranked the issues affecting grayling populations differently. Pollution was most important in Areas 1, 3, 4, 5, 6, 7, and 8; and regulation of water including abstraction in Areas 2, 9, and 10. Angling restrictions was the highest ranked issue in Area 14 (Wales) (see Project Record).

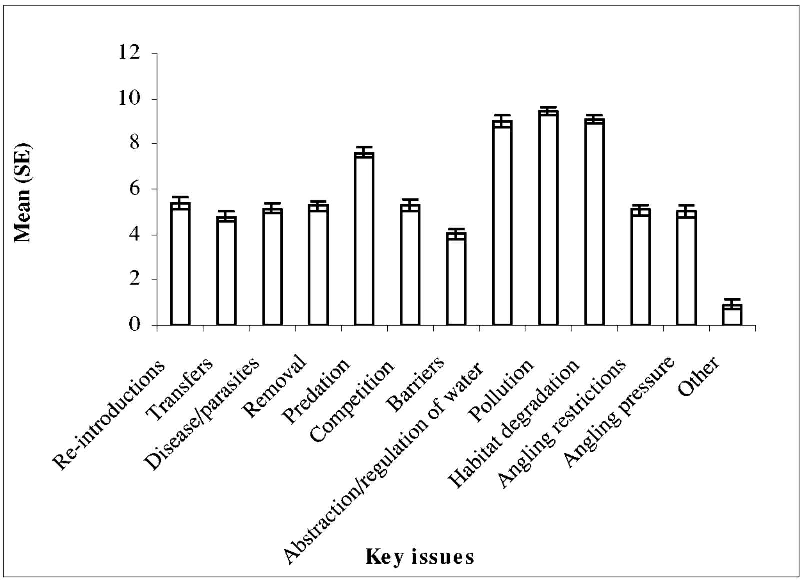

Figure 5.2 The most important issues (mean rank) affecting grayling fisheries as ranked by Grayling Society members (n=196)

5.2.3 Agency requirements for guidance on management practice

The main requirement for guidance on management practice by Agency officers was for habitat management, reflecting the high ranking of habitat degradation as a factor affecting grayling fisheries (Figure 5.3). Other issues with high requirements for management advice included transfers and the asset value of grayling.

Individual regions had their own particular requirements for management advice. Anglian Region's highest priority was for management advice on transfers; Midlands, North East, North West, South West, Thames and Wales regions on habitat management; and Southern Region on monitoring (see Project Record).

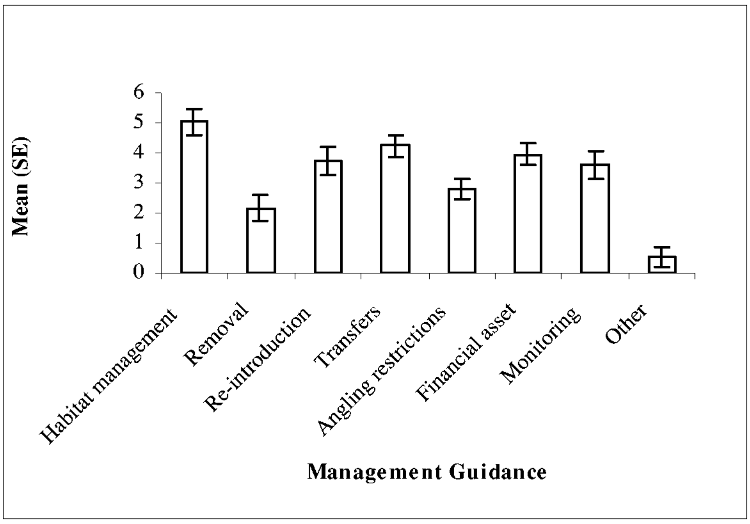

Figure 5.3 Agency requirements (mean rank) for guidance on management practice (n=26)

5.2.4 Grayling Society member requirements for guidance on management practice

As with the Agency fishery officers the main requirement for management advice by Grayling Society members was habitat management. Other issues with high requirements for management advice included monitoring, re-introductions and the asset value of grayling (Figure 5.4).

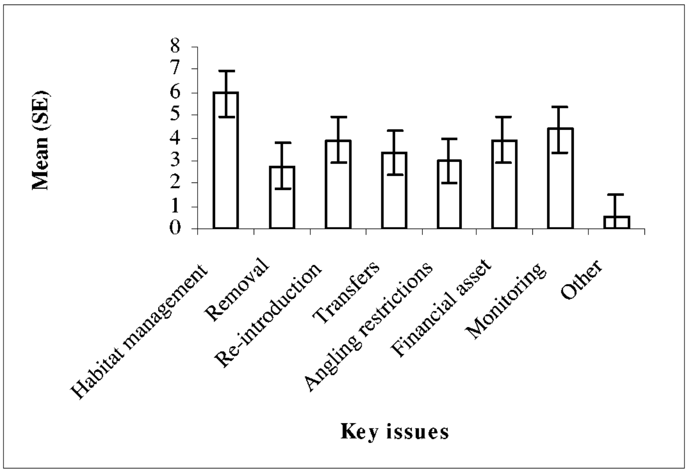

Figure 5.4 Grayling Society members requirements (mean rank) for guidance on management practice (n=196)

All the areas of the Grayling Society had a highest priority for management advice on habitat management apart from Area 14 (Wales) whose highest priority was for management advice on monitoring (see Project Record).

5.3 Habitat Management

Few, if any, instances were identified where habitat has been managed or improved specifically for grayling. Where grayling and habitat management coincided, it invariably occurred where the improvement was targeted specifically at trout. In a few cases, the impacts of the habitat enhancement on existing grayling populations were monitored.

Stabilisation of the river channel at a narrower dimension produced higher water velocities on the River Gwash. This was thought to contribute to higher numbers of grayling by creating cleaner gravel beds for spawning (Environment Agency, 1996e). Similarly occasional narrowing of the river channel on the Malmesbury Avon has resulted in an increase in grayling recruitment, probably through the same process (Giles, 1998). Reinstatement of river margins and riffle areas are thought to have contributed to some recovery in the numbers of grayling in the Great Eau (Environment Agency, 1995c) although the exact mechanism is not clear.

In part, the rarity of habitat management for grayling stems from the paucity of work on the biology of grayling (see Section 4). As well as being identified as the topic area where guidance was most needed by Agency fisheries officers it is a recommendation of the Salmon and Freshwater Fisheries Review (MAFF, 2000) that grayling fisheries should be supported by habitat management and research which underpins our understanding of their long-term sustainability. It is a recommendation in Section 6 of this report that the Agency commissions a study on the habitat requirements of grayling and this should be given a high priority. Until such a study is undertaken, establishing features that satisfy the general habitat preferences of grayling at all life stages (described from European research in Section 4) offers the best available advice for habitat improvement and management.

5.4 Removal or Culling of Grayling

In many areas of England and Wales grayling have historically been removed from rivers. Originally these fish may have been transferred to other rivers, depauparate of grayling or simply culled (eaten by humans or disposed of by burying). The latter was actively encouraged in some parts of England where grayling were regarded as vermin because a number of anglers believed they compete with or predated on juvenile trout. Even, if that was not the anglers' perception, grayling and coarse fish were seen as a nuisance because they often took the trout anglers' lures. In general removal practices are now less common but they still occur.

Past examples of culling exercises include:

- In the 1970s and early 1980s annual culls of grayling took place on the West Beck at Driffield (Firth, pers. comm.). Grayling were removed from the Driffield Angling Club waters between Bradshaw Mill at Driffield and Whinhill where a trout farm was installed in the 1970's (Table 5.1) (Firth, pers. comm.).

- Up to the early 1990s they were removed from the Dove (between Okeover and Rocester). The keeper of the Norbury Fishing Club waters removed between 1000 and 1500, 6-12 oz grayling annually by rod fishing. Originally these were destroyed until the Agency intervened and began restocking grayling in other rivers including the Upper Severn (Jacklin, pers. comm.).

- Southern English chalk streams, most notably the River Test and Hampshire Avon. On the Hampshire Avon and its tributaries grayling have been intensively manipulated for at least the last 30 years (Strevens, pers. comm.). Huge numbers were removed by electric fishing or netting on an annual basis. Up until the early 1990s, most were transferred out of the catchment (Table 5.2) or killed. Since then, the Agency has insisted they be returned elsewhere within the Avon catchment. In practice, this means they are relocated to the river downstream of Salisbury, however many do not survive the journey (Strevens, pers. comm.). The eventual fate of the survivors is not known, but it is possible that they may simply return to their original location.

Table 5.1 Removals conducted between 1952 and 1979 on the West Beck (Environment Agency, various)

Date	**Removals quoted as number of fish and mean weight (lbs)/length (").**		
	Golden Hill	**West Beck Preservation Society**	**Driffield Anglers**
1952	/	/	1000 (.3 lbs)
1953	/	/	Several hundred
1955	/	/	6000 (1 - 1.75 lb)
1958	/	1000 (1.5 - 2 lb)	/
1959	60 dead fish removed	200 (12 oz)	/
1960	600 (1 lb)		
1961	550	/	/
1962	1000 (1 lb)	300	1000 (1 lb)
1963	750 (1 lb)	/	1150
1964	1480, 1600	/	2100 (.9"), 1100
1965	900	/	/
1967	635 (6oz-2.5 lb)		/
1968	861 (4oz-2 lb), 100 dead fish	417 (0.5 - 2 lb)	/
1969	256	/	641
1970	240	/	543 (1 lb)
1971	1578	185	/
1972	712	/	580
1973	/	/	396
1977	/	/	1800
1978	/	/	550
1979	/	/	220

Removal and culling can occur at any life stage. Grayling are removed by netting, electrofishing and angling. In most cases, the timing coincides with the end of the trout angling season (October), to reduce the disturbance to the trout fishery. Fewer fisheries prefer to complete the exercise in the spring as the grayling adults are concentrated in shallower water as they prepare to spawn making them easier to catch.

The various methods employed to remove grayling tend to preferentially exploit different age classes in the population. The behaviour of grayling during electrofishing is similar to that of cyprinids. Unlike brown trout, which dive for the nearest refuge, grayling swim in front of the electric field, sometimes in ever-increasing shoal size until they come to a barrier or go too far and scatter. Electrofishing preferentially captures larger fish and is poor at capturing 0+ grayling (Figure 5.5). Angling will be similarly size biased against 0+ fish.

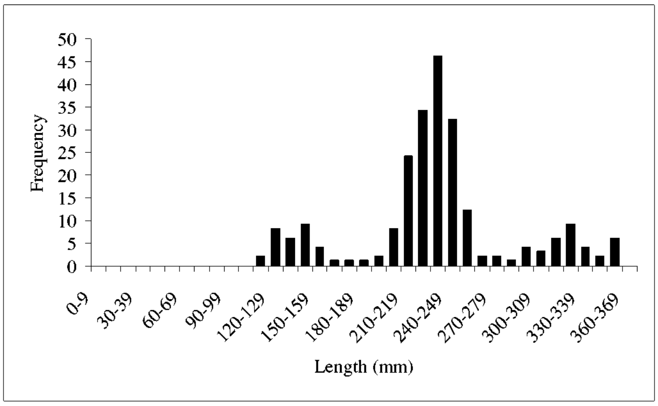

Figure 5.5 Size frequency histogram of grayling captured during a removal exercise on the River Nadder (Barford St. Martin) by electrofishing (29.10.73) (Frake, unpublished)

Netting can only be conducted in shallow, open water. This, combined with the small mesh size, means this method preferentially catches the smaller grayling (Figure 5.6). As with electrofishing, netting can alter the age structure of a population but the limited availability of habitats in rivers where netting can be used effectively, probably makes this method less effective than electrofishing. On the River Wylye, where netting was used to remove grayling and coarse fish in the 1960s and 1970s, there were no appreciable long-term changes on the numbers of fish removed annually (Frake, unpublished).

5.4.1 Population effects of large scale removal

In typical examples only single run/shock electrofishing passes (semi-quantitative) are made and only 30-40% of the population is captured. Thus, it is unlikely that spawning stock can be reduced significantly enough to reduce recruitment to the younger age classes and removal exercises have to be repeated every year with little change to the numbers removed. One exception occurred on the River Nadder where evidence suggested a long-term decline in the population at some sites where removal has taken place (Lightfoot, pers. comm.). This was probably because the age structure was dominated by the older fish which were easier to catch by electrofishing. In this instance the removal exercise was having a marked effect on recruitment.

Where these methods were employed, the remaining population consisted of many small individuals and few larger grayling. The reduced competition amongst the remaining grayling caused them to grow faster and mature at a generally younger age and smaller size (Crundwell, 1991). That is, fish that mature at two years will tend to be smaller than those that wait another year. Spawning mortality will therefore increase at a younger age and the mean size of the population will be smaller.

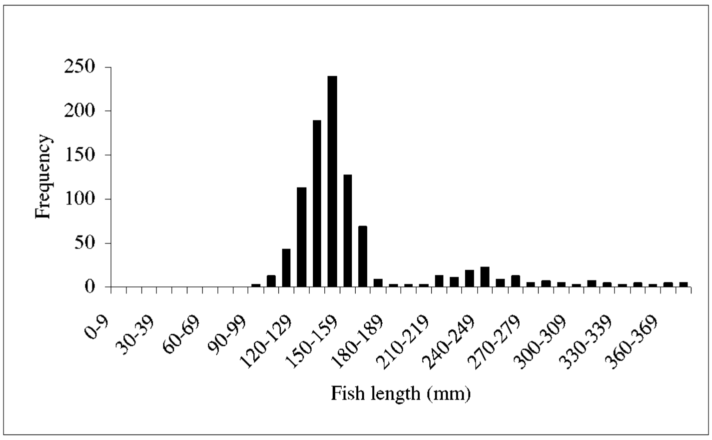

Figure 5.6 Size frequency histogram of grayling captured during a removal exercise on the River Wylye (Swan Inn/Bell Inn) by netting (21.11.73) (Frake, unpublished)

Ultimately, the result is a population of smaller and younger fish (Figure 5.7), similar in number to the original population, which causes at least as much and probably more nuisance to anglers than the original population.

The limited scientific evidence suggests that removal of large numbers of grayling is likely to have at best no effect and is more likely to create a greater nuisance population than before. Thus it is a recommendation of this report that the Agency should cease permission for this practice where it relates to grayling. This recommendation is given further weight in Section 5.6 as large scale removal activities are viewed as contravening the EC Habitats Directive (see Project Record).

Recommendation 1: The Agency should not consent any deliberate large scale attempts to remove grayling from any water by any method.

