European Grayling Conservation, Ecology & Management

A Practical Conservation Guide for the United Kingdom

A Grayling Research Trust Publication

Preface and Acknowledgments

The Grayling Research Trust (GRT) was formed in 1994 to facilitate study and research related to grayling (*Thymallus spp*), their habitats, ecology, associated water quality and environment. The Trust promotes the awareness of grayling populations, the results of recent grayling research, and the need for their conservation**.**

Despite grayling being a member of the salmon family and having a “distinct” river zone assigned to it, there is less understanding of their ecology and management requirements compared to brown trout (*Salmo trutta*) and salmon (*Salmo salar*). However, this gap is gradually diminishing as interest in the species and its fisheries accelerates.

This conservation guide concentrates on issues specific to grayling and highlights some of the excellent research and advances in grayling management undertaken in the UK since 2001. However, topics with wider implications, especially for trout and salmon, such as habitat management and monitoring, also feature strongly. Also highlighted are areas of strength and gaps in our knowledge and management of the species. This guide describes the habitat requirements of grayling and how some of the relevant parameters can be measured. Detailed case studies are included, some of which illustrate the value and use of angling data at local, regional and national levels in grayling management and conservation.

About the Guide

The guide is multi-authored and has been produced with the intention of informing clubs, fisheries, and organisations such as The Grayling Society, Wild Trout Trust and River Trusts about the need for grayling conservation as pressures increase on UK aquatic ecosystems. It describes some of the management techniques that can be adopted to protect the future of the European grayling and its fisheries. Staff with some knowledge of grayling ecology within the Environment Agency, Natural Resources Wales & Scottish Government (in England, Wales & Scotland) should find the document informative and of use in protecting and safeguarding the future of UK populations - it is not a panacea but should help to guide the reader, be they fisheries professional or keen amateur, in the direction of useful knowledge, technical advice and practical assistance.

A river assessment checklist and simple flowchart in the appendices, should help to identify potential issues causing / contributing to declining populations or life-cycle bottlenecks.

Authors:

Rich J. Cove
Ryan J. Taylor
Ross Gardiner

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Introduction

Grayling (*Thymallus spp*) are a group of freshwater fish species distributed across parts of the Northern hemisphere. The presence of an adipose fin places them within the Salmonidae (salmonid) family - subfamily Thymallinae. They are typically similar in size to wild river brown trout with the largest UK specimens reaching a weight of around 2kg. The largest species is the Mongolian grayling *(Thymallus brevirostris)*; one form of which grows to over 4kg.

The European grayling *Thymallus thymallus* is familiar to game and coarse anglers; it is a well-known and easily recognizable species that often features in anglers' autumn and winter catches. However, there is a misperception that grayling have identical habitat and feeding requirements to brown trout simply because they are often found co-existing in the same stretches of river.

European Legislation

The European grayling is listed as an Annex V species in the *Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitats Directive)*. This means that their exploitation must be compatible with maintaining grayling populations at a favourable conservation status. There is an obligation to report to Europe on their conservation status. The most recent reports are for 2007-2012 and cover England and Wales http://jncc.defra.gov.uk/page-6391. The conservation of current grayling populations is important, and many organisations are involved in trying to maintain and improve the status of UK grayling; unfortunately, some populations are currently in a state of decline. Across mainland Europe, although not in danger of extinction, the species is endangered in some areas at the population scale. They persist mainly in river stretches of secondary importance that are isolated from one another (Persat, 1996).

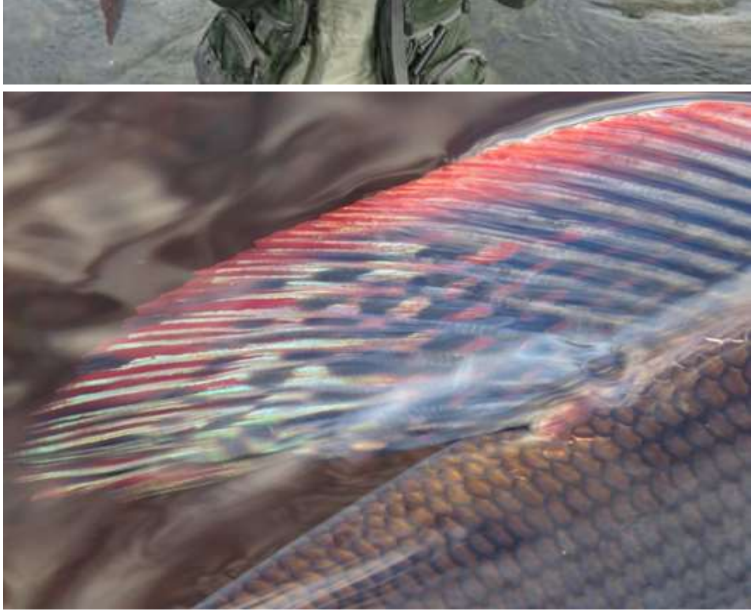
The international organisations, The Grayling Research Trust and The Grayling Society foster the protection and preservation of the grayling and its habitat; promoting sustainable angling for the species and actively encouraging the practice of catch and release by anglers.

Grayling Species

There has been confusion concerning the diversity of grayling throughout the distribution range of the genus. Some newly described species have received little international attention, whereas other names commonly occur in the literature, although modern investigations based on morphology or genetics fail to reveal their existence. Dr. Steven Weiss, a leading researcher in grayling taxonomy, has provided the following list of 10 species of grayling for which there is strong data support, and further sub-species listed as such due to minimal genetic divergence from their most closely related relative.

1. *Thymallus arcticus* (Pallas, 1776) - Arctic grayling
2. *Thymallus baicalensis* (Dybowski, 1874) - Baikal grayling
    2.1 *Thymallus baicalensis baicalensis* (Dybowski, 1874) - Baikal black grayling
    2.2 *Thymallus baicalensis nigrescens* (Dorogostaisky, 1923) - Khovsgol grayling
3. *Thymallus baicalolenensis* (Matveyev, Samusenok, Pronin & Tel'pukhovsky, 2005) - Lena grayling
4. *Thymallus burejensis* (Antonov, 2004) - Bureya grayling

5. *Thymallus brevirostris* (Kessler, 1879) - Mongolian grayling
6. *Thymallus grubii* (Dybowski, 1869) - Amur grayling
    - 6.1 *Thymallus grubii grubii* (Dybowski, 1869) - Upper Amur grayling
    - 6.2 *Thymallus grubii flavomaculatus* (Knizhin, Antonov & Weiss, 2006) - Yellow-spotted grayling
7. *Thymallus nikolskyi* (Kaschenko, 1899) - Upper Ob' grayling
8. *Thymallus svetovidovi* (Knizhin & Weiss, 2009) - Upper Yenisei grayling
9. *Thymallus thymallus* (Linnaeus, 1758) - European grayling
10. *Thymallus tugarinae* (Knizhin, Antonov, Safronov & Weiss, 2007) - Lower Amur grayling



Origin of UK Grayling

At the peak of the last glacial period over 20,000 years ago, ice sheets covered most of Great Britain, extending from North Yorkshire in the east to North Wales in the west, with a further tongue of ice pushing south through Wales. Around this time, much of what is now the North Sea was tundra or ice-covered land. The River Rhine discharged to the south west through what is now the English Channel, with the major rivers of eastern England at times as far north as the Humber forming tributaries. This remained the main drainage system of what is now the southern North Sea until rising sea levels isolated Great Britain from Europe several thousand years ago. Although there is a broadly well-established understanding of the flooding of the North Sea following the last glacial, there is still much uncertainty over the details, particularly with regard to changes in drainage patterns and connectivity.

It is now known from various genetic studies that, although conditions would have been too cold for any freshwater fish life to have existed at the peak of the last glacial anywhere in the British Isles, grayling continued to survive in refuges in the northern part of what is now continental Europe and grayling from these refugia colonised parts of Great Britain via watercourses which no longer exist following the flooding of the North Sea.

Grayling scales found at archaeological sites in Yorkshire, Northamptonshire and Herefordshire, and records in early written accounts, strongly support European grayling being native at least to rivers draining into the Humber Estuary, the Welsh Wye and probably the Hampshire Avon. Colonisation of the Welsh Wye and Hampshire Avon may have involved river ‘capture’ events as water courses merged.

The Grayling Research Trust co-sponsored a genetics study by Dawnay *et al*., (2010) (see section on UK Genetics) which showed that the grayling from different British rivers are genetically distinct from each other and cluster into four or five groups - a Severn-Welsh Wye group; a Northern group, one or possibly two Midland groups, which include the Welsh Dee; and a Southern group. These groups resulted from either isolation after colonisation, or reflect separate colonisation events by grayling which were already genetically distinct.

The study also provided valuable information on introductions of grayling. Over the past two hundred years or so, grayling have been introduced to a number of rivers that did not previously host them. In many cases, the genetic make-up of introduced populations matched historical records of their stock origin or, in the absence of stocking records, could be used to help pinpoint their likely source area (see below). It is likely that, in time, the picture will become more refined by further sampling, new methods of genetic analysis, better understanding of the past connectivity of rivers, and improved information on the colonisation history of other freshwater fish species.

Wilson (1963) provided a detailed account of many of the grayling introductions and the following paragraphs are adapted, and expanded, from this:

Davy (1818) recorded that grayling were not present in the River Test in 1808 and that they had been taken from the Hampshire Avon and liberated into the Test, other records suggesting that this took place in 1816.

Grayling were first introduced into Scottish rivers in December 1855, when 36 two-year-old fish from the Derbyshire Derwent were sent by rail from Rowsley to Abington to stock the River Clyde. Then on April 13th 1857, 20,000 ova were obtained from grayling netted from the Derbyshire Wye at Bakewell, fertilised, placed in wine bottles and dispatched the same night by train to Abington, where facilities had been prepared for their reception.

Some grayling were placed in a burn-fed pond on Lord John Scott's dairy farm at Monteviot. They escaped when a dam was accidently breached and became established in the Teviot and spread upstream and downstream into the Tweed and the Leader, and ultimately into the wider Tweed system. Grayling in the Ayr and Irvine (now extinct in the latter) probably originated from the nearby Clyde and/or Nith. However, the study of Dawnay *et al*., (2010) indicates that the River Annan grayling population - which appeared about the same time as those in the Ayr and Irvine, probably derives from the Severn-Welsh Wye group, although the details of this introduction are unknown.

Attempts to introduce grayling, as fry, into the main Thames in 1859 and 1860, were a failure, but fish migrated upstream and established in the Windrush. In 1864 a move to establish grayling in Walton's beloved Lee, by introducing 1,500 fry into stretches three miles above Hertford, also failed. Grayling were introduced in 1886 to the Lowman, a tributary of the Exe, and they spread to the incoming Barle. Attempted grayling introductions into the Tass and other tributaries of the Yare in 1870 failed but were successful in the Kennet. Introductions in 1880 into the Eden, the Tay and Yorkshire Esk were also successful.

Stockings didn't always go according to plan; grayling introduced into the Tay at Kenmore by Lord Breadalbane dropped downstream and established an early stronghold in the Isla, prior to spreading more widely across the Tay system. A tank of fry received by rail by a local farmer and emptied into the river over a church wall at Musgrave was intended to establish grayling in the higher reaches of the Eden, but a huge flood the following spring took them down into Appleby. From there, they spread downstream for 20 miles into the Eamont, and Lyvenett, and then back upstream to their starting location.

The first introductions into the Whitby Esk of 60 large adult grayling obtained from the Costa were unsuccessful, but others introduced above and below Lealholm by Sir Francis Ley in 1890 became so successful that anglers were permitted to kill them in and out of season. Later however, they were almost wiped out by a huge flood.

In 1900, grayling were successfully introduced into the lower reaches of the Tees and upper reaches of the Durham Derwent which was followed by introductions into the Itchen in 1901 and Tamar in 1919. In the early 1930s, 5,000 fish were introduced into the Kennet and Avon canal. These survived but appeared unable to recruit because of unsuitable spawning habitat.

In the mid 1980s, adult grayling were transferred from the River Lambourn (Berkshire) into the Rivers Taff and Rhymney (south Wales), where they have established self-sustaining populations.

There are further details on the history of grayling in Scottish rivers in Gardiner (1993) and since that paper was published, grayling have also become well-established in the Water of Leith, River Teith and River Forth downstream of this, and in the lower reaches of the Perthshire River Garry.

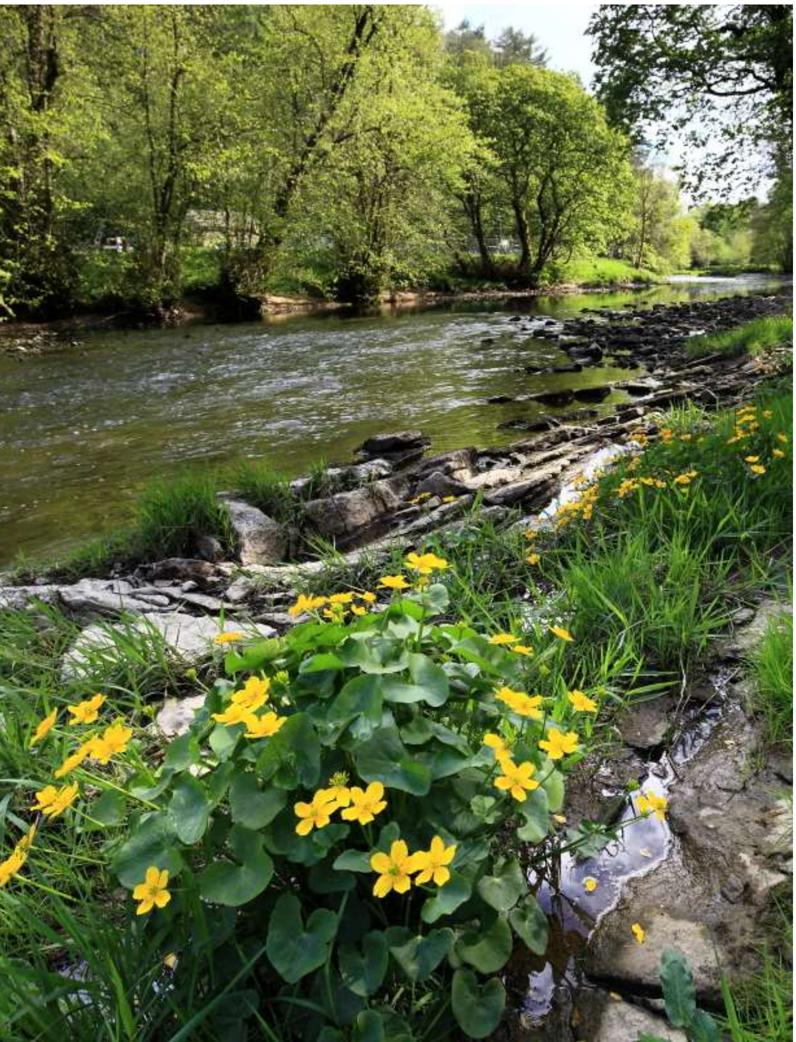
Mapped information on the spatial distribution of grayling in England and Wales can be found in Ibbotson *et al*., (2001) with little change of distribution since publication. A list of current UK rivers where grayling are present is given in Appendix I.

European Grayling Ecology

Zonation

More specifically in the UK than mainland Europe (where, in the case of the latter, temperature can play a more crucial role in fish distribution than gradient), rivers can be divided into four zones based on physical, chemical and biological qualities associated with different fish habitat preferences. These zones are termed the ‘trout’, ‘grayling’, ‘barbel’ and ‘bream’ zones (Huet, 1959). The most important factor dictating zones is gradient, the gradient of the “grayling zone” is typically 5.7m/km. However, stream width is also a key factor as wider streams have faster flows for any particular gradient. In addition, adult grayling and barbel (*Barbus barbus*) are rarely found in streams of less than 5m wide even when the gradient is suitable.

Zone	Definition
Trout	Upland streams with very steep gradients; water cool and well oxygenated; riverbed largely comprised of rock, boulders and pebbles.
Grayling	Further downstream, river wider, water cool and well oxygenated, steep gradients. Riverbed of gravel and sand. Riffles and rapids separated by pools and runs.
Barbel	Further downstream, river wider, gentle gradients, riverbed comprises sandy / muddy silt. Water warmer and less well oxygenated.
Bream	Most downstream species, river widest, very gentle gradients, riverbed comprises fine silt. Water warmer and less well oxygenated.



Expected Fish Species Composition

	Zone			
	Trout	**Grayling**	Barbel	Bream
Gradient	Very steep	Steep	Gentle	Very Gentle
Water velocity	Very rapid	Rapid	Moderate	Slow
Type of fish fauna	Salmonid	Mixed, with salmonids predominating	Mixed, with cyprinids predominating	Cyprinids with predators
Dominant species (common name)	Brown trout Salmon (juv.)	**Grayling** Brown trout Salmon (juv.) Minnow Bullhead Stone loach	Barbel [1] Chub [1] Dace [1] Gudgeon [1] Bleak [1] Rudd [2] Roach [2] Perch [3] Pike [3] Eel [3]	Rudd [2] Roach [2] Perch [3] Pike [3] Eel [3] Tench [4] Bream [4] Silver bream [4] Carp [4]
Uncommon species	Minnow Bullhead Stone loach	Barbel [1] Chub [1] Dace [1] Gudgeon [1] Bleak [1] Rudd [2] Roach [2] Perch [3] Pike [3] Eel [3]	**Grayling** Brown trout Salmon (juv.) Minnow Bullhead Stone loach Tench [4] Bream [4] Silver bream [4] Carp [4]	Barbel [1] Chub [1] Dace [1] Gudgeon [1] Bleak [1]

[1] Cyprinids of running water [2] Complementary cyprinids [3] Complementary predators
[4] Cyprinids of still water

Stillwaters / Lakes

Unlike parts of Scandinavia where grayling are fairly common in stillwaters, they are known to be well established in only two United Kingdom stillwaters, Llyn Tegid (Bala Lake) in North Wales (probably native) and Gouthwaite reservoir in the Nidd catchment, Yorkshire, England (impounded).

Life Cycle & Habitat Requirements

Key River Habitat Zones

It is a common misconception that grayling have the same habitat requirements as brown trout. Grayling have specific requirements for their various life-stages; these can be divided into three categories (Sempeski *et al.,* 1998):

i. Dead zone; marginal areas with the slowest flow rate
ii. Transition zone; between the Dead zone and Main channel with an intermediate flow rate
iii. Main channel; generally the middle of the river with the fastest flow rate

Grayling fry (particularly post-emergent), being poor swimmers, develop in the Dead zone moving to the Transition zone as their ability to withstand greater velocities increases.

Once grayling attain a length of greater than 6cm, they migrate to the Main channel.

Adult grayling move to deeper slower-flowing habitats in winter and shallower faster flowing water in spring, ready for spawning. Fish of similar age have been observed adopting shoaling behaviour (Ibbotson *et al.,* 2001).

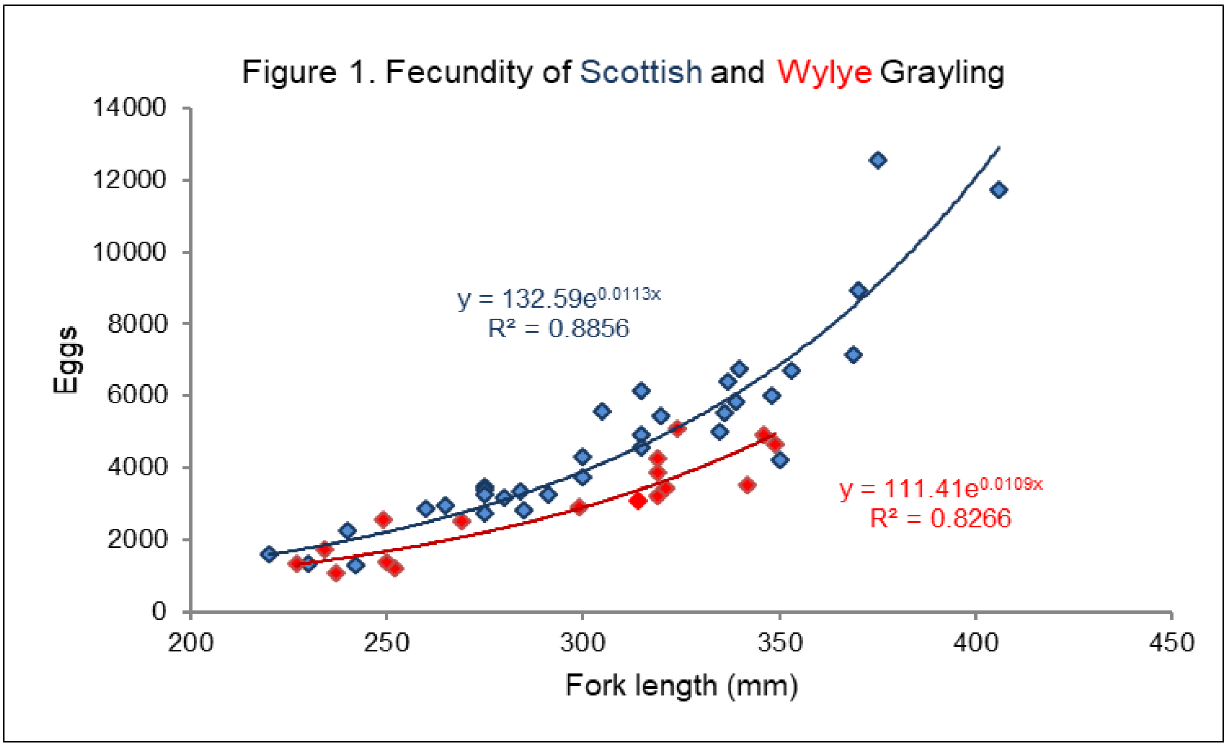
As a general rule, riverine grayling prefer a good sequence of pool, riffle / glide and run; diverse habitat that can fulfil their lifecycle requirements. Good connectivity of these habitats is a pre-requisite for healthy self-sustaining populations. Optimal water pH for grayling is 7, with a typical range of pH 6.5-9.0. They can survive at pH 5 but are more susceptible to disease and poor health. Dissolved oxygen (DO) requirements of 5-7mg/l at a water temperature of 18-20°C are minimal (note: DO described as mg/l or ppm is the same). Sustained DO of <4 mg/l and water temperatures >25°C are fatal for all grayling.

In UK stillwaters, grayling are principally found in the littoral zone (0-3m deep) near to feeder stream inlets, with small numbers in the sublittoral region (3-15m). They do not occupy a restricted home range in lakes and adults migrate from Llyn Tegid into feeder streams to spawn in April-May and drop back down into the lake in autumn (Woolland, 1972).

Spawning

UK grayling mature at an age of 2 to 4 years (generally measuring 25-30cm fork length) and spawn annually once sexually developed. This occurs in spring between March and mid-May (dependent upon geographical location - with more southerly populations spawning earlier). Spawning commences when river temperatures are between 3-11°C, up to a maximum of 14°C. Males arrive on the spawning grounds several days before the females and defend their territories, courting females as they approach (Ibbotson *et al.,* 2001). Males usually outnumber females with the oldest and largest grayling mating first. Spawning is initiated by the males vibrating display, which attracts females, and olfactory stimuli could also be involved. The physical size of the substrate is of importance even though grayling do not create a large redd. For spawning and successful egg development, grayling require good clean, well oxygenated and silt-free gravel in the 2-8cm range, with a depth of c. 5cm or more. Nykanen and Huusko (2002) developed generalized suitability curves for spawning habitat of grayling by combining new preference data with information available in the literature. These provided optimal ranges for dominant substratum size of 16-32mm, water depth 30-40cm and mean water velocity of 50-60cm s^{-1}.

Adult grayling can be sexed by differences in the size and shape of their dorsal fin. Male grayling have a large, colourful dorsal fin with a serrated top edge, whereas female grayling have a smaller, less-colourful dorsal fin with a smoother edge. The fecundity of female grayling increases with size (see Figure 1). Ibbotson *et al.* (2001) reported that UK females produce between 3,500-8,700 eggs per kg. As a result of egg production, the weight of individual females increases prior to spawning. Therefore, over winter, female grayling, particularly larger females, are often heavier than males of the same length.



The eggs are laid in pockets on the surface of gravel but can be buried to a depth of 5cm as a result of spawning activity (Ibbotson *et al.,* 2001). At 3 to 4mm in diameter, the eggs are smaller than those of salmon & trout, and are yellow in colour.

Egg, Fry and Juvenile Requirements

The development of eggs is temperature dependent, although there is no clear minimum temperature below which development does not occur. Egg development rate is temperature-dependent, with eggs developing more slowly at lower temperatures. Eggs "eye" around 110-degree days (DD) and hatch after approximately 177 DD (~25 days at a temperature of 7°C); the optimum temperature for hatching ranges between 7-11°C. An increase in temperature increases the hatching rate, up to 15°C where after any further increase in temperature has little effect. Eggs can suffer mortality from biotic (predation, disease, genetic fitness) and abiotic (flooding, drought, temperature) factors.

Hatching mortality is highly site specific (Ibbotson *et al.,* 2001). Post hatching, grayling feed on their yolk sac for 4-5 days before emerging from the gravel at a length of between 15-19mm (Scott, 1985). Emergence from the gravel, unlike other salmonids, is diurnal (occurring during the day) rather than nocturnal. Emergence peaks at dawn, but displacement downstream does not occur until nightfall. They don't begin feeding near the water surface until the yolk sac has been fully absorbed (at ~22mm); complete re-absorption occurs after 12 days (~156 DD). They remain in the surface waters (upper third of the water column) close to the river margins with the slowest flow and no turbulence (the Dead zone) and remain within this marginal zone until their length reaches approximately 25-28mm. They are highly habitat selective at this life stage (Scott, 1985) and often form small schools (up to 15 fish; mean 6). Thereafter they migrate to near-benthic habitats. The Dead zone typically has a depth of approximately 1m, with a sand / silt / gravel substrate. In a medium-sized Finnish river, Nykanen & Huusko (2003) noted that larval grayling shifted with growth from shallow habitats with slow velocities, fine substrata and abundant vegetation cover to deeper sites with swifter velocities, coarse substrata and sparse vegetation cover within 3 weeks. Small larvae (17-21mm) preferred water depths 10-30cm, substrata dominated by mud or sand (50cm depths, substrata dominated by sand or boulders, <20% vegetation cover and 10-50cm s^{-1} velocities. The strict habitat requirements of the smallest larval group suggest that these habitats are important to the early survival of grayling.

Fry can tolerate dissolved oxygen levels (DO) as low as 1.4mg/l at 8°C and 1.8mg/l at 20°C. Successful embryonic and fry development occurs in gravels with DO of 10mg/l or greater. Their temperature preference is 4 to 18°C (Crisp, 1996) with an upper tolerance of 18-25°C and an absolute maximum of 26.6°C depending on exposure time.

In-stream distribution of grayling varies between day and night (diurnal variation). As the younger fry become larger (juveniles), they can manage stronger currents allowing them to move from the Dead zone to the Main channel during the day. Once grayling have attained a length of 6-18cm they leave the Dead zone for the Transition zone where depths range between 0.45 to 0.90m and velocities are <0.1m/s. Mallet *et al.*, (2000) identified that three juvenile grayling year-classes (0+, 1+ and 2+) required increasing water depth relating to their length and therefore age (depths of 50-60, 80-120 and 100-140cm respectively) with all ages preferring small substrata. Riley *et al*., (2006) used a portable multi-point decoder system in a River Itchen tributary, to record habitats used by PIT-tagged juvenile grayling, with a high degree of spatial and temporal resolution during autumn and winter 2001/02. All age groups (0+, 1+ and 2+) tended to occupy hard gravel substrate at all times using deeper and faster water with increasing age. The 1+ and 2+ groups were generally found in water 40-70cm deep with a velocity between 0.3 & 0.5m s^{-1}, whilst the 0+ groups showed a preference for shallower water with reduced velocity at night, particularly in the winter. There were greater differences in the habitats used between age groups than between the autumn and winter periods, and the distribution of fish was more strongly influenced by substrate type than water depth or velocity.

Adult Requirements

Grayling have a more limited environmental tolerance compared to brown trout and are less widely distributed within catchments, among catchments and across Europe than trout. Furthermore, grayling succumb to organic pollution and higher water temperatures more rapidly than trout (see section on Pollution). This may possibly be in part because the liver of the grayling (the organ dealing with toxins in the body) is proportionately smaller than those of salmon and trout (Jervis, 2006).

Species	Liver / Body weight ratio (%)
Salmon	1.12
Brown trout	2.00
Rainbow trout	1.53
Grayling	0.95

Adult grayling (25-55cm fork length) generally occupy the Main channel of the river, preferring water depths of 75-165cm; shallower depths are preferred during summer, and deeper water in winter. Adults prefer substrates comprising cobble, gravel and boulders, typically much larger than that preferred by fry and juveniles. Adults also prefer higher water velocities, usually in the range 0.2-0.5m/s.

Interestingly, at night, all size classes of grayling can be observed in the shallower water of the Dead zone. This change in habitat is characterised by a shift in depth from deep to shallow water at night for all size classes. As previously mentioned, local habitat use is limited by the ability of the grayling to hold station against the velocity of the water.

Feeding

Inevitably, the availability of food (prey items) plays an important role in the growth and density of grayling populations. The food available must be suitable for all life stages in order for grayling to develop and survive, irrespective of whether the river has the necessary environmental conditions (temperature, flow and habitat).

As grayling mature, the composition of their food changes along with changes in habitat. Post-emergent fry forage pelagically and feed on drift in the upper layers of the river where larval, pupal and adult chironomids (non-biting midge) account for over 80% of their diet, regardless of the diversity of invertebrates available (Scott, 1985). Grayling feed in the upper layers until they reach a length of 15cm.

Larger juveniles migrate away from the river margins into the main channel, where they hold benthic feeding stations (within 5cm of the river bed), feeding on drifting invertebrates. At these greater sizes/ages grayling begin bottom feeding on prey such as Ceratopogonidae (biting midge larvae) and *Sialis* (alderfly) larvae, although they still frequently rise to the surface to intercept drifting prey. The prey consumed by grayling changes with increasing age. Grayling fry feed mainly on chironomid larvae or (dipteran (true fly) larvae) irrespective of diversity of invertebrates available. Although juveniles feed on a greater diversity of prey items, copepods, oligochaetes, chironomid larvae and pupae still constitute more than 90% of prey ingested. Other prey items include *Simulium* (blackfly) and *Ithytrichia lamellaris* (caddis fly) larvae.

Older grayling (aged >1+) consume larger prey such as *Gammarus* (freshwater shrimp) in addition to the prey eaten by juvenile fish (aged 0+). Generally, adult grayling become predominately benthic feeders with increasing age; the contribution of aerial prey to their diet falls correspondingly. They have wide-ranging tastes, and demonstrate the ability to consume a wide variety of prey items. For example, Martyn (2004) recorded 235 prey items and seventeen different taxa retrieved from one dead grayling.

Grayling consume terrestrial prey when aquatic food items are scarce; fish eggs are also eaten opportunistically. The size of prey items and variety consumed generally increases with mouth gape as fish mature and grow larger. The shift in habitat with life stages is closely related to changes in foraging strategy. Grayling usually begin feeding on invertebrates once they are able to swim to the surface. Feeding rate is related to temperature and oxygen levels, which in turn affect grayling activity. Feeding activity peaks at dawn and dusk, but although grayling feed during the day, they seldom feed during the hours of darkness.

Many European and UK studies have been made on the diet of grayling, and these can be reviewed in Ibbotson *et al.*, 2001.

Water Quality and Flow Assessments

Introduction

Grayling are a pollution sensitive species and require good water quality to survive and thrive. Historical methods of classifying river quality relied too heavily on physico-chemical characteristics to assess the quality of UK rivers and hence the implied suitability for fish species, particularly salmonids; essential measurements of hydromorphological and biological characteristics, as required in any holistic assessment of river quality, were neglected.

The **Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000: Establishing a framework for Community action in the field of water policy)** changed the way the UK and EU member states assessed the quality of surface and groundwaters. The Directive commits member states to achieve good qualitative and quantitative status of all water bodies. It is a framework in the sense that it prescribes steps needed to reach common goals in water quality, rather than adopting the more traditional limit-value approach. The Directive aims for 'good status' for all ground and surface waters (rivers, lakes, transitional waters, and coastal waters) in the EU.

The Directive requires the following classification schemes:

- Ecological status and chemical status classification schemes for surface water bodies. There will be differing ecological status classification schemes for rivers, lakes, transitional waters and coastal waters;
- Heavily modified and artificial water bodies will be assessed in relation to their ecological potential and chemical status classification schemes; and
- Groundwater quantitative status and groundwater chemical status classification schemes for bodies of groundwater.

The quality elements or characteristics relevant in assessing **ecological status** and **ecological potential** for surface waters are:

- Biological quality (covering algae, plants, fish and invertebrates)
- General physico-chemical quality. (Annex V of the WFD defines those general conditions (i.e. physico-chemical) and hydromorphological quality characteristics as ‘supporting’ the biological elements).

Development of classification tools for surface waters

For classification schemes of ecological status and ecological potential, the WFD provides detailed definitions of the degree of human disturbance to each relevant quality characteristic that is consistent with each of the ecological status/potential classes. These definitions are used to develop classification tools and appropriate numeric class boundaries (or Ecological Quality Ratios) for each quality characteristic. The results of applying these classification tools is used to determine the status of each water body or group of water bodies.

The WFD classification scheme for water quality includes five status classes: high, good, moderate, poor and bad. ‘High status’ is defined as the biological, chemical and morphological conditions associated with no or very low human pressure. This is termed the ‘reference condition’ as it is the best status achievable - the benchmark. These reference conditions are type-specific, so they are different for different types of rivers, lakes or coastal waters, taking into account the broad diversity of ecological regions in Europe.

Assessment of quality is based on the degree of deviation from reference conditions, following the definitions in the Directive. ‘Good status’ means ‘slight’ deviation, ‘moderate status’ means ‘moderate’ deviation, and so on. The definition of ecological status considers specific aspects of the characteristics of biological quality, for example “composition and abundance of aquatic flora” or “composition, abundance and age structure of fish fauna”.

Assessing Water Quality - BMWP

The BMWP (Biological Monitoring Working Party) method is an effective method of gaining an overview of river water quality using living aquatic organisms. Aquatic invertebrate groups have varying tolerances to polluting substances and any incident (even short lived) will affect their distribution and abundance. Samples are collected by a 3-minute kick / sweep technique with a standard pond net, e.g. 2-minute kick sample and 1-minute sweeping. The invertebrates captured are ‘scored’ based on the table below; high scores from standardised samples result from the presence of clean water species, low scores indicate pollution-tolerant groups or just a very few animals present (e.g. in a mountain beck). Relevant authorities such as the EA, NRW and the Scottish Environment Protection Agency (SEPA) should be able to supply historic BMWP results as well as WFD classifications for your river.

The total BMWP score is divided by the total number of taxa (effectively families) to produce the Average Score Per Taxon ($\text{ASPT}_{\text{BMWP}}$). ASPT is independent of sample size.

Group	Families	Score
Mayflies	Ephemerellidae Ephemeridae Leptophlebiidae	10
Caddis flies	Brachycentridae Goeridae Lepidostomatidae Leptoceridae Phryganeidae Sericostomatidae	10
Dragonflies	Agriidae Libelludidae	8
Caddis flies	Psychomyiidae	8
Caddis flies	Limnephilidae Polycentropidae Rhyacophilidae	7
Mayflies	Caenidae	7
Shrimps	Gammaridae	6
Dragonflies	Coenagriidae	6
Caddis flies	Hydroptilidae	6
Snails	Ancylidae Neretidae Viviparidae	6
Beetles	Dytiscidae Elminthidae	5
Caddis flies	Hydropsychidae	5
Flatworm	Dendrocoelidae Planariidae	5
Cranefly / Blackfly	Tipulidae Simuliidae	5
Leeches	Piscicolidae (fish leech)	4
Mayflies	Baetidae	4
Snails	Hydrobiidae Lymnaeidae Planorbiidae Valvatidae	3
Leeches	Erpobdellidae Glossiphoniidae Hirudidae	3
Hog Lice	Asellidae	3
Midges	Chironomidae	2
Worms	Oligochaetae - Lumbriculus Tubificidae	1

BMWP Score	Category	Interpretation
0-10	Very poor	Heavily polluted
11-40	Poor	Polluted or impacted
41-70	Moderate	Moderately impacted
71-100	Good	Clean but slightly impacted
>100	Very Good	Unpolluted / unimpacted

In 2015, the Walley Hawkes Paisley Trigg (WHPT) index of river invertebrate quality was introduced in the UK for invertebrate classification under the Water Framework Directive, replacing BMWP. The new index aimed to improve the accuracy of invertebrate assessments and compliance against WFD classifications by taking into account invertebrate abundance derived from the analysis of very large data sets of real observations. $ASPT_{WHPT}$ responds to the same environmental pressures of $ASPT_{BMWP.}$ However, this index is more sensitive due to a greater number of taxa being counted. Contact your relevant environmental protection agency or authority for more detail.

Assessing Water Quality - Riverfly Partnership

The Riverfly Partnership (RP) score is a simplified version of BWMP, considering species abundance as well as presence / absence. The results from the two methods are similarly effective at assessing poor water quality, but the RP score doesn't differentiate between "good" and "very good" quality classes. RP is a good method of gaining a quick understanding of river water quality and can be used to monitor for pollution incidents, whereas BMWP can be used for analysis of characteristics other than water quality e.g. flow. The total score (known as Anglers Score Index, ASI) is calculated by summing over the various categories. This is repeated monthly until a baseline is established and from this any monthly samples deviating from the norm can be investigated by the relevant authority. For further information contact the riverflies.org; http://www.riverflies.org/armi-equipment-list-and-suppliers

Dissolved Oxygen and pH measurements

Hand-held meters / probes can be readily purchased from several suppliers; Oxyguard, YSI and Hanna are well known brands. However, regular calibration of these instruments is required to ensure accuracy, reliability and reduced maintenance. Alternatively, contact the local EA, NRW or SEPA offices are likely to have historical to present-day records DO and pH data for many watercourses.

Flow Requirements

For good survival, flows need to be favourable for that particular life stage; the requirements for spawning and survival of grayling eggs and fry are particularly demanding. Timing and frequency of high flows can be important for initiating behaviours in salmonids, specifically spawning migrations. Flow regulation and compensation release schemes rarely consider the impacts on the life history of grayling, and as with habitat management, there is sometimes a belief that flow management for trout or salmon will also be appropriate for grayling. This may not always be the case particularly given their difference in spawning season (timing), habitat utilisation and swimming ability. Salmon (and brown trout) are usually the target organisms for setting management of flow regimes, even though grayling may be the dominant fish species in the watercourse where flows are managed. This is primarily because, being an iconic conservation species, salmon figure more significantly in terms of nature conservation designations and socio-economic benefits.

Life stage	Depth range	Flow (velocity) range
Fry	10-90cm	6-50cm s^{-1}
Juvenile	40-60cm	<10-110cm s^{-1}
Adult	20-400cm	20-110cm s^{-1}
Spawning	10-50cm	23-92cm s^{-1}

Rivers across the grayling's natural global range can be broadly classified into those with annual flow patterns dominated by seasonal flood pulses caused by snowmelt in the spring and those with more random flood pulses caused by rainfall, although there is often seasonality dictating when flood pulses are most likely; in the UK these more commonly occur in the winter. Individual river systems also have individual hydrological regimes, varying with local climate, location, geology, topography and vegetation cover. All components of a natural flow regime are ecologically important to stream-dwelling fishes, with the amplitude, frequency, seasonal timing, reliability, duration and rate of change of flow conditions all playing their part.

In addition to day-to-day requirements, fish have evolved life history strategies which are compatible with the general patterns of flow. Such life history adaptations increase recruitment success by increasing the survival of particularly vulnerable life stages, i.e., eggs, fry and juveniles. One such adaptation performed by many fish species is to spawn at a time which ensures that fry emergence is likely to coincide with seasonal periods of low flood risk and optimal availability of food. However, spawning times vary between the otherwise-similar salmonid species. For example, brown trout and salmon spawn in late autumn and winter months, excavating egg nests (redds) sufficiently deeply in the gravel to offer some protection against scour during elevated flows; not surprisingly, larger fish tend to produce deeper redds. Grayling spawn between March and mid-May when the risk of wash-out is lower. Thus, eggs are generally buried less deeply (up to 5cm) or are laid on the gravel surface as discussed above. Such an approach may bring advantages. For example, elevated flows over winter may serve to clean silted gravels, thus improving the spawning substrate in the spring. With significantly higher water temperatures at the time of egg deposition, coupled with a much shorter incubation period (i.e. the time that eggs spend in the gravel), there should be advantages over winter-spawning salmonid species in terms of egg survival rates. Conversely, unseasonal high rainfall and concomitant high flows during incubation and emergence could lead to large-scale failure in recruitment, resulting in almost completely absent year-classes.

Grayling are a key fish species on many chalk rivers, especially those on the south coast (e.g. rivers Test and Itchen), which are generally groundwater-fed, with limited variability in flow, high base flows and smoother transitions in the flow regime; these rivers are also highly managed.

Measuring Flow

By measuring river flow at specific locations along a river course over extended periods (years), it is possible to determine whether the flow regimes are sufficient to meet the requirements of grayling during the three key stages in their life cycle; in the Dead marginal, Transition and Main channel zones, and the flow characteristics over gravels required for successful spawning. Detailed flow data can be obtained from the EA, NRW, SEPA, or the National River Flow Archive (https://nrfa.ceh.ac.uk/). For those wishing to undertake their own investigations, information on techniques can be found at: http://www.appropedia.org/How_to_measure_stream_flow_rate

Migration, Home Range, Spawning Migration & Barriers

Migration

Grayling generally make small migrations to forage within a home range (the domain within which an animal will normally travel). Greater but less frequent migrations occur with shifts in habitat with age or season or occasional long-distance migrations such as spawning migrations from main river to tributary or within a river. Migrations to find suitable habitat for spawning can result in grayling travelling <100m or many kilometres (>10). In each case a degree of homing behaviour is displayed. Grayling regularly perform small short term foraging movements, returning to a specific spot in their own territory - sometimes termed a “lie”.

According to Woolland (1972), grayling display two distinct groupings in terms of their behavioural strategies:

i. A large static group that occupy a home range and hold a specific station in their territory, occasionally foraging trips within a specified area around it (high site fidelity and territorial behaviour).
ii. A smaller group which forage widely and do not appear to hold any particular territory.

This second behaviour may be related to poor habitat or high population density.

Grayling often make seasonal movements, changing shifts in relation to depth and position. They move to deeper, slower flowing water in winter (especially associated with spawning) and faster, shallower, better oxygenated water in the summer.

Home Range

Home range is the geographic area to which an organism normally confines its activity. A radio-tracking study by Lucas & Bubb (2005) found that outside the spawning season, grayling in the River Rye (Yorkshire) tended to adopt restricted (<1km) home ranges, although in some cases, the day-to-day movements of grayling were quite substantial. Extensive and erratic spatial behaviour was evident on the downstream river section in autumn and winter (where, it should be noted, habitat in this section was less typical of the “grayling zone”). It is most likely to have resulted from avian predator avoidance (Lucas & Bubb, 2014), but possibly also from increased movement between habitat patches during changing discharge conditions. Martyn (2004) reported very small home ranges (24m ± 18) for grayling on a southern English chalk stream indicating that the habitat requirements of adult fish can be met within a very short spatial distance (<100m) in chalk streams.

Spawning Migration

Unlike salmon and sea trout, all grayling in the UK exhibit a potadromous life history strategy, i.e. they migrate solely within freshwater reaches. This is generally true for populations elsewhere although grayling do occur in relatively low salinity water in the northern Baltic Sea with some fish spawning along the shoreline. Radio-tracking studies in Yorkshire have shown that grayling spawning migrations are triggered by decreasing flows and increasing temperatures in the spring, much like spring-spawning cyprinids rather than salmonids. However, the migration may stall if water temperatures become too high and water levels too low; such temporal variations lead to adjustments in the timing of spawning migrations between years.

Lucas and Bubb (2005) recorded spawning occurring over a three-week period in which individual fish migrated up to 11 kilometres upstream. Such migratory activity generally occurs during the day, with peaks in movement around noon. Typically, fish travel upstream to spawning areas at a rate of around of 1km per day, although journeys may be interspersed with periods of rest. Sexually mature fish can remain on the spawning grounds for up to a month before spawning and can perform post-spawning homing movements to return to the precise pool-riffle sequence they had previously occupied. The mechanism controlling such homing behaviour is unknown but the use of chemical cues as guidance has been suggested. Parkinson *et al*., (1999) also noted small-scale but variable spawning migrations (between 230 and 4,980m) in a small Belgium stream. The migrations took place under decreasing flows, increasing temperatures and low turbidity. Males occupied a single spawning ground whereas females moved between several different grounds (Ibbotson *et al.,* 2001).

Other continental European studies have revealed very extensive upstream spawning migrations in comparison to those in the UK. It is therefore speculated that the distance grayling travel to and from spawning grounds is a function of river size and the proximity of habitats required to fulfil their lifecycle.

Barriers to Migration

The inhibition of grayling migration is of concern where habitats required for the different life stages are separated by man-made obstacles, or where local extinction has occurred in areas above impassable natural or artificial barriers, preventing recolonisation from extant populations downstream. Where the former pertains, grayling distribution may become patchy, with populations demonstrating high local fluctuations in both abundance and size distribution; such properties provide evidence of fragmented populations.

Under the Water Resources Act 1963, regulatory authorities in England & Wales are required to assess and manage water resources, including hydrometric flow measurement schemes. As a result, there are over a thousand flow gauging stations throughout England & Wales (Environment Agency, 2013). In Scotland, there are several hundred river level gauging stations (SEPA website). Many of these gauging stations are associated with weirs which potentially impact on the freedom to migrate for grayling and other species.

There is very limited evidence of grayling populations becoming extinct in the UK as a direct consequence of structures constraining migration between essential habitats, but this does not mean such extinctions have not occurred (Ibbotson *et al*., 2001). However, patchiness in the size distribution of local grayling populations that may result from barriers is more readily identifiable. In many cases, apparently minor barriers appear strongly to inhibit grayling mobility and therefore, the opportunity to populate otherwise suitable habitats. Similarly, grayling have been found below barriers, having been washed downstream of an impassable barrier during flooding and thus unable to regain their original upstream territory (Ibbotson *et al.,* 2001).

The degree of river connectivity or fragmentation on grayling larvae and fry movement must also be considered. Upstream migration by adults for spawning is followed by downstream "drift" as larvae/fry dissipate in the river current. Van Leeuwen *et.al*., (2017) investigated the downstream movement of larval grayling demonstrating that this takes place predominantly at night. Active, large-scale downstream movements (amounting to several kilometres) are apparent in the months after hatching; few young-of-the-year still resided close to the spawning areas in autumn. This research emphasises the critical importance of unimpeded longitudinal connectivity in large river systems. Human alterations to flow regimes and the construction of potential barriers may not only affect the movement of adult fish, but may also interfere with migratory behaviour during early life stages.

Case Studies: Ability to Pass Barriers

The University of Durham was commissioned by the EA and GRT to examine the seasonal movements and habitat use of adult grayling in rivers dominated by unregulated surface flow. The study was carried out mainly in the River Rye catchment, North Yorkshire. Radio-tracking was undertaken over two periods: January to July 2004 and October 2004 to January 2005; habitat surveying, environmental monitoring and limited electric fishing surveys and mark-recapture were also undertaken as part of the study. A subsidiary radio-tracking study was carried out on the River Ure, North Yorkshire, between February and April 2004.

The main investigation (Lucas and Bubb, 2005) featured two major barriers to migration in the middle section of the study reach; a 1.2m high Flat-V gauging weir and a larger 1.4m high disused mill weir. A number of grayling were detected moving several hundred metres upstream to these weirs, but none passed. It should also be noted that in several cases during tracking, high flow events were associated with downstream movements. Later in the study, Passive Integrated Transponder (PIT) telemetry was used to examine fish passage over two gauging weirs utilising the homing tendency of translocated grayling. A very high proportion (96%) of PIT-tagged grayling successfully ascended a 0.2m high Crump flow-gauging weir on Costa Beck (water velocity 0.87-1.85m s^{-1} on the downstream face). Conversely, at a 0.4m Flat-V gauging weir on the River Dove (water velocity 1.07-2.98m s^{-1} on the downstream face), only 36% of tagged grayling attempting to ascend the structure were successful, compared to 84% of brown trout. The great majority (92%) of grayling translocated upstream of the weir on the River Dove successfully “homed” to their original lower river section. This suggests strongly that, for adult grayling, such structures are unlikely to hinder downstream passage.

A series of recommendations were made based upon this research. The adaptive pattern of seasonal movements by grayling in many rivers, which probably helps to enhance survival probability and sustain populations (especially in those rivers with variable flow and/or greater spatial dispersion of key habitats), needs greater consideration in river management.

In spring 2009, the Environment Agency (2013) attempted to assess the impacts on fish migration of a retrofitted Larinier super active baffle fish pass on a crump weir at Louds Mill weir on the Dorset Frome. This entailed capture, tagging and relocation of brown trout and grayling. Seventy-one percent of trout and 54% of grayling successfully negotiated the pass; these figures are minima because of failure in the logging equipment. These figures fall short of efficiencies recommended for maintenance of salmonid populations (Lucas and Baras, 2001). There was also evidence to suggest that small (sexually immature) grayling were less successful than small trout and that flow & temperature had no significant effect on fish movements.

Subsequent studies, commissioned by the Environment Agency, have been undertaken by FISHTEK (2014) and APEM (2016). The first study examined fish pass efficiency at a site where a pre-barrage had been installed downstream of a Flat-V weir on the River Ecclesbourne. Half Duplex PIT tags and antenna loops were deployed, one immediately above the pre-barrage and the other immediately upstream of the weir crest. Fish were tagged with PIT tags and released into a pool below the pre-barrage. Although the grayling sample size was small (n = 16), 31.3% (attraction efficiency) of tagged grayling entered the pre-barrage compared to 33.3% chub

(*Squalius cephalus*), 83.3% brown trout. Of those grayling entering the pre-barrage, only 12.5% completed total upstream passage over the Flat V weir (100% for chub and 53.3% for trout).

The APEM study in 2015 attempted to investigate the effectiveness of a novel low-cost baffle (LCB) solution to provide upstream fish passage on a Flat-V gauging weir. This was a two- phase investigation - pre and post construction. Unfortunately, the latter wasn't undertaken due to flood damage. During the pre-construction period, brown trout and grayling were captured and PIT tagged, and antenna loops set up immediately upstream and at the downstream of toe of the weir. Again, only a small number of grayling were tagged in comparison to trout - trout being far more abundant. Similar proportions of both species approached the weir (75 and 86% respectively) however only 27% of the tagged grayling passed upstream using the LCB compared to 73% of the brown trout.

In Belgium, Ovidio *et al*., (2017) investigated fine-scale individual fish behaviour around a fishway built to by-pass an Archimedes' screw. Such fishways are installed to facilitate accessibility to functional habitats and to increase the ecological continuity of rivers. With the current push for increased production of "green energy" through micro-hydroelectric schemes, this type of structure is likely to become more common in the UK. A combined PIT-tag and radio-telemetry system was designed and placed in the fishway to analyse fine-scale behaviour of individual fish. Three fish species (brown trout, grayling and barbel) were captured, tagged and released downstream of the fishway. Measures of behaviour were used to provide a comprehensive assessment of fishway efficiency, including attraction and entrance efficiency, searching and passage delays, and overall and adjusted passage efficiency. The results indicated a major problem in terms of attraction efficiency (48.9% for trout, 20.5% for grayling, and 41.2% for barbel) and time to find the entrance of the fishway (mean 65.1 hr for trout and 538.9 hr for grayling). For fish that succeeded in approaching the entrance of the fishway, passage efficiency was 86.9% for trout, 55.5% for grayling, and 7.1% for barbel. The time taken to cross the structure was reasonable for the salmonids (mean <1.5 hour for trout and grayling) but very long (mean 21 hours) for barbel. This research underlines the necessity of a holistic approach to evaluating fishway efficiency using precise, comprehensive metrics and hydraulic characterization.

These studies strongly suggest that grayling are less able or even perhaps less willing than brown trout to ascend barriers; this is particularly evident for small Flat-V gauging weirs characterised by complex or circulatory flow patterns. Recommendation: Where possible, barriers to migration should be removed or effectively mitigated and there should be a very careful assessment of the need for new structures. Where existing structures must be retained, there should be guidelines for effective operation that ensure minimal impact on the migration of grayling and other species.

Fish Pass Design

Introduction

Fish passes are designed to facilitate the upstream and downstream migration (longitudinal connectivity) of fish around different types of structural barrier - for example weirs, dams, sluices, culverts and natural waterfalls where removal is not an option. To accomplish this, they must be designed and sited following current best practice and available evidence - developers are advised to consult the Environment Agency Fish Pass Manual (EA-FPM) (Armstrong *et al*., 2004). Currently in England & Wales, formal fish pass approval legislation **only** applies to watercourses frequented by **migratory** salmonids. However, both in areas where migratory salmonids are **not** present and where they are present, fish pass design should suit all fish species, whether resident or transient through the watercourse and agreed with local EA and NRW fisheries leads. In Scotland, the regulatory authority for ensuring that there are suitable fish passage arrangements at dams and weirs is SEPA.