Recommendation 2: The Agency should actively target those fisheries that remove grayling with educational material about the effects of removal. This should form part of a leaflet already planned for wider distribution.

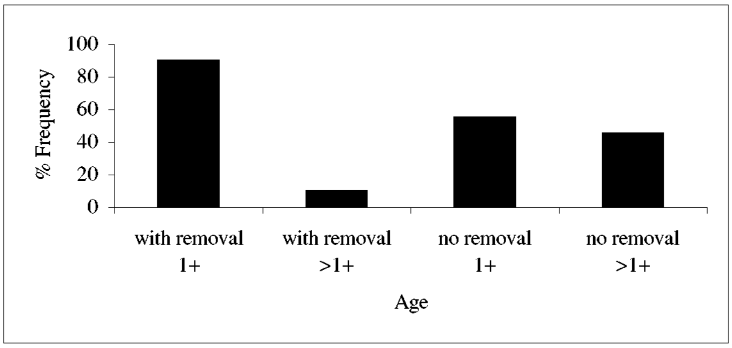

Figure 5.7 Comparisons of grayling population structure at chalk stream sites where removal has taken place over a number of years and at sites where removal does not take place (Ibbotson, unpublished)

5.5 Stocking, Transfer, Introduction and Reintroduction

With a general decline in salmon abundance in England and Wales, anglers may look to other sources of sport for wild fish and well managed, self-sustaining grayling fisheries offer an alternative source. Occasionally requests are made to the Agency to introduce grayling to new rivers and with the increase in popularity and standing, these requests are likely to become more frequent.

Providing that physico-chemical parameters are suitable for grayling to survive, stocking for introduction, re-introduction or transfer, can be used as a management tool to maintain grayling populations where they are rare (Armstrong, 1986). Indeed, the stocking and transfer of grayling has been common in England and Wales; the great majority of grayling populations resulting from introductions or transfers conducted over the past 200 years (Gardiner, pers. comm.).

The Agency's 'National Fisheries Stocking Policy' (see Project Record) is designed to ensure proper regulation of stocking and that it is only permitted where the benefits exceed the disadvantages. Similar guidelines are recommended in the Salmon and Freshwater Fisheries Review (MAFF, 2000) and the Grayling Society guidelines on introducing grayling to new waters (see Project Record). These combined policies are not specific to grayling but apply to all fish including grayling. Transfer and re-introduction stocking consent should not be given outside the terms of those guidelines. However, there are some particular aspects about grayling where supplementary guidance may be useful.

5.5.1 Source of stock

The Environment Agency fish farm at Calverton supplies many Agency regions with fish for maintenance stocking, most of which comprise coarse species. Grayling are a very minor concern for Calverton as they only rear around 12-20K grayling per annum; most of which are stocked out as 0+ fish between 6-12 cm. All brood stock originated from the Derwent, Derbyshire Wye or Dove.

The majority of the farmed grayling were stocked by the Agency, and its predecessors, to the following rivers to maintain and improve population levels:

- North East Region: Rivers Wharfe, Ure, Loxsley, Rivelin, Colne, Holme and Barlow Brook

- Anglian Region: Rivers Eau, Ise and Lark

- Midlands Region:
  Upper Trent Area - Rivers Dove and Manifold, Henmore Brook, Staffs Blithe, Foston Brook

  Upper Severn Area - Rivers Tanat, Perry, Severn, Worfe, Teme and tributaries, Rea Brook and Cound Brook

  Lower Severn - River Avon

  Lower Trent - Rivers Derwent and Ecclesbourne

There are two issues particular to grayling concerning the source of maintenance stock.

- Calverton find grayling hard to rear under hatchery conditions with specimens growing at approximately half the rate of wild fish (Henshaw, pers. comm.). Consequently, farmed fish are not as good 'quality' as wild fish and are likely to be stocked at small sizes. The survival of these fish has not been investigated but is probably lower than that of wild fish and perhaps the economic benefits of rearing farmed grayling using current practices need to be assessed.

- In the past 'surplus' stock from other rivers has been abundant from the practice of routine removal. This practice has been declining in frequency and consequently the numbers of fish available from this source will also decline. Further, one of the recommendations of this report is that the Agency should cease to consent large-scale removal of grayling. If implemented this would curtail a potential source of stock.

The Agency does not monitor the survival of grayling reared at Calverton post-stocking. More information is needed about their survival but even if this proves to be satisfactory, Calverton may not be able to meet all the future demands. Poor survival of farmed fish and the cessation of routine removals of wild fish may present a dilemma for maintenance stocking and re-introductions of grayling.

Recommendation 3: The survival of grayling stocked from Calverton Fish Farm and other fish farms to rivers in England and Wales should be monitored to ascertain whether it is economically viable to continue rearing these fish.

5.5.2 Success of stocking

A large number of attempts have been made to introduce or re-introduce grayling in rivers with varying degrees of success and some of these are listed in the Project Record. Of these two have been selected to illustrate inadvisable and more appropriate practices.

River Stour

The unacceptability of culling grayling has led to the transferral of live fish to other rivers, frequently without taking account of the suitability of the receiving water for grayling. An example of this was the practice of moving grayling from the Hampshire Avon to the River Stour (Table 5.2) in the 1970s and 1980s. Up to 6400 fish were transferred at one time during this period. Although healthy grayling populations exist in tributaries of the Stour, an Agency electric fishing survey in 1992 found only four grayling (one at White Mill Bridge and three at Corfe Mullen). A fish kill later revealed more grayling than previously thought present but it is unlikely that the habitat in the Stour was capable of supporting such large injections of grayling. Transportation in particular, combined with increased competition and lack of suitable habitat probably resulted in mass mortality. The practice of fish transfer in the Wessex Area of South West Region was ceased in the 1990s and fish removed from the Hampshire Avon tributaries must now be re-introduced into the same catchment.

Table 5.2 Examples of transfer of grayling from the Hampshire Avon and its tributaries to the River Stour (Environment Agency, various)

Date	Source	Destination	No.	Other info.
7.10.77	R Wylye, Wilton FFC water	Britford	1479	All at mixed stages of growth
		R. Stour, Shapwick	337	
7.11.79	R. Wylye, Wilton Club	R. Stour, Julian's Bridge	500	4 - 14"
6.11.79	R. Wylye, Wilton Club	R. Stour, Canford School	1033	4 - 14"
7.11.79	R. Wylye, Wilton Club	R. Stour, Newmans Boat Yard	833	4 - 14"
8.11.79	R. Wylye, Wilton Club	R. Stour, Wimborne	1133	4 - 14"
12.11.79	R. Wylye, Wilton Club	R. Stour, Wimborne	1340	4 - 14"
13.11.79	R. Wylye, Wilton Club	R. Stour, Wimborne	1535	4 - 14"
10.12.79	R. Wylye	R. Stour	6374	
8.01.81	Witchampton	R. Stour	30	
8.01.81	R. Allen	R. Stour, Gillingham	30	

River Don

In 1982, grayling were entirely absent from the River Don, a watercourse recovering from industrial pollution. Initially, stocks of trout fry were introduced, followed by grayling in the early 1980s (Crofts, 1994). The Yorkshire Water Authority stocked 200-250 grayling of between 6 and 12 inches from the Driffield Beck in East Riding, Yorkshire to the Pennine Upper Don in the Bullhouse area. Additions of *Ranunculus* were made to enhance cover and improve invertebrate habitat and productivity. The first recorded spawning of grayling took place in the same year (Crofts, 1994). Since this time rod-catch data have shown a steady increase in the number of grayling with virtually constant fishing effort (Figure 5.8).

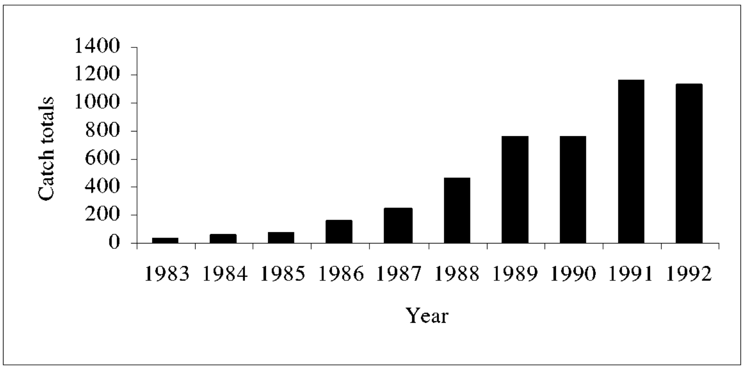

Figure 5.8 River Don total grayling rod catch between 1983 and 1992 (From Crofts, 1994)

The introduction to the recovering River Don can therefore be considered a success resulting from assessment of existing habitat and implementing appropriate improvements.

Often stocking via transfers, introductions and re-introductions have taken place with little or no proper assessment of the suitability of habitats with the result that they frequently failed. However, the Agency National Stocking Policy (Project Record) makes clear the procedures that should be followed in deciding whether or not to transfer of re-introduce fish. Amongst others these include ensuring that any factors limiting populations, in rivers where grayling are already present, are removed beforehand, completing an assessment of the physicochemical conditions of receiving waters, guarding against the introduction of disease and parasites and weighing up the costs and socio-economic benefits of stocking.

5.5.3 Guidance on introductions to new waters

The Agency has a duty to protect native salmon, trout, freshwater fish and eel stocks against the risks presented by the introductions of both native and non-native fish. They adopt a precautionary approach in terms of the suitability of the fish, the risks of introducing or spreading disease and the risks to all components of the aquatic environment. Stocking of fish can bring socio-economic benefits to fisheries by increasing numbers and species of fish available for capture however, inappropriate introductions may adversely effect resident populations either directly, or indirectly by means of:

- direct predation;
- competition with indigenous fish for food, cover or spawning sites;
- the introduction of new disease or parasites;

The Agency should therefore give preference to managing existing populations and maintaining sustainable grayling fisheries but where applications are made for new introductions to rivers, consent should only be given where the following criteria are satisfied:

i) There is proof that grayling were historically and legally present in the river concerned.

ii) Current habitat satisfies the general criteria for all grayling life stages (otherwise the introduction is unlikely to be successful).

iii) The stock fish are obtained from a local source and subject to Section 30 health screening.

iv) The socio-economic benefits of introducing grayling should be demonstrable.

Where i) is not satisfied, professional judgement should be applied to individual cases and based on good justification for an introduction i.e. river recovering from poor water quality and wide consideration of the species stocked and type of fishery that might be developed. In such circumstances, all fishery interests (riparian owners, LFGs, etc.) in the catchment concerned must be consulted and provide written agreement prior to any introduction. If the habitat is suitable, which it must be, grayling are likely to thrive and it will not be possible to remove them at a later stage. The applicant should meet the cost of these actions.

5.6 Exploitation and Regulation of Grayling

5.6.1 Introduction

Over exploitation is a serious concern for all fisheries. Too high an exploitation rate cannot be sustainable and consequently stocks will decline. In any fisheries management strategy, the fishing effort, yield and catch per effort should be monitored carefully (Cowx, 1991).

Regulation of fisheries and the resource supporting the fishery is the mechanism used by regulatory organisations to ensure exploitation and other factors do not threaten the fishery and its resource. Mechanisms of regulation commonly include restrictions on season, size, and numbers of fish that can be taken and the fishing method.

5.6.2 Exploitation of grayling stocks

Angling pressure has been shown to exert an influence on the grayling populations of some rivers. Grayling appear to be easier to catch than brown trout (Linloekken, 1995).

Following a mark-recapture study on the River Dove using angler catches it was thought that over exploitation was a real threat to the grayling population. It was estimated that within a 875 m length of the river 100 angler days would result in a near 100% exploitation rate if all fish were killed. In addition, bait fishing can result in deep hooking and severe hook damage was thought to be high on the Dove. A fly-fishing only policy was suggested as a way to combat such high levels of exploitation (Jacklin, 1998).

A study on the status of the River Dee grayling population, considered the potential impacts of angling pressure (Environment Agency, 1997c). The report concluded from the numbers of trips and time spent fishing, that there was a high demand for grayling angling. The pinnacle for grayling angling on the River Dee was reached when it hosted the World Flyfishing Championships in 1990. However, such high demand was not thought by local anglers to have affected the grayling population. Anglers were asked to record all grayling that were killed. The rate of catch and release was very high with only 2% of grayling being recorded as killed, indicating a low angling impact (Environment Agency, 1997c).

The Grayling Society actively encourages its members to catch and release grayling. The dangers of over-exploitation of grayling are real where populations are small or imbalanced. Arctic grayling in North America are reported as being highly vulnerable to angling, (Northcote, 1995). As a result, grayling populations have been subject to severe over-fishing (Michiel, 1992; Nelson and Paetz, 1992).

5.6.3 Legislation relevant to the conservation of the European grayling

Council Directive 78/659/EEC of 18 July 1978 on the quality of fresh waters needing protection or improvement in order to support fish life (Project Record).

This directive requires member states to designate salmonid waters and cyprinid waters. A salmonid water shall mean waters which support or become capable of supporting amongst other salmonid fish species, the grayling. Once designated as a salmonid water, member states are required to protect and improve the quality of those waters (Article I).

Article 3 (Project record) requires member states to set values for quality parameters for designated waters as listed in Annex I of the directive. Those standards are required to be met within five years of any water being designated (Article 5, Project Record).

The Agency should already have designated all running waters since this directive was established in 1978. However, with grayling being regarded as coarse fish for legislative purposes until quite recently, it is conceivable that some waters that support or are capable of supporting grayling were designated as cyprinid waters rather than salmonid waters. Since designation is an ongoing process, (Article 4, Project record) sites can be designated or re-designated as water quality improves and more waters become capable of supporting grayling (Article 1, Project Record).

Recommendation 4: The Agency should check that rivers that support or are capable of supporting the European grayling are designated as salmonid waters. Where they have not been designated as salmonid waters they should be in order to conform to Council Directive 78/659/EEC of 18 July 1978.

Recommendation 5: To ensure consistency with Council Directive 78/659/EEC of 18 July 1978, the European grayling should be treated for all legislative and fishery purposes as a salmonid species and not as a coarse fish.

Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitats Directive).

Grayling are listed in Annex V as an animal of community interest whose taking in the wild and exploitation may be subject to management measures. There are a number of articles relevant to the management of grayling within the Habitats Directive that require action. The articles and the actions required are as follows:

Article 10 states that member states shall endeavour in their land use planning and development policies to encourage the management of features of the landscape which are of importance for wild fauna and flora. Such features are those which, by virtue of their linear and continuous structure (such as rivers) are essential for the migration, dispersal and gene exchange of wild species.