Types of Fish Pass

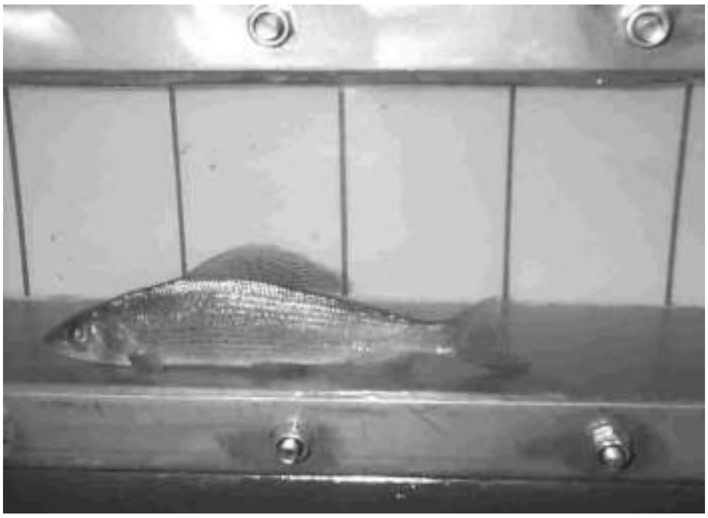
The design of fish passes can vary greatly, depending upon the complexity of the site and target species. Most fish passes are one of the following:

- Rock Ramp
- Super active baffle (Larinier)
- Vertical slot
- Baffled (Denil)
- Pre-barrage
- Low-cost baffles
- Bypass channel
- Pool and weir
- Alaskan A

Details of the above passes and selection criteria can be found in the EA-FPM (page 75).

Where possible, natural solutions such as Rock ramps or Bypass channels should be used. Multi species technical passes (Larinier or Vertical slot) are likely to provide good grayling passage, with restricted species technical passes (Denil / Alaskan A) avoided.

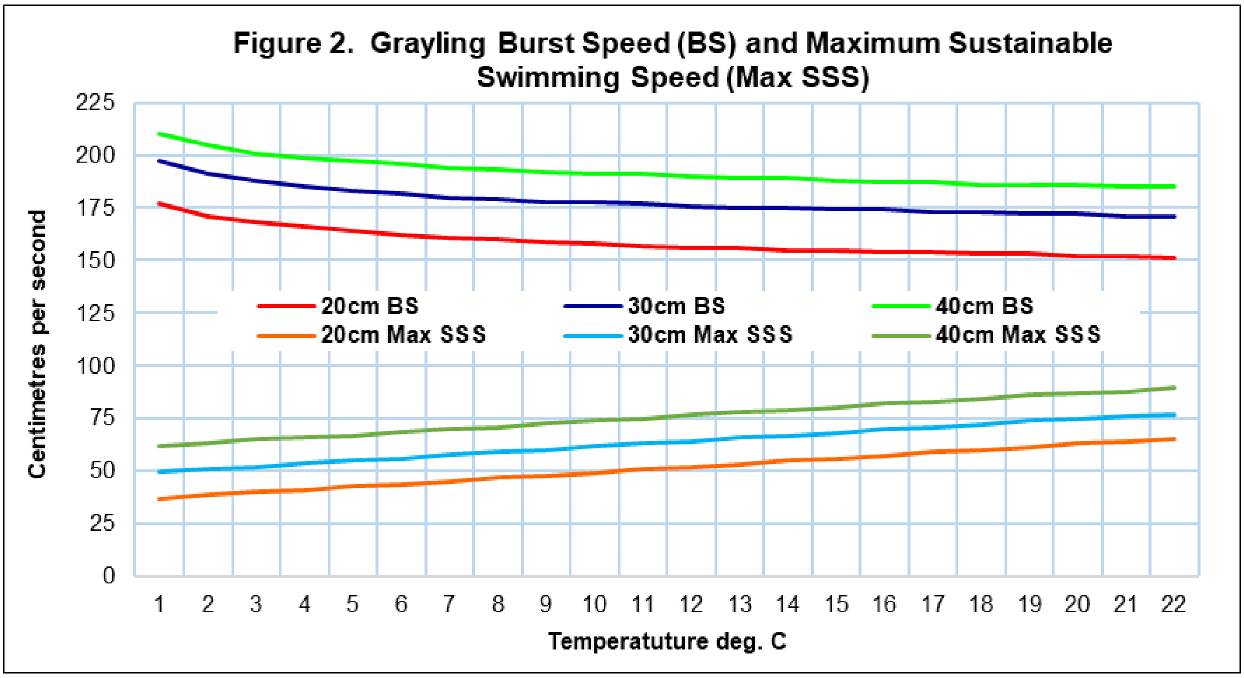
Swimming Performance of Grayling



An Environment Agency Research and Development (R&D) project assessed the swimming speeds of specific types of fish; this included grayling in a second phase of the project (Clough *et al*., 2004). The software developed during this project (SWIMIT v3.0), was used to calculate swimming ability of grayling and other species. This information should be used in fish pass design in catchments where grayling are present. The results are summarised below:

- Swimming ability including both burst speed (BS) and maximum sustained swimming speed (Max SSS) increases with increasing fish length (Figure 2).
- Burst speeds of grayling show a decline as water temperature increases.
- Sustained swimming speed increases with increasing water temperature.
- Grayling have good burst speeds similar to brown trout (Figure 3) and superior to chub at temperatures <15 degrees centigrade.
- Grayling are poor endurance swimmers compared to brown trout (Figure 4) at all temperatures.
- Grayling are considered a “cold-water” species and are approaching the southerly limit of their geographical range in the southern UK. It is likely that as they approach the upper end of their preferred thermal range (greater than 20 degrees centigrade), swimming performance, or at least the ability to achieve their maximum performance, is likely to fall markedly.

Further details of swimming speeds can be found within the EA-FPM or through discussions with local EA or NRW fisheries leads.



BS - Burst speed (the highest swimming speed that can be maintained by a fish for ≥20 seconds). SSS - Sustainable Swimming Speed (the maximum swimming speed which can be maintained for in excess of 200 minutes).

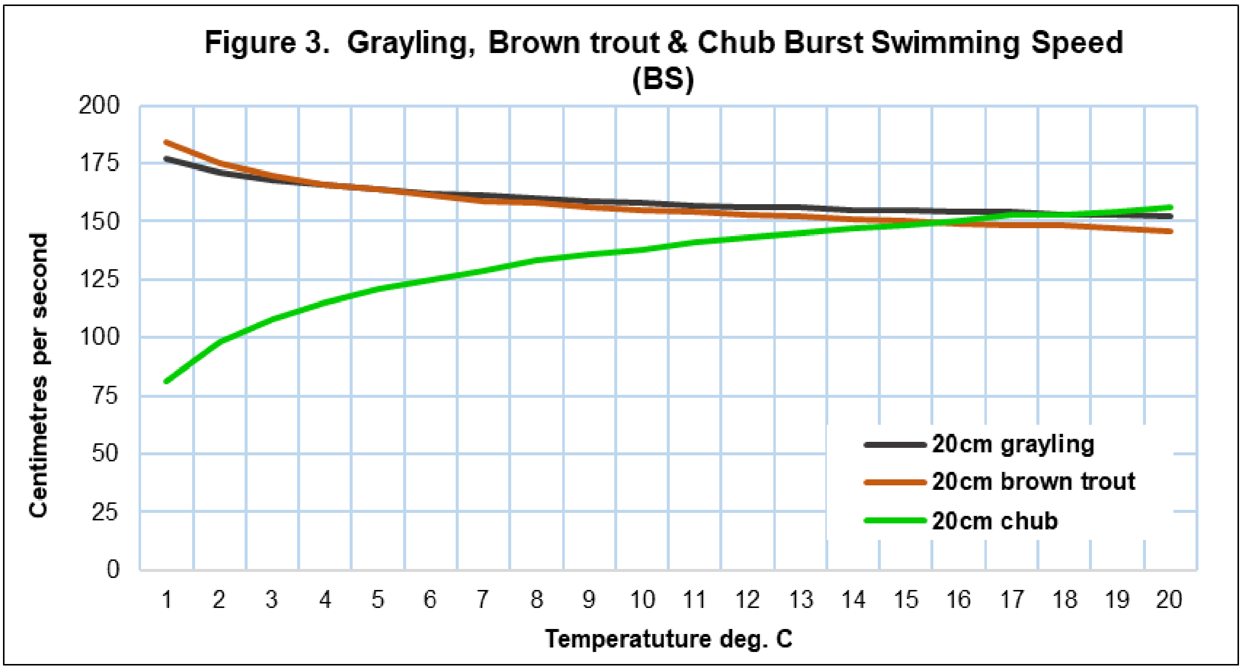
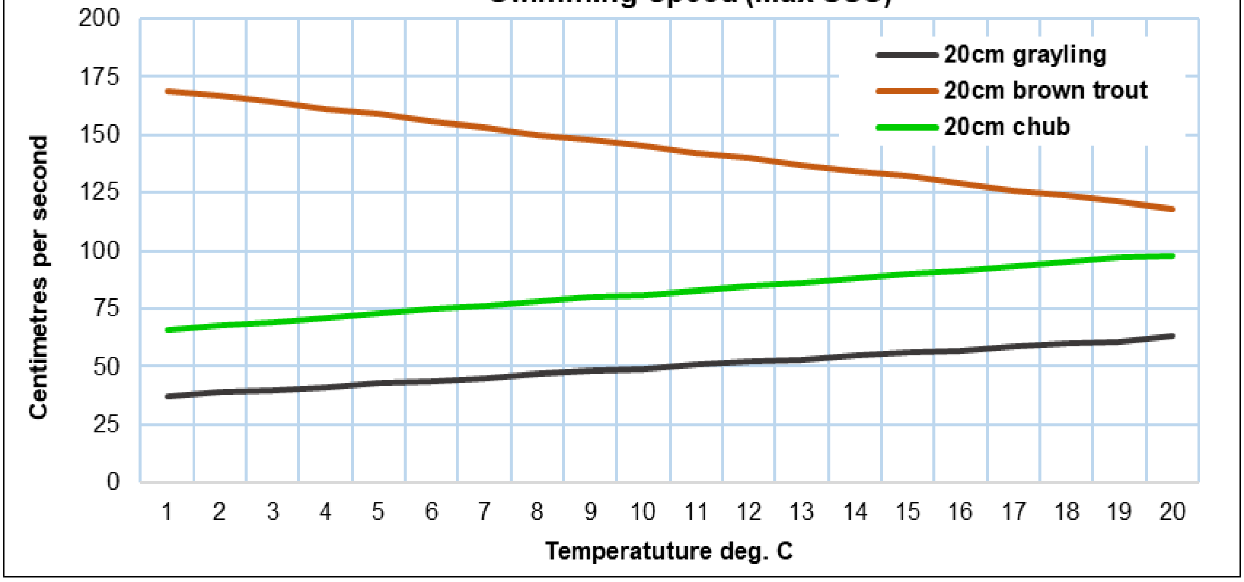


Figure 4. Grayling, Brown trout & Chub Maximum Sustainable Swimming speed (Max SSS)



Fish Pass Design Guidance

Fish passes should be designed to achieve a minimum water depth at all flows that the pass is designed to operate under, ensuring that water velocity is appropriate for the target species.

Fish pass design is site specific and dependent on a range of parameters, including:

- Size of channel
- Impoundment structure
- Geomorphology of the area
- Hydraulic conditions
- Target fish species

General points regarding specific design criteria:

- The fish pass entrance should be positioned so that it is easy for fish to locate - generally this means at the upper most end of the obstruction and co-located with any other discharge (for example an HEP scheme).
- Hydraulic conditions near the entrance are important, ensuring velocities and flow patterns are suitable for the target species.
- Discharge from the fish pass must be sufficiently ‘attractive’ to migrating fish to compete with the flow coming over the weir or hydropower scheme. Generally, fish pass flow should be 2-5% of the competing flow (Larinier, 2008). The entrance needs to discharge into an area of water that has a reduced velocity to the main flow so that its presence can be distinguished from the main flow / obstruction.
- The exit should be positioned so fish do not depart into high velocity water.
- Additional flow (augmentation) can be added into the fish pass to make its discharge more attractive. However, care should be taken to ensure that the fish pass flow does not exceed that of the swimming ability of target species.
- Water depth below the entrance must be sufficient for fish to be able to rest with minimal effort and secure from predation.

Velocity

The maximum flow velocity used for designing passes for salmonids (salmon and trout) can vary between 1-5m/s. Larger species such as salmon can ascend structures with water velocity exceeding 5m/s. While considering other species <1m/s is recommended (Szalay, 1967) - grayling fall into this category.

Turbulence

Turbulence should not exceed 200watts/m^3 within a fish pass designed for salmon and 100-150w/m^3 for species other than salmon (Mallen-Cooper, 1993). The lowest value would be preferable for grayling (Armstrong *pers. comm*.). Anecdotal evidence suggests that salmon prefer to run a fish pass with smooth water rather than white water; this may also be true for grayling.

Maintenance

In a river with a wide assemblage of fish species, it is vital that the fish pass is operational year-round to allow all species unimpeded access both up and downstream at all times and at all life stages. Therefore, a maintenance manual should be produced during the design process. A correctly designed and sited fish pass should require minimal maintenance.

Monitoring

The reasons for and methods of monitoring fish pass function and efficiency are fully detailed for England & Wales within the EA-FPM (pages 231-242).

In summary, the main reasons for monitoring a fish pass are:

- To determine whether the pass is working as designed, or to support an application for Final Approval
- To assess any mitigating measures that may be needed to ensure effective operation, or which may be withdrawn
- To aid in future designs

There are many methods of monitoring the efficiency of a fish pass, all of which are detailed in the EA-FPM. Discussions with local fisheries officers are advised in order to determine the most appropriate methods of assessment and the level and frequency of scrutiny required.

The Environment Agency Fish Pass manual can be found at:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/298053/geho0910btbp-e-e.pdf

Further advice is available from:
https://www.dpi.nsw.gov.au/fishing/habitat/rehabilitating/fishways

Case Study: River Taff Fish Pass

Adult grayling were introduced into the River Taff in the late 1980s/early 90s with fish that were removed, and were due to be culled, from preserved brown trout fisheries in the River Lambourn and possibly the River Kennet (both in Berkshire). These fish survived well, spawned successfully and their progeny supported a popular mixed fishery for over 20 years, dispersing a little in the lower Taff, downstream of Pontypridd. They did not progress upstream due to an impassable barrier of Treforest Weir. In 2002, a multi-species deep vertical slot fish pass was completed at the weir. Water passes through a 36m long by 2.5m wide channel containing 11 pools, which are separated by a wall with a 30cm slot to allow fish to swim from one pool to another. This construction slowed the velocity of water to a metre per second; well within the swimming abilities of the fish present. The pass was the second of its type in the UK and a first for Wales; enabling brown trout, eels and grayling to access approximately 27km of river upstream (mainly the Taff and Rhondda). Anglers reported a quite rapid colonisation of upstream river by grayling in the first year of access and entry to the tributary River Rhondda. Good angling success continues to indicate natural recruitment and a self-sustaining population in the upstream section of river.

Monitoring Grayling Populations

It is widely acknowledged that grayling are a difficult fish species to monitor and for several reasons. The difficulties result primarily from the utilisation of different habitats during their life-cycle, as discussed in section Key River Habitat Zones, and also the great diversity of the rivers they inhabit in the UK. Grayling were identified by Beaumont *et al*., (2002) as the fish species most sensitive to electric fishing. Monitoring requires considerable resources, both financially and in terms of time. Although the type and level of monitoring should be dictated primarily by the kind of data required, it is inevitable that financial and physical constraints will impact on the design of the monitoring programme. Distinction needs to be made between monitoring fishery performance (e.g. angler catches) and monitoring the population itself. The resulting data may be used to assess population status. The data may also reveal specific underlying causes of problems and thus prompt remedial action, such as habitat restoration. However, the data may also raise as many questions as they answer, requiring further studies.

A carefully designed programme with clear, achievable objectives is the key to successful monitoring, and one should plan carefully before adopting any of the methods outlined here. A poorly designed programme will fail to yield the requisite data, wasting time and financial resources. The questions that need to be addressed need to be set out as clearly as possible before considering how best to go about answering them. For example:

- What is meant / understood by the “population” of interest ? (e.g. age component, age structure, locations, etc.)
- Is the purpose to generate a time-series of data for the population of interest ? If so, what length of time is required to yield meaningful data, and what should the sampling frequency be ?
- What constitutes “change” in a population ? (a simple decrease or increase in numbers / density, change in age structure, etc.)
- What are the meaningful time intervals relevant to the population dynamics (e.g. how will normal natural ‘random’ variation be distinguished from long-term non-random trends and changes ?)

Careful consideration of these points should make evident the kind of data required to answer the specific questions.

Commonly, when designing an experiment, a specific type of simulation called “power analysis” might be used. This requires definition of specific pieces of information, such as the actual or likely spatial and temporal variability in fish densities, the number of survey locations, number of samples taken at each location, annual variability in the number of samples, sampling frequency, etc. Where such data are lacking, a search of published literature, examining similar studies may yield the necessary information. Provided it is properly parameterised, the power analysis should yield a better understanding of the timescales, number of sites and samples and the sampling frequency required to detect change in a population by a specific time for a given degree of certainty (usually at the 95% confidence level). Ultimately, an appropriate experimental design will be situation-specific, and not necessarily applicable generally.

Angler Logbook Schemes

Information gained from angling logbook schemes can provide vital evidence of broad changes in fish populations (e.g. adult grayling populations) that occupy large rivers or still waters and are thus difficult or impossible to sample using small-river survey methods - principally electric fishing. Electric fishing is perhaps the most widely applied method of sampling riverine fish populations in the UK and elsewhere, especially for salmonids. Such surveys tend to be biased toward smaller rivers (~10m wide) with the sites surveyed representing only a small proportion of the catchment. In contrast, logbook schemes can be adopted for nearly all salmonid species (trout, salmon and grayling) and, where widely and rigorously used by anglers, can provide long-term assessment of fish populations and fishery performance in the entire catchment. They have been run successfully by many organisations including the EA, Eden Rivers Trust, NRW and the Tweed Foundation.

The logbook information, collected over many years, has helped to inform and direct management of species and advance the scientific knowledge that underpins it. A great advantage of angler logbooks is that they can be used to collect a good deal of useful information both quickly and cheaply, but to do so requires lasting commitment from participating fishermen as well as from the organisation promoting the logbook scheme. Provided good planning and design are adopted, logbooks and catch returns can provide fisheries manager with an acceptably good indication of fish abundance and size structure. For example, catch-per-unit-effort (CPUE) can provide a useful index of real population abundance (Environment Agency 2004).

Case Study: National Grayling Anglers Logbook Scheme

An extensive grayling logbook scheme operated in England, Wales and Scotland between 2001 and 2009, covering 149 rivers (Cove, 2007). It recorded 82,343 grayling in eight angling seasons (annual catches ranging from 4,457 to 13,928 fish) with captured fish split into seven fork length categories (<15cm, >15 to 20cm, >20 to 25cm…, up to >40cm). The scheme also asked anglers to record their by-catch of other fish species, as well as provide details on angling method (fly, bait, etc.), river height & colour, date, weather conditions.

The national grayling scheme showed remarkable consistencies in data in many areas. This included, for example, measures of size composition which, on a national scale, were stable across all eight seasons with the notable exception of a 10% increase in the abundance of fish of <15cm in the 2006/07 season; probably reflecting good recruitment in that year (Cove, 2007). At a regional scale, size distribution varied markedly with the greatest proportion of grayling in the specimen category (>40cm) occurring in Scotland (Figure 5). In all other regions, >40cm grayling represented less than 6% of the rod catch. (It should be noted here that angling is generally size-selective with anglers preferring to avoid fish in the smallest size classes.)

Angling catch per hour (or catch-per-unit-effort) varied little with fishing method (fly v bait) or river conditions (anglers tending to avoid the poorest river conditions e.g. when waters were turbid or coloured). Marked differences were however evident in CPUE between the nine regions but were consistent within individual regions over the eight seasons. The highest catch rates were observed within the South West & Southern regions - areas dominated by chalk streams. The lowest rates (which probably reflects grayling abundance) were recorded in the North East, Anglian, North West and in Scotland (Figure 6).

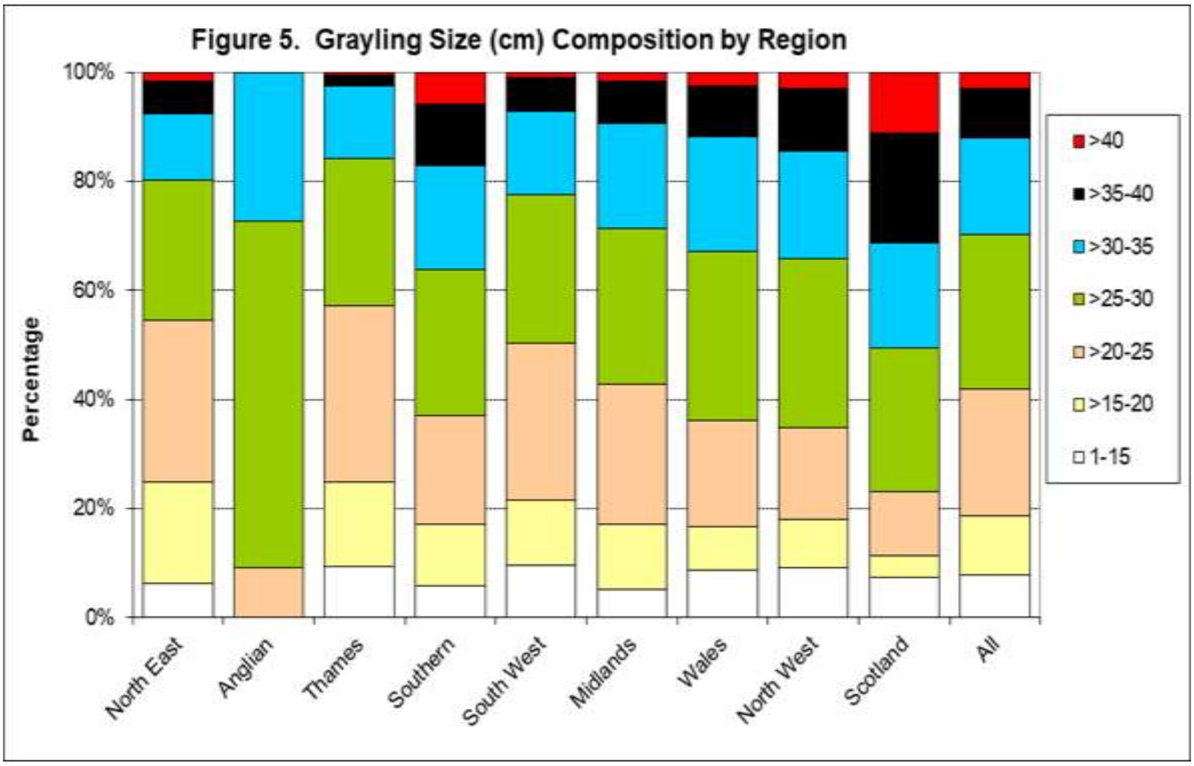


Figure 5. Grayling Size (cm) Composition by Region

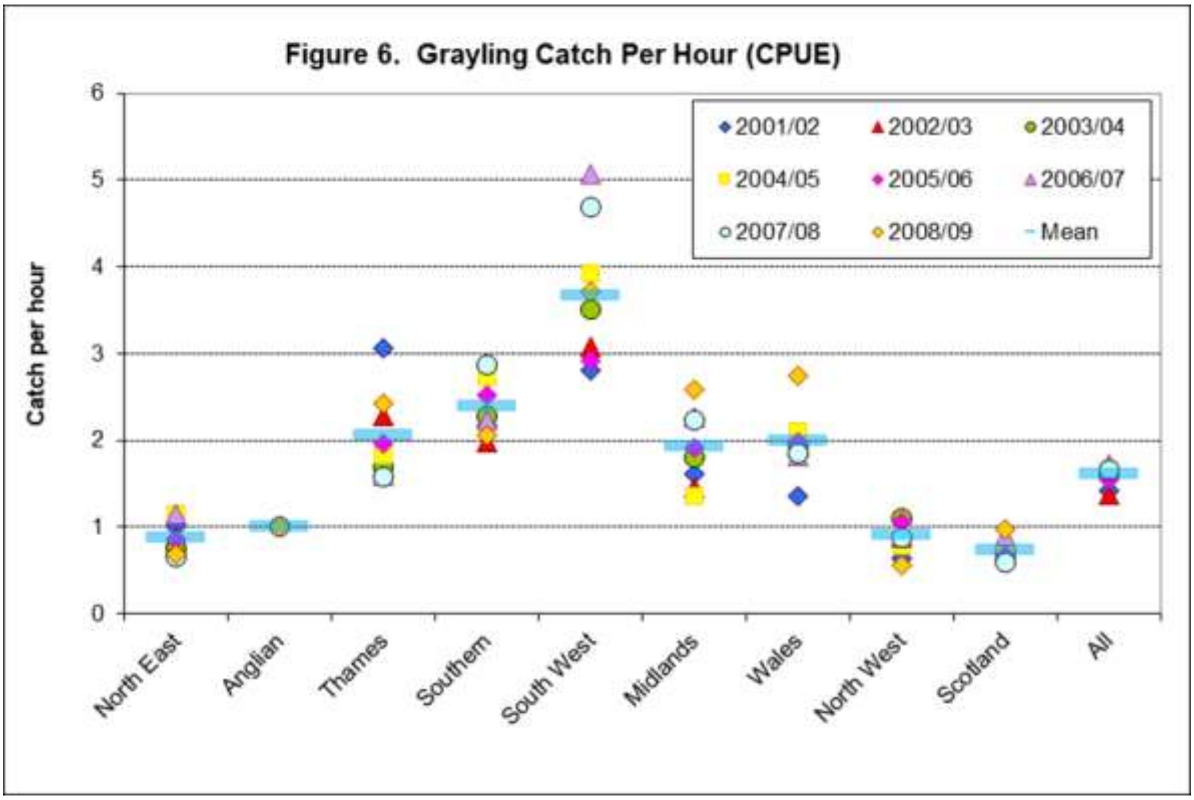


Figure 6. Grayling Catch Per Hour (CPUE)

Logbook Outcomes

The results from the logbook scheme were used to influence and finally establish the angling “kill” slot limit currently adopted in England and Wales (see section on UK Angling Legislation). Cove (2007) used catch and catch-effort data to rate fishery performance from “Excellent” to “Absent” (A to E) for all rivers fished and for different ‘life stages’; namely: juveniles, small and large adults. A re-analysis of CPUE data in Table 1, is provided to give those seeking to start their own logbook scheme an indication of catch rates that might be expected within various regions of the UK, including a measure of fishery performance for immature fish, adults and all size groups combined.

Table 1. Angler Catch Rate Per Hour Guide by Size Class and Region

	Juveniles (<25cm)				Small Adults (>25cm - 35cm)				Large Adults (>35cm)				All Grayling Sizes			
	Catch per hour (**greater** than)				Catch per hour (**greater** than)				Catch per hour (**greater** than)				Catch per hour (**greater** than)			
Region	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
North East	0.731	0.359	0.182	0.000	0.522	0.320	0.138	0.000	0.128	0.063	0.028	0.000	1.213	0.638	0.309	0.000
Anglian	Too few data				Too few data				Too few data				Too few data			
Thames	1.629	0.839	0.344	0.000	1.600	0.948	0.507	0.000	0.080	0.054	0.030	0.000	3.572	1.600	0.649	0.000
Southern	1.026	0.774	0.449	0.000	1.378	0.870	0.588	0.000	0.618	0.309	0.206	0.000	2.541	1.880	1.367	0.000
South West	1.621	0.926	0.339	0.000	1.462	0.687	0.333	0.000	0.331	0.275	0.160	0.000	3.364	1.669	0.938	0.000
Midlands	1.000	0.500	0.250	0.000	1.125	0.571	0.258	0.000	0.239	0.127	0.082	0.000	1.891	0.973	0.511	0.000
Wales	0.955	0.585	0.283	0.000	1.075	0.724	0.378	0.000	0.314	0.200	0.097	0.000	2.009	1.218	0.670	0.000
North West	0.500	0.333	0.201	0.000	0.564	0.376	0.253	0.000	0.126	0.089	0.058	0.000	1.061	0.712	0.482	0.000
Scotland	0.276	0.138	0.051	0.000	0.364	0.222	0.120	0.000	0.342	0.189	0.107	0.000	0.859	0.556	0.286	0.000
UK	0.848	0.400	0.183	0.000	0.827	0.414	0.200	0.000	0.292	0.147	0.066	0.000	0.802	0.313	0.069	0.000

Category A = Excellent i.e. in top 25%, B = Good, top 50%, C= Fair, bottom 50%, D = Poor, bottom 25%, E (not shown in table) = Absent i.e. no grayling caught

Catch rates per hour can be converted to hours per grayling by inverting the above figures: for example, 0.500 = $^{1}/_{0.500}$ = 2 hours per grayling.

The Environment Agency (2004) states "local decisions based on the best available catch and population survey information is the way forward for sound grayling fishery management. CPUE should be managed so that stock levels and structures remain stable in the medium to long-term".

The national logbook scheme ended when angler interest in the scheme fell-off to such a level that the resources required to maintain the scheme outweighed the benefits associated with ever-diminishing returns. Maintaining interest for the long term is a major challenge for any logbook scheme, but one that is perhaps more likely to be overcome by a locally run scheme compared to one managed on a national scale. Another shortcoming of using angling as a measure of fish abundance is that, with the onset of any decline in a fishery or river system, anglers tend to move to fish more productive catchments.

Case Study: Angler Catch Return Cards

There is broad consensus amongst anglers and fisheries scientists that grayling populations have suffered declines in northern England since the 1980s - particularly on a number of Yorkshire rivers. In November 2011, an angling club on the Yorkshire Derwent offered their historical records and angler catch returns to assist an on-going investigation into the perceived decline of the grayling population (Johnson, 2012).

Club records confirmed that there had been a significant decrease in the fishing success of grayling anglers post 1980, irrespective of any annual fluctuations. During the same period, there was an overall increase in mean weight of grayling. Similarly, there were fluctuations in the number and size of brown trout caught, specifically the weight of brown trout, which began increasing in 1977. It is possible that the reduced number of grayling and the increased fluctuations in trout numbers resulted in larger individuals in both species. These changes possibly reflected poor recruitment in some years (due to flooding events) and reduced competition amongst individuals. This study also highlighted that given favourable conditions, grayling and trout populations could recover from relatively low abundance in a very short period (2 to 3 years). The study recommended management action to improve habitat and spawning areas and an improved system of monitoring grayling influenced by poor results from electric fishing methods.

‘Grayling fishing days’ are a worthwhile way of monitoring populations, allowing anglers to fish for a specific number of hours on a specific day (such events are held annually on the River Annan). The number of grayling caught, and their length, weight and sex, have been variously recorded; on some days, scale and adipose fin-clip samples were also obtained for further analysis. From such information, growth rates, sex ratios, age structure and condition of populations can be established, and their genetic characteristics determined. Because the number of hours fished is standardised or recorded, results from different events are comparable.

Electric Fishing

As the name suggests, electric fishing uses an electrical field to facilitate the capture of fish. Patented by Isham Baggs in 1863, the electrical field stimulates the nervous system in fish and induces muscle contractions (either voluntary or involuntary), resulting in forced characteristic swimming behaviour and/or immobilisation of the fish. Approval for electric fishing in England is controlled by the EA and NRW in Wales, and by Scottish Ministers in Scotland in the case of electrical fishing for grayling.

Electric fishing is a popular technique among river managers and has been used with considerable success to monitor many aquatic species under a range of environmental conditions. For example, electric fishing has been used to monitor changes in grayling population abundance on the River Wylye in Wiltshire since 1996: by following a standardised procedure with the use of stop nets, the Wylye grayling monitoring programme (known as the Wylye Grayling Study) now boasts over 20 years of grayling population monitoring data collected at 6 long-term sites.

Under appropriate conditions, electric fishing can be very effective, especially if stop nets are used to close off a population within a river reach for assessment. However, the electrical field required to immobilise grayling can be very close to that which can cause injury or even fatality. The species recognised as most sensitive to the effects of electric fishing are grayling, chub and dace (*Leuciscus leuciscus*), and those most robust are eel (*Anguilla anguilla*) and carp (*Cyprinus carpio*) (Beaumont *et al*., 2002). Whilst some injuries may possibly occur, they should be put into context regarding the population and mortality dynamics of the fish. Schill and Beland (1995) considered that at a population level, even high electric fishing mortality rates have limited impact on species with high natural mortality rates. Pusey *et al*., (1998) found that fishing mortality (for a range of species) was generally less than 5%; this compares with annual mortality rates of >80% for many juvenile salmonids. Modern electric fishing equipment allows for fine tuning; in the hands of skilled operatives very few fish are harmed, as is evident from the extensive number of recaptures made by the Wylye Grayling Study on an annual basis (Cove and Gregory, unpublished data).

Physical differences in habitat, such as depth, river width, substrate and flow types, will result in some electric fishing sites being more difficult to fish than others. Similarly, catch-efficiency will vary temporally with changes in temperature, flow and turbidity. Grayling inhabit a wide variety of river types and sizes in the UK, and electric fishing is less effective in large deep rivers. Woolland (1972) failed to catch any grayling by electric fishing during his study on the main stem of the Welsh Dee (>15m wide). Catch efficiency will be affected by differences in fishing methodology and equipment; thus the type of electrofishing gear, number of anodes, direction of removal (upstream or downstream) and level of staff experience must all be considered.

One important factor that will determine catch-efficiency is the presence or absence of stop-nets. The “removal” and “mark-recapture” methods assume a closed population and stop-nets are used to achieve this (providing an estimate of *absolute* abundance within that netted reach). However, for semi-quantitative methods, stop-nets are not employed, thus permitting the movement of fish in and out of the site (generating an index of *relative* abundance). The overall likely effect is reduced efficiency when fishing without stop-nets compared to fishing with nets. The absence of stop-nets will clearly reduce the efficiency of electric fishing, but the magnitude of the effect is likely dependent on the habitat and species present. Adult grayling tend to swim in front of the anode and continue to do so until they reach an obstacle or obstruction, at which point, they will turn and try to flee downstream past the anode (Cove, *pers. ob*.). If electric fishing were to be undertaken purely to monitor grayling populations, fishing in a downstream direction with stop-nets may prove to be the most effective technique. This technique is adopted on rivers where *Ranunculus* beds are common and during salmonid (including grayling) broodstock collection (Beaumont *et al*., 2002) but its use to sample grayling should be undertaken only by experienced electric fishing teams to avoid mortalities.

Electric Fishing Experimental Design

There has been a lack of power analyses (see Monitoring Grayling Populations) carried out on the number of sites required to achieve robust estimates of population change. However, the Wylye Grayling Study indicates what can be achieved with consistent effort over two decades. The study began in 1996. Twelve 100m long reaches were electro-fished semi-quantitatively until 2008. From 2009 until present (2017), six 200m reaches were fished quantitatively (incorporating half of the old sites). The electric fishing is undertaken at the beginning of October. This level of monitoring is exceptional because of the costs and resources required but has yielded important long-term data on the dynamics of the grayling population in the river system. Experience suggests that a minimum of three 200m sites (or 6 x 100m), representative of habitat within the catchment, should be fished annually to provide reasonably robust estimates of grayling population dynamics within a catchment (see Population Estimates).

Seine Netting

Although not specific to grayling, post-fry stages and juvenile fish can be readily captured using a micromesh seine net, set in shallow marginal water (Cowx *et al*., 2001), between April and

September. Fish can be captured during daylight hours, using a micromesh seine (25m long x 3m deep, with 3mm hexagonal mesh) set in a rectangle parallel to the bank either by wading or a small inflatable boat. Using this method, fry as small as 5mm standard length (LS) were captured, although efficiency was reduced for fishes <15mm. In all cases, sampling was most efficient in water <2m deep (but rarely needs to exceed this depth). In these areas, water velocity was slowest and 0+ year fish tend to aggregate. The net is fished to the bank and captured fish transferred to large water-filled containers prior to analysis, once processed the fish are released unharmed. A hand net is also useful in capturing additional specimens from marginal areas; this approach preserves the condition of smaller specimens (<25mm) better than seine netting.
http://www.efish-solutions.com
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/290344/sw2-054-tr-e-e.pdf

Sampling post-juvenile grayling using seine nets can have variable degrees of success. Woolland (1972) found it to be totally ineffective for adult grayling on the main river of the Welsh Dee. However, NRW found seine netting highly effective on a heavily modified channelised section of the upper Dee (the Afon Tryweryn) in which there were limited in-river obstructions and macrophytes. The Tweed Foundation has also used seine netting successfully for grayling survey work in the Tweed catchment.

Underwater Surveys

Snorkel surveys can provide quantitative information on abundance and size structure, permitting population estimates to be made in reaches of rivers where other sampling techniques are inappropriate or ineffective. This approach is good at detecting presence or absence but only works efficiently in deep pools during cooler periods (e.g. winter) when grayling inhabit deeper water. Stop nets can be deployed to close off a reach - preventing fish escaping or entering the area of assessment. Snorkelling can also be used to assess habitat use and to measure the effectiveness of different types of habitat structure and cover which may have been installed.

Survey timing is critical to facilitate easy viewing of fish, as are water depth, width, velocity, clarity and temperature. As with all field surveys, personal safety is of paramount importance. A thorough risk assessment for each site (including water velocity & temperature) should be completed before work commences and an assessment made to ensure that the technique will meet the needs of the monitoring programme. This technique has been trialled on grayling in a large Scottish river (Gardiner, 1984) and in Europe (Näslund *et.al,* 2005).

Case Study: Lubbock River (Yukon)

Snorkel counting conducted in the Lubbock River in 2010 was found to be an effective, low-impact, and inexpensive way of counting Arctic grayling. The study concluded that Arctic grayling are the species most frequently caught by anglers in Yukon (DFO, 2007). Several grayling populations in Yukon have declined, prompting the introduction of restrictive regulations to prevent over-harvesting (Environment Yukon, 2010). Despite the importance of grayling fisheries and the potential for over-harvest, the information currently available for making management decisions is limited and there is no monitoring programme in place. Several potential methods for monitoring populations in the Yukon were reviewed resulting in development of a grayling monitoring programme in 2010.

Snorkel counting was employed to test its effectiveness and to obtain instantaneous population estimates during the annual spawning migration. To test effectiveness, the proportion of the population observed by snorkelers (termed “sightability”) was estimated by “marking” grayling then comparing the number of marks observed with the number known to be present. Population estimates were made by raising numbers seen by a calculated sightability. Peak estimated numbers of grayling in a ~250m surveyed reach were 210 (20th May), 183 (26th May) and 91 (3rd June). There was low variation in both sightability and grayling population estimates for surveys done on the same day; the method provided a precise estimate of counting grayling in the Lubbock River.

Overall snorkel counting was considered to provide a relatively rapid, non-intrusive survey technique, probably adaptable to an array of different stream types. The study suggested that future work should focus on developing a snorkel sightability model which considers measurable variables such as underwater visibility or habitat type. The study recommended testing this method in other Yukon streams; this technique may also be suitable for UK rivers where other methods are not appropriate (particularly large rivers) or where resources are limited. More details of the Yukon snorkel survey study can be found at:
http://www.env.gov.yk.ca/publications-maps/documents/grayling-population-study2013.pdf

Fisheries Management

The majority of rivers hosting grayling in the UK can be considered as “wild” and naturally functioning fisheries. There may be little need to manage such “wild” fisheries if grayling and other fish populations are healthy and well-balanced. This commonly hasn’t been the case with brown trout fisheries where discontent in ‘performance’, rivers have been stocked with overly large non-local fish, rather than tackling the root issues with impacts on the river from the catchment. The Wild Trout Trust is helping to reverse this trend by advocating better river management and habitat restoration to provide for more robust, self-sustaining populations of brown trout and other species. Therein lie dilemmas: Is there a need to manage our “wild” fish and at what point should intervention take place. Grayling have previously suffered persecution (mass culling), particularly on southern chalkstreams. However, given good environmental conditions, populations can recover fairly quickly from a low point; it could be argued that we should not therefore interfere with natural recovery. Initiatives to ‘manage’ grayling populations will invariably be angler-led and, given that there is little routine monitoring of this species, anglers will often be the first to report declines in abundance, size or condition. At this point fishery managers should consider taking appropriate action, even if the first step is to investigate further the issues of concern.

Disease and Parasites

It is not the intention here to list all the diseases and parasites that might affect grayling but rather to provide a simple guide to where specific professional advice can be sought. A more comprehensive review of this topic can be found in Ibbotson *et al.*, (2001).

Grayling are susceptible to a range of common diseases and parasites such as Furunculosis caused by the bacteria *Aeromonas salmonicida*; this can at times cause high mortalities. Grayling can often be seen, especially after spawning, with open wounds and sores. *Aeromonas salmonicida* is a common infection causing such lesions and boils combined with fungal infections from opportunistic fungi *Saprolegnia sp*. These can challenge both individual fish and at the population level.

The gut parasite *Pomphorhynchus laevis* (common name yellow peril) is a parasitic acanthocephalan worm commonly found in chalk stream fish populations; including grayling. This parasite is visible as a brightly coloured worm in the gut of the fish, but can also be seen as an orange 'dot' within the intermediate host, the freshwater shrimp *Gammarus pulex*.

Grayling can host fish ectoparasites such as the monogenean gyrodactylid species *Gyrodactylus thymalli*. The grayling is considered unable to sustain *Gyrodactylus salaris* (commonly called salmon fluke) in the natural environment, nevertheless the risk of dispersal of this species by grayling cannot be totally discounted; with potential catastrophic risks to other fish species.

Fish Disease Management

Several UK government organisations / agencies are involved in fish disease management. The Fish Health Inspectorates (FHI) in England, Wales and Scotland have responsibility for notifiable and emerging fish diseases. Notifiable diseases are those which must be reported to Cefas' Fish Health Inspectorate by law and include exotic (not present in the EU) and non-exotic diseases. These include:

- *Gyrodactylus salaris* (GS)
- Viral haemorrhagic septicaemia (VHS)
- Infectious salmon anaemia (ISA)
- Koi herpes virus (KHV)
- Epizootic ulcerative syndrome (EUS)
- Infectious haematopoietic necrosis (IHN)
- Spring viraemia of carp (SVC)
- Bacterial kidney disease (BKD)
- Epizootic haematopoietic necrosis (EHN)

The Environment Agency, Natural Resources Wales and Scottish Government all play a role in fish disease management. If you suspect a disease outbreak, the following guidance should help to plan and manage any incidents or outbreak of fish disease. **Remember** do not delay in making contact.

Guidance on Actions to Take

- In England and Scotland call the 24-hour Incident line on 0800 807060. In Wales, Natural Resources Wales Customer Contact Centre 03000 653000.
- Do not remove any fish from the watercourse but make a note of the species, location and numbers of fish seen, and take photographs if possible. Pass this information onto the Incident Team who will assess the potential risk and respond accordingly. If appropriate to do so, they will attend the site to visually assess the situation.
- The Incident Team will normally decide, in consultation with their fisheries management advisors and laboratory, if it is appropriate for the fish to be removed and sent alive to the laboratory for analysis.
- Do not kill any fish even if they appear in distress. To conduct a full laboratory analysis, it is essential for the fish to be **alive**, where possible. Little can be gained from an autopsy of fish that have been dead for several hours.
- Any fish caught should be returned to the river, irrespective of its condition.

Avoiding the Spread of Fish Diseases, Parasites and Non-Native Species by Anglers

All anglers should follow the Check Clean Dry biosecurity procedures; simple instructions that help to prevent the accidental transfer / spread of problem non-native species. While most anglers are vigilant about such risks, there is potential that those that aren't, could accidentally spread these organisms, harming the environment and potentially damaging the reputation of the sport. Non-native species could be spread in any water or material and anglers should take care to avoid moving these between water bodies.
http://www.nonnativespecies.org/checkcleandry/

Actions for Anglers

- Anglers should make themselves aware of the priority non-native species.
- Adequate signage or guidance should be in place, making anglers aware of the risk, and providing advice on how to prevent spread.
- Ideally, access and egress for anglers should be limited, preferably to a single point. Anglers should log in and out, confirming that they have cleaned and inspected their equipment.
- Remember: everyone, every time, everywhere.
- If visiting a site where an invasive non-native species is known to be present, ensure that you don't spread it. Failure to do so risks prosecution under the Wildlife & Countryside Act, 1981.
- Risk can be reduced by condensing the contact time in which equipment is exposed to the water.

Check, Clean, Dry Disinfection Procedure

Check - All clothing and equipment should be thoroughly inspected and visible debris (mud, plant or animal matter) removed and left at the water body where found. Particular attention must be paid to seams and seals of boots & waders. Any pockets of pooled water should be emptied.

Clean - Equipment should be hosed down on site. If facilities are not available, equipment should be carefully contained in plastic bags. Any washings should be left at the water body where the equipment was used or contained and not allowed to enter other watercourses or drainage systems (i.e. do not put them down the drain or sink). Where possible, clean equipment should be dipped in disinfectant solution (e.g. Virkon) to kill potential diseases, however this is unlikely to kill non-native species.

Dry - Thoroughly drying is the best method for disinfecting clothing and equipment. Boots, waders and nets should be hung-up to dry. Equipment should be thoroughly dry for 48 hours before use elsewhere. Some non-native species can survive for 15 days in damp conditions and up to 2 days in dry conditions, so the drying process must be meticulous.

Further information on Biosecurity guidance for angling clubs can be found on the Institute of Fisheries Management (IFM) website.
https://ifm.org.uk/product/biosecurity-guidance-for-angling-clubs/

Angling

Recreational grayling fisheries are becoming more culturally and economically important in the

UK at a time of increasing demand for “wild” fisheries over “stocked” fisheries. With national salmon stocks currently in a state of decline (CEFAS, 2016), there is further opportunity to promote many of the excellent grayling river fisheries in the UK that attract anglers from across Europe. Angling and anglers are playing increasingly important roles in good fisheries management; having numerous fishermen regularly visiting our rivers potentially places them at the forefront of environmental management in reporting distressed fish, pollution, poaching, etc. Anglers take this role seriously such that individuals, local clubs and national societies active in practical work in rivers and in lobbying agencies & governments for action in dealing with environmental issues affecting rivers.

UK Angling Legislation and Regulation

Angling regulations currently vary throughout the UK. The most comprehensive provisions are in England and Wales (under SAFFA 1975) with local and national byelaws; these currently prevent fishing during a close season which coincides with the spawning season (protecting vulnerable fish) and limit the numbers and sizes of fish which can be retained. The need and adequacy of these provisions are kept under review. In addition, many rivers and clubs impose additional restrictions for grayling. The promotion of good angling practice by The Grayling Society and the willingness of anglers to practice “catch-and-release” (C&R) means that the vast majority of UK grayling are returned alive to the water to contribute to future stocks and for anglers to catch another day. This was evident from the national grayling angler’s logbook scheme (England, Scotland & Wales) from which the following release rates were recorded (Cove, 2007).

Country	Total Catch	Total killed	Release rate (%)
England	56,025	84	99.85
Scotland	6,888	131	98.10
Wales	19,430	35	99.82
United Kingdom	82,343	250	99.70

The Environment Agency gave an undertaking in Policy 9 of the National Trout and Grayling Fisheries Strategy, 2003 (NTGFS) to review size limits of non-migratory trout, sea trout, Arctic charr (*Salvelinus alpinus*) and grayling (Hindes, 2008). The study utilised data from the grayling logbook scheme to develop new angling byelaws in England & Wales to protect grayling by introducing a national slot size limit to ensure that all fish have an opportunity to mature and spawn at least once. At the other end of the size scale, the byelaw protects “specimen” fish. This byelaw allows anglers to kill:

2 grayling of between 30 and 38cm fork length (12 and 15 inches) each day.

It is enforced by the EA in England and Natural Resources Wales (NRW). There is currently no national restriction in Scotland, but many angling clubs and associations operate C&R rules as part of their permit schemes.

It is readily accepted that a very high percentage of angler caught grayling are released in the UK but this byelaw in England and Wales offers long-term protection of stocks and reduces the opportunity for the “systematic” removal of grayling within trout and salmon fisheries where grayling may not be so popular. This has previously occurred, particularly in southern chalk streams, under the to a large extent misguided belief that it would give clear benefits to the trout populations.

The close season in force on rivers throughout England and Wales from March 15th - June 15th (but currently none statutory in Scotland) aims to protect fish stocks from the impacts of angling during the fish breeding season.

Good Angling Practice

It has been demonstrated that angling can provide important information for fisheries management however fish welfare for anglers must be paramount. To minimise injury and mortalities post-rod capture, grayling anglers are encouraged to adopt The Grayling Society’s Angling Code, which can be found at: http://www.graylingsociety.net/angling.

Anglers should use barbless hooks and play fish quickly. Fish should be returned to the water with minimal handling to maximise post-capture survival rates. If used, landing nets should be knotless and ideally made of rubber. Recent research from Norway (Lennox *et. al.,* 2016) into the impacts of post-capture exposure to air, shows that grayling should be returned quickly (<30 seconds) and carefully to the river. Jervis (2017) provides a very useful overview of relevant information and the latest information on good fish handling practice can be found at: https://www.keepemwet.org/

Anglers should always check local byelaws and regulations before fishing. The Environment Agency and Natural Resources Wales can provide further information on local byelaws. In Scotland, regulations given on club and association permits must be adhered to.

Age and Growth

Understanding the structure of a fish population is an important step in their management. Being able to assess recruitment, age structure and population size may reveal which part, or parts of the population (if any) may be being affected most by poor habitat or biological bottlenecks (e.g. lack of recruitment or mature fish). The following section discusses several methods for understanding the structure of a grayling population.

Ageing Grayling

The easiest and least damaging (non-lethal) method of ageing grayling is by carefully removing a couple of scale samples from live fish for examination under a low-powered microscope or microfiche reader at a later date. Scales develop when grayling reach a length of 33-40mm, forming first along the lateral line close to the caudal fin and provide protection for the fish. Small ridges (circuli) are formed on the scale surface at intervals reveal patterns of wider-spaced summer rings, when growth is rapid, and more narrowly-spaced winter rings (forming an annulus), as growth slows.

Grayling become more difficult to age from scales as they get older because their rate of growth decreases and the distinction between summer and winter growth becomes less obvious. Evidence of spawning marks on grayling scales is generally restricted to a small area of surface scarring found near the annuli and is similar to those found in brown trout. These scars are nowhere near as pronounced as those observed on scales of previous-spawning migratory salmonids such as salmon and sea trout.

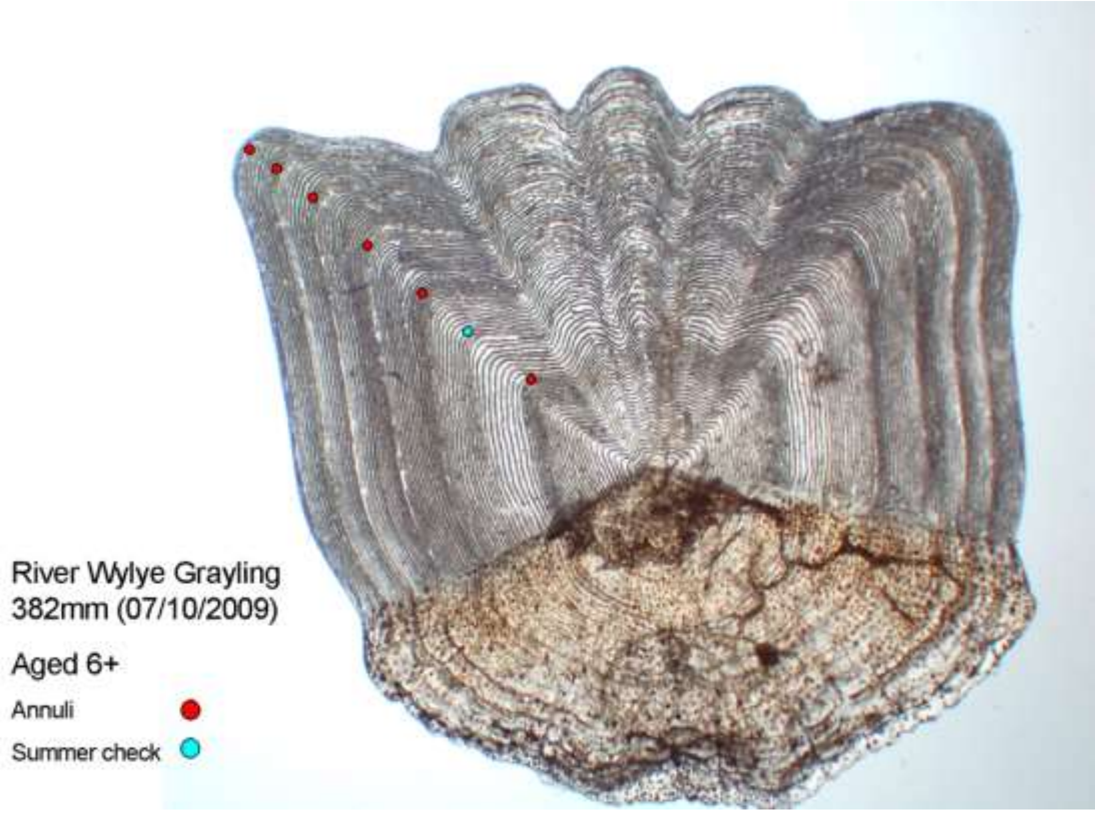
Horká *et al.,* (2010) validated ages determined from grayling scales (scale-read age) against the true age obtained by tag-recapture analysis. Nearly 4,000 individual fish were tagged with visible implant (VI) tags and PIT tags in the River Wylye, Wiltshire, between 1999 & 2007. Scales were collected in annual surveys and read without prior knowledge of tag-recapture age. Accuracy of ages determined from scales was highest in 1+ and 2+ year-old fish (less than 5% error) but decreased in older fish. In later life stages (fish of 4+ years), underestimation of age by scale reading occurred in one third of the sample, rising to a maximum of 51.9% in 5+ year-olds. Ages assigned from scales underestimated the tag-recapture age by as much as 3 years. This study suggested that use of scales may be an appropriate method of ageing a short-lived population of *T. thymallus* inhabiting productive lotic systems. However, the underestimation of age in older fish from scale readings needs to be considered in the management of fish stocks because it may lead to undesirable exploitation of a population (Horká *et al.,* 2010). Subsequently, all grayling in this study were re-aged by a more experienced scale reader to identify why such errors occurred. In this chalkstream population, growth slows markedly once fish become sexually mature and can result in only 4 to 8 circuli being formed after the previous annuli (Cove, *pers. comm.*) (Plate 1). It is recommended that grayling scale reading is undertaken by or under the supervision of a proficient reader.