There is very little known about the migratory behaviour of grayling (See Section 4) but there is evidence that barriers to migration are restricting the range or interfering with the free movement of grayling in some rivers. In both the River Ise and Wharfe, grayling were thought to be carried downstream of particular barriers by floods and were then unable to migrate back upstream (see Section 4). In order for the Agency to encourage the management of rivers in a way that is sensitive to the migration needs of grayling, they first need to know more about the migration behaviour of grayling and the type of structures that act as barriers.

Article 14 states that Member States shall take measures to ensure that the taking in the wild of specimens of species of wild fauna and flora listed in Annex V as well as their exploitation is compatible with their being maintained at a favourable conservation status. Where it is deemed necessary, they shall include surveillance of the population provided for in Article 11. Such measures may include (amongst others):

- Temporary or local prohibition of the taking of specimens in the wild and exploitation of certain populations
- Regulation of the periods and/or methods of taking specimens
- Application, when specimens are taken, of hunting and fishing rules which take account of the conservation of such populations
- Establishment of a system of licences for taking specimens or of quotas

- Regulation of the purchase, sale, offering for sale, keeping for sale or transport for sale of specimens

- Assessment of the effect of the measures adopted

Currently the Agency imposes a number of restrictions on the exploitation of grayling through 'Fishery Byelaws' which are particular to each region. These byelaws vary between regions but most include restrictions on size limits, bag limits and closed season (Table 5.3).

To ensure that exploitation of a species is compatible with their being maintained at a favourable conservation status, it is necessary to limit exploitation of juvenile fish. This allows reproduction to occur unimpeded and keeps exploitation of adult stages at levels that will ensure sufficient adults survive to spawn and maintain population levels.

Size and bag limits

In some regions the size limits appear to protect juvenile fish from exploitation (Table 5.3) since grayling tend to mature at around 23-30 cm (see Section 4). There are notable exceptions within Southern, Midlands, Anglian, North East regions and Wales. There are either no size limits (Southern, Anglian regions and Wales) or they are lower than the expected size of maturation i.e. 15 cm for the River Severn (Midlands Region) or 18 cm for Dales and Ridings area (North East Region). It is acknowledged that individual fisheries/clubs within these regions may impose their own size limits.

Bag limits for grayling are imposed for grayling in South West, North East and Thames regions, but not in North West, Southern, Midlands, Anglian regions and Wales (Table 5.3).

Regulations of exploitation under the terms of the Habitats Directive have to balance the maintenance of populations at a favourable conservation status along with recreational requirements. Provided the regulations serve to maintain a favourable conservation status then they are acceptable as they are. However where the lack of bag limits is combined with a low size limit there is potential for the population to be damaged by over exploitation. This risk is increased by the lack of method restrictions, although these are often enforced (i.e. fly fishing only) by fishery owners. A precautionary stance is adopted in this report to allow a greater proportion of grayling to attain sexual maturity. It is recommended that size limits are raised to 28 cm (11 inches) fork length. In regions where there are no bag limits, the regulations may need reviewing in the light of the status of the population contained in those regions.

Table 5.3 Current angling restrictions for grayling contained in Environment Agency fishery byelaws

Region	Area	Size limit/cm	Bag limit/day	Closed season
North East	Dales/Ridings	18	6	15/3 – 15/6
	Northumbria	23	6	15/3 – 15/6
Anglian	All areas	None	None	15/3 – 15/6
Thames	South east	25	2	15/3 – 15/6
	North east/ North west	25	2	15/3 – 15/6
Southern	All areas	None	None	15/3 – 15/6
South West	Devon/Cornwall	25	2	15/3 – 15/6
	South/ North Wessex	25	2	15/3 – 15/6
Wales	All areas	None	None	15/3 – 15/6
Midlands	All areas	15 (Severn, Vyrnwy, Banwy and Tanat); 20 (everywhere else)	None	15/3 – 15/6
North West	All areas	23	None	15/3 – 15/6

Recommendation 6: All regions of the Agency should impose a byelaw to include a size limit of 28 cm (11 inches) fork length and where bag limits are not currently imposed, they should review the need for these considering the potential damage to grayling populations without them. Although bait restrictions are not widely recommended, in exceptional circumstances i.e. where small or threatened populations exist, regions should consider imposing these.

Closed seasons

All regions operate a closed season for grayling between 15 March and 15 June (Table 5.3), that coincides with the coarse fish closed season. Closed seasons are designed to protect fish immediately before, during and after spawning, allowing that activity to proceed undisturbed. There is good evidence that in southern England that spawning can take place as early as the end of February (see Section 4) and therefore the current closed season within at least Southern, South West and Thames regions does not adequately protect spawning fish. Outside these regions there is very little information on spawning times.

Recommendation 7: The Agency in Southern, South West and Thames regions should all amend the closed season for grayling to run for 3 months commencing 1 February. Other regions should ascertain the local timing of spawning of grayling and amend their byelaws for the close season to commence one month prior to the commencement of first spawning.

Under the Salmon and Freshwater Fisheries Act 1975, freshwater fish can be removed during the closed season from 'several' fisheries where trout and salmon are protected. Where grayling are concerned this could conflict with the Habitats Directive.

A perceived lower value of grayling compared to trout and salmon has in the past resulted in grayling being treated as vermin and removed in large numbers by electrofishing, netting or angling. Although the extent of removals has reduced in recent years, it is still a regular occurrence in Southern (e.g. Test), South West (e.g. Hampshire Avon) and Thames (e.g. Kennet) regions.

The Agency currently regulates deliberate large scale removals of grayling through the Salmon and Freshwater Fisheries Act 1975, which requires the prior written consent before any netting or electrofishing takes place. Thames Region has produced a 'Code of best practice for fish removals' (Project record) which states that no grayling may be removed without the additional prior written permission of the Agency. It also suggests that removals of grayling should not take place unless there are benefits in removing them. The evidence currently available (see section 5.4 on grayling removals) suggests that far from providing benefits, removal of grayling often result in disadvantage.

It is already a recommendation that the Agency cease granting permission for this practice where it relates to grayling. Since the objective of this activity is usually to eliminate or significantly reduce the population size, this is not compatible with maintaining grayling at a favourable conservation status and should also be viewed as contravening the Habitats Directive, providing further reason for banning the removal practice.

Provided that there is no satisfactory alternative and the derogation is not detrimental to the maintenance of the population of the species concerned at a favourable conservation status, Article 16 allows Member States to derogate from the provisions of articles 12, 13, 14 and 15:

- To prevent serious damage to fisheries
- For the purpose of research and education, of repopulating and re-introducing these species and for the breeding operations necessary for these purposes.

Member States shall forward to the Commission every two years a report in accordance with the format established by the Committee on the derogations applied under Article 16.

The Agency needs to ensure that where Article 16 is invoked, a report is being sent to the Commission. This will include any instances where deliberate large scale removals of grayling have taken place since May 1992.

Recommendation 8: The Agency National Salmon and Trout Fisheries Centre should collate all the information on past and planned derogations from the provisions of articles 12, 13, 14 and 15 of the Habitats Directive and report to the commission in accordance with Article 16 of that directive.

Article 18 states that Member States shall encourage the necessary research and scientific work that will ensure the maintenance and restoration at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest.

Considering the general lack of information on the biology of the grayling in the UK, it is difficult to ensure that grayling populations are maintained at favourable conservation status. The greatest gaps in knowledge occur with habitat requirements and migratory behaviour and a number of recommendations for future R&D that will help fill some of the gaps in knowledge are made below (see Section 6).

The current status of grayling populations in England and Wales is unclear and therefore it is difficult to establish whether populations are at favourable conservation status or not. A monitoring programme for grayling needs to be instigated by the Agency and a recommendation is made for this (see Section 5.8).

Article 22 requires Member States to promote education and general information on the need to protect species of wild flora and fauna and to conserve their habitats and natural habitats.

Recommendation 9: The Agency should disseminate the conclusions and recommendations from this report as widely as possible including the distribution of a leaflet promoting good management practice. Assistance from the Grayling Society should be considered.

5.7 Socio-economic Value of Grayling Fisheries

5.7.1 Introduction

Assessing the economic value of grayling stocks and their fisheries is problematic mainly because grayling inhabit mixed fisheries, creating a difficulty in disassociating the grayling fishery from the coarse or trout fishery. Therefore, no attempt was made to quantify the value of grayling fisheries financially within this report. An Agency R&D project (W2-039) '*Economic Evaluation of Inland Fishing in England and Wales*' is currently underway but does not address grayling specifically. In order to assist the prioritisation of the recommendations in this report, it would be of benefit to put them into the context of the overall national value of these fisheries. Therefore it is recommended that the Agency makes some effort to place a financial value on the grayling fisheries of England and Wales. This is also a recommendation of the Salmon and Freshwater Fisheries Review (MAFF, 2000) that all recreational activities to do with freshwater have assessed socio-economic values.

Recommendation 10: The Agency should attempt to estimate the economic value of grayling fisheries in England and Wales.

5.7.2 Grayling Angling Activity

The numbers of anglers currently participating in grayling angling cannot be estimated given that both salmonid and coarse fishermen angle for them. Some measure of interest in grayling angling can be gained from the membership of the Grayling Society. This currently stands at 865 members in England and Wales and appears to be increasing at a rate of 10-15% per annum.

5.7.3 Definitions of Economic Value

Preferences for a good or service are reflected in the willingness to pay (WTP) for that good or service. In the valuation of recreational fisheries, economic value (EV) is usually related to a willingness to pay for the good or service and this provides economists with a monetary measure. It should be noted that the product of a fishery is the experience of fishing enjoyed by anglers not the catch (as such) although this will effect the willingness to pay for the fishing experience.

The minimum Net Economic Value of grayling fisheries may be defined from the sum of:

- Value to fishery owners (market value of grayling fishing rights): Recreational fisheries in the UK are generally privately owned and owners charge anglers for access to the fishing site. Such payments are known as economic rent. Whether they let their fishing or not, a potential income is available and the rights to charge rent can be bought and sold (known as market value of fishing rights). No study has yet been undertaken to establish the market value of grayling fisheries but the economic rent charged (day ticket sales and from rentals of fisheries by riparian owners) offers some insight into their value. The cost of day tickets advertised in the angling press varies widely across England and Wales ranging from £1.50 in the northern spate rivers (Yorkshire) to £25 on the southern chalkstreams, with prices averaging around £10 in 1999.

- Value to anglers (or consumers' surplus): The difference between what consumers (or anglers) are prepared to pay (aggregate WTP), and what they actually pay (i.e. their expenditure – such as on tackle, petrol, bait, accommodation etc.) is known as consumers' surplus. This is estimated because it represents much of the net economic value of the fishery to society but no figures are currently available.

5.7.4 Other aspects of Economic value including non-consumptive use of grayling stocks

The enjoyment of natural resources like the countryside and wildlife is fundamentally different from manufactured goods and services. Wildlife assets such as fish stocks give rise to non-consumptive economic values:

- through activities such as wildlife photography, reading about wildlife or watching TV programmes, individuals may derive enjoyment from a resource without direct contact with the natural resource

- through knowing that the resource exists and will remain for future generations (existence and bequest values).

The significance of these in relation to grayling stocks is unknown.

Angling for grayling provides an 'extended' salmonid-angling season. Whilst angling for migratory salmonids generally takes place between March and October, grayling are fished for throughout the year (currently excluding the coarse fish closed season) with the most productive angling season generally being winter. This effectively offers salmonid anglers all year round sport and presents the opportunity for clubs and riparian owners to generate revenue at a time when many other salmonid fisheries are experiencing declining stocks. On the Rivers Eden and Wye, for example, once exclusive salmon beats are now available for day-ticket grayling fishing in the winter.

5.7.5 Impact on the economy

Grayling fisheries will generate economic activity that contributes to employment and income in a given area.

Anglers require both capital and consumable equipment to practice their craft. The market for angling equipment is reasonably competitive (with retail outlets and mail order companies). From a direct telephone survey made of four of the largest retailers of angling tackle advertising in the national angling press, it was established that tackle sales are currently stable with declines in some specific areas. It was recognised that sales of capital items of fishing equipment for grayling angling could not be distinguished from equipment used for other types of angling, particularly trout angling. Sales of the smaller items such as grayling flies were increasing slightly but in terms of overall sales were negligible. Estimating the value of tackle sales specifically used for grayling fishing was not possible.

Some of the best grayling rivers in the UK are situated in low-income rural or disadvantaged areas. These attract visiting anglers and the revenue generated may be of some significance. For example, the the grayling fishing in the middle and upper Dee regularly attract anglers from the Midlands, the south of England and held the World Flyfishing Championships in 1990. These are rural communities that generally rely upon income from tourism and good quality grayling angling attracts income to the area through payments for services such as overnight accommodation that otherwise would not have occurred.

Although there is currently no economic value placed on good quality grayling river fisheries, the willingness of anglers to pay for grayling fishing would suggest that grayling fisheries have a significant economic value. This value will grow along with increasing demands for natural salmonid river fisheries, further improvements in angler attitude toward grayling and if English and Welsh salmon stocks continue to decline.

Two key objectives recommended by the Salmon and Freshwater Fisheries Review (MAFF, 2000) have relevance to grayling fisheries. These are:

- to enhance the contribution salmon and freshwater fisheries make to the economy, particularly in remote rural areas and in areas with low levels of income

- to enhance the social value of fishing as a widely available and healthy form of recreation.

Encouraging and developing the changing attitudes to grayling should facilitate greater use of current grayling fisheries and contribute to meeting the above objectives. It is already planned to produce a leaflet on grayling for wider circulation. The contents of that leaflet should promote grayling fishing through good management practice leading to balanced, sustainable populations which give a further boost to the improving attitudes towards grayling.

Recommendation 11: The contents of a leaflet on grayling being produced by the Agency/CEH should promote grayling fishing through good management of the species and give a further boost to the improving attitudes to grayling.

5.8 Monitoring

5.8.1 Objectives of monitoring

Currently, there is very little background information on the grayling populations of England and Wales either in terms of population size or information on growth rates, age composition, spawning times, migration patterns etc. It is recommended that some of this information, i.e. on migration patterns should be the target of other specific studies (see Section 6). There is also a need to improve the general collection of base line data on grayling populations in areas where they are regarded as an important fishery resource. Natural resources should be given high economic value (see Section 5.7) especially where it is shown that people will pay to make use of that resource as is the case with grayling fisheries. As such they warrant monitoring.

The Oxford English dictionary defines monitoring as to regularly check how something is performing or changing over time. It can be targeted at general issues, i.e. to check the development of existing populations or more specific themes such as examining the effects of habitat improvement or stocking schemes. It can provide data as a benchmark for measuring future changes and can be used to detect alterations in population size and structure. Therefore, the objectives of any monitoring programme for grayling should specifically enable the detection of significant change to both the size of the population and individuals within the population from one year to another over many years.

5.8.2 Current monitoring methods for grayling

Electrofishing - Rolling Programmes

There are currently no ongoing rolling programmes within the Agency that collect information on grayling abundance yet most regions operate programmes targeted specifically at sampling juvenile salmon and trout. Some of these surveys take place in river sections that contain grayling, but when captured, they are simply returned without examination. In general, the major drawback of routine salmonid electrofishing is that the habitat sampled is predominantly shallow riffle type (<30 cm). This is not representative of habitat preferred by juvenile or adult grayling. To monitor grayling populations effectively on a national scale using electrofishing would require careful planning and considerable additional resources (using quantitative sampling techniques) to be able to measure changes in population size or structure. Realistically, such programmes are unlikely to collect the necessary information about grayling abundance on a national basis and it is not recommended that routine electric fishing programmes are instigated for grayling.

Netting Surveys

Currently no netting surveys are undertaken by the Agency to monitor grayling stocks in England and Wales however this technique has been used to study grayling on the Dee (Woolland, 1972). For national monitoring of grayling stocks, netting is unlikely to offer an ideal solution given the wide-ranging habitats occupied and the different flows and substrate preferred by juvenile and adult grayling. This technique may be favourable in some chalkstreams with even depths and constant flows but is unlikely to adequately sample spate and regulated rivers and detect changes in population size and structure. The resources required in association with netting (i.e. labour and financial costs) would also preclude this method for routine monitoring.

Fish Kills

Only a handful of pollution incidents in England and Wales have recently resulted in large-scale mortalities of grayling (e.g. Calder and Ewenny) although post-spawning mortalities are regularly witnessed on southern chalkstreams. This method is unlikely to offer a source for the monitoring of existing populations but following pollution incidents any grayling carcasses should be retrieved and examined to improve knowledge of distribution, abundance and population structure.

Mark-Recapture techniques

Two recent examples exist of population estimates using mark-recapture techniques on grayling. Ibbotson (unpublished) tagged 425 grayling of mixed age using visible implant tags. These were sampled as a by-catch of semi-quantitative electrofishing monitoring for trout on the River Wylye (12 x 200 m sites). A follow-up survey in 2000 allowed for population estimates of separate year classes. Jacklin (1998) and Williamson (2000) used panjet marked angling recaptures on a 760 m stretch of the Dove to estimate population size in two years and achieved tight confidence limits around his estimates. Mark-recapture can offer the opportunity for robust population estimates but the effort and expense incurred limit its use to discreet studies where population estimates are required within river sub-catchments.

Angling Returns/Logbook Schemes

The effort and expense of monitoring can be partly offset by organising the collection and collation of angling returns from waters where grayling are regularly fished for. A good model is the annual grayling match on the Hampshire Avon. The annual fishing effort remains constant and the data are collected voluntarily on numbers of fish captured, their location and size frequency. This data provides good quality information on the status of the fishery and significant changes in population size or structure should be detectable using this method. It is interesting to note that over the last seven years catches in this grayling fishery have remained stable (Ibbotson, unpublished).

5.8.3 Future monitoring of grayling populations

Although there are not necessarily the equivalents of annual grayling matches on every river, on the most important grayling fisheries, a significant amount of angling takes place. In some cases data will already have been collected and the Agency should make use of this data for monitoring as has occurred on rivers such as the Dee (Environment Agency, 1997c). On rivers where monitoring data are absent, its collection should be actively encouraged. The Agency currently collates and reports catch statistics for migratory salmonids and the data are used to identify trends such as increases/declines in salmon and sea trout abundance.

Similarly, information should be collected for non-migratory salmonids. The Agency should seek to develop a logbook scheme for grayling anglers and operate it through the Grayling Society. There are many active enthusiasts within the Society that would be willing to assist and the Agency should seek to utilise this resource. It is recommended that data should be collected nationally for a minimum of five years and preferably longer, to identify both spatial and temporal trends in catch, catch-rates, population size and structure. All grayling anglers should be encouraged to partake and accurately record the following parameters: location fished (river and nearest town), date fished, hours fished, numbers captured and killed, angling method used, size of individual fish (length or weight to be determined) and possibly some scale sub-sampling of larger specimens. Provided that anglers participate and accurately record their fishing effort, this monitoring strategy should be able to identify changes in population size and the size of fish captured. It will be possible to use this database to identify trends or sudden changes in grayling populations nationally as well as provide data on catchment specific changes in response to natural and anthropogenic events such as pollutions, natural disasters and habitat alterations.

Recommendation 12: This report identifies the distribution of grayling in England and Wales and from this information the Environment Agency, in collaboration with the Grayling Society, should attempt to monitor changes in grayling abundance and population structure in these rivers through rod catches, catch-effort and other angling details for a minimum period of five years. This should take the form of a joint Agency / Grayling Society logbook scheme for anglers.

5.9 Conservation of Indigenous Stocks

Under the heading of other issues, Agency fishery officers requested management guidance on the conservation of the original indigenous stocks and which rivers contained these. This is of relevance to a wide range of management issues including stocking, removal, transfer and conservation.

At present, it is not completely clear which English and Welsh rivers contain the original indigenous stocks. There are probably few and most rivers contain grayling that originated from transfers from one or more of the native rivers. Thus the considerations of reducing the genetic integrity or of polluting environmentally adapted populations has less significance for grayling than for trout and salmon. This does not apply to those rivers where it is thought the original stocks are native and these need to be protected from mixing with other stocks until the origin is established.

The catchments that are thought to have contained the original stocks are the Rivers Ouse, Trent, Hampshire Avon and possibly the River Severn, Wye, Thames, Ribble and Welsh Dee (Gardiner, 1989). However, even with these few rivers there is some doubt about their origins. A good example is the Hampshire Avon where Gardiner (1989) states the stock in that river is part of its natural distribution, although no evidence is presented. In contrast the renowned angler Frank Sawyer (pers. comm.) was of the opinion that the grayling in the Hampshire Avon result from stocking by man, again with no evidence presented.

Whatever the case the original indigenous stocks have an important conservation value. Placing a high conservation value on these stocks will require justification and thus it is recommended that the source of the stocks in all of the rivers named in Gardiner (1989a) should be investigated and the data stored as evidence in the relevant Agency offices. Until this information becomes available a precautionary approach should be adopted and when any of these populations appear to be under threat all possible means should be employed to ensure their survival.

Currently, there is no information on how similar genetically the grayling populations in England and Wales are to each other and the degree of diversity in each. Work is being completed in Europe on the genetics of grayling in the United Kingdom using a very small number of samples, but to date it does not include material from all the rivers which potentially contain indigenous stocks. Further, it is not clear how such a study would separate genetic strains that had been introduced from an original stock and the original stock itself.

Alternative sources of information are likely to be obtainable in historical and possibly archaeological records. Sourcing this need not be an expensive exercise if history students were used and this may provide the best evidence on which to base a view on whether any river contains indigenous stocks.

Recommendation 13: The Agency should seek and store evidence on the source of grayling in the Rivers Ouse, Trent, Hampshire Avon, Severn, Wye, Thames, Ribble and Welsh Dee and their tributaries, making best use of historical and archaeological records.

Recommendation 14: Until it is clearer which rivers contain the original indigenous grayling stocks, grayling populations in the Rivers Ouse, Trent, Hampshire Avon, Severn, Wye, Thames, Ribble and Welsh Dee and their tributaries should be treated as having high conservation value. This will mean that any fisheries related and other management proposals will need to include an assessment of their impacts on the grayling populations in these catchments as part of the planning procedure.

5.10 Water Regulation

Under the heading of other issues, Agency officers requested management guidance on water regulation and its impacts on grayling. This heading includes any influences that change flow regimes (i.e. magnitude, timing, frequency, and duration). Many rivers in England and Wales subject to water regulation contain grayling populations and the impacts of regulation can be beneficial or detrimental (see Section 4.8). However, the regulation of these rivers rarely consider the impacts on grayling, more frequently concentrating on the other salmonids trout and salmon. In some notable cases this was done even where grayling are the dominant species in the areas of the river where there is most concern (e.g. River Kennet). It is a recommendation of this report that where grayling are the dominant species in reaches subject to water regulation, they are considered in the planning process. This is given further weight by the recommendation of the Salmon and Freshwater Fisheries Review (MAFF, 2000) that the needs of all fish should be taken into account when establishing abstraction regimes.

Recommendation 15: In any river that is subject to planned changes in river flow regime and where grayling are common, an assessment of the impacts of the changes on grayling should form part of the planning process.

6. FURTHER RESEARCH AND DEVELOPMENT

6.1 Introduction

Although this review of the biology of grayling identified a wealth of information on that species it was also apparent that there were serious gaps in knowledge which make it difficult to include any recommendations for the enhanced management of grayling fisheries. Current programmes of monitoring and research on grayling will not provide the data necessary for the management of grayling fisheries in England and Wales.

If the Agency wishes to provide advice on the management of grayling fisheries to its officers based on good science, it should be prepared to make a commitment to funding the relevant research.

This Section identifies areas of research where the need for information and data are greatest taking account of the Agency fishery officers prioritised list of issues where management guidance was required.

6.2 Habitat Management

In this context habitat refers to the physical structure and form of the river channel. This is an area where anthropogenic influence has historically been great with the engineering of river channels. It is also something over which fishery managers can have some influence at the local level and hence habitat manipulation is a useful tool for managing fisheries. This probably explains why Agency fishery officers and scientists most frequently requested for guidance on habitat management. It is also a recommendation of the Salmon and Freshwater Fisheries Review (MAFF, 2000) that both wild brown trout and grayling fisheries should be supported by habitat management and research that underpins our understanding of their long-term sustainability. Unfortunately, for grayling it is a topic where data are severely deficient.

A recent manual on the restoration of trout habitats quoted more than 200 references relevant to the habitat requirements of trout and the impacts of restoration programmes on trout. By comparison this report could only quote 15 equivalent references for grayling, two of which were unpublished PhDs and only four of which provided information at the macro-habitat or reach scale, most useful for habitat management. There is an obvious imbalance in the amount of scientific literature relevant to the habitat requirements of trout and to the habitat requirements of grayling and this imbalance needs to be addressed to satisfy the need for guidance on habitat management.

Collection of all the scientific data relevant to this topic cannot be achieved through one simple study. Instead it will be a long-term ongoing process but will need encouragement, co-ordination and financing. There are three methods by which data can be collected all of which are important in providing the database necessary to complete a manual on habitat restoration and management equivalent to the one produced by the Agency for trout. These are:

- Monitoring on a national scale provides baseline information on the status of grayling populations, which can be used to assess the effects of alterations to physical habitat.

- Specific impact assessments can be carried out where it is known that alterations to physical habitat are going to take place, whether that is for habitat improvement or any other reason. Impact assessments must be properly planned and designed so that they collect the data required to measure the impact properly and the results should be reported.

Recommendation 16: Where known habitat alterations are to take place which may impinge on any grayling population an impact assessment study should be completed and reported on to the National Salmon and Trout Fisheries Centre.

- The development of empirical relationships between grayling abundance and physical habitat characteristics of rivers where grayling are present. This is the only method that could form the basis of a complete study in its own right and would provide information on habitat requirements within a quicker time scale than the other methods.

The first two of these methods can be seen as experimental approaches. Although there is no specific experimental design to the alterations, any perturbation can be viewed as an individual experiment. It will be necessary to encourage and provide resources for studying impacts using a case study approach and the Agency National Salmon and Trout Fisheries Centre should encourage this in individual cases as well as take responsibility for collating the reported information.

The development of empirical relationships between grayling abundance and physical habitat characteristics would provide easily identifiable attributes of river reaches that are of benefit to grayling populations. This will enable fishery officers to predict potential effects, good or bad, of proposed changes to river channels as well as assist remediation of degraded channels. This information could also form the basis of a habitat quality index for grayling that can be used to assess the status of any grayling population against its expected status.

One problem in trying achieve this is that some grayling populations live in large rivers that are difficult to sample quantitatively and calibration of a habitat model using absolute abundance may not be achievable in all rivers. Therefore it is recommended that a habitat model for grayling be calibrated with semi-quantitative estimates of abundance, in this case, using an index or score. The scores would be derived from local knowledge at a selection of sites (~100+) within the known grayling distribution.

The scores given for different rivers using different local knowledge would not be directly comparable. That is, what one person considers as an excellent fishery on the River Wharfe may only be seen as an average fishery on the River Dee. Therefore, scores will need to be calibrated across catchments using quantitative estimates of population abundance where possible. An estimated cost for such a study would be £80k.

Recommendation 17: The Agency should commission a study coordinated across regions that uses local knowledge of grayling distribution to calibrate an empirical habitat model for grayling.

6.3 Barriers to Migration

There are two gaps in knowledge relevant to the management of grayling under this heading:

- it is not known what the unimpeded migratory behaviour of grayling is in the rivers of England and Wales
- and although there is evidence that barriers impede the natural movement of this species it is not known what constitutes a barrier to grayling movement through a river catchment.

Although this was not a management issue about which Agency fishery officers required advice it did score highly as an issue affecting grayling populations. The Salmon and Freshwater Fisheries Review recommends that any new obstruction should have a fish pass installed and that the design of this should determine the size and species of fish that should be able to use it. If this is ever to include grayling it warrants attention.

Article 10 of the Habitats Directive requires member states to encourage the management of the linear features of rivers which are important to migration of fish. Similarly, the Salmon and Freshwater Fisheries Act 1975 requires that new structures in rivers do not impede the migration of fish. With the two current gaps in knowledge detailed above it is not possible to give advice on whether any structure will act as a barrier to grayling migration or not.

Since it can be expected that grayling behaviour will differ in upland and lowland rivers it is recommended that in two rivers, one upland (e.g. Dee) and one lowland (e.g. Hampshire Avon) 20 grayling should be tracked continuously over the course of one to two years using radio tags. The study should not only describe migration patterns but should make use of the data to improve our knowledge of habitat use under different conditions, supplementing the information collected above. This study will have to be completed under the auspices of the Animals (Scientific Procedures) Act 1986.