Grayling in some UK waters have a relatively short life span of 4-5 years, but other populations are longer lived - up to 9 years (Ibbotson *et al*., 2001). Particularly old individuals can be found at higher latitudes and altitudes with associated lower water temperature. Males often mature at a lower mean age than females.

Scales grow as the grayling grows, but not directly in proportion to fish length. Appropriate correction for this allometric growth allows fisheries scientists to estimate the length of the fish at the end of each year's growth. This is called back-calculation (see following sections). The rate of length increase is fastest in the first two years, but decreases with age. Grayling become sexually mature between 2 and 4/5 years old (Ibbotson *et al*., 2001), the latter figure being very unusual in the UK. Male grayling grow faster than females, this often becomes evident with the onset of sexual maturity, and the terminal length (L_{infinity}) is usually greater in males.

Many factors abiotic and biotic affect the growth rate of grayling including; temperature, flow, food availability, population density and predation.

Plate 1.



Age Composition

Age structures for grayling populations vary markedly from river to river and between geographical regions; it is difficult to describe a ‘typical’ age structure. There are very few UK data on population age structures given the financial cost, resources and skills required to collect scale samples & accurately determine the age of grayling. Example studies of note include Hellawell (1969) and Woolland & Jones (1975). The long-term monitoring and research Wylye Grayling Study, provides insights into the composition of population in a relatively stable environment within one catchment. Figures 7 and 8 detail the ages of samples collected routinely in October as part of this study (Cove & Gregory, unpublished data). These graphs show large samples of grayling collected using semi-quantitative fishing (open site with single pass or run) and quantitative (closed sites using stop nets and triple pass depletion technique). There is a marked difference in the percentage of 0+ grayling (less than 20cm) in these samples and this is replicated when catches from each individual pass are compared. These data also strongly suggest that electric fishing is invariably age and size selective i.e. it favours the capture of larger specimens (see section on Electric Fishing) and this needs to be considered when assessing the age composition of a stock. One feature of an imbalanced (and probably declining) grayling population is that several age-classes are missing, and larger, older fish dominate.

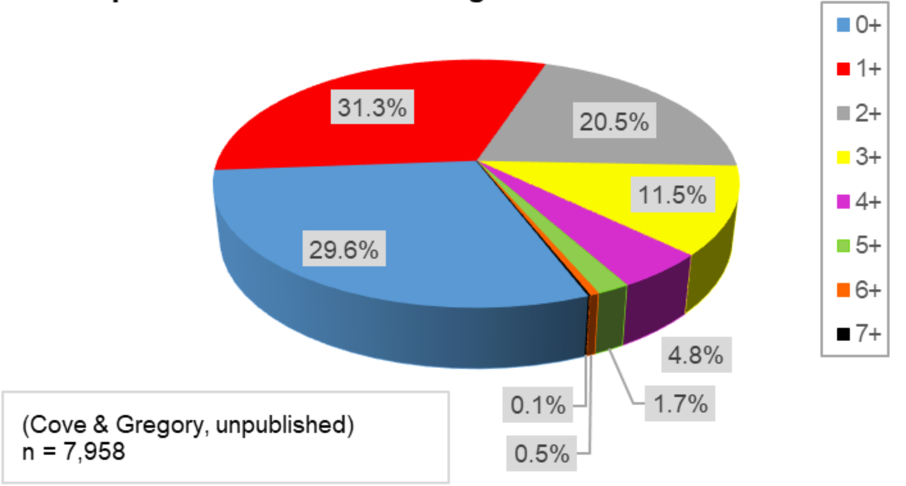


Figure 7. Grayling age composition, River Wylye semi-quantitative electric fishing 1996-2008

(Cove & Gregory, unpublished)
n = 7,958

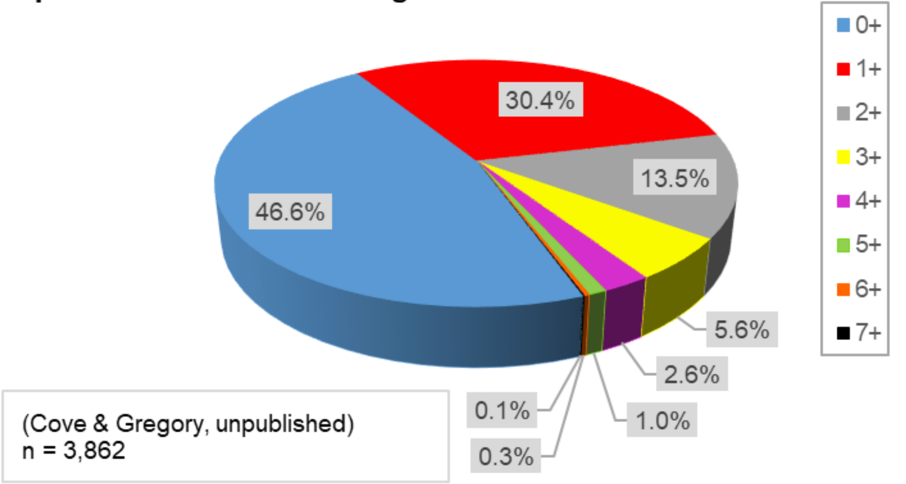


Figure 8. Grayling age composition, River Wylye quantitative electric fishing 2009-2017

(Cove & Gregory, unpublished)
n = 3,862

Back Calculating Length at Age

Generally, fish scales do not appear until fish are a few centimetres in length, then appear as a small plate. As the fish grows, the scales also grow. To estimate the length reached at the end of each year's growth, the first step is a simple back calculation which assumes proportional growth. Generally, scale measurements are made from the centre of the scale growth out to the edge (or margin) of the scale on its anterior axis (anterior radius). For some fish species, these measurements can be used without correction to give reasonably accurate back-calculations of fish length in each winter. However, this does not apply to grayling. Bigger grayling have scales much larger than expected assuming simple proportional growth. To correct for this, back-calculation requires knowledge of the relationship between the size of scales and fish length. Figure 9 shows the fork length of grayling sampled in the UK plotted against the average anterior radius measurement of a sample of scales taken from the shoulder of each fish. The equation of the fitted line shows that the relationship is non-linear, following a power-law. The relationship can be used to correct back calculations of length at a specific age:

$l_1 = (U / l_2)^{0.63} \times l_2$ Where: U = the uncorrected back calculation
l_1 = fork length at intermediate stage (unknown)
l_2 = final length of fish (known)

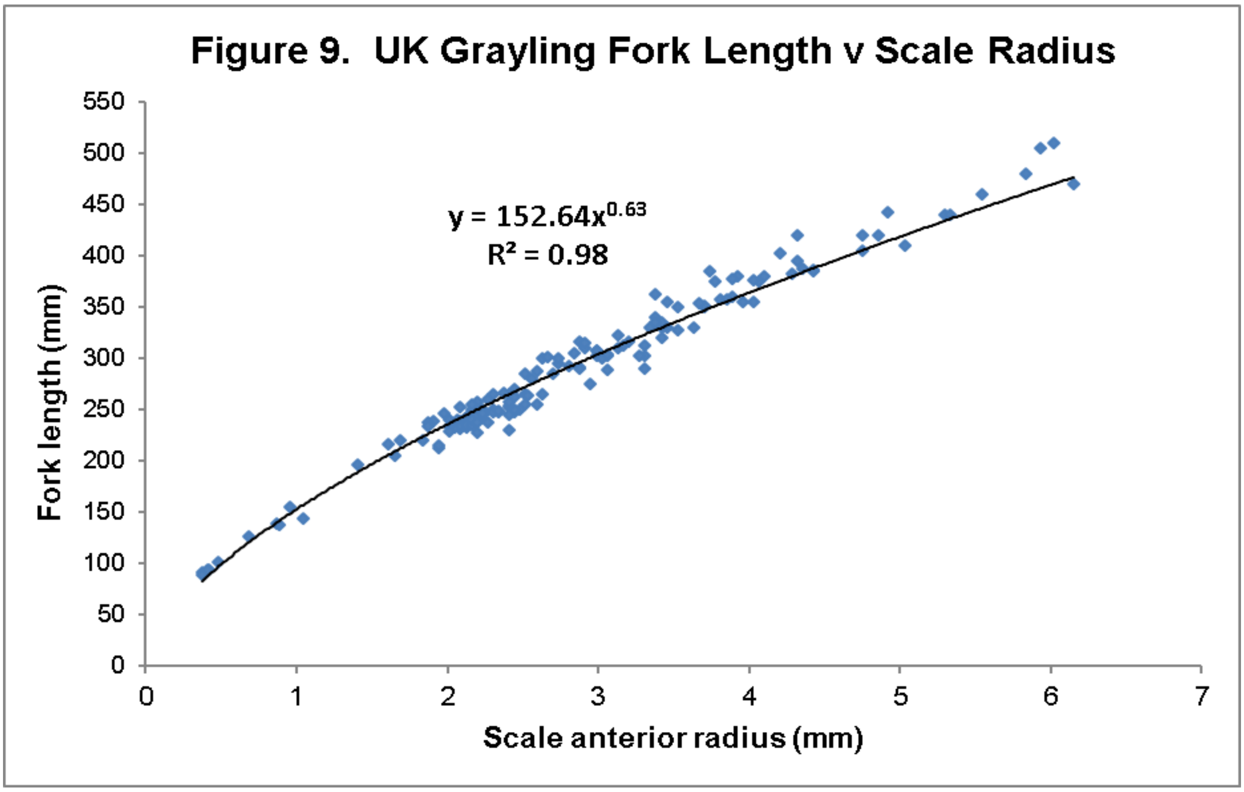


Figure 9. UK Grayling Fork Length v Scale Radius

Back Calculation Example

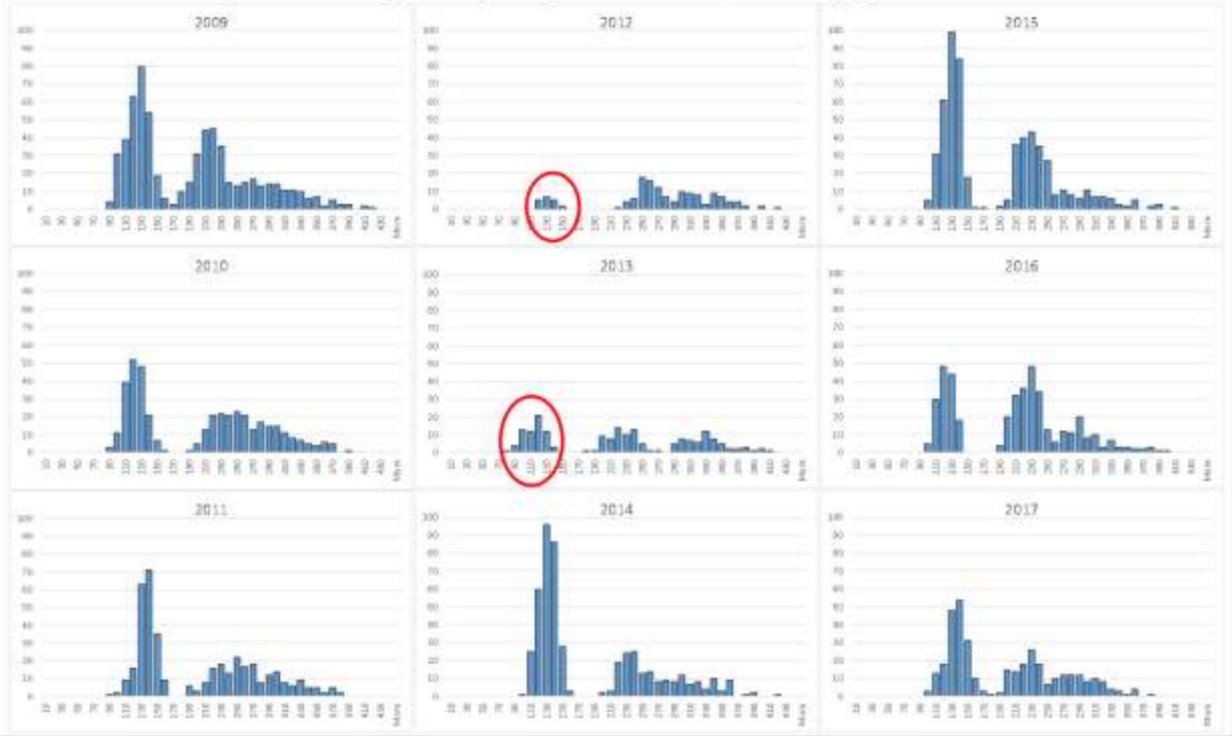
For example, taking a grayling with a fork length of 360mm, with an uncorrected back-calculated length from the scales of 70mm reached in the first winter, the corrected length reached in the first winter would be $(70 / 360)^{0.63}$ x 360 = 128mm.

Length Frequency Distribution

The length-frequency distribution of a grayling population will often exhibit distinct modes, with the smallest fish (aged 0+ and 1+) showing the strongest modes. These modes are often more pronounced in grayling than other species because they have a short spawning season with rapid and uniform growth. As a consequence, the first few age groups can readily be determined (Figure 10). In this example from the Wylye Grayling Study (Cove and Gregory, unpublished), a marked failure in recruitment (very few 0+ fish) in both 2012 and 2013 is easily identifiable (circled in red).

Although age can be determined from scales, length composition alone may allow different age groups to be identified with confidence - a technique which serves greatly to reduce the amount of scale reading (age determination) required. This can be especially useful if scale ageing equipment is unavailable or only size data (e.g. from angler catches) are provided, or no scale samples have been collected. As fish get older their growth slows and modes converge and begin to overlap, such that it may no longer be possible to identify separate age groups graphically. Thus, age determination from scales of larger fish may be required, particularly in southern chalk stream populations where growth rates slow markedly after maturation.

Figure 10. Length frequency distribution, River Wylye: 2009-2017



Calculating Length Frequency

For anyone wishing to represent their length-frequency data graphically using Microsoft Excel software:

1. Enter fish lengths into *column A*
2. Enter a series of “bins” in *column B* into which the lengths will be sorted, say 0, 10, 20, 30, 40, 50...up to say 500 for fish lengths in mm
3. The maximum number in the bin range is dictated by the largest fish in the sample, for most UK sites 450 will suffice

4. Go to *DATA -Data Analysis - Histogram*
5. Define the *Input range*, *Bin range* and select *Labels*
6. Select a place for the *Output Range*
7. Select OK to produce the output
8. Whilst the new table is still highlighted, select *INSERT Column Chart*
9. Edit the graph as necessary

Age-Length Frequency Distribution

In the long-term monitoring programme Wylye Grayling Study resourced by The Game and Wildlife Conservation Trust (GWCT), NRW, the GRT and Piscatorial Society, grayling have been aged from fish scales since 1996. The length-age frequency distribution is shown for a typical year (2009) in Figure 11. This population demonstrates very fast growth in the first two years to sexual maturity (distinct modes), then growth slows markedly creating considerable overlap in the ages of fish greater than >300mm.

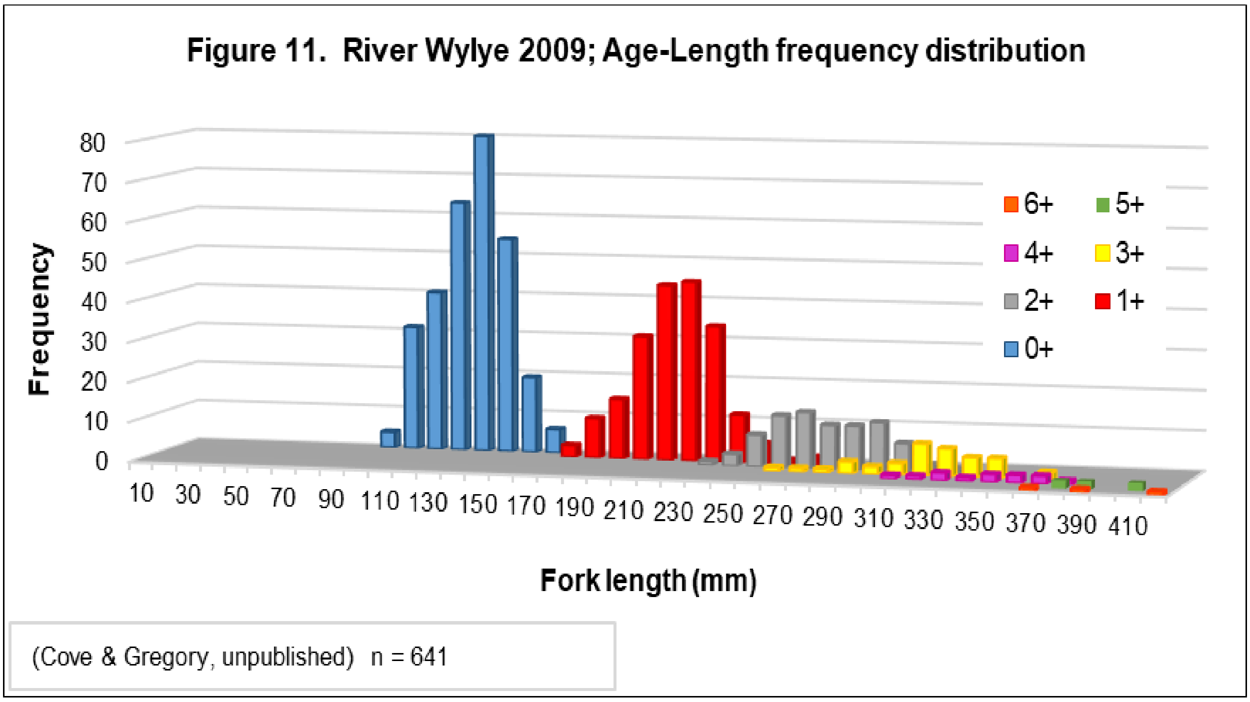


Figure 11. River Wylye 2009; Age-Length frequency distribution

(Cove & Gregory, unpublished) n = 641

Population Estimates - Depletion Methods

Fish abundance in freshwater systems can be estimated by several methods:

- Capture / recapture
- Depletion
- Gear calibration methods
- Catch effort sampling strategies, such as creel censuses, log books, catch statistics
- Remote sensing using hydroacoustics

Of these, depletion methods are commonly used for routine surveys of streams and small rivers. The principle of depletion is that fish are removed progressively from a netted off section of river in several successive fishings, using, for example, electrofishing equipment. The rate at which the catches "fall off" is then used to estimate the most likely size of the population (with statistical confidence limits). The estimation of population size assumes that the chance of catching a fish in any fishing is constant. Two statistical methods are in common use: the original Zippin (1956) method, and the Carle and Strub (1978) method, which uses a more complicated weighted estimation procedure. With high numbers of fish, and a high and reasonably constant proportion of fish caught in each fishing, both give similar results, but if these conditions are not met, the Carle and Strub method will generally provide a better estimate. Although the calculations in the Carle and Strub method are more complex, software such as that available from Pisces Conservation http://www.pisces-conservation.com/ is now used to make these calculations, greatly simplifying the procedure. The likelihood that a fish is caught depends on the species and the size of fish, and generally the calculations are done separately for each age class of each species present.

Below is an example from an electric fishing survey at a site on the River Hull. The section of river was "closed" using stop nets, isolating 50m of river (hence a quantitative survey site). The same equipment and team were used for each fishing (sometimes termed "run") so that fishing effort remained the same.

Fishing	Number of fish caught
1	52
2	27
3	18
Total catch	97

Estimates of population size

Method	Estimated population size	95% confidence limits
Zippin	119	± 22.2
Carle and Strub	116	± 19.5

Condition Factor and Length-Weight Relationships

The similarity of several different data sets indicates that despite varying growth rates, the relationship between length and weight in grayling varies little between most UK rivers. There will be slight deviation from river to river and across regions however a general measure can be adopted which should be strongly indicative of weight from length. Condition factor also varies between sexes and is dependent upon time of the year (females become heavier than males of the same length over the winter with the on-set of sexual maturation). Figure 12 represents the relationship between length and weight (centimetre to kilogram), based on the fork length to weight relationship data recorded by Woolland (1972) for Welsh Dee grayling, with some extrapolation. Although the relationship between length and weight varies only marginally between rivers, sexes, ages, etc., those difference can be important for individuals at the extremes of the size, weight or condition range. To better account for this, it is possible to estimate the relationship between length and weight for a specific sample of fish using non-linear least squares

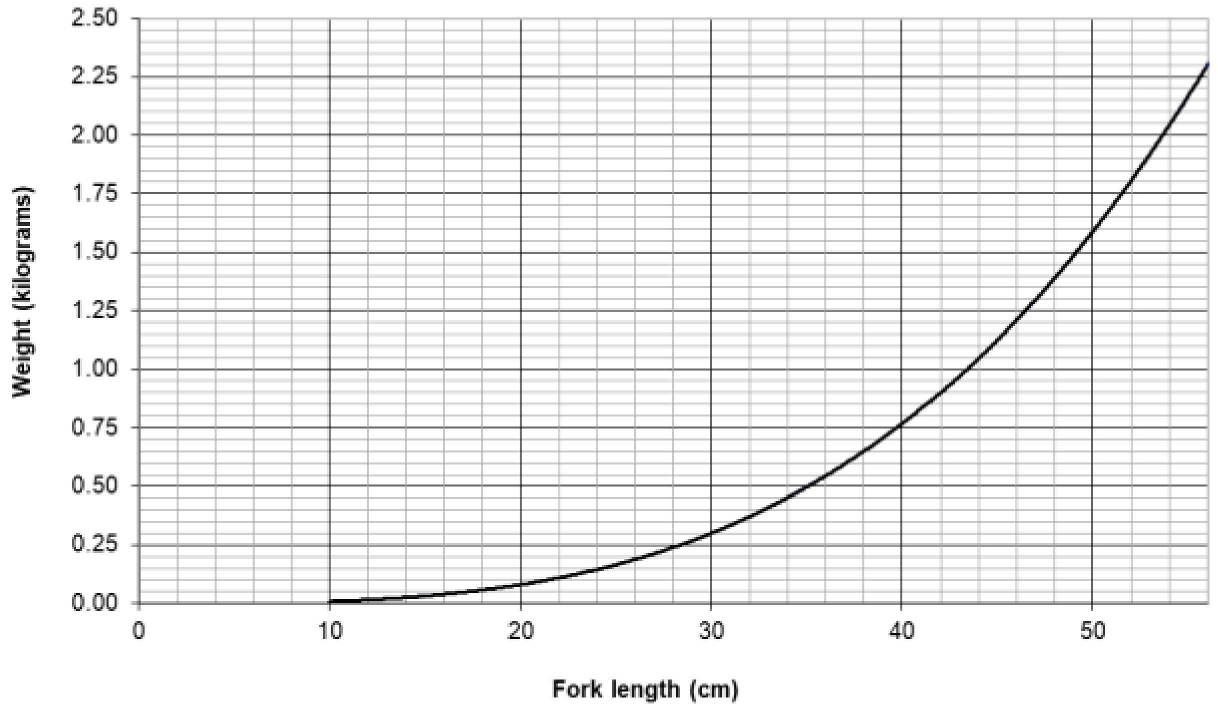


Figure 12. Typical Weight for Length of Grayling

Grayling Tagging / Marking Techniques

Introduction

Application of a tag (or mark) is a means of identifying a fish either as an individual or as a member of a batch or group. Fish tagging programmes are undertaken for a number of reasons:

1. Population estimates
   - Densities (fish per unit area - usually per 100m^2)
   - Mortality / survival rates
   - Exploitation rates
   - Rates of recruitment
2. Movements and migration
3. Growth and age determination
4. Behaviour research where the recognition of individuals is involved

Although many techniques and methods are available, those most appropriate for UK grayling studies are identified. Rivers where these techniques have previously been used are shown in square brackets [], with the country (England - E, Scotland - S or Wales - W) indicated in curly brackets {}. Many of these procedures should be completed by an experienced operative and may require a Home Office Licence (dependent upon the purpose). Research or scientific study, must by law be conducted by a Home Office licensed operator (PIL) and be assigned to an approved Home Office project licence (PPL). A licence may not be necessary if fish are being tagged for identification for management purposes only; however the reader should check before undertaking any tagging operations.

Mark-Recapture

Estimation of population size by mark-recapture experiments is based on the assumption that the proportion of marked or tagged fish in a random sample is the same as the proportion of a known number of marked fish in the population.