This is the type of study that could be completed, at least in part, by a PhD student, making the financial burden considerably less than using a contractor. There will be some expense on capital equipment (e.g. fixed listening stations). Tags are £100 each and fixed stations £7,000. To track fish all year will require 130 tags on each river and the number of fixed stations will be dependent on the size of the river but a suggested number might be 3 or 4. PhD students cost about £10,000 per annum. With travel and consumables the total cost would be £90k.

Recommendation 18: The Agency should give studies with the objective of describing and defining natural and unimpeded migratory behaviour in the European grayling a high priority.

With grayling it is not clear whether the passage of fish over certain barriers is a physical or behavioural constraint as many apparent barriers e.g. Dorchester Weir and many hatches on chalk streams do not at first sight appear to be particularly impassable. Therefore it is recommended that two complementary studies are commenced:

- one on the swimming abilities of grayling which should be a species included in the 'Swimming speeds in fish, stage 2' Agency National R&D project.

- and a review of the impacts of barriers to grayling migration and population distribution. This will include accounting for the structure and form of current barriers. An estimated cost is £30k.

Recommendation 19: The Agency should ensure that grayling are included in the 'Swimming speeds in fish; stage 2' National R&D project.

Recommendation 20: The Agency should complete a review of the impact of barriers on grayling migration and population distribution. This will include a study of the structure of current barriers and will take account of the results from the swimming speeds R&D study.

7. CONCLUSIONS

The biology and ecology of grayling is poorly understood and there is insufficient scientific knowledge to underpin the current demand for management advice in many areas.

This is particularly the case with habitat requirements. A recent manual on restoration of trout habitats (Environment Agency, 1996f) quoted approximately 200 references concerned with the habitat requirements of brown trout. By comparison this report only quotes 15 references for grayling, two of which were unpublished PhDs and only four which provided information at the macro-habitat scale, most useful for habitat management. Indeed current knowledge appears to be partly contradictory, especially regarding flood relief channels with some views that homogeneous channels are not suitable for grayling and others suggesting that adults are most abundant in these. Of course, both observations may be correct with other factors such as hydrological differences between channels explaining these differences. This clearly highlights how without more scientific data, it is not possible to define what constitutes good and poor habitat for grayling.

Habitat management, migratory behaviour, and the influence of barriers on the distribution of grayling were highlighted by Agency fishery officers as being important to future management of this species in England and Wales. It is recommended that the lack of strategic science in these areas be met through further Agency R&D.

There are aspects of reproductive behaviour, age, growth rates and interactions with other species that provide valuable background information. In some cases there is information to assist management of grayling stocks and a number of recommendations are made for amending byelaws. However, more information is required for greater justification of management practice. This is particularly the case for reproduction where it is recommended that Agency Region-specific close seasons are introduced based on the local times of spawning. The recommended close season is explicit for Southern, South West and Thames Regions, but all Regions should be required to collect more information on the times of spawning of their stocks before amending their byelaws.

Competition between grayling and trout is a major, yet contentious issue. The belief that competitive interactions are strong has been the driving force behind grayling removal programmes. Clear advice on the predicted impacts and outcomes of competition between these two species is highly desirable. Interactions with other species are hard to elucidate, demonstrate or quantify because they are mediated by so many physical, chemical and biological conditions that to complete the experiments required to deal with all these conditions is a resource and cost prohibitive task. Thus there is no recommendation that more information is collected on this aspect of grayling biology.

Grayling have been ignored in many operational studies, usually in favour of trout and salmon. Although grayling are a salmonid fish they occupy a distinct zone where they are frequently the most abundant fisheries resource. As such their requirements for the physical, chemical and biological environment will be different from the other salmonid species. Recommendations are made that grayling are considered more frequently in future operational studies where alterations to their environment require impact assessment as part of the planning stage.

There are already procedures within the Agency to limit the spread of parasites and disease and there were no issues identified in this area which were special to grayling.

Sustainable management of grayling fisheries in England and Wales suffers from the lack of baseline scientific data described above. In the past grayling have been treated for management and regulatory purposes as a coarse fish. This has generally led to inappropriate regulation, negative management in the case of removal programmes, and a lack of species specific habitat management. The lack of baseline data is at odds with the obvious demands for advice for management of grayling from Agency and other fishery officers. A questionnaire survey of this group of people highlighted a number of issues where guidance on management was required.

There was greatest demand for advice on habitat management and no cases were identified where habitat had been managed specifically for grayling, although there were a few instances where the impacts on grayling of habitat alterations had been observed. Clearly Agency fishery staff would like to manage habitats for grayling but do not have the knowledge or guidance to be able to do so. Recommendations associated with improving the scientific information on habitat requirements for grayling must therefore be given a high priority.

Historically grayling have been removed in large numbers from many rivers in England, usually with the objective of reducing population size in the hope that will reduce competition with trout and that anglers lures will be less frequently taken by grayling. The success in meeting these objectives of grayling removal are not always obvious. In most cases effects on absolute numbers are small and removal does not generally control grayling populations. The impacts upon age structure, growth, age and size at maturation and maximum size, are more noticeable. There is now strong evidence that attempts at removal only serve to exacerbate the conditions that removal is attempting to reduce, that is, by producing populations of grayling of similar number but with a smaller average size. Many fisheries on the Hampshire Avon, where removal has ceased, have recently expressed the view that grayling are now not regarded as a problem and that the mean size of those fish has increased making them a much more valuable asset.

The removal of grayling is not generally advocated by the Agency. Thames Region has produced an additional 'Code of Best Practice for Fish Removals on the River Kennet Catchment' (see Project Record). However these practices do still occur and it is a recommendation of this report that the Agency ceases to give permission for these practices both for biological as well as legislative reasons as this practice is not compatible with Article 14 of the Habitats Directive. It is also a requirement of that directive that member states inform the European Commission each time they give permission to derogate from provisions of a number of Articles including Article 14. As this practice has been continuing since the Habitats Directive became law in 1992 the Agency will need to collate information on these removal programmes and inform the European Commission.

Where the practice of removal continues it is usually the result, of cultural attitude and a lack of knowledge of the effects. Thus there is an additional recommendation for the Agency to initiate a programme of education for external fishery managers about the effects of removal to deal with the potential cultural barriers to ceasing the activity.

The Agency has developed a National Fisheries Stocking Policy (see Project Record) to ensure the proper regulation of stocking and that it is only permitted where the benefits exceed the disadvantages. Although many of the current populations of grayling in England and Wales result from a past introduction by man, permission for cross catchment stocking is not generally given by the Agency. Other sources of stock include Calverton Fish Farm but production is low and the fish are of lower quality because currently they do not grow well in hatchery conditions. The efficacy of continuing to rear these fish at Calverton needs to be assessed.

Previously grayling have been treated as 'coarse' fish which has led to some inappropriate regulation within local byelaws. To bring the regulation of grayling into line with two pieces of legislation, Council Directive 78/659/EEC and the Habitats Directive it is recommended that grayling are classed as salmonids for regulatory purposes and that byelaws on close seasons, size and bag limits are introduced or updated.

There is currently no economic value placed on grayling fisheries in England and Wales. Since this report makes a number of recommendations that will require resources to complete, the Agency will need to prioritise these recommendations to take account of the relative value of grayling fisheries to other fisheries, mainly salmon and trout. Thus it will be necessary to place an economic value on these fisheries. One of the objectives of the Salmon and Freshwater Fisheries Legislative Review was to enhance the contribution freshwater fisheries make to the economy and therefore it is recommended that the contents of a leaflet being produced by the Agency and CEH Dorset should help promote grayling fishing through good management.

One of the most striking aspects of this report was the almost complete lack of monitoring of grayling populations in England and Wales, other than some electrofishing surveys carried out by the Agency. It was rarely possible to make an accurate assessment of any grayling population. There were some notable exceptions on the Rivers Teme, Don and Avon where monitoring had been carried out through well kept angling records. It is therefore recommended that the Agency and the Grayling Society commence a collaborative monitoring exercise that addresses specific objectives and uses anglers catches to establish both current population status of English and Welsh rivers and to monitor changes in grayling populations over the next five years.

There are probably few rivers in England and Wales containing indigenous grayling populations, and these cannot be identified with certainty at present. As a result, there is some doubt regarding the origin of the grayling in a few important fisheries. It will also be necessary to justify additional management for those stocks of conservation importance. It is recommended that the source of grayling in each of the rivers suspected of containing the original indigenous stock should be identified. Until such evidence is collected a precautionary stance should be adopted and the Rivers Ouse, Trent, Hampshire Avon, Severn, Wye, Thames, Ribble and Welsh Dee should be considered to contain stocks with high conservation value.

Overall it was found that the management of grayling in England and Wales had little focus or objectives to direct it. This has led to a wide variety of management practices across different regions. For example, permission for removal of grayling is commonplace in some regions but others have stricter guidelines on when it can occur. Similarly, the byelaws are quite variable between regions due to a lack of national guidance. Therefore a final recommendation is that the Agency develops and agrees through consultation a strategy for grayling management. Such a strategy could have the objective of bringing both the management and strategic science underpinning that management up to the same level as for trout and salmon and ensuring that all the recommendations in this report are carried through in each region to a given timescale.

Recommendation 21: The Agency should develop and agree through consultation a strategy for the management of grayling and their fisheries in England and Wales. This strategy should define its objectives, which could include:

- Planning and carrying through the recommendations contained in this report.
- Improving both the management and the quantity of strategic science underpinning that management to the same level as trout and salmon.

8. RECOMMENDATIONS

This section lists the twenty-one recommendations from this report. Each recommendation is annotated with the:

- Section it is relevant to
- its priority (high, medium or low)
- and the target date for the recommendation to be effected.

Recommendation 1: The Agency should not consent any deliberate large scale attempts to remove grayling from any water by any method. (Section 5.4), High, 06/2001.

Recommendation 2: The Agency should actively target those fisheries that remove grayling with educational material about the effects of removal. This should form part of a leaflet already planned for wider distribution. (Section 5.4), High, 09/2001.

Recommendation 3: The survival of grayling stocked from Calverton Fish Farm and other fish farms to rivers in England and Wales should be monitored to ascertain whether it is economically viable to continue rearing these fish. (Section 5.5), Low, ongoing.

Recommendation 4: The Agency should check that rivers that support or are capable of supporting the European grayling are designated as salmonid waters. Where they have not been designated as salmonid waters they should be in order to conform to Council Directive 78/659/EEC of 18 July 1978. (Section 5.6), High, 03/2002.

Recommendation 5: To ensure consistency with Council Directive 78/659/EEC of 18 July 1978, the European grayling should be treated for all legislative and fishery purposes as a salmonid species and not as a coarse fish (Section 5.6), High, ongoing.

Recommendation 6: All regions of the Agency should impose a byelaw to include a size limit of 28 cm (11 inches) fork length and where bag limits are not currently imposed, they should review the need for these considering the potential damage to grayling populations without them. Although bait restrictions are not widely recommended, in exceptional circumstances i.e. where small or threatened populations exist, regions should consider imposing these. (Section 5.6), High, 03/2002.

Recommendation 7: The Agency in Southern, South West and Thames regions should all amend the closed season for grayling to run for 3 months commencing 1st February. Other regions should ascertain the local timing of spawning of grayling and amend their byelaws for the close season to commence one month prior to the commencement of first spawning. (Section 5.6), High, 03/2002.

Recommendation 8: The Agency National Salmon and Trout Fisheries Centre should collate all the information on past and planned derogations from the provisions of articles 12, 13, 14 and 15 of the Habitats Directive and report to the commission in accordance with Article 16 of that directive. (Section 5.6), High, 03/2002.

Recommendation 9: The Agency should disseminate the conclusions and recommendations from this report as widely as possible including the distribution of a leaflet promoting good management practice. Assistance from the Grayling Society should be considered. (Section 5.6), High, 09/2001.

Recommendation 10: The Agency should attempt to estimate the economic value of grayling fisheries in England and Wales. (Section 5.7), Medium, 03/2002.

Recommendation 11: The contents of a leaflet on grayling being produced by the Agency/CEH should promote grayling fishing through good management of the species and give a further boost to the improving attitudes to grayling. (Section 5.7), High, 09/2001.

Recommendation 12: This report identifies the distribution of grayling in England and Wales and from this information the Environment Agency, in collaboration with the Grayling Society, should attempt to monitor changes in grayling abundance and population structure in these rivers through rod catches, catch-effort and other angling details for a minimum period of five years. This should take the form of a joint Agency / Grayling Society logbook scheme for anglers. (Section 5.8), High, 06/2001.

Recommendation 13: The Agency should seek and store evidence on the source of grayling in the Rivers Ouse, Trent, Hampshire Avon, Severn, Wye, Thames, Ribble and Welsh Dee and their tributaries, making best use of historical and archaeological records. (Section 5.9), Medium, 03/2003.

Recommendation 14: Until it is clearer which rivers contain the original indigenous grayling stocks, grayling populations in the Rivers Ouse, Trent, Hampshire Avon, Severn, Wye, Thames, Ribble and Welsh Dee and their tributaries should be treated as having high conservation value. This will mean that any fisheries related and other management proposals will need to include an assessment of their impacts on the grayling populations in these catchments as part of the planning procedure. (Section 5.9), High, ongoing.

Recommendation 15: In any river that is subject to planned changes in river flow regime and where grayling are common, an assessment of the impacts of the changes on grayling should form part of the planning process. (Section 5.10), High, ongoing.

Recommendation 16: Where known habitat alterations are to take place which may impinge on any grayling population an impact assessment study should be completed and reported on to the National Salmon and Trout Fisheries Centre. (Section 6.2), High, ongoing.

Recommendation 17: The Agency should commission a study coordinated across regions that uses local knowledge of grayling distribution to calibrate an empirical habitat model for grayling. (Section 6.2), High, 03/2005.

Recommendation 18: The Agency should give studies with the objective of describing and defining natural and unimpeded migratory behaviour in the European grayling a high priority. (Section 6.3), High, 03/2004.

Recommendation 19: The Agency should ensure that grayling are included in the 'Swimming speeds in fish; stage 2' National R&D project. (Section 6.3), High, 08/2001.

Recommendation 20: The Agency should complete a review of the impact of barriers on grayling migration and population distribution. This will include a study of the structure of current barriers and will take account of the results from the swimming speeds R&D study. (Section 6.3), High, 03/2004.

Recommendation 21: The Agency should develop and agree through consultation a strategy for the management of grayling in England and Wales. This strategy should define its objectives, which could include:

- Planning and carrying through the recommendations contained in this report.
- Improving both the management and the quantity of strategic science underpinning that management to the same level as trout and salmon. (Section 7), High, 06/2002.

9. REFERENCES

Alabaster, J.S. and Lloyd, R. (1982) Water Quality Criteria for Freshwater Fish. London: Butterworths.

Anon. (1622) *Transactions of the Thoroton Society*, **2**, p29.

Armstrong, R.H. (1986) A review of the Arctic grayling studies in Alaska, 1952-1982. *Biological Papers of the University of Alaska*. **23**, 3-17.

Baars, M. (1999) *Charakterisierung von Aschenbiotopen und Aschenpopulation in Bayern.* Lehrgebiet Fischbiologie. Technische Universitat Munchen Friesing/Weihenstephan.

Bagliniere, J.L. (1999) Introduction: The brown trout (*Salmo trutta* L.): its origin, distribution and economic and scientific significance. In '*Biology and Ecology of the Brown and Sea Trout*' (ed. J.L. Bagliniere and G. Maisse), vii, p.286. Springer-Praxis, Chichester.

Bakke, T.A. and Jansen, P.A. (1991) Susceptibility of grayling (*Thymallus thymallus*) to *Gyrodactylus salaris* Malmberg (monogenea). *Bulletin of the Scandinavian Society for Parasitology,* **1**, 61.

Ball, J.N. (1961) On the food of the brown trout of Llyn Tegid. *Proceedings of the Zoological Society. London*. **137**, (4), 599-622.

Bardonnet, A. and Gaudin, P. (1990) Diel pattern of first downstream post-emergence displacement in grayling, *Thymallus thymallus* (L., 1758). *Journal of Fish Biology*. **37**, 623-627.

Bardonnet, A. and Gaudin, P. (1991) Influence of daily variations of light and temperature on the emergence rhythm of grayling fry (*Thymallus thymallus*). *Canadian Journal of Fisheries and Aquatic Sciences,* **48**, 1177-1180.

Bardonnet, A., Gaudin, P. and Persat, H. (1991) Microhabitats and diel downstream migration of young grayling (*Thymallus thymallus* L.) *Freshwater Biology*. **26,** 365-376.

Bardonnet, A., Gaudin, P., Grolet, O. and Thorpe, J. E. (1993) Diel rhythm of emergence and of first displacement downstream in trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*) and grayling (*Thymallus thymallus*). *Journal of Fish Biology*. **43,** 755-762.

Beauchamp, D.A. (1990) Movements, habitat use and spawning strategies of Arctic grayling in a subalpine lake tributary. *Northwest Science*, **64** (4), 195-207.

Bishop, F. (1971) Observations on the spawning habits and fecundity of the Arctic grayling. *Progressive Fish Culturist*. 27, 12-19.

Blachuta, J., Witkowski, A. and Kokurewicz, B. (1991) An hermaphrodite grayling, *Thymallus thymallus* (L.), from the Nysa Klodzka river (Lower Silesia, Poland). *Journal of Fish Biology*. **38**, 955-957.

Bovee, K.D. (1982) A guide to stream habitat analysis using the instream incremental methodology. *U.S. Fish and Wildlife Service.* Fort Collins, CO.

Bradley, T. (1894) *Guide to the Rivers of Yorkshire.*

Brannan, E. (1987) Influence of photoperiod and temperature on hatching and emergence of Baltic salmon (*Salmo salar*). *Canadian Journal of Zoology.* **65**, 1503-1508.

Broughton, R. (1989) *Grayling: The Fourth Game Fish.* The Crowood Press.

Brown, C.J.D. (1943) Age and growth of Montana grayling. *Journal of Wildlife Management.* **7**, 353-364.

Bruno, D.W. and Poppe, T.T. (1996) *A Colour Atlas of Salmonid Diseases.* Academic Press.

de Bruyn, M. and McCart. (1974) Life history of the grayling (*Thymallus arcticus*) in Beaufort Sea drainages in the Yukon Territory. In *Fisheries Research Associated with Proposed Gas Pipeline Routes in Alaska, Yukon and Northwest Territories*, edited by P. J. McCart, p.39. Canadian Arctic Study Ltd., Calgary, Biological Report Series, 15 (2).

Carlstein, M. (1997) Effects of rearing technique and fish size on post-stocking feeding, growth and survival of European grayling, *Thymallus thymallus* (L.). *Fisheries Management and Ecology.* **4** (5), 391-404.

Carlstein, M. and Eriksson, L.O. (1996) Post-stocking dispersal of European grayling, *Thymallus thymallus* (L.) in a semi-natural experimental stream. *Fisheries Management and Ecology.* **3** (2) 143-155.

Carlstein, M., Jansson, E., Ljungberg, O. and Svensson, K.M. (1990) Ulcerative disease of grayling (*Thymallus thymallus*) infected with *Aeromonas salmonicida* var. *achromogenes.* Poster paper. *International Scientific Conference*; Bacterial *Diseases of Fish 26-29 June*, University of Stirling, Scotland.

Carmie, H. and Cuinat, R. (1984) *Elevage de l'Ombre commun. Premièrs résultats obtenus à la salmoniculture du Conseil Supérieur de la Pêche à Augerolles.* Rapp. CSP 6ème Dél Région (Auvergne Limousin).

Carmie, H., Morelet, B., Maisse, G., Jonard, L. and Cuinat, R. (1985) Observations sur la reproduction artificielle de l'Ombre commun (*Thymallus thymallus*). *Bull. Fr. Peche Piscic.*, **296**, 2-16.

Canning, E.U., Curry, A., Feist, S.W., Longshaw, M., and Okamura, B. (1999) *Tetracapsula broyosalmonae* N.Sp for PKX organism, the cause of PKD in Salmonid Fish. *Bulletin of the European Association of Fish Pathologists,* **19**, p5.

Chubb, J.C. (1977) *A Review of the Parasite Fauna of the Fishes of the River Dee System.* A Report for the Central Water Planning Unit. University of Liverpool.

Cihar, J. (1998) *Freshwater Fish.* Blitz Editions.

Clark, R.A. (1992) Influence of stream flows and stock size on recruitment of Arctic Grayling (*Thymallus arcticus*) in the Chena River, Alaska, Canada. *Journal of Fisheries Science.* **49**, 1027-1034.

Cowx, I.G. (1991) *Catch Effort Sampling Strategies - Their Application in Freshwater Fisheries Management.* Oxford: Fishing News Books, Blackwell Scientific Publications.

Craig, P.C. and Poulin, V.A. (1974) Life history and movements of grayling (*Thymallus arcticus*) and juvenile Arctic Char (*Salvelinus alpinus*) in a small tundra stream tributary to the Kavik River, Alaska. In *Life histories of anadromous and fresh water fishes in the western Arctic* (ed. P. J. McCart). p 54. Canadian Arctic Gas Study Ltd., Calgary, Biological Report Series **20** (2).

Craig, P.C. and Poulin, V.A. (1975) Movements and growth of Arctic Grayling (*Thymallus arcticus*) and juvenile Arctic Char (*Salvelinus alpinus*) in a small Arctic stream, Alaska. *Journal of Fisheries Research Board of Canada.* **32** (5).

Crisp, D.T. (1996) Environmental requirements of common riverine European salmonid fish species in fresh water with particular reference to physical and chemical aspects. *Hydrobiologia.* **323**, 201-221.

Crofts, S. (1994) *Grayling in the Upper Don-A Ten-Year Review.* Unpublished report.

Crundwell, C.R. (1991) *A study of the Grayling, Thymallus thymallus on the River Test at Leckford and Longparish, Hampshire, England.* Unpublished Diploma. Sparsholt College, Hampshire.

Dahl, J. (1962) Studies on the biology of Danish stream fishes. The food of grayling (*Thymallus thymallus*) in some Jutland streams. *Meddr. Danm. Fisk. –og Hauun-deis.* **3**, 1370-1373.

Darchambeau, F. and Poncin, P. (1997) Field observations of the spawning behaviour of European grayling. *Journal of Fish Biology.* **51**, 1066-1068.

Davies, E.H. (1967) *Parasite Fauna of Fish of the River Lugg, a Tributary of the River Wye, Herefordshire.* Unpublished Ph.D. Thesis. University of Liverpool.

Deering, C. (1751) *The History of Nottingham.* S.R. Publishers.

Degerman, E., Naslund, I. and Sers, B. (In press) Stream habitat use and diet of juvenile (0+) brown trout and grayling in sympatry. *Ecology of Freshwater Fish.*

Denham, K.L. and Long, J. (1998) Occurrence of *Gyrodactylus thymalli* Zitnam, 1960. On grayling *Thymallus thymallus* (L) in England. *Journal of Fish Disease*, **22**, 247-252.

Døving, K.B., Selset, R. and Thomnesen, G. (1980) Olfactory sensitivity to bile acids in salmonid fishes. *Acta Physiologica Scandinavica.* **108**, 123-131.

Duigan, C., Millband, H. and Gritten, R. (1998) The Llyn Tegid Symposium: The ecology, conservation and environmental history of the largest natural lake in Wales. *Freshwater Forum*, **10**, 64-73.

Duvernay, J. (1975) Croissance, temperature et taux d'oxygene dissous letaux chez l'Ombre commun *Thymallus thymallus* (L.1758). *D.E.A. Universities of Lyon* **I**, 1-27

Elliott, J.M. (1986) Spatial distribution and behaviour movements of migratory trout, *Salmo trutta*, in a Lake District stream. *Journal of Animal Ecology,* **55**, 907-922.

Elliott, J.M., Humpesch, U.H. and Hurley, M.A. (1987) A comparative study of eight mathematical models for the relationship between water temperature and hatching time of eggs of freshwater fish. *Archiv für Hydrobiologie.* **109**, 257-277.

Ellison, M. (1992) A *Comparative Study of Growth Rates in Populations of European Grayling (Thymallus thymallus) Sampled from Wessex Rivers.* Unpublished Diploma. Farnborough College of Technology.

Eloranta, A. (1985) Grayling (*Thymallus thymallus* (L.)) in the lower part of the Rautalampi watercourse, Finnish Lake District. *Verhandlungen Internationale Vereinigung für theoretische und angewandte Limnologie.* **22**, 2555-2559.

Environment Agency. (1982) *Report on Fish Population Survey of the Leintwardine Fishery.*

Environment Agency. (1984) *Fisheries Survey of the River Wharfe-Summer 1984.* Fisheries Science Report 56/85.

Environment Agency. (1990) *Fish populations of the River Dibb-October/November 1990* Fisheries Science Report 30/91.

Environment Agency. (1991) *A Fisheries Survey of the River Witham; Easton Park to Aubourn, May – October 1991.*

Environment Agency. (1992a) *A Fisheries Survey of the Great Eau, Long Eau, Maplesthorpe Cut, Greyfleet Drain and South Dyke, April-September1992.*

Environment Agency. (1992b) *Fish Population Survey River Stour, 1992.*

Environment Agency. (1992c) *Fisheries Survey Report of the River Medway.*

Environment Agency. (1992d) *Lower Severn Area-Fisheries Report- River Avon.*

Environment Agency. (1993) *Fish Population Survey of the Little Ouse Blo Norton to Brandon. February/March 1993.* Fisheries Science Report CFR 35/93.

Environment Agency. (1994a) *Fish Population Surveys in the River Wharfe at Ilkley 1972-1993.* Fisheries Science Report 3/94.

Environment Agency. (1994b) *Fisheries Survey of the River Wharfe 1993/94.* Fisheries Science Report 74/94.

Environment Agency. (1994c) *Rolling Programme Surveys of the River Hull 1990 and 1993/4*. Fisheries Science Report 66/94.

Environment Agency. (1995a) *A brief note on age, length and growth characteristics of grayling caught from the River Nidd, Ramsgill, on April 20th 1995, as part of Bolton Abbey grayling. production project*. Project Report 25/95.

Environment Agency. (1995b) *Fish Population Survey, River Ise 1995*.

Environment Agency. (1995c) *A Fisheries Survey of the Great and Long Eau River System 1995*.

Environment Agency. (1996a) *Fish population survey. River Chater and Morcott Brook 1996*.

Environment Agency. (1996b) *Fisheries Survey of the River Wharfe and Mill Goit at Pool-in-Wharfedale, July 1995*. Fisheries Science Report D16/96.

Environment Agency. (1996c) *Fisheries Survey of the Lower Holbeck, 20th July 1995*. Fisheries Science Report D14/96.

Environment Agency. (1996d) *River Blyth Brown Trout Survey Report*.

Environment Agency. (1996e) *River Gwash. Fish Population Survey*.

Environment Agency. (1996f) *Restoration of Riverine Trout Habitats. A Guidance Manual*. The Game Conservancy Trust. Fisheries Technical Manual 1. Report W18.

Environment Agency. (1997a). *900 Years of the Don Fishery*.

Environment Agency. (1997b) *Environmental Effects of Drought and Abstractions on River Wharfe Fisheries, Summer 1996*. Project Reference D14/97.

Environment Agency. (1997c) *River Dee Grayling Population Status*. Technical Memo EAN/97/TM26. Project Reference FF73996.

Environment Agency. (1998a) *Analysis of Angling Match Returns 1998*. Fisheries Science Report 11/99.

Environment Agency. (1998b) *An Investigation into the Impact of Flow Regulation on Fisheries of the River Dee*. Final Report. APEM.

Environment Agency. (1998c). Economic Evaluation of inland Fishing in England and Wales. Case Study Report: Thames, Teifi and Leeds. McAlister, Elliot & Partners Ltd. For the National Coarse Fisheries Centre. (R&D Technical Project No. W2/039).

Environment Agency. (1999a) *River Ise Habitat Assessment for Grayling*.

Environment Agency. (1999b) *Application of PHABSIM on the Rivers Dibb, Wharfe and Ure*. Time Series Application Report. AK221/65/DG/018.

Environment Agency (1999c) *National Fisheries Laboratory Category 2 Parasite Guide*. Unpublished document.

Fausch, K.D. (1984) Profitable stream positions for salmonids: relating specific growth rate to net energy gain. *Canadian Journal of Zoology*, **62**, 441-451.

Fabricius, E. and Gustafson, K.J. (1955) Observations on the spawning behaviour of the grayling, *Thymallus thymallus* (L.). *Reports of the Drottningholm Freshwater Research Institute*. **36**, 75-103.

Feldmuth, C. R. and Eriksen, C.H. (1978) An hypothesis to explain the distribution of native trout in a drainage of Montana'a Big Hole River. *Verh. Interat. Verein. Limnol.* **20**: 2040-2044.