The basic formula is: $n = mc/r$ where: n = number of fish in a population
m = number of marked fish in a population
c = number of fish in a sample
r = number of marked fish in c

There are modified forms of this equation designed to reduce a bias which occurs if the basic formula is used with small sample sizes. Mark-recapture methods have been successfully used in UK rivers to estimate population size within defined stretches. [Dee {W} Derbyshire Dove {E} Wylye {E}]

Fin Clipping

This technique has the advantage of being quick, simple and requiring a minimal amount of equipment. Where a fin is completely removed, full regeneration is uncommon. Regeneration tends to be more rapid and complete among young fish, among spiny-rayed fish and for single fins compared to paired fins. Partial fin amputation may be preferable to complete removal as it causes less damage to the fish and makes the marking of large fish easier. Distinct fin clips can be used to identify different years or locations of marking. Grayling have the added benefit of an adipose fin which can be clipped or removed with potentially minimal damage; although research by Buckland-Nicks (2011) supports the theory that the adipose fin may act as a precaudal flow sensor, where its removal can be detrimental to swimming efficiency in turbulent water. Until more evidence of damage is available, the adipose fin remains the favoured area for batch-marking grayling and other salmonids. [Ceiriog {W} Dee {W} Wylye {E}]

Pan Jetting

Pan Jetting uses a photonic marking gun with a spring-loaded trigger system or CO_2 canister to force a pigmented solution from a nozzle at high pressure through cell membranes (equivalent to a tattoo). The hand-held injector is portable and useful for field studies for individual or batch marks. This technique is cheap, fast, and able to distinguish groups of fish or individuals and has minimal impact on fish of all sizes. Marks vary in longevity dependent upon mark location, water temperature and growth rate. Retention rates on marked fish can be low and is not permanent but it has been successfully adopted in mark-recapture studies in central England. [Derbyshire Dove {E}]

External Tagging (including T-bar or anchor tags)

External tagging is one of the oldest and extensively used marking methods. T-bar tags (anchor or “Floy”® tags) are usually attached to the fish with a T-shaped nylon monofilament which anchors between the fin rails at the base of the dorsal fin. Tags are fixed using a Kimble gun similar to those used on clothes labels. The technique is inexpensive, simple, applicable for various fish sizes, individual fish can be easily identified, requires minimal fish handling and has good retention and fish welfare if performed by an experienced operative. Buzby & Deegan

(1999) found retention rates of 85% over 3 years on arctic grayling. This type of tag is no longer recommended for grayling as less invasive and more suitable alternatives have become available. [Tweed {S}]

Visible Implant Tag

Far more suited to grayling is the visible implant (VI) tag which is injected behind the eye in the clear periocular tissue. Adult grayling have a generous area of clear tissue allowing for good visibility (in recaptured specimens) and excellent long-term retention rates given the significant number of tags recovered in the Wylye Grayling Study (Cove and Gregory, unpublished data). Smaller VI tags have also been used successfully on juvenile grayling with retention rates of 93% achieved in a hatchery prior to stocking (Cove, 2009); this was despite smaller fish (range 84-188mm) having far less and thinner periocular tissue. [Ceiriog {W} Dee {W} Wylye {E}]

Passive Integrated Transponder Tag

Passive Integrated Transponders (PIT) tags, sometimes referred to as RFID (Radio Frequency Identification Device), consist of a small glass-encapsulated electromagnetic coil and microchip. The smallest full-duplex PIT tags can be inserted into the body cavity of a fish using a veterinary syringe and the slightly larger half-duplex PIT tag can be surgically inserted into the body cavity using a small incision. The tag does not contain a battery and is inert until an inductive pulse is sent by the antenna / reader. When the tag has charged, it responds with a short radio message that contains a unique serial number, thus identifying individuals. Tag readers can consist of a hand-held wand, antenna (PIT loops), or even a series of plates that can be placed on the river bed. PIT tags can be used to identify individual fish, assess migration success over weirs and other barriers or to investigate habitat use within defined areas. Buzby & Deegan (1999) observed retention rates of 83% over 3 years but recent studies in southern English chalk streams suggest that some tags inserted into the peritoneal cavity may be extruded / rejected by grayling during the spawning process (Cove & Gregory, Riley, *pers. ob.*) and a secondary inert tag or mark (such as a VI tag or fin clip) would readily identify PIT tag rejection. Other studies have successfully inserted PIT tags intra-muscularly just beneath the dorsal fin where long-term tag retention may be improved. [Brandy Stream {E} Costa Beck {E} Derbyshire Dove {E} Dorset Frome {E} Ecclesbourne {E} Wylye {E} Yorkshire Dove {E}]

Acoustic Tag

Acoustic tags utilize ultrasonic wavelengths to transmit signals to submerged receivers (hydrophones) as acoustic signals are greatly attenuated in air. These tags require an internal battery to power a transmitter - the size of the battery dictates tag dimensions and therefore minimum fish size. Tag life is dependent upon battery size, transmitter size, signal rate and range. Acoustic tags are usually surgically implanted into the fish and typically tag detection data is gathered with hydrophones. As with radio telemetry, there are a limited number of distinct codes that can be transmitted per frequency. This technology has not been used on UK grayling. However, given the successful application of the Vemco™ system to the tracking of migrating wild salmon smolts, these tags offer great potential for use in UK grayling studies, particularly to investigate, fish passage success, behaviour studies around potential barriers to migration and habitat use and preference. The high cost of individual acoustic tags (~£200) would undoubtedly limit any study sample size in comparison to using cheaper inert PIT tags (~£2).

Radio Telemetry (VHF)

Radio telemetry uses VHF transmitter tags to emit signals through fresh water and air to receivers that detect and record them. Transmitted signals can be detected and recorded with antenna receivers and/or logging stations (passive tracking). However, the number of distinct codes that can be transmitted per frequency is limited. Tagged fish are tracked via periodic detection by fixed, remote antenna/receivers or, more commonly, by roving boat, road vehicle, airborne craft or on foot (active tracking). As with acoustic tags, the size of the tag is dependent upon the size of the battery required to power the tag electronics. Radio telemetry tags are usually surgically implanted and, in common with similar technologies, can provide data on habitat use, behaviour, fish pass success, avian predator avoidance and identify home ranges. [Lambourn {E} Rye {E} Ure {E}]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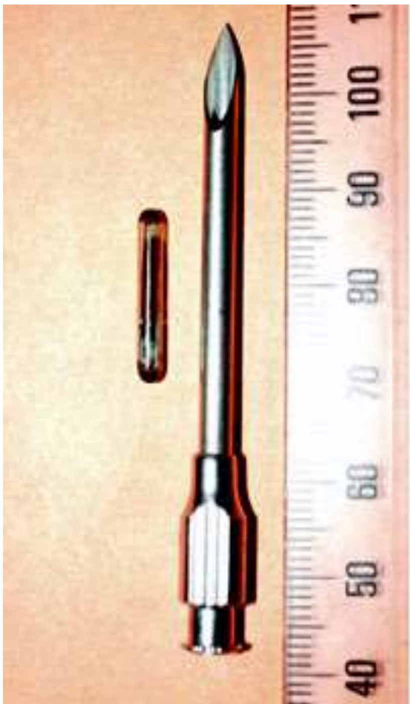
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Stocking, Genetics and the Role of the Hatchery

Stocking Guidance

The stocking and transfer of grayling between UK catchments is not well documented post World War II. However, it is apparent that they were commonly transferred between catchments. In 2003, the Environment Agency issued its National Trout and Grayling Fisheries Strategy (NTGFS). This document offered advice on grayling stocking and movements with the intent of preventing further spread of the species beyond its current range in England & Wales. Policy 21 states:

"We will only permit stocking of rivers, streams or other unenclosed waters in catchments where the grayling is **already present**, except possibly:

- To re-establish a previous population (even if introduced); or
- For rivers recovering from long-term gross pollution where wider consideration will be given to the species stocked and the type of fisheries that might be developed.

Stocked grayling must have a **suitable, generally local**, provenance."

Furthermore, the EA Work Instruction on Determining Fish Movement Consents states: "In considering whether or not to consent a fish movement, the following guiding principles will be adopted:

- Fish movements must not be allowed to jeopardise the well-being of naturally established ecosystems;
- There must be no detriment to the fisheries (stock, habitat, performance) of the donor water or the receiving water, or to the viability of the fish involved in transfer or introduction.

With regard to fish species:

- A precautionary approach must be taken regarding the suitability of the species to be introduced; the presumption will be against the introduction or spread of fish species outside of their natural range.
- Where the species for proposed introduction is not naturally present and/or is judged to be potentially detrimental to the balance of existing species, they must not be introduced to unenclosed waters."

UK Genetics

In 2008 Bangor University, the Environment Agency and the Grayling Research Trust collaboratively undertook a genetic census of UK grayling populations. Anglers from The Grayling Society, GRT, Wild Trout Trust (WTT) and EA obtained nearly 1,200 tissue samples, which were subsequently analysed at Bangor University. A successive investigation was undertaken by the same University, EA and GS.

Case Studies: Dawnay *et al.,* (2010); Johnson (2011)

The foremost study demonstrated that UK grayling display pronounced genetic structuring and restricted connectivity between all but a few populations. Despite the high degree of differentiation among the 27 populations sampled, analyses of microsatellite data revealed four or five groups (depending on the analysis method) that, with the exception of two populations, grouped largely by geographic location.

Using the four-group split (A, B, C and D), Group A is composed of native Welsh or Welsh borderlands populations plus the Annan (Scotland), suggesting grayling may have been introduced to the Annan from a Welsh river (probably from the Wye or Severn catchments). Group B includes most Northern England populations, Group C contained only Southern England populations, while Group D contained all the remaining UK populations (Figure 13).

Progeny for recent UK introductions have originated from the River Test (a southern chalk stream). For many years, wild adult broodstock were captured from the River Test, stripped and the offspring raised within the Environment Agency's Calverton hatchery. Stocking records indicate that the Aire, Wharfe and Derbyshire Dove have received large numbers of individuals from the Test since 2006. One individual fish within the Aire sample and three fish from the Dove were likely to be of River Test origin, indicating that some stocked individuals were surviving within these recipient rivers. No individuals within the Wharfe sample were assignable to River Test origin but sample sizes for each catchment were relatively small (usually 50 or less).

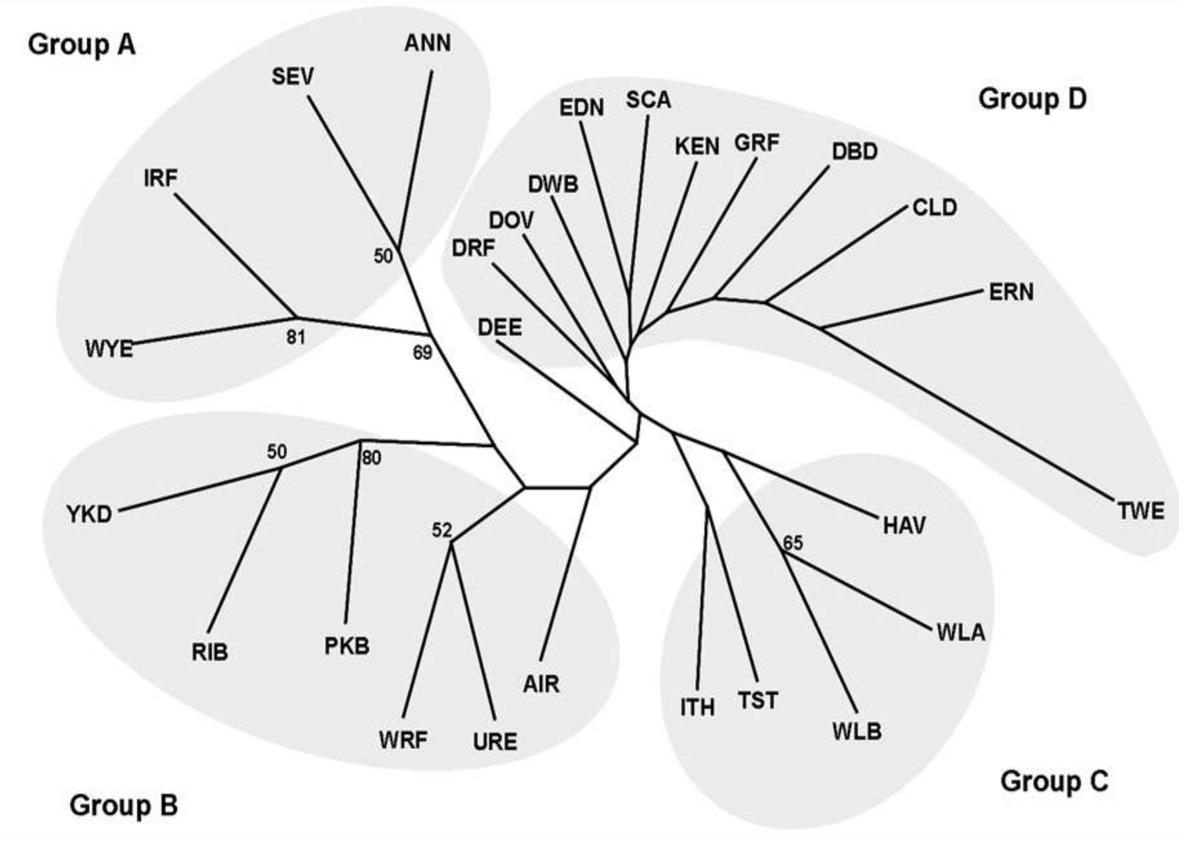
For most of the 27 samples, effective population sizes (Ne values) were small and in nineteen catchments, less than 50 - such values suggest populations are at risk of inbreeding depression. However, due to high site fidelity found among grayling, low Ne estimates may reflect a subset of a population rather than the population as a whole (Swatdipong *et al.*, 2010).

Further research investigated potential population genetic structure within a single catchment, the River Dee in North Wales (411 samples spanning 85 kilometres of river) to help determine the level at which population genetic structure becomes apparent. Based on methods available at the time, the research (Johnson, 2011) indicated no significant differentiation within the entire Dee grayling population. Although the data was interpreted as indicating that substantial structures that may represent potential barriers to upstream movement had not impeded the movement or spawning migration of Dee grayling, it would be desirable to test this again with the improved methods of genetic analysis now available. Genotypic data indicated an effective population size (Ne) of less than 60 individuals yet no inbreeding depression within the population. This study also developed a non-invasive technique for sampling DNA in UK fish using buccal swabs (97.8% success from fish caught and sampled by anglers).

Implications of Genetic Studies

Grayling introductions occur far less often in comparison to trout stocking and in most cases, have been undertaken as a public relations exercise to temporarily alleviate concerns of some anglers, this despite potentially having detrimental effects on the conservation status of the existing population. Despite the National Trout and Grayling Fisheries Strategy, controls on grayling stocking and introductions appear to have been only partially successful. The 2010 genetic study identified distinct genetic differences in grayling populations across the UK and as a result, populations could be managed as individual units. Where populations are struggling, improvements to habitat diversity, water quality and exploitation control should always take priority. If, however, there is a requirement to re-stock, progeny should come from genetically similar broodstock, preferably from the recipient catchment. With only one hatchery successfully rearing grayling in the UK (Calverton), this should be manageable. For the few truly native grayling populations (thought to be restricted to the Rivers Yorkshire Ouse, Trent, Hampshire Avon, Severn and Wye, and possibly the Ribble and Welsh Dee and their tributaries), only grayling sourced from within the catchment or produced using broodstock from the catchment should be introduced. NTGFS policy 21 was re-enforced by the 2010 genetic study - a rare example of grayling research leading to improved management action in the UK.

Figure 13. Un-rooted phylogram of population-level relatedness constructed from microsatellite frequencies using Nei's D measurement of genetic distance. Bootstrap support (based on 2000 replications) suggests four main groups are present within the UK.



Group A: Comprised native Welsh populations (**WYE**, **IRF**on and **SEV**ern) and the **ANN**an, population, suggesting **ANN**an grayling may have been introduced from Welsh stock.

Group B: Included most Northern English populations (**Y**or**K**shire **D**erwent, **RIB**ble, **P**ic**K**ering **B**eck, **W**ha**RF**e, **URE**, **AIR**e).

Group C: Contained only Southern English populations (**IT**c**H**en, **T**e**ST**, **H**ampshire **AV**on, **W**y**L**ye **A**, **W**y**L**ye **B**).

Group D: Contained all remaining populations in the UK including one Welsh (**DEE**), two Southern (**D**o**R**set **F**rome, **KEN**net), two Midland (**DOV**e, **D**er**B**yshire **D**erwent), two Northern (**D**riffield **W**est **B**eck, **ED**e**N**) and all Scottish populations except **ANN**an (**E**a**RN**, **S**outh **CA**lder, **GR**y**F**fe, **CL**y**D**e, **TWE**ed).

Role of the Hatchery

In the past two hundred years, adult grayling have been successfully relocated (with appropriate authorisations / permissions) to other catchments particularly in South Wales and in Scotland (without appropriate consent). Currently "declining" populations are supported using juveniles sourced from the EA fish farm at Calverton. This facility rears approximately 60,000 grayling per annum from broodstock now originating from three English rivers: Derbyshire Derwent, River Test and the Yorkshire Ouse.

Historically, rivers were stocked to provide sport for anglers and not for conservation purposes and this may sometimes still be the case. The main problems with such fish transfers is that they took no note of genetics or the risks of disease transfer from source to receiving water. Until recently, this also applied to fish sourced from hatcheries where the additional problem of introducing genetic introgression arose leading to weakening of local adaptation. However, these past transfers did avoid the problems of hatchery-sourced fish having not developed predator avoidance strategies and needing to learn to source food naturally. More recently, emphasis has shifted toward the sustainability of populations through effective river management and conservation (Dawnay *et al*., 2010).

It is appreciated that grayling can provide social and economic value for angling, particularly during winter periods when other fish species are reluctant to feed or are subject to a close season (e.g. trout in Scotland). However, there are several problems associated with stocking grayling:

- Fertile hatchery grayling can reduce genetic variation within populations if significant inter-breeding occurs with wild fish.
- Reduced genetic variation reduces local adaptation and fitness (i.e. their ability to survive and reproduce).
- Hatchery-derived grayling don't have the equivalent genetic potential to adapt, survive and reproduce compared to wild fish;
- There is increasing evidence that stocking, as a strategy to halt or reverse population decline, has failed in most rivers. Against a background of stocking, population decline often continues.

Currently EA & NRW policy is not to stock grayling into rivers where they do not naturally or currently exist, except for those recovering from long-term gross pollution. Although not obligatory, stocked fish should also be genetically equivalent to the population already present within the water body. The 2010 genetic study raised the possibility that grayling with the genetic signature of River Test fish were not present in the River Wharfe, despite years of stocking from Test broodstock. One stocked individual within the Aire sample and three Dove samples were likely to be of Test origin. Thus, the contribution of stocked fish to the long-term population appears marginal.

Damage to existing grayling populations could potentially occur when farmed fish breed with wild individuals, resulting in loss of adaptations and diversity. This may be crucial in rivers having unique characteristics, e.g. chalk streams or spate rivers. Each population will have adapted characteristics to deal with different environments. There is significant evidence to suggest that stocked fish, when contributing to a population, genetically reduce the population's ability to survive, losing genetic traits the original population had adapted for that river system. Although most of the evidence for loss of adaptation arises from other salmonids, there is now evidence particularly from Europe, of similar effects in grayling.

A study of the grayling populations of two rivers in the Danube drainage, the Inn and the Drau

(Duftner *et al*., 2005), has shown that, whereas there is only marginal evidence of genetic impacts in the Inn, the Drau population has suffered serious alteration of its genetic composition, with almost 40% of individuals affected. A similar result was found in the Adriatic Soča river system where, after four decades of stocking, 50-60% of individuals have been identified as having insufficient genetic material to restore original populations (Sušnik *et al.,* 2004). These findings, comprehensively reviewed in a recent paper by Meraner *et al.*, (2014), support stocking only after the identification of specific "management units" in an attempt to restore, as far as possible, the genetic integrity of original populations. This mirrors current EA policy based on the genetic work of Dawnay *et al.*, (2010) on UK grayling population structure and stocking implications.

Stocking with fish reared in hatcheries may do more than provide easily caught food for predators. In addition to deleterious effects, it focuses the attention and efforts of individuals / angling clubs away from the main issues of why populations are under-producing or in decline in the first place. With many British rivers containing failing Waterbodies under the Water Framework Directive, structural, catchment-wide improvements are urgently needed rather than simply using stocking for symptomatic relief, leaving the underlying problems unaddressed. Stocking of juvenile grayling is just one of several tools available to restore diminished populations, but perhaps an option of last resort. Prior to stocking, the probable causes of population decline must be established and addressed. Development of suitably diverse habitat (Ibbotson *et. al*., 2001) should take precedence over stocking. If stocking is deemed necessary, it should be part of a wider, long-term restoration strategy and plan.

Low abundance has resulted in increasing interest in rebuilding actions for grayling, including the potential for stocking. However, as recognised in guidelines, there are risks and benefits associated with such interventions and understanding of these. Much can be achieved to rebuild stocks without the need for stocking. While hatchery and stocking programmes may have a role to play in kick-starting the restoration of lost river stocks or where the stocks are at critically low levels, it was suggested that much stocking continues for socio-political reasons irrespective of the risks associated with such activities and without evidence of benefits. Given the substantial information now available and that if the genetic integrity is a management priority, stocking of hatchery fish should only be contemplated after careful evaluation of the risks and benefits and only after other alternatives have been considered. There should be a strong presumption against stocking for socio-political reasons and the use of tools such as Population Viability Analysis should be used to inform decisions to stock where wild populations are considered at risk of extirpation, and then as an interim measure while other rebuilding efforts are being implemented.

Good Stocking Practice

Good stocking practice should be adhered to when introducing grayling. Studies have indicated that downstream dispersal of grayling can be considerable post stocking (several kilometres) (Carlstein & Eriksson, 1996, Cove, 2009), usually taking place within two hours of release (Thorve & Carlstein, 1998). The extent of migration is greater with fish of hatchery origin than naturally occurring wild fish (Horká *et al.*, 2015). Cove (2009) found that downstream dispersal of juvenile grayling within the stocking area was common but not universal (median distance travelled 450m, range -268m to 1,700m) and larger stocked grayling tended to disperse less distance than smaller fish. This study proposed retention of grayling in the recipient river near to the upstream limit of the stocking zone prior to release to allow acclimatisation to local conditions and the changes in water chemistry from the hatchery. This reduced downstream dispersal and potentially secures higher survival rates. An overall survival rate of ~5%, 108 days post-stocking was attained. Turek *et al*., (2010) demonstrated that the condition factor of surviving reared grayling can be equal to that of wild fish, suggesting effective adaptation of introduced grayling to their new environment under the right conditions.

The European grayling should **<u>not</u>** be spread beyond the current UK range by stocking. Rather, efforts should be focused upon the conservation and good management of existing populations. Under **<u>no circumstances</u>** should grayling be stocked for enhancement of an existing fishery.

River Restoration and Rehabilitation Techniques

Introduction

River restoration and rehabilitation practice now encompasses a great variety of ecological, biological, spatial, physical, management methods & measures, and is a rapidly evolving area of environmental activity. The overall aims are, as far as possible, to restore the natural state and function of a river system in support of biodiversity, recreation, flood management and landscape development. Wider benefits from river restoration include:

- Benefits to local economies, tourism and social well-being via recreation
- Significant contributions to flood risk reduction by increasing the natural retention capacity of catchments and their rivers; excess water can be absorbed by restored or new peatlands and wetlands, floodplains, former meanders and other natural storage phenomena, including groundwater in deep and near-surface aquifers
- Benefits to and the enhancing of biodiversity by restoring natural habitats for animals and plants, both in the river and on the wider riparian margins

River restoration techniques can vary widely in type and scale and only the main practices are summarised. For anyone contemplating a restoration scheme, advice and support should be sort from skilled practitioners. That said, the authors are **not** aware of any habitat schemes undertaken in the UK specifically aimed at restoring / or enhancing grayling abundance or measuring the impact of habitat restoration schemes on a grayling population. Most schemes have been undertaken to benefit brown trout and salmon in the belief (which may be misguided) that grayling benefit equally. Restoration schemes may take a multi-species approach such as those undertaken in the River Taff (including grayling), however the requirements of all species must be understood and incorporated in the project design. The Environment Agency (2004) produced an advisory document titled “Management advice for trout, grayling and Arctic char fisheries” promoting a holistic approach to fisheries management. This can be found at:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/290646/sw2-045-tr-e-e.pdf

The legislation surrounding river restoration is complex and different in Scotland, where different legislative frameworks and agencies exist and act for the natural environment. As a result, it is recommended that contact is made with the local EA or NRW Fisheries Officer in England and Wales, or with the Scottish Environment Protection Agency (SEPA) or rivers trust (where one exists) in Scotland. Staff in these bodies should be able to advise and guide through designing plans, legislation and applications. An Advisory Visit (AV) by the Wild Trout Trust (WTT) is recommended. AVs can be arranged through the WTT or The Grayling Society and involve a walk-over survey and written report advising on the best course of action to improve river habitat for grayling. More details can be found at the WTT and GS websites:
http://www.wildtrout.org/; http://www.graylingsociety.net/

Ancestral Connectivity

Although grayling populations may be able to maintain themselves in rivers with obstructions to free passage, it is highly desirable, particularly in rivers which contain native populations, that ancestral connectivity is maintained, or restored (see section on Fish Pass Design).

Vegetation in Grayling Habitat

Unlike trout, grayling tend to make very little use of in-river vegetation. Riley & Pawson (2010) found that grayling actively avoided macrophyte cover and Ibbotson (1993) found a negative correlation between grayling densities and the percentage aquatic macrophyte cover in chalk streams. Lucas & Bubb (2005) observed greater utilisation of riparian overhead cover in the spring and summer, but sufficient water depth was deemed to be a more important habitat characteristic than weed. The Environment Agency (2004) suggests that physical habitat improvements for grayling should include gravely weedy shallows for juveniles.

However, aquatic weed cover can significantly increase invertebrate abundance and diversity (vital food sources for grayling) and can offer protection from increased flow (protection for fry from being washed downstream) and from predators (more so trout than grayling). *Ranunculus* (Water Crowfoot, various species) is amongst the most commonly-known of aquatic instream plants because of its easily-recognised white flowers. Where conditions allow, *Ranunculus* will quickly establish itself - providing cover for invertebrates and fish. It can be transplanted within a river catchment with minimal equipment. However, it is important that *Ranunculus* should not be transferred (similar to other plants) between catchments or transplanted further upstream within a catchment, as both actions carry the risk of transferring invasive species. Consent may be required from the EA, NRW or Scottish Natural Heritage, so consult your local office. A video detailing *Ranunculus* planting can be seen at:
http://www.wildtrout.org/news/video-electro-fishing-survey.

Channel Narrowing

Rivers which have become over-widened due to lateral erosion can develop silt-laden beds due to reduced water velocity. Narrowing rivers and increasing the flow rate can help reduce sediment dropping out of the water column and helps develop more mobile substrate sediment within the channel; increasing the diversity of the physical habitat. Rivers can be narrowed by:

- Pushing the present bank further out into the river using an excavator and backfilling the void with brash and inert material
- Creating a new bank from faggot bundles or coir rolls
- Creating burns and two-stage channels. The latter have the benefit of accepting elevated flows and can be useful in areas with high flooding risk
- Geo-textiles can be used to stabilise and protect loose material

In areas at high risk of flooding, Large Woody Debris (LWD), or the use of potentially “mobile” material (e.g. coir rolls) may be challenged as part of the Land Drainage Consenting process. If this occurs, an alternative approach can be to use large stones to stabilise the new bank.

However, unless such blocks are a feature already of the river, such a solution is generally less aesthetically pleasing and requires considerable care in selection and placement if to be successful.

Suitable natural and sustainable materials for narrowing river channels includes, chestnut, hazel, alder and willow spilling, faggot bundles and coir fibre products; willow can be very useful, since it will root and grow quickly in channel banks or wet ground. It is general recommended that newly created banks should be 10-20cm above summer river level, extend for a minimum length of 15m, and have a width of c. 1m. Although channel narrowing can have benefits for grayling, reducing siltation and providing deep-water refuges, the technique can be “over used”. Habitat diversity may actually be reduced, favouring other species, particularly brown trout, as has happened in some rivers in southern England. In considering channel narrowing, it is important to note that, generally, shallow “overwide” channels offer ideal grayling nursery areas. Although not a desirable option for grayling, the adaptability of species means that grayling can sometimes survive well in relatively uniform engineered river channels, like those found in the River Tern and lower Test (Environment Agency, 2004).