Frenz, C., Klinga, H. and Schumacher, H. (1997) Interim report on the factors affecting grayling (*Thymallus thymallus* L.) and brown trout (*Salmo trutta* L.) populations in the River Lenne (North Rhine – Westphalia): Habitats, cormorants and angling. (Zwischenbericht zur situation von pesche (*Thymallus thymallus* L.) und bachforelle (*Salmo trutta* L.) in der Lenne (NRW) – Lebensraum, kormorane und angelfischerei. *Nat – Landschaft*. **72** (9), 401-407.

Gardiner, R. (1989) The distribution of grayling. In *Grayling: The Fourth Game Fish*. (ed. Broughton, R) p24. The Crowood Press: Wiltshire.

Gardiner, R. (1994) Scottish grayling: History and biology of the populations. *The Journal of the Grayling Society*. Spring 1993.

Gaudin, P. and Persat, H. (1985) Rythmes d'émergence et de dévalaison des alevins d'ombre commun (*Thymallus thymallus*). *Compte rendu hebdomadaire des Séances de l'Academie des Sciences*, **301**, 843-846.

Gerrish, C.S. (1934a) Notes on the feeding of trout and grayling in chalk streams-I. *Game and Gun and the Anglers Monthly*. **Volume II**, 234-237.

Gerrish, C.S. (1934b) Notes on the Feeding of trout and grayling in chalk streams-II. *Game and Gun and the Anglers Monthly*. **Volume II**, 292-296.

Gibbins, C.N. and Heslop, J. (1998) An evaluation of inter-basin water transfers as a mechanism for augmenting salmonid and grayling habitat in the River Wear, North-East England. *Regulated Rivers: Research and Management*, **14**, 357-382.

Giles, N. (1998). Malmesbury Avon habitat improvement research project 1997/998. Dr. Nick Giles and Associates. Second Annual Report. p28.

Godin, J.G.J. (1982) Migration of salmonid fishes during early life-history phases: daily and diurnal timing. In: *Salmon and Trout Migratory Behaviour Symposium* edited by E.L. Brannon and E.O. Salo, 22-51. Seattle, WA: University of Washington Press.

Gordon, N.D., McMahon T.A. and Finlayson B.L. (1992). (Stream hydrology: an introduction for ecololgists), p521. J. Wiley & Sons.

Gonczi, A.P. (1989) A study of physical parameters at the spawning sites of the European grayling (*Thymallus thymallus* L.). *Regulated rivers: Research and Management,* **3**, 221-224.

Greenberg, L.A. (1999) Effects of predation and discharge on habitat use by brown trout, *Salmo trutta* and grayling, *Thymallus thymallus,* in artificial streams. *Archiv für Hydrobiologie.* **145**, (4), 433-446.

Greenberg, L., Svendsen, P. and Harby, A. (1996) Availability of microhabitats and their use by brown trout (*Salmo trutta*) and grayling (*Thymallus thymallus*) in the River *Vojman, Sweden. Regulated rivers: Research and Management,* **12**, 287-303.

Grimble, A. (1913) *The Salmon Rivers of England and Wales.* London: Kegan Paul, Trench, Trubner & Co Ltd.

Gustafson, K.J. (1948) Movements and growth of grayling. *Report of the Institute of Freshwater Research, Drottningholm,* **29**, 35-44.

Gustafson-Marjanen, K.I. and Dowse, H.B. (1983) Seasonal and diel patterns of emergence from the redd of Atlantic salmon (*Salmo salar*) fry. *Canadian Journal of Fisheries and Aquatic Sciences,* **40**, 813-817.

Haugen, T.O., and Rygg, T.A. (1996) Food- and habitat-segregation in sympatric grayling and brown trout. *Journal of Fish Biology.* **49,** 301-318.

Hayne, D.W. (1949) Calculation of size of home range. *Journal of Mammals*, **30**, 1-18.

Hellawell, J.M. (1969) *A study of the Chub (Squalius cephalus* L.*), the Dace (Leuciscus leuciscus* L.*), the Roach (Rutilus rutilus* L.*) and the Grayling (Thymallus thymallus* L.*) of the Afon Llynfi and the River Lugg, Tributaries of the River Wye, Herefordshire.* Unpublished Ph.D. Thesis, University of Liverpool.

Hellawell, J.M. (1971) The food of the grayling *Thymallus thymallus* (L.) of the River Lugg, Herefordshire. *Journal of Fish Biology,* **3** (2) 187-197.

Henricson, J. (1980) Increased mortality rate in char *Salvelinus alpinus,* caused by Infections of *Diphyllobothrium dentriticum. ISACF Workshop on Arctic Char, Askoe laboratory, Stockholm (Sweden) October.*

Henriksson, J. and Müller, K. (1979) Stream regulation in Sweden with some examples from Central Europe. In: *The Ecology of Regulated streams* (ed. J.V. Ward and J.A. Stanford). pp183-199. New York and London: Plenure Press.

Hobbs, D. (1937) Natural reproduction of quinnat salmon, brown trout and rainbow trout in certain New Zealand waters. *Fish. Bull. New Zealand Marine Department.* **6**, 1-104.

Hoffmann, R., Berg, R., Blank, S., Dehus, P., Gramm, R. and Rösch, R. (1995) Fische in Baden-Württenberg-Gefährdung und Schutz. *Min. für Ländlichen Raum, Ernährung, Landwirtschaft und Forster*. Baden-Württemberg, Stuttgart.

Hubert, W.A., Helzner, R.S., Lee, L.A. and Nelson, PC. (1985) Habitat suitability index models and instream flow suitability curves: Arctic grayling riverine populations. Fish and Wildlife Service. *Biological Report* **82** (10.110). US Department of the Interior.

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

Hughes, N.F. (1992) Ranking of feeding positions by drift-feeding Arctic Grayling (*Thymallus arcticus*) in dominance hierarchies. *Canadian Journal of Fisheries and Aquatic Sciences,* **49**, 1994-1998.

Hughes, N.F. (1998) Use of whole-stream patterns of age-segregation to infer the interannual movements of stream salmonids: A demonstration with Arctic grayling in an interior Alaskan stream. *Transactions of the American Fisheries Society*, **127**: 1067-1071.

Huitfeldt-Kaas, H. (1927) *Studier Over Aldersforhalde og Veksltyper hos Horske Ferskvannsfiskar*. Oslo.

d'Hulstere, D. and Philippart, J.C. (1982) Observations sur le comportement d'eclosion et de post-eclosion chez l'ombre commun, *Thymallus thymallus* (L.). Observations on the hatching and post-hatching behaviour of the European grayling, *Thymallus thymallus* (L.). *Cahiers de Ehologie et Applications*. **2** (1), 63-80.

Humpesch, U.H. (1985) Gibt es optimale Wasswetemperatruen fuer die Erbruetung von Salmoniden und Thymallideneiern? (Is there an optimum temperature for hatching success of salmonid and grayling eggs?). *Oesterr. –Fisch.* **38** (10), 273-279.

Hutton, J.A. (1923). Something about grayling scales. *Salmon and Trout Magazine. London*, January 1923, 3-8.

Ibbotson, A.T. (1993) *Some Aspects of Fish Habitat Relationships in Southern English Chalk Streams*. Unpublished Ph.D. Thesis. University of London.

Ibbotson, A.T. (1999). Environment Agency R&D Project No. W2-017.

Jacklin, T.E. (1998). *Estimation of the grayling (Thymallus thymallus,* L.*) population in the River Dove, U.K., using anglers' catches*. Environment Agency, Midlands Region, Upper Trent Area.

Jagsch, A., Kossner, G., Weiss, S., Gollmann, P. and Kainz, E. (In press) Untersuchungen zu lokaler Anpassung, Gefahrdung und Schutz der Asche (*Thymallus thymallus*) in drei Gewassern in Oberosterreich. *Osterreichs Fischerei*, **53** (4).

Jankovic, D. (1964) *Synopsis of biological data on European grayling (Thymallus thymallus (Linnaeus) (1758))*. No. 24, F16/S24 (Rev. 1). FAO Fisheries Synopsis.

Jankovic, D. (1978) Effects of anthropogenic factors on the zonal distribution of fishes in the Danube River System in Serbia (Yugoslavia). *Verhandlunger Internationale Vereinigung für theoretische und ungewandte Limnologie*. **20** (4), 2150-2153.

Jervis, L. (1999) Sheep Dip and Bull Shit. *The Journal of the Grayling Society*. Spring. 25.

Jervis, L. and Hirst, S. (1997). Grayling in South West Britain. Part 1. *The Journal of The Grayling Society.* Autumn 1997. 33-41.

Jervis, L. and Hirst, S. (1998). Grayling in South West Britain. Part 2. *The Journal of The Grayling Society.* Spring 1998. 28-31.

Jones, J.W. (1953) Part I. Scales of roach. Part II. Age and growth of the trout, grayling, perch and roach of Llyn Tegid (Bala) and the roach of the River Birket. *Fisheries Investigations. London.* (Ser I), **5**, (7), 1-8.

Jungwirth, M. (1996) Bypass channels at weirs as appropriate aids for fish migration in rhithral rivers. *Regulated Rivers: Research and Management*, **12**, 483-492.

Kabata, Z. (1979) *Parasitic Copepoda of British Fishes*. The Ray Society.

Keay, I.S. (1990). *Some Aspects of the feeding ecology of grayling Thymallus thymallus* L. *in the River Frome*. Institute of Freshwater Ecology.

Kettler, S. (1987) *Histological survey of Bacterial Kidney Disease (BKD) of salmonid especially related to grayling (Thymallus thymallus).* Ludwig-Maximilians-Univ., Muenchen (FRG). Tieraerztl. Fak. (In German)

Kraiem, M.M. and Duvernay, J. (1981) Comparison des temperatues limites de nage chez deux populations d'ombres communs *Thymallus thymallus* (L.). d'Origine differente (Baviere et Scandinavie). *Cybium*, **5** (3), 45-49.

Kraiem, M.M. and Pattee, E. (1980) La tolerance a la temperature et au deficit en oxygene chez le Barbeau (*Barbus barbus* L.) et d'autres especes provenant des zones piscicoles voisines. *Archiv fürHydrobiologie*. **88**, 2, 250-261.

Kristiansen, H. and Døving, K.B. (1996) The migration of spawning stocks of grayling, *Thymallus thymallus*, in Lake Mjosa, Norway. *Environmental Biology of Fishes*. **47**, 43-50.

Kruse, T. (1959) Grayling of Grebe Lake. Yellowstone National Park, Wyoming. *US. Fish and Wildlife Services Fisheries Bulletin*, **149**. 59: 305-351.

Laffineur, B., Delvingt, W. and Lamotte, A. (1992) *Improvement of grayling culture (Thymallus thymallus L.).* Namur-Belgium Min-Reg.-Waloone,-Dir.-Gen.-Ressour.-Nat-Environment (in French).

LaPerriere, J.D. and Carlson, R.F. (1973) Thermal tolerances of interior Alaskan Arctic grayling, *Thymallus arcticus. Institute of Water Resources Report*. IWR-46. Univ. Alaska, Fairbanks.

Leman, H. (1994) *A Study to See Whether Grayling (Thymallus thymallus) are Selective Feeders of Invertebrates*. Unpublished Diploma. Sparsholt College.

Libovársky, J. (1967) The spawning run of brown trout, *Salmo trutta m. fario* L., and its analysis. *Zoologicke Listy*. 16, 73-86.

Linloekken, A. (1993) Efficiency of fishways and impacts of dams on the migration of grayling and brown trout in the Gomma River System, SE Norway. *Regulated Rivers: Research and Management*. **8** (1 and 2), 145-153.

Linloekken, A. (1995) Angling pressure, yield and catch per effort of grayling, *Thymallus thymallus* (L.) and brown trout, *Salmo trutta* L. on the rivers Glomma and Rena, SE Norway. *Fisheries Management and Ecology*. **2** (4) 249-262.

Liversedge, D.B. (1982). The Distribution of Grayling in England, Wales and Scotland. First Edition. The Grayling Society. 32pp.

Liversedge, D.B. (1992). The Distribution of Grayling in England, Wales and Scotland. Updated Edition. The Grayling Society. 51pp.

Mackay, D.W. (1970) Populations of trout and grayling in two Scottish rivers. *Journal of Fish Biology*. **2**, 39-45.

MAFF. (1999) *The assessment of the effectiveness of management measures to control damage by fish-eating birds to inland fisheries in England and Wales* (McKay H., Furness R., Russell, I., Parrott, D., Rehfisch, M., Watola, G., Packer, J., Armitage, M., Gill, E., and Robertson, P.). Report to the Ministry of Agriculture, Fisheries and Food (MAFF Project VC0107). Central Science Laboratory, York 1999.

MAFF. (2000) *Salmon and Freshwater Fisheries Review*.

Magee, L. (1992) The grayling, an endangered species. *Bull. Yorkshire Naturalists Union*. **17**, 1-3.

Magee, L. (1993) A review of the grayling (*Thymallus thymallus*) in Yorkshire and some records of transfers of fish and ova. *Naturalist*. **118** (1007), 115-122.

Maitland, P.S. and Campbell, R.N. (1992) *Freshwater Fishes of the British Isles*. London: Harper Collins, The New Naturalist.

Maki-Petays, A. Vehanen, T. and Muotka, T. (In Press) *Microhabitat use age-0 brown trout and grayling: Seasonal responses to streambed restoration under different flows*. Finnish Game and Fisheries Research Institute.

Mallet, J.P., Charles, S., Persat, H. and Auger, P. (1999) Growth modelling in accordance with daily water temperature in European grayling (*Thymallus thymallus* L.). *Canadian Journal of Fisheries and Aquatic Sciences*, **56**, 994-1000.

Mallet, J.P., Lamouroux, N., Sagnes, P. and Persat, H. (2000) Habitat preferences of European grayling (*Thymallus thymallus* L.) in a medium size stream, the Ain river, France. *Journal of Fish Biology*, **56**, 1312-1326.

Mayr, E. (1968) *Animal Species and Evolution (in Russia)*. Mir Press, Moscow.

McCart, P., Craig, P, and Bain, H. (1972) Report on fisheries investigations in the Sagavanirktok River and neighbouring drainages. Report to Alyeska Pipeline Service Company, Bellvue, WA.

Meier, W., Schmitt, M. and Wahli, T. (1994) Viral haemorrhagic septicaemia (VHS) of non-salmonids. *Annual Revue of Fish Disease,* **4**, 359-373.

Michiel, P. (1992) *Float trip grayling*. B.C. Outdoors (April), 40-42.

Mills, D.H. (1971) Preliminary observations on fish populations in some Tweed tributaries. *Annual Report Tweed Commissioners.* p16-22.

Milner, N.J., Hemsworth, R.J. and Jones, B.E. (1985) Habitat evaluation as a fisheries management tool. *Journal of Fish Biology,* **27 (Supplement A)**, 85-108.

Mitenev V.K and Shyl'man B.S (1985) Eco-Geographic Analysis of the Parasites of the European Grayling, *Thymallus thymallus* (Thymallidae) in Various Parts of its Range. *Journal of Ichthyology,* **24** (5), 125-136.

Moravec. F. (1994) *Parasitic Nematodes of Freshwater Fishes of Europe*. Kluwer Academic Press.

Muller, K. (1954) Productionsbiologische Untersuchengen in Nordschwedischen Fliessgewassern. Tiel 2. Untersuchungen uber Verbreitung, Wachstum und Errahrung der Fische der Nord-schwedischen Waldregion. *Report. Institute of Freshwater Research. Drottiningholm*, **35**, 149-183.

Nagy, S. (1984) On the age, growth and food of grayling (*Thymallus thymallus L.*) in the River Bela (western Tatra mountains). Limnology of the Bela River/Limnologia Rieky Bela. Ertl,M. ed. *Laboratorium Rybarstva a Hydrobiologie Bratislava Czechoslovakia.* **4**, 301-326.

Nelson, J. S. and Paetz, M.J. (1992) *The Fishes of Alberta*, 2nd edn. Edmonton: Univ. Alberta Press.

Nordeng, H. (1961) On the biology of char (*Salvelinus alpinus*) in Salangen, North Norway. *Nytt Magasin for Zoologi*, **10**: 67-121.

Northcote, T.G. (1995) Comparative biology and management of Arctic and European grayling (Salmonidae, *Thymallus*). *Reviews in Fish Biology and Fisheries.* **5**, 141-194.

Northcote, T.G. (2000) *An Updated Review of Grayling Biology, Impacts, and Management.* Peace/Williston Fish and Wildlife Compensation Program Report No. 211.

Nykanen, M., Huusko, A. and Maki-Petays, A. (2001) Seasonal Changes in the Habitat Use and Movement of adult European Grayling (Thymallus thymallus (L.)) in a Large Subarctic River. *Journal of Fish Biology,* **58**: 506-519.

Ocvirk, J. (1992) Main health problems in grayling (*Thymallus thymallus*, Linnaeus) Culture. *Ichthyos*, **11**, 23-30 (Croatian).

Olifan, V.I. (1956) Daily feeding rhythms in the fry of the Baikal grayling and others. *Compte rendu de l'Acadomie des Sciences. USSR*, **114**, 591-593.

Parkinson, D., Philippart, J.C. and Baras, E. (1999) A preliminary investigation of spawning migrations of grayling in a small stream as determined by radio-tracking. *Journal of Fish Biology.* **55**, 172-182.

Pavlov, D.S., Nezdolii, V.K., Ostrovskii, M.P. and Fomin, V.K. (1998) Homing in the grayling *Thymallus thymallus* in the basin of the Upper Volga. *Journal of Ichthyology.* **38** (7), 552-553.

Penaz, M. (1975). Early development of the grayling *Thymallus thymallus* (Linnaeus 1758). *Acta. Sci. Nat. Acad. Sci. Bohemoslov.* **9** (11), 3-35.

Persat, H. (1996) *Threatened populations and conservation of the European grayling, Thymallus thymallus* (L. 1758*).* In '*Conservation of Endangered Freshwater Fish in Europe*'. (eds. A. Kirrchofer and D. Hefti). Basel Switzerland Birkhaeuser Verlag.

Persat, H. and Patee, E. (1981) The growth rate of young grayling in some French rivers. In: *Proceedings of the International Association of Theoretical and Applied Limnology.* edited by Sladecrk, **21**, 1270-1275.

Persat, H., and Zakharia, M. E. (1993) The detection of reproductive activity of the grayling *Thymallus thymallus* (L. 1758) by passive listening. *Archiv für Hydrobiologie.* **123** (4), 469-477.

Peterson, H.H. (1968) The Grayling, *Thymallus thymallus* (L.), of the Sundsvall Bay area. *Institute of Freshwater Research, Drottingholm.* **48**, 36-56.

Poleo, A.B.S., Ostbye, K., Oxnevad, S., Anderson, R.A., Heibo, E. and Vollestas, L.A. (1997) Toxicity of acid aluminium-rich water to seven freshwater fish species: A comparative laboratory study. *Environmental Pollution*, **96** (2), 129-139.

Poncin, P. (1994) Field observations on a mating attempt of a spawning grayling, *Thymallus thymallus* with a feeding barbel, *Barbus barbus. Journal of Fish Biology.* **45**, 904-906.

Rahkonen, R. Aalto, J., Koski, P., Saerkkae, J. and Juntunen, K. (1996) Cestode larvae *Diphyllobothrium dentriticum* as a cause of heart disease leading to mortality in hatchery-reared sea trout and brown trout. *Diseases of Aquatic Organisms*, **25**, 1-2, 15-22.

Ritz, C. (1959) *A fly Fisher's Life.* Max Reinhardt.

Sagnes, P., Gaudin, P. and Statzner, B. (1997) Shifts in morphometrics and their relation to hydrodynamic potential and habitat use during grayling ontogenesis. *Journal of Fish Biology.* **50,** 846-858.

Sale, P. (1979) Habitat partitioning and competition in fish communities. In '*Predator-Prey Systems in Fisheries Management*' (eds. Stround, R .H. and Clepper, H.). pp 70-90. Sports Fishing Institute, Washington.

Satou, M., Takeuchi, H., Takei, K., Hasegawa, T., Okumota, N. and Ueda, K. (1987) Involvement of vibrational and visual cues in eliciting spawning behaviour in male himé salmon (landlocked red salmon *Oncorhynchus nerka*). *Animal behaviour*. **35**, 1556-1558.

Schmidt, D. and O'Brien, W.J. (1982) Planktivorous feeding ecology of Arctic grayling (*Thymallus arcticus*). *Canadian Journal of Fisheries and Aquatic Sciences*. **39**, 475-482.

Scott, A. (1985) Distribution, growth and feeding of postemergent grayling *Thymallus thymallus* in an English river. *Transactions of the American Fisheries Society*. **114**, 525-531.

Sempeski, P. and Gaudin, P. (1995a) Habitat selection by grayling-II. Preliminary results on larval and juvenile daytime habitats. *Journal of Fish Biology*. **47**, 345-349.

Sempeski, P. and Gaudin, P. (1995b) Etablissement de Courbes de preferences d'Habitat pour les frayeres et les jeunes stades d'Ombres commun (*Thymallus thymallus*, L.). *Bulletin Francais de la Peche et de la Pisciculture*, **337**, 277-282.

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

Sempeski, P. and Gaudin, G. (1996) Size-related shift in feeding strategy and prey-size selection in young grayling (*Thymallus thymallus*). *Canadian Journal of Zoology*. **74**, 1597-1603.

Sempeski, P. Gaudin, P. and Herouin, E. (1998) Experimental study of young grayling (*Thymallus thymallus*) physical habitat selection factors in an artificial stream. *Archiv für Hydrobiologie*. **141,** No.3 pp 321-332.

Sempeski, P., Gaudin, P., Persat, H. and Grolet, O. (1995) Diet selection in early-life stages of grayling (*Thymallus thymallus*). *Archiv für Hydrobiologie*, **132** (4), 437-452).

Severn Fishery Board. (1931) *Annual report.*

Severn Fishery Board. (1932) *Annual report.*

Severn Fishery Board. (1934) *Annual report.*

Severn Fishery Board. (1940) *Annual report.*

Severn Fishery Board. (1941) *Annual report.*

Severn Fishery Board. (1944) *Annual report.*

Severn Fishery Board. (1945) *Annual report.*

Shimura, S. and Inoue, K. (1984) Toxic effects of extract from the mouth-parts of *Argulus coregoni* Thorell (Crustacea:Branchiura) .*Bull-Jap-Soc-Fish-Nissuishi*, **50**, 4 , 729.

Shubin, P.N. and Zakharov, A.B. (1984) Hybridization between European Grayling, *Thymallus thymallus* and Arctic Grayling, *Thymallus arcticus*, in the contact zone of the species. *Journal of Ichthyology*. 24 (4), 159-163.

Solewski, W. (1963) The Grayling (*Thymallus thymallus* L.) of the Rogoznik Stream. *Acta Hydrobiologica, Krakow*, **5**, 229-243.

Sømme, S. (1935) Verst og naering hos harr og ørret (*Thymallus thymallus* L. og *Salmo trutta* L.). *Nytt Magasin for Naturidenskapene*. **75**, 187-218.

Staub, E., Egloff, K., Kramer, A., and Walter, J. (1998) The effect of predation by wintering cormorants *Phalacrocorax carbo* on grayling, *Thymallus thymallus*, and trout (Salmonidae) populations: two case studies from Swiss rivers. Comment. *Journal of Applied Ecology*. **35**, 607-610.

Stuart, T.A. (1953) Water currents through permeable gravels and their significance to spawning salmonids. *Nature*. **172**, 407-408.

Tack, S.L. (1971) Distribution, abundance and natural history of the Arctic grayling in the Tanana River drainage. *Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Report of Progress,* 1970-1971. Project F-9-3, **12** (R-I).

Tack, S.L. (1980) Migrations and distribution of the Arctic grayling in interior and arctic Alaska. *Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Report of Progress,* 1990-1980. Project F-9-12, **21** (R-I).

Uiblein, F., Jagsch, A., Kossner, G., Weiss, S., Gollmann P. and Kainz, E. (2000). Untersuchungen zu lokaler Anpassung, Gefahrdung und Schutz der Asche (Thymallus thymallus) in drei Gewassern in Oberosterreich. Osterreichs Fischerei, **53** (4), 87-165.

Valentin, S., Sempeski, P., Souchon, Y. and Gaudin, P. (1994) Short-term habitat use by young grayling, *Thymallus thymallus* L., under variable flow conditions in an experimental stream. *Fisheries Management and Ecology*, **1**, 57-65.

Vehanen, T., Yrjana, T., Huusko, A., Maki-Petays, A. and Lahti, M. (In press) *Habitat Restoration under hydropeaking: A case study to enhance grayling habitat in a large river.* Finnish Game and Fisheries Research Institute.

Vincent, R.E. (1962) *Biogeographical and Ecological Factors Contributing to the Decline of the Arctic Grayling, Thymallus arcticus (Pallas), in Michigan and Montana.* Unpublished Ph.D._Thesis. University of Michigan, Ann. Arbor MI. Univ. Microfilms Internatl., Ann Arbor, MI.

Walker, R.J. (1983) *Growth of Young-of-the-Year Salmonids in the Chena River, Alaska.* Unpublished MS. Thesis, University of Alaska, Fairbanks, Fairbanks, AK.

Wanstall, S.T,. Robotham, P.W.J. and Thomas, J.S. (1986) Pathological changes induced by *Pomphorhynchus laevis* Muller (Acanthocephala) in the gut of Rainbow Trout *Salmo gairdneri* Richardson. *Z-Parasitenk,* **72** , 1, 105-114.

Wheeler, A. (1969) *The Fishes of the British Isles and Northwest Europe.* Macmillan, London.

Whitfield, T. (1999) *The Helminth Parasites of Grayling (Thymallus thymallus) from the Rivers Test and Itchen, Hampshire. A Comparative Study.* Unpublished B.Sc. University of Southampton.

Williamson, M. (2000). Grayling, graffiti and gullability. *Journal of The Grayling Society.* Spring 2000. 36-39.

Wilson, D. (1989) Foreword. In '*Grayling: The Fourth Game Fish*' (ed. R. Broughton), p.11-12. The Crowood Press, Wiltshire.

Witkowski, A. and Kowalewski, M. (1988) Migration and structure of spawning population of the European grayling, *Thymallus thymallus* (L.) in the Dunajec basin. *Archiv für Hydrobiologie.* **112** (2), 279-297.

Witkowski, A., Blachuta, J., Kokurewicz, B. and Kowalewski, M. (1989) Changes of gonadosomatic index in *Thymallus thymallus* (L.) in annual cycle. *Acta Ichthyologica et Piscatoria.* **19**, 21-28.

Witkowski, A., Kowalewski, M. and Korkurewicz, B. (1984) Grayling. *Warsaw Pañstwowe Wydawnictwo Rolnicze I Lesne.* (in Polish).

Wizigmann, G. Baath, C. and Hoffman, R. (1980) Isolation of viral haemorrhagic septicaemia virus from fry of rainbow trout, pike and grayling, *Zentralbl.-Veterinarmed.-B.*, **27**, 1, 79-81 (in German).

Woolland, J.V. (1972) *Studies on Salmonid Fishes in Llyn Tegid and the Welsh Dee.* Unpublished Ph.D. Thesis. University of Liverpool.

Woolland, J.V. (1986a) Grayling in the Welsh Dee. *Journal of the Grayling Society.* **Spring**, 17-20.

Woolland, J.V. (1986b) Grayling in the Welsh Dee Part 2, Movements. *Journal of the Grayling Society.* **Autumn**,. 35-37.

Woolland, J.V. (1987) Grayling in the Welsh Dee Part 3, Feeding. *Journal of the Grayling Society.* **Spring**, 15-20.

Woolland, J.V. (1988) The feeding relationships of grayling and trout in the Welsh Dee. *Journal of the Grayling Society*, **Spring**, 28-29.

Wootton, R.J. (1990) *Ecology of Teleost Fishes.* Chapman and Hall. Fish and Fisheries Series 1.

Yorkshire Water Authority. (1980) *Electrofishing survey of the West Beck, October and November 1979.*

Yorkshire Water Authority. (1982a) *A further electrofishing survey of the West Beck, October and November 1982*. Fisheries Science Report 38/83.
Yorkshire Water Authority. (1982b) *Electrofishing survey of the West Beck, January and February 1982*. Fisheries Science Report 40/82.

Yorkshire Water Authority. (1984a) *Rolling programme fisheries survey of the River Hull, October 1984*. Fisheries Science Report 59/85.

Yorkshire Water Authority. (1984b) *Grayling removals from the West Beck 1983 and 1984*. Fisheries Science Report 6/84.

Zeh, M. and Donni, W. (1994) Restoration of spawning grounds for trout and grayling in the River High-Rhine. *Aquatic Sciences*, **56/1**, 1994.