Large Woody Debris

Large Woody Debris (LWD) is generally regarded as the staple technique of brown trout river restoration and is broadly defined as dead wood with a diameter greater than 0.1m and length in excess of 1m. LWD provides a number of important benefits:

- Retention of leaf litter and fine sediment
- Increased velocity and flow diversity
- Promotion of bed scour
- Gravel sorting and deposition
- Cover for invertebrates and fish (although more suited to brown trout than grayling)

Masses of LWD is used as refuges by brown trout but generally not by grayling. Riley & Pawson (2010) suggest that grayling avoid both marginal habitat and tree roots, unlike brown trout which actively seek such habitats as refuges. However, LWD does offer many benefits in river systems, particularly in diversifying habitats on a range of scales. It comes in two forms; natural LWD and that used as an ‘engineered’ solution. Where used, LWD should be pinned in place using steel rebar (as used for ground works) and wire. This reduces the likelihood of it moving during periods of elevated flow, and also reduces the likelihood of increased flood risk. Natural in-stream woody debris should not be cleared unless it presents a risk to infrastructure (e.g. blocking bridges); such material is generally mobile and will be moved each season. While present, it helps in the development of dynamically variable habitat diversity. Advice can be obtained from numerous sources including your location fisheries office and the WTT.
https://www.wildtrout.org/sites/default/files/library/Woody_Debris_Apr2012_WEB.pdf

Flow Deflectors

Large Woody Debris, large stone and/or gabion baskets are commonly used to create flow deflectors. These concentrate flow, promoting bed scour, reducing deposition of fine sediment in the wrong places, and increasing gravel mobility, deposition and sorting. Flow deflectors or groynes can be used to create several different habitats. For example, if juvenile habitat is limited, then a single flow deflector will provide reduced flow behind itself. Two deflectors positioned in V-shape facing upstream, will increase scour and bed depth creating deeper water suitable for adults and larger juvenile grayling. Multiple deflectors can be used to good effect, taking over when the benefit of the upstream deflector begins to decline. Deflectors 'V-ing' downstream tend to cause bank erosion. Boulders placed in-stream as small isolated deflectors can provide small but important resting areas for fish, especially during elevated flows.

Instream Enhancements

Sometimes, a river restoration project will require more significant interventions, such as re-meandering or the introduction of new river gravel. These techniques can be very successful at increasing habitat diversity and suitable spawning habitat. Gravel introductions can be used to create riffles, which should ideally be a minimum of 15m in length with depths of 50cm. The depth of water that will flow over these gravels needs to be considered carefully, especially if the intention is to increase spawning habitat. In order to optimise spawning conditions for grayling, water depth over the riffle in April should be between 10-50cm and water velocity between 23-92cm s^{-1}. Creation of a riffle can increase water levels upstream of 15-30cm, this may be a consideration for assessing the flood risk of the project.

Cleaning gravels can offer a temporary solution where recruitment is poor. This is easily achieved by either raking gravels (as Roy Shaw did to achieve the "famous" images of grayling spawning in Driffield canal, in the 1970s), or by using high pressure water jets or petrol leaf blowers. This type of works should be done in a downstream direction and only small sections targeted annually to avoid causing issues arising from the fine sediment being displaced downstream. The relevant authorities should be consulted prior to any works

commencing. However, it is clear from work reported in the Wild Trout Trust's journal *Salmo trutta*, that gravel cleaning is generally not successful, particularly in the long term.

Where fine sediment consistently occludes gravels in spawning reaches of rivers, the only real solution is to undertake a survey of the river upstream to ascertain the sources of the sediment and the processes by which it is being mobilised. This may be a 'local' problem (e.g. excessive run-off from land upstream causing diffuse pollution, or caused by cattle-poaching of river banks), or it may require solutions only implementable at the catchment-scale, in which case, other agencies will need to be engaged.

Livestock Management and Fencing

Fencing is probably the simplest and most cost-effective measure that will benefit a river, especially through its middle and lower reaches through arable and pastoral farm land. Fencing prevents overgrazing of riverbanks, cattle poaching, and creates buffer strips that capture field sediment and helps prevent sediment transfer between fields. Fencing also prevents general access of cattle and sheep to the river, preventing pollution from their faeces and urine. Because vegetation increases in riparian margins protected from grazing by fencing, invertebrate food supply is increased since it provides shelter for adult aquatic insects and habitat for terrestrial invertebrates. The joint value of fencing and increased marginal vegetation have been linked to increased salmonid abundance on southern chalk streams (Environment Agency, 2004).

Wooden post and wire (three-strand) fences are generally sufficient to protect the river banks and can be approved under Land Drainage Consents, although different styles may be required for sheep or cattle. Fencing can be funded from farming environment support schemes or through EA, NRW and SEPA river and catchment management programmes. Although scheme titles may alter, their objectives are often very similar.

Unless drink-points are inserted into the fencing, livestock fenced off from rivers will require alternative supplies of drinking water. Pasture pumps, modern cattle-operated ram pumps (e.g.

papa pumps), solar powered auto-filling water troughs, or piped supply will be necessary if the river can’t be accessed at drink points.

Although it is better if cattle don’t have free access to rivers, cattle drink areas can act as important nursery habitat for young grayling, providing shelter from the main river flow, particularly important during summer floods. Because the drinks are generally shallow, they warm up quickly in spring and summer and provide an abundant food supply. This benefit is further enhanced if they lie immediately downstream of spawning gravels, because the refuge the drinks provide can help to stop newly hatched and young grayling being washed downstream. As a result, cattle drinks can increase the survival rates of newly hatched and young grayling and protect larger fish during flood events.

Trees

It is now clear that trees have an important role to play in the management of rivers. They are important in the riparian margins, where they provide shade and wider habitat for animals and insects. In the wider landscape, trees are increasingly recognised as an important component of measures used in ‘natural flood management’ schemes, designed to hold water back in the upper catchments.

Trees in Riparian Margins

Shading of water courses is important, particularly with the potential warming impacts associated with climate change, but the balance between light and shade must be considered carefully. Simply opening up gravel riffles to natural light can significantly improve recruitment, for example, or increase invertebrate productivity of the river itself. Thus, rivers should have a mosaic of light and shade. Reducing tree cover not only promotes instream vegetation and invertebrates, but also increases bank-side vegetation reducing the risk of erosion and sedimentation.

Trees can be managed by removal, coppicing (removing shoots at ground level), pollarding (cutting trees above the height at which cattle can graze), and singling, where the most upright stem of a tree is retained whilst the rest are removed. In those tree species which respond well to cutting, coppicing and pollarding will result in regeneration of new shoots and so be a useful, sustainable source of material for bank-side, ‘soft’ or ‘green’ engineering. Suitable trees for coppicing include ash, hazel, willow and alder; crack willow is especially suitable for pollarding. Trees should be managed outside of the bird nesting season (April to September), and are also less likely to hold hibernation roosting bats.

Trees and Natural Flood Management

Tree planting (combined with other approaches to what is now termed ‘natural flood management’) have been shown to have reduced the risk of flooding in some places. In a particularly successful example, at Pickering, in North Yorkshire, the ‘Slowing the Flow’ scheme has reduced peak river flow by 15-20%. The scheme was initiated in 2009 after the town had suffered four serious floods in 10 years, with the flooding in 2007 estimated to have caused £7m of damage. The scheme included planting 40,000 trees, 300 “leaky” dams and the restoration of heather moorland. In combination, these actions are all intended to slow the flow of water into the main river and reduce the peak height of a flood event. A new flood storage area was also set aside in fields near Newtondale, the upper reaches of Pickering Beck. The project cost £500,000 - significantly less than a proposed flood wall in the town.

Trees and Climate Change Mitigation

Evidence indicates that some salmon, trout and grayling populations in England and Wales are under stress from increased river temperatures attributed to climate change. Temperature on some rivers have exceeded the lethal limit for salmonids in recent hot, dry summers. It has been demonstrated that riparian tree cover can help reduce local stream temperatures on hot summer days; mean and maximum summer water temperatures are on average 2-3ºC lower in shaded versus open rivers. “Keeping Rivers Cool” was a four-year project led by the Environment Agency from 2012 to 2016, that focused on using trees to cool river temperatures. This approach aims to moderate the pressures of climate change on freshwater ecosystems. The project catchments included the Wye, Hampshire Avon, Tyne, Ribble, Frome and Tywi. Subsequently, the Environment Agency has been working with charitable organisations such as the Woodland Trust and the Rivers Trusts to plant trees and install riparian fencing in appropriate sites. The approach aims to create a mosaic of tree cover along riparian banks, thus providing maximum benefit to the river. To support the identification of key areas to target and increase riparian shade, LiDAR (Light Detection And Ranging) data for England and Wales is being used to produce accurate maps of riparian tree distribution to identify key target areas for riparian planting. It is recognised that riparian shading is not the only measure required to keep rivers cool, but it is low-risk and easily manageable and has many additional benefits. It is possible to check the shading of a river using the following tool:
https://catalogue.ceh.ac.uk/documents/6ea94e39-4463-4f41-9774-42a529de0a55

http://www.woodlandtrust.org.uk/mediafile/100814410/pg-wt-060216-keeping-rivers-cool.pdf

Consents and Legislation

Quite apart from the planning and design, the legislation and consents that may be required in order to proceed with a river project can appear daunting and advice will be required from appropriate authorities in England, Wales and Scotland, noting that legislation and procedure will differ in several ways in the three countries. Where they exist, the rivers and fisheries trust in Scotland can offer advice and support. Valuable advice can also be sought from the Wild Trout Trust, The Grayling Society and The Grayling Research Trust. Speaking with the local Fisheries Officer and submission of the Land Drainage consent is favourable to assess further requirements and ensure designs and plans are fully understood. They will be able to recommend designs that are likely to be accepted and predict the outcomes of plans and whether they will meet their objectives i.e. reducing habitat bottlenecks. It can be quite difficult to decipher poorly written or drawn planning applications, so keep it simple working closely with a few key people in the larger organisations to help get plans across clearly and gain the necessary permissions. Detailed below are the fundamental legislation or consents likely to be required in England and Wales.

Site of Special Scientific Interest (SSSI), Special Area of Conservation (SAC) or Special Protected Area (SPA). The Land Drainage consent should consider this legislation and relevant authorities, Natural England, Natural Resources Wales or Scottish Natural Heritage need to be consulted.

The Wildlife and Countryside Act 1981, Countryside and Rights of Way Act 2000, EU Habitats and Species Directive are other legislations that may require consideration. Not to forget the Salmon and Freshwater Fisheries Act (1975) and the Eel Regulations (2009).

Land Drainage Consent - Looks at the risk of flooding and its impact on the broader environment as a result of the proposed works. Issued by Environment Agency and Natural Resources Wales.

Waste Regulation Licence / Exemption - This is a requirement of whether excess spoil will need to be moved from the excavation site. In some instances, it may be possible to dispose of spoil on the banks of the river. Issued by EA & NRW.

Abstraction Licence - This is likely to be required if water is to be divided or removed from the river, e.g. online ponds, water meadows, or bypass channels. Abstractions less then 20m^3 per day are exempt from licensing under the Water Act. Issued by EA and NRW.

Minerals Licence - This is a requirement if significant volumes of minerals (e.g. Stone or gravel) are to be removed from the site (e.g. Creation of a backwater or bypass channel). Issued by Local Council.

Town and Country Council Planning Act - Generally referred to as ‘planning permission’. This may be required for large works, which involves a change of land use or significant changes to landscape. Issued by District Council.

Environmental Impact Scheme - If the scheme is particularly large, the local authority will give guidance if one is required.

Felling Licence - This may be required if felling or pollarding trees**.** Issued by the Forestry Commission or NRW in Wales.

Tree Preservation Order - Details of protected trees are held by the local authority.

Land Owner Permission - Don’t forget to get the land owners consent.

Perceived Threats to UK Grayling

There are few wild populations unaffected by human-induced environmental changes, such as climate change, overexploitation and invasive species. While these stressors can have substantial impacts on their own, they might also act synergistically, amplifying their impacts (Brook *et al*., 2008).

Avian Predation - Cormorants / Goosanders

The question of predator impact on fish species can be a contentious one. On one side, those with an optimistic viewpoint believe that predators don't prey on the species of concern, or if they do, they only remove life-stages where surplus numbers are present. On the other side are those who believe that every juvenile fish taken will proportionately impact numbers of fish surviving to adulthood, and every adult fish taken will proportionately affect numbers in the next generation. Only to an extent can this difference in viewpoint be addressed by careful studies. Even with good data, people may interpret the results differently depending on the extent they value the prey species or the predator species.

The damage caused by cormorants (*Phalacrocorax carbo carbo & Phalacrocorax carbo sinensis)* has been extensively and vigorously discussed since the mid 1990s, their numbers found on rivers having increased significantly since the 1980s. There are estimated to be between 275,000 and 310,000 pairs across Europe, with 8,400 pairs resident in the UK; increasing to 35,000 individual cormorants are estimated to over-winter in UK (British Trust for Ornithology website). Depending on the fish species and life stage taken, each bird can consume between 1-2lb of fish per day and the total weight of fish eaten by cormorants each winter has been estimated at more than 1,000 tonnes. Depending on the number of birds present locally, there is the potential for serious damage.

Cormorants are protected under the Wildlife and Countryside Act (WCA) 1981 and cannot be killed, or their eggs or nests (when in use or being built) taken or destroyed, except under licence. This act implements provisions in the EEC 1979 Birds Directive (similar legislation protects birds throughout Europe). In England and Wales, anyone in breach of the WCA legislation can be fined up to £5,000, given six months imprisonment, or both.

If it is proven that cormorants are damaging a fishery, the owner or manager can apply for a licence to shoot these birds, although the number allowed to be killed is likely to be too few to control or reduce the total population size. Shooting can be successful at removing problem birds and from deterring other birds from feeding at specific locations. Often alternative methods must be tried before a licence is approved, e.g. bird-scarers, habitat creation. There are published examples of cormorants impacting upon grayling populations in mainland Europe and Jepson *et al*., (2018) give a well-documented example of recent impacts on Danish rivers. In the winter many cormorants in Denmark now forage in rivers rather than on the coast, and this has coincided with a massive decline in grayling and brown trout abundance. The study used results from radio tagging, PIT tagging, and traditional fish surveys to estimate the impact of predation in Danish rivers. Recovery of PIT tags revealed that an estimated 72% of wild grayling and 30% of wild trout tagged in a small river were eaten by cormorants. In another medium-sized river, 79% of radio-tagged adult grayling were removed during winter, apparently also by cormorants. The predation by cormorants appeared to be at a level that explained the observed collapse of grayling and brown trout populations in many Danish streams.

In 2014, a Cormorant and Goosander Management Plan was established in England & Wales. The Angling Trust employed three Fisheries Management Advisors (FMAs), funded by EA rod licence income, to help fishery managers and angling clubs reduce predation, co-ordinate applications for licences to cull birds and to gather data on the number of birds in each catchment area. These data are used to review the existing national limit on the number of cormorants that can be shot each year; the number of licences issued to shoot cormorants is significantly below the number available. The whole licence application process has been simplified to make it easier for fishery managers to apply to control cormorants and goosanders (*Mergus merganser*).

A key response of animals to local environmental variation is altered use of space, but studies simultaneously examining local variation in habitat use and use of space are uncommon. Lucas and Bubb (2014) predicted that increased numbers of avian predators would result in grayling using mesohabitats containing more cover, superimposed on seasonal changes in use of key resources (and hence space use) for functions such as reproduction. Using radio-telemetry, the pattern of space and habitat use by 40 resident grayling was determined in neighbouring stream sections in relation to season and predator density. Grayling used different habitats between seasons, but displayed similar patterns of habitat use in adjacent stream sections. Although patterns of habitat use were stable between stream sections, space use was not. In two winter periods, grayling ranged significantly more widely where there were significantly greater densities of avian predators, especially cormorants. No such differences were apparent in summer when cormorants were absent, but experimental manipulation of predator densities was not possible, so results are correlative. Support for a predator effect is provided from significantly greater rates of injury, associated with avian beak scar marks, present on grayling from the section with highest avian predator densities, compared with adjacent sections with lower levels of avian predators. Unlike many studies of fish behaviour to elevated predation risk, in which fish make greater use of 'refuge' habitat, grayling exhibited wide-ranging behaviour and high activity, possibly reflecting avoidance behaviour.

Otters

Otters (*Lutra lutra*) are apex predators, feeding mainly on fish, water birds, amphibians and crustaceans. They raise cubs in an underground burrow known as a 'holt'. Otters are well suited to aquatic to life having webbed feet, dense fur and the ability to close their ears and nose underwater. They are distinguished from non-native mink (*Neovison vison*) by their much larger size, more powerful body, paler grey-brown fur and broader snout. There are several misconceptions surrounding otter predation. Firstly, otters are native to the UK and have re-established themselves naturally. Secondly, otters do not decimate fish populations, although they may target larger fish. Their impact on a healthy natural river population is usually minimal as they will hunt and fish over a natural range extending up to 20km. Problems usually occur where fish are artificially stocked beyond the natural carrying capacity of a water, such as in put-and-take trout and still water coarse fisheries. Anglers regularly report otters swimming through swims whilst fly fishing or trotting and the presence of the otter has not impacted fish rising or their angling. It is also believed that otters will displace mink. More can be found out about otters by visiting: http://www.wildlifetrusts.org

Competition with Trout and the Effect of Grayling Culls

Grayling were previously regarded as vermin, particularly in southern chalk streams where brown trout were the anglers' quarry. They were systematically removed in large numbers (several thousand). Removals were made by netting, electric fishing and angling in the misguided belief that it would have a major positive effect on brown trout abundance and size. These methods tended to eradicate medium or large grayling. Whichever size group was removed, competition was reduced amongst the remaining grayling, thus enhancing prospects for the remaining fish. In fisheries where grayling were culled over many years there is no evidence that the quality of trout fishing improved because of the removal of the grayling. On the contrary, the evidence suggests that grayling removal negatively impacted on the fishery. With less competition, small grayling grow faster and become sexually mature at an earlier age and smaller size. Fish maturing at two years will be smaller than those waiting until their third year to mate. Grayling that mature at a younger age are shorter lived due to increased spawning mortality and the average size of the fish in the fishery decreases. The resulting small average size further reinforces a belief that grayling have a low fishery value and adds weight to the argument for still further removals. Where culling ceased, grayling fishing greatly improved with no detectable impact on the quality of the trout stocks (Environment Agency 2002). The larger, older grayling that have re-established now enhance the economic value of the fishery, especially where angling is permitted during the winter months.

Attitudes toward grayling have changed, especially under the influence of The Grayling Society, formed in 1977. They are now valued as a fishery resource and fishermen appreciate the sporting qualities that grayling offer both during and outside of the trout angling season. The EA recognises the economic importance of grayling stocks to angling through its National Trout and Grayling Fisheries Strategy and policy 11 states “we will not undertake any large-scale removal of grayling, except to re-establish a grayling fishery elsewhere”. This practice is given additional weight, albeit indirectly, on rivers with species afforded protection under Special Area of Conservation legislation - large-scale removals by electric fishing would only be allowed where it can be demonstrated not to harm SAC species.

There is little evidence to suggest strong, negative effects of grayling on brown trout populations through competition (Ibbotson *et al.,* 2001). Although some competition is likely between the two species, in most cases the effect is negligible because the two species have different habitat and feeding preferences, although it was suggested by Greenberg *et al*. (1996) that competition between the species may contribute to this. It is, in any case, clear that the two species can and do co-exist successfully. However, there is evidence that rainbow trout (*Oncorhynchus mykiss*) have a negative effect on grayling numbers, as rainbow trout are often larger and more aggressive than brown trout. Furthermore, rainbow trout and grayling may share the same spawning season.

Hydropower

Hydro-electric Power (HEP) schemes harness the energy from flowing water to generate electricity, using a turbine or other device. Developing HEP schemes requires permissions from several organisations to reduce negative impacts to a minimum, because such schemes can adversely affect the aquatic environment. All new schemes have to be assessed by the EA, NRW or SEPA. Fish populations may be impacted in a number of ways, including:

- Physical damage to fish through contact with HEP infrastructure
- Dis-connectivity due to barriers created within the river
- Reduced conveyance of spawning gravels built up behind the HEP infrastructure
- Potential reduction in flow within the depleted reach below the HEP scheme leading to reduced habitat availability

In order to protect fish populations, hydropower applications should have:

- An efficient fish pass, with adequate flow at all times to attract fish (on some streams only downstream passage is required). Note this is currently not a requirement for all developments and only for designated salmonid rivers
- A "hands off flow", that allows fish to ascend the fish pass at all times - maintaining longitudinal connectivity and ensuring low flows are protected.
- Adequate screening of intakes and tail races and / or bypass channels if required, to prevent ingress of fish and other fauna into the turbines.

Overall, hydropower in the UK probably presents little threat to grayling at the population level and may even be advantageous as many schemes are developed on existing structures that may currently present barriers to migration. The addition of an efficient fish pass or fishway may help to alleviate the issue of population fragmentation.

Pollution

Potential Sources

Grayling are thought to succumb to pollution and higher temperatures more readily than trout, although there is little hard evidence to substantiate a lesser tolerance to pollution. The claimed low tolerance may occur because the organ of detoxification, the liver, is smaller in grayling (as a percentage of the total body mass) than in salmon, trout and coarse fish (Jervis, 2006). However, other results (Jervis, unpublished), indicate that the levels of specific detoxifying enzymes were found to be higher in European grayling liver than in other salmonids, hence likely balancing the smaller liver size. A French study (Monod *et al*.,1988) on the effects of organic pollutants on grayling and several coarse fish, suggests that grayling are at least as tolerant as the non-salmonids. There has been very little definitive work done on the ability of grayling to tolerate and detoxify organic pollutants and the conclusions in Ingram *et al.*, (2000) state that "the effects of water pollution have not been well documented with respect to Arctic grayling" can confidently be expanded to include European grayling. Consequently, although there is much anecdotal evidence and many assertions made on the susceptibility of grayling to pollution, there is an urgent need for more research. In observations published by Jervis (2011, 2013), the presence of grayling has been noted in sewage outflows, where large numbers of chironomid larvae and pupae and other detritivores are present, providing plentiful good food sources.

Pollutants lethal to grayling include organochlorines, organomercury, acid rain resulting in river acidification, polychlorinated biphenyls (PCBs), Dichloro-bis (p-chlorophenyl) ethylene (DDE), dioxins, high levels of suspended solids, free sulphides and high organic inputs resulting in high biological oxygen demand (BOD) levels. In addition, there is increasing pollution of waterways by endocrine-disrupting chemicals, pharmaceuticals and “personal care” products. Although the visual appearance of sewage treatment works effluent has improved in recent years and BOD of effluent has largely decreased, there are many “new” chemicals, and their partial breakdown products, in the effluent. Being dissolved, these pollutants are easily ingested by fish, potentially affecting behaviour, gender, fecundity (usually reduced or disrupted) and have general diffuse adverse effects that insidiously affect all fish populations, leading to overall slow population decline; these pollutants will also likely affect invertebrates and thus potentially disrupt the food chain.

Pollution has been linked to a decline in grayling populations in the Danube (Keiter *et al*., 2008). The decline has occurred since the 1990s against a background of continuous stocking, and continuously improving sewage purification and water quality. All fish species were affected, but grayling suffered particularly significant declines. Sample fish were found to have elevated levels of enzyme activity to break down organic pollutants. These were traced, not to priority pollutants but to non-priority pollutants that were responsible for the induction of high-level responses. In aqueous environments, these pollutants are intimately associated with suspended particles and sediments. This work reinforces the importance of further research in the UK to explore the potential for similar links between non-priority pollutants, sediments and grayling population declines. Unfortunately, most of the statements linking population decline with pollution do not originate from research findings but anecdotal observations. As the work from the Danube illustrates, while water quality is improving in some key aspects, compounds previously considered benign are having insidious deleterious effects on grayling and other fish species. More research is required to identify the true cause of many of the declines in grayling populations and to understand the effects of previously unsuspected pollutants.

Key sources of pollution include:

- Discharge from Sewage Treatment Works and domestic storm drain runoff
- Industrial and agricultural discharges (chemicals and waste in released waters)
- Runoff from roads and fields (fine sediment, pollutants and fertiliser)
- Fish farm and water cress farm effluent that breaches regulated discharge consents

As already noted, pollutants can also affect invertebrates and potentially impact on fish indirectly through their food supply chain. Jervis (2018) recently reviewed current research into two pollutants, suspended sediment and orthophosphate, which may be involved in widely reported declines in aquatic fly life.

Ammonia

Excess ammonia (NH_3) causes many problems for fish, with significant damaging effects to the gills. Although the most obvious consequence of this is impaired respiration, this isn't the only problem. Gills are also important for acid-base balance (keeping the pH of the fish's blood correct for normal physiological function) and ion exchange (maintaining ion balance in the blood).

Ammonia also causes damage to skin, fins and the intestine. More chronic ammonia exposure can cause kidney damage, decreased growth and overall immune suppression. Ammonia also affects the nervous system, resulting in erratic swimming behaviour.

NH_3 is the principal form of toxic ammonia. It has been reported toxic to fresh water organisms at concentrations >0.2 mg/l. Toxicity increases as pH decreases and as temperature increases. Plants are more tolerant of ammonia than animals, and invertebrates more tolerant than fish. Hatching and growth rates of fishes may be affected. In the structural development, changes in tissues of gills, liver, and kidneys may also occur.

Ammonia usually enters rivers via sewage effluent or other organically-rich inputs. Ammonia (NH_3) become ionised to form the ammonium ion (NH_4^+) in waters of reduced pH (more acid), in which hydrogen ions (protons) are more abundant. Increasing pH and temperature reduces the proportion of ammonium ions in solution; thus such waters are richer in ammonia - the form that is toxic to fish. Dissolved oxygen is also reduced by ammonia pollution as NH_3 oxidises first to nitrite (NO_2^-) and then nitrate (NO_3^-) reducing Dissolved Oxygen levels as oxidation of the ammonia occurs.

Ammonia levels can be easily tested by using kits such as those supplied by Galco UK Ltd (CHEMetrics ammonia K-1510). A 25 ml water sample is collected, and two drops of stabiliser added. The narrow end of a CHEMet ampoule is immersed into the water sample and the tip gently snapped off. The correct volume of sample is automatically drawn in, filling the ampoule. After 1 or 2 minutes, the colour developed in the solution in the test ampule can by compared against the colour standards. An indication of suspected pollution (including excessive ammonia) should be reported immediately to the relevant authority.

Heavy Metals

Mine waters can also have a detrimental effect as they may be associated with low DO levels, elevated ion concentrations such as aluminium, cadmium, chromium, copper, iron, mercury, nickel and zinc, and lower pH. Toxicity of copper and zinc is reduced in waters of increasing water hardness - acid waters increase the toxic effects. Zinc-polluted flushes / spates can irritate salmonid gills. Aluminium can affect salmonid ova and alevins, causing cell necrosis, gill lamellae fusion and blocking of gills with excess mucus, with consequent respiratory difficulties.

Sedimentation

Sedimentation is a relatively easy to identify as a point source pollution. In contrast, identifying sediment pollution from diffuse sources can be more difficult, although its cumulative effects can be equally damaging. Sources of sedimentation include; bank erosion due to livestock poaching and run-off from fields ploughed too close to the water edge. Sedimentation can smother river beds, which in turn affects spawning gravels, plant life and invertebrates. Changes in farming practices, including buffer strips and the alternative provision of drinking water for livestock, and river restoration techniques can be successful at reducing sedimentation and improve the quality and cleanliness of gravels.

The importance of sediment in binding chemicals that can affect fish adversely is rarely recognised yet it has been implicated as a probable factor in the decline of grayling, and other fish in Europe (Keiter *et al*., 2008).

Acidity

Acidity is the concentration of hydrogen ions, expressed as pH, ranging between 1 (most acidic) and 14 (most alkaline), pH 7 being neutral. This is a logarithmic scale so a pH of 1 is ten times more acidic than pH of 2, and so on. Chalk rivers are harder, more alkaline, whilst peaty moorland water tends to be softer and more acidic. Chalk streams and waters from calcareous substrates tend to have a higher pH value. Ammonia toxicity increases with increased temperature and pH (see contradictions above) so warm alkaline productive water is potentially more vulnerable to organic pollution; important for grayling populations in chalk rivers.

Eutrophication

Eutrophication is associated with excessive algal and weed growth, resulting in unwanted ecological consequences. Implications include fluctuations in pH and dissolved oxygen because of intense photosynthesis and decay of organic matter, increases in ammonia, nitrite and nitrate. Effects can be seen for between 5-10km from the initial source. Sources include; Sewage Treatment Works (STW) effluents, Combined Sewer Outfall (CSO), intensively farmed riparian fields. Changes in water quality is reflected in the invertebrate community, where closest to the pollution source, there are more tolerant species, tubificid worms, midge and blackfly larvae, some snails and water lice. As the pollution dilutes, species such as caddis larvae become more common. Grayling, along with trout, prefer uncontaminated water but will tolerate some eutrophication where levels of organic material do not lower available oxygen levels to the point where respiration is affected adversely. This is particularly important when river levels are low and little dilution of inflowing organic loads occurs. It is also very important at higher temperatures where dissolved oxygen levels are lower. The combination of low water levels and higher temperatures can precipitate fish deaths due to asphyxiation.

Cultural eutrophication of running waters is known to be associated with benthic algal proliferation, clogging river beds and degrading water quality leading to fish kills. Hübner *et al.*, (2009) investigated the changes of interstitial water quality in relation to a treated wastewater effluent and their effects on the survival of grayling eggs and larvae. Eggs were buried into the sediment at sites with different nutrient load. The characteristics of the interstitial water (oxygen, pH, nitrates, nitrites, ammonia, phosphate and conductivity) were assessed at different times and related to the embryonic and larval development. Mortality rates of the eggs and larvae downstream the wastewater treatment plant (WWTP) were significantly higher than those of the control field and no eggs placed in the WWTP effluent plume survived until emergence. Critical parameters for the survival of the early life stages were the ammonia concentration and pH values. Their results suggest that eutrophication may be a limiting factor for the survival of the early life stages of the grayling. The temporal coincidence of alevins and spring algal bloom has been identified to be of critical importance. The invertebrate community can be investigated to monitor water quality (see section on Biological Monitoring Working Party).

Reporting Pollution Incidents

The EA, NRW, SEPA and water companies all have pollution hotlines, allowing pollution incidents to be reported by mobile phone or website. The advice is not to wait until you get home if a pollution incident is suspected; rapid action may save rivers from extensive and disastrous fish kills and damage to the wider environment. Ideally, the pollution hotline number should be stored on your mobile phone. In Scotland, such incidents should also be reported to Scottish Water, the publicly-owned water supply company.

Visible evidence of pollution includes (but is not restricted to) extensive fish or other faunal kills, discoloured and/or foul- or chemically-smelling water, and heavy sediment load under average flows. Unpleasant discharges from septic tank pipes may also cause pollution and should be reported; these may be common in rural areas where dwellings or villages are not connected to main sewerage treatment systems. Discharges from septic tanks may require frequent monitoring and reporting if there is a systemic problem.

Photographic evidence of any incidents or suspected pollutions is useful so date and time stamp any photographs - this is generally automatic on digital cameras and mobile phones; many also offer the facility to tag photographs with GPS satellite-derived location data. These data are stored in the header data of the image file (usually in .jpg or RAW format, depending on the device).

Climate Change

Climate change is a global phenomenon and the average air temperature of the Earth has increased by 0.06°C per decade over the last century; Europe has been referred to as the cauldron of climate change (IPCC, 2009). Predicted changes in temperature and precipitation (IPCC, 2009) are expected to result in all areas of the UK becoming warmer, more so in summer than in winter, particularly in southern England, and precipitation decreasing during summer and increasing during winter. The latest projections for the UK are available on the Met Office's interactive climate projections website http://ukclimateprojections.metoffice.gov.uk/. Although no studies have yet assessed the impact on UK grayling, Elliott and Elliott (2010) found small increases (<2·5°C) in winter and spring would be beneficial for growth with 1-year-old salmon smolts. However, water temperatures would have to increase by about 4°C in winter and spring, and 3°C in summer and autumn before they had a marked negative effect on trout (cold preference) growth.

Data collected in a long-term study on the grayling of the River Ain in southern France, outlined by Henri Persat (University of Lyon) at the GRT International Grayling Conference in York in 2006, shed light on the responses of grayling populations to very high water temperatures. The highest temperatures were recorded in 2003, with water temperatures up to 27^{o}C, associated low flows and low dissolved oxygen concentrations. Acute mortalities occurred at the highest temperatures, but most of the mortality was over a longer period and resulted indirectly as a result of a long period of starvation, as the fish did not feed at high temperatures despite their increased metabolism. Some grayling, potentially those with a higher resilience to the adverse conditions, survived, including one which had been scale sampled in 2002 and which had been caught again in autumn 2003; it showed a complete absence of growth in 2003. The conditions also resulted in a failure of fish to mature and reproduce in the succeeding year. The data obtained in the Ain study has been used to underpin modelling of the effects of temperature and discharge on the population dynamics of the various life stages of grayling in the River Ain (Charles *et al.,* 2006) and the effects of temperature on grayling growth (Mallet *et al.,* 1999).

The impacts of climate change are further complicated because spawning events of many riverine fish species are triggered by temperature, although the photoperiod also plays an important role in driving the maturation process (Baras & Philippart, 1999; Norberg *et al.*, 2004). An increase in spring temperatures caused by climate change may result in spawning events occurring earlier in the year (Gillet & Quentin, 2006; Daufresne *et al.*, 2009). Whilst this could extend the growing season and counteract the reduced lengths predicted in this study, there would need to be synchronicity of food availability (Li & Mathias, 1987). It is possible that protracted or multiple spawning species such as *L. cephalus* and *G. gobio* (Nunn *et al.*, 2007b) would have a distinct advantage over species such as grayling in which all individuals spawn at about the same time of year at any site, as the risk of failure in larval development and exogenous food mismatch, leading to larval mortality, would be reduced.

Our climate is undeniably changing with warmer wetter springs and drier summers in the UK, but with unclear consequences for spring spawning cold-water species. European grayling are likely to be susceptible to changes in climate because they cannot avoid suboptimal temperatures, especially during early developmental stages. Wedekind & Kung (2010) analysed data collected in a 62-year-long (1948-2009) population monitoring programme. Male and female grayling were sampled three times per week during the yearly spawning season in order to follow the development of the population. The occurrence of females bearing ripe eggs was used to approximate the timing of each spawning season. In the latter years, the spawning season was more than 3 weeks earlier than in the first years. This shift was linked to increasing water temperatures as recorded over the last 39 years with a temperature logger at the spawning site. In early spring water temperatures rose more slowly than in later spring. Thus, embryos and larvae were exposed to increasingly colder water at a stage that is critical for sex determination and pathogen resistance in other salmonids. In summer however, fry were exposed to increasingly warmer temperatures. The changes in water temperatures that embryos, larvae, and fry were exposed to, could be contributing to the decline in abundance that occurred over the last 30-40 years.

The value of long-term monitoring / research isn’t always appreciated until factors begin to impact upon fish populations. Fortunately, this type of dataset is being collected and has recently allowed the exploration of the drivers of grayling recruitment in a southern UK chalk stream in a study supported by the GRT (Bašić *et al*., 2018). This includes analysis and impacts of temperature and flow variables (potential egg washout, egg development, fry survival). As this dataset increases, it should allow exploration in other important areas such as growth and density dependent mortality. However, this level of monitoring needs to be undertaken on other UK rivers.

Water Quantity and Quality Pressures

As the UK human population continues to expand in some areas, the demands made on water supply are increasing and sources of water come under pressure. Sufficient aquifer recharge and a decline in the water quality in aquifers is a growing problem, especially in the heavily populated regions of southern England underlain by chalk. Water demands are such that many smaller chalk streams may run dry in the summer months, with disastrous consequences for the river ecosystems. Research is currently occurring on an English chalk stream (Itchen) to examine the impact of reduced flows on salmonids (particularly salmon and trout) and fortuitously will include limited information on grayling. Once again, the Wylye Grayling Study may be able to provide important input. Hopefully these studies will give an insight into the likely impacts of reduced flows upon a species that requires cool river temperatures, clean water and sufficient depth to survive and thrive.

Summary: The Future of UK Grayling

There have been several excellent advancements in both grayling science and management since the turn of the century with the Review of Grayling Ecology and Management (2001) and the introduction of the National Trout and Grayling Fisheries Strategy (2003) to drive better management of the species. With continued support and extended knowledge through continued research and investment, the future for grayling across the UK is positive despite evidence that some populations are in decline. There are knowledge gaps that can be filled through collaborative research / study but there is also a requirement for a better understanding of the drivers for recruitment (year-class strength), mortality and growth, what constitutes “ideal” grayling habitat, the impact of avian predation and achieving uninterrupted fish migration. Pressures will be exerted particularly on water quality and quantity as the UK human population expands particularly in Southern England. Below are itemised areas where we feel that we have good knowledge and feasible management solutions, but we also highlight deficiencies which need addressing.

Areas of Strength

1. The introduction of a national angling “slot limit” and daily quota for anglers. This allows anglers in England and Wales with an inclination to consume their catch, to take the occasional fish for the table without a risk to the population as a whole. Catch & release has been well promoted and readily adopted by UK grayling anglers, but this byelaw affords additional protection against anglers who deliberately target grayling for removal.

2. Most grayling populations experience some degree of natural variation in both abundance and particularly year-class strength. However, provided that habitat and water quality are good, the species is fairly resilient and will invariably “bounce back” naturally given a little time and improved environmental conditions. That said, the danger signs such as falling abundance or an imbalance in size distribution (dominated by larger older fish), should be heeded and acted upon through investigation followed by decisive management action.

3. Genetic research and its application to promote good stocking practice but also placing the emphasis on restoration stocking as a last resort. **Investigating** and addressing the **causes** of declining populations must take precedence over stocking.

4. There is good knowledge of the swimming ability of the species at various temperatures. However, this information should not be used in isolation to develop fish passes where grayling are one of the dominant species.

5. The various organisations involved in promoting grayling, its conservation and management including The Grayling Society, Grayling Research Trust, Game and Wildlife Conservation Trust, CEFAS, Wild Trout Trust and the willingness of the regulatory authorities (EA, NRW & FMS) to sponsor good research and apply best practice in management of the species. Strong support and financial commitment from the relevant authorities in England & Wales is paramount to build upon advances made through development such as the National Trout and Grayling Fisheries Strategy.

Evidence Gaps and Opportunities

1. Monitoring grayling populations (spatial): Currently semi-quantitative electric fishing (with no stop nets) is the main method of assessment of salmonid abundance used in England & Wales, yet grayling are rarely the **main** target species. There is a tendency for 0+ grayling to keep away from the fishing team as fast moving mid-water shoals, rather than seeking shelter; this generally

results in low and highly variable capture rates. A more active fishing strategy and multiple fishings (3-run depletion) with stop nets can help. In addition, larger grayling are often concentrated in deep water rather than being more evenly dispersed and it is important to include such areas in sampling targeted at grayling. It is also recommended that the national anglers logbook scheme be re-instated and run by The Grayling Society in collaboration with interested authorities (data share scheme). This will offer a spatial view of UK grayling fisheries performance and allow for comparisons with previous data collected from 2001-09.

2. Monitoring grayling (temporal): There are very few UK grayling rivers where we have a good understanding of true abundance, trends in abundance, or age structure / size distribution. Grayling populations quite often demonstrate large variations in year-class strength and there is a requirement, for the few rivers where grayling stocks are monitored, to investigate the factors affecting recruitment, growth and mortality. Some of these factors are currently under investigation but ideally quantitatively electric fishing for the species on a select group of “sentinel” or “Index” rivers (minimum of 3) would improve our understanding of grayling and provide temporal trends of index river performance.

3. In-river connectivity: The physical swimming ability of grayling can be calculated using SWIMIT software but there is little understanding of their “willingness” to pass barriers; they have been proven far less likely to successfully pass barriers than brown trout in the limited number of UK studies involving grayling despite having strong “homing” instincts. This generally relates to barriers with complex / turbulent flow patterns which cause significant problems for the species. There are over one thousand gauging weirs present within the UK and yet there is very limited evidence of monitoring the efficiency of UK fish passes for grayling. Louds Mill on the River Frome (a combined gauging weir / fish pass) is probably the only public reported example, although subsequent EA sponsored studies have been attempted with varying degrees of success. There may be potential solutions to improve free upstream passage across structures including low-cost options such as baffles and pre-barrages. However, further research and development is required urgently in this area. The GRT should initiate communication with the National Fish Pass Panel and potential collaborative partners to alleviate the problems associated with fragmented grayling populations.

4. Habitat restoration techniques: There are no known UK examples of habitat restoration schemes specifically targeted at grayling. This probably relates to a lack of understanding, data and knowledge about what actually constitutes “ideal” grayling habitat and therefore habitat is generally rehabilitated to suit brown trout in the belief that these changes also benefit grayling. Chalk stream restoration of “overly-wide” channels needs to be sympathetic to the requirements of juvenile grayling forming a mosaic of habitats for all fish species and life-stages. Equally important is pre and post restoration monitoring to increase our knowledge base. There are also a lack of understanding and a need for better information about the extent to which grayling can tolerate different pollutants. Education should improve awareness of the specific needs of grayling, leading to some properly grayling-focussed habitat restoration schemes, or possibly of similar benefit, ensuring that more general schemes are designed with the graylings’ requirements in mind. Information from structured temporal monitoring should feed into this evidence gap.

5. Stocking and population restoration: All grayling stocking (in England and Wales) **must** comply with existing National Trout and Grayling Fisheries Strategy guidance and be evidence-based. A greater emphasis should be placed on thorough investigation of the issues constraining grayling populations to ensure that stocking is addressing an identified population bottleneck. Enhancement stocking should not be considered. Any restoration stocking should be carried out

in conjunction with habitat improvements and perhaps the development of an ecosystem restoration plan, to initiate the re-establishment of self-sustaining populations.

Stocking has taken place in unsuitable receiving rivers, although the practice now appears more under control by the regulating authorities. In Scotland, because the grayling is not native, any stocking with grayling would require the consent of both Scottish Ministers and Scottish Natural Heritage.

6. Climate Change: Southern English chalkstream grayling populations are near the extremity of their geographic range and being a “cold-water” species, the impact of climate change on grayling in these areas is unknown. Climate change presents a potential threat, particularly with conflicting pressures on water arising from expanding human populations in the region. We require a much better understanding of how UK grayling will react and (hopefully) adapt to increasing water temperatures and reduced flows. Research is currently being undertaken by CEFAS to look at these potential impacts on brown trout & juvenile salmon (limited grayling data); this research needs to be scrutinised and supported. There is also scope for developing mitigating measures in river management with interested parties), such as tree planting for shading, and promoting better management and more sustainable use of water resources.

7. Whilst much is known of summer habitat use by juvenile grayling, almost nothing is known of habitat use in other seasons, despite this being a potential recruitment bottleneck in environments where refuges from predators or high flows may be limited (including in modified rivers). Substantial research is needed to understand the habitat requirements of juvenile grayling during autumn and winter, and how these influence survival, growth and space use. Collaborative research opportunities in this area should be sought.

8. Scottish grayling: As previously stated, the grayling is not native to Scotland, despite suitable habitat in many rivers and residency for over 150 years in several catchments. They are not well protected in Scotland, except where a river is subject to a Protection Order, which makes the act of fishing for grayling and other freshwater fish, without appropriate permission, a criminal offence in return for there being sufficient provision for anglers to access the waters. Such Orders have resulted in much improved access to winter grayling fishing. There is no legislation in Scotland specifically to protect grayling and no statutory close seasons. Several very good and popular grayling fisheries exist with balanced populations which can include very large specimens, particularly in the Clyde, Annan and Tweed catchments. Although in the past, the profile of grayling was often poor in Scotland, this situation is improving; however more could be done to promote the grayling as a fish to value in its own right, rather than as a by-catch for anglers targeting trout. Whether policies and protection measures currently in place in England & Wales could usefully be applied in Scotland, should be explored.

Overall, the future appears positive for the European grayling in UK waters. Initiatives to progress scientific research and improve management of rivers where grayling exist continue. Such activities should provide for the continued success of the species. Research is still required in specific areas, more efficient monitoring methods need to be developed and implemented, and grayling management plans need to be developed for rivers that are failing to reach their true potential in terms of sustainable stocks and viable fisheries. Finally, it remains to be said that many of the issues faced by grayling as a species are common to those faced by river fauna and flora in general. Over and above, positive actions for grayling at the “river” scale (or even at the “reach” scale), including grayling in the development of holistic management plans at the “catchment” scale will ensure the species benefits positively along with all other species.

We hope that you find this guide both informative and practically useful, advancing knowledge in fisheries communities, raising the profile of the species and promoting the importance of research into grayling biology and ecology.

Further information and expertise can be sourced through The Grayling Research Trust and The Grayling Society.

Websites:
http://www.graylingsociety.net/grayling-research-trust/
http://www.graylingsociety.net/

Recommended Reading:

Ibbotson, A.T., Cove, R.J., Ingraham, A., Gallagher, M., Hornby, D.D., Furse, M., Williams, C. (2001). A Review of Grayling Ecology and Management. Environment Agency Technical Report W245. ISBN: 1 85707 370 2.

Glossary

Abiotic

Non-living physical and chemical elements of an environment.

Alevin

A newly hatched salmon, trout or grayling still carrying the yolk.

Benthic

Relating to or occurring at the bottom of a body of water.

Biotic

Relating to or resulting from living organisms.

BMWP

Biological Monitoring Working Party Score. A method for the assessment of water quality using macroinvertebrate assemblages.

Catch and Release

A "no-kill" policy adopted for one or more species of fish within a fishery.

Climate Change

A change in the statistical distribution of weather patterns when that change lasts for an extended period of time.

Connectivity

The connection between habitats or between a river and its floodplain.

Coppicing

A periodic cutting of a tree just above ground level, resulting in the re-growth of a number of shoots.

Degree Days

Popular method for explaining variation in fish growth and development. For example, 150-degree days may be 15 days at 10^{o}C or 50 days at 3^{o}C.

Density Dependent Mortality

A level of mortality for a species that varies with respect to the density of that species, i.e. greater numbers present leads to higher mortality rates, for example through competition for resources.

Discharge

River discharge is the volume of water flowing through a river channel. This is the total volume of water flowing through a channel at any given point and is measured in cubic metres per second (cumecs).

Dissolved oxygen

The amount of gaseous oxygen (O_2) dissolved in the water. Oxygen enters the water by direct absorption from the atmosphere, by rapid movement, or as a waste product of plant photosynthesis. Water temperature and the volume of moving water can affect dissolved oxygen levels.

Electric fishing / Electrofishing

A common scientific survey method used to sample fish populations to determine abundance, density, and species composition.

Faggot

A bundle of brushwood tied together into a cylindrical shape. Used as bank revetment and to promote the deposition of sediment in marginal areas.

Fragmentation

The process by which habitat loss results in the division of large, continuous habitats into a greater number of smaller patches, isolated from each other.

Fry

The short transition stage when the trout emerges from the gravel, starts to feed and disperses.

Geomorphology

The scientific study of the origin and evolution of topographic and bathymetric features created by physical, chemical or biological processes operating at or near the Earth's surface.

Groyne

A constructed flow deflector designed to constrict water flow and promote preferential scouring and deposition of sediments.

Habitat bottlenecks

Limitations in habitat (e.g. extent, or connectivity) that affect the abundance of one or more of life stages of a species.

Habitats Directive

A European Union directive adopted in 1992 as an EU response to the Berne Convention. It is one of the EU's two directives in relation to wildlife and nature conservation, the other being the Birds Directive.

Holt

Resting or breeding site for otters; commonly the root system of large trees.

Hydrology

The scientific study of the movement, distribution, and quality of water on Earth and other planets, including the water cycle, water resources and environmental watershed sustainability.

Lotic

Refers to flowing water, from the Latin lotus, washed. Lotic ecosystems can be contrasted with lentic ecosystems, which involve relatively still terrestrial waters such as lakes and ponds.

LWD

Large Woody Debris. Pieces of naturally derived timber, generally held to have dimensions greater than 0.1m diameter and 1m length.

Mesohabitat

Habitat units defined by reference to hydrological and geomorphological features. Typical mesohabitats include riffles, cascade, glides and pools.

Ova

Female gamete or egg with potential to develop, through cell division, into a new individual.

Pasture pump

A cattle watering pump powered by the action of cows’ muzzles on a handle that they push away in order to obtain access to drinking water in a trough.

Point source

Single, discrete source of input into a water body.

Potadromous

A potadromous fish, like an anadromous or catadromous fish, is a migratory fish. Unlike anadromous or catadromous fish, a potadromous fish spends its entire life in fresh water.

Pre-Barrage

A low-level partial barrier or in-river modification that raises the water level downstream of an obstruction. This results in a smaller traverse for fish to pass over the obstruction.

Redd

A ‘nest’ excavated in suitable gravel by female salmonid fish into which its eggs are subsequently deposited.

Riffle

A length of shallow, gravel dominated in-stream habitat with a fast flow and broken water surfaces.

RIVPACS

The Riverine InVertebrate Prediction And Classification System. A methodology for the scoring of actual against predicted macroinvertebrate communities.

Runoff

Runoff of surface water (often with associated nutrients and sediment) from a large area of land, with no discrete point of entry into a waterbody.

SAC

Special Area of Conservation, designated under the Habitats Directive.

Seine netting

A method of fishing that employs a seine or dragnet which hangs vertically in the water column with its bottom edge held down by weights and its top edge buoyed by floats.

Sorting

Term applied to the grading of river substrates by size.

Spiling

The use of live willow branches to create a woven ‘fence’ that grows and protects banks from erosion.

Velocity

Speed in a given direction.

WFD

The Water Framework Directive is a European Union directive which set a primary target, with various waivers, for European Union member states to achieve good qualitative and quantitative status of all water bodies by 2015.

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Appendix I. UK Grayling Rivers and Major Tributaries

England

Thames - Evenlode, Windrush, Coln (Glos), Churn (Glos), Darent, Blackwater, Brain, Kennet, Kennet & Avon Canal, Lambourn (Berks), Dun (Berks), Aldbourne, Enbourne (Berks), Wet (Surrey/Hants), Tillingbourne (Surrey), Wandle, Lee, Charwell, Colne, Wey, Windrush

Itchen

Meon

Test - Wallop Brook, Anton, Pill Hill Brook, Golden Brook, Dever, Bourne, Blackwater, Dun. King’s Somborne Brook

Medway - Teise

Rother (Sussex)

Welland - Gwash

Witham

Great Eau (Withern) - Ludd

Yare - Wensum

Lark (tributary of Great Ouse) - Isle, Chater

Bristol Avon - Chew, Marden, Midford Brook

Hampshire Avon - Bourne, Wylye, Nadder, Ebble, Till

Dorset Frome - Piddle, Brue, Tone

Stour - Allen, Shreen

Exe - Batherm, Culm, Barle, Lowman, Brockey, Creedy, Haddeo

Tamar - Carey, Lyd, Inny, Kensey, Otter, Thrushel, Lew, Bolesbridge, Deer, Claw

Parrett - Hillfarance Brook, Tone

Tyne - Derwent

Pont - Blyth

Wear

Tees

Severn (some tributaries are in Wales) - Onny, Tannat, Banwy, Vyrnwy, Teme, Clun, Corve, Rea

Trent - Soar, Erewash, Derwent, Wye (Derbyshire), Lathkill, Dove, Bentley Brook, Churnet, Amber, Manifold, Anker, Blythe, Sence, Henmoor Brook, Noe, Tean, Sutton Brook

Eden - Eamont, Lowther, Crowdundale Beck, Bleah, Helm Beck, Hilton Beck, Hoff Beck, Irthing, Lyvennet, Leith, Scandal Beck, Trout Beck

Ribble - Calder, Hodder

Dean - Bollin

Mersey - Gowy, Goyt

Weaver - Dane, Peover Eye

Esk (Yorkshire)

Ure - Cover, Skell, Laver

Ouse - Wharfe, Skirfaire

Nidd

Swale - Bedale Beck, Cod Beck, Isle Beck, Wiske

Aire - Calder, Colne, Holme, Ryburn

Derwent - Rye, Thornton Beck, Seven, Dove, Riccall, Pickering Beck, Costa / Oxfolds Beck

Hull - Driffield Beck, Driffield Canal, West Beck

Don - Dearne

Scotland

Tay - Tummel, Earn, Ruchill, Isla, Ericht, Dean, Kerbert, Alyth, Braan, Machany, Pow, Ruthven, Keithick Burn, Ericht, Lyon, Shochie, lower Garry

Almond

Midlothian Esk

Water of Leith

Clyde - Avon, Douglas Water, Mouse, Medwin N&S, Duneaton Water, Gryffe, Green Water, Lochar Burn, Culter Burn, South Calder

Ayr - Lugar, Coyle, Greenock Water

Tweed - Kale, Jed, Till, Glen, Leet, Teviot, Breamish, Beaumont, Rule, Eden, Leader, Oxnam, Whiteadder

Annan - Kinnel

Nith - Cairn

Forth - Allan Water, Eas Gobhain, Leny, Teith, Venachar

Wales

Dee - Alwen, Alyn, Ceiriog, Dyfrdwy, Lliw, Tryweryn, Twrch

Teifi

Ewenny

Wye - Arrow, Dore, Elan, Irfon, Ithon, Lugg, Llynfi, Marteg, Monnow,

Rhymney - Ely

Taff - Rhondda

UK Stillwaters

Bala Lake (Llyn Tegid), River Dee, North Wales

Gouthwaite Reservoir, River Nidd, Yorkshire

Appendix II. Grayling River Checklist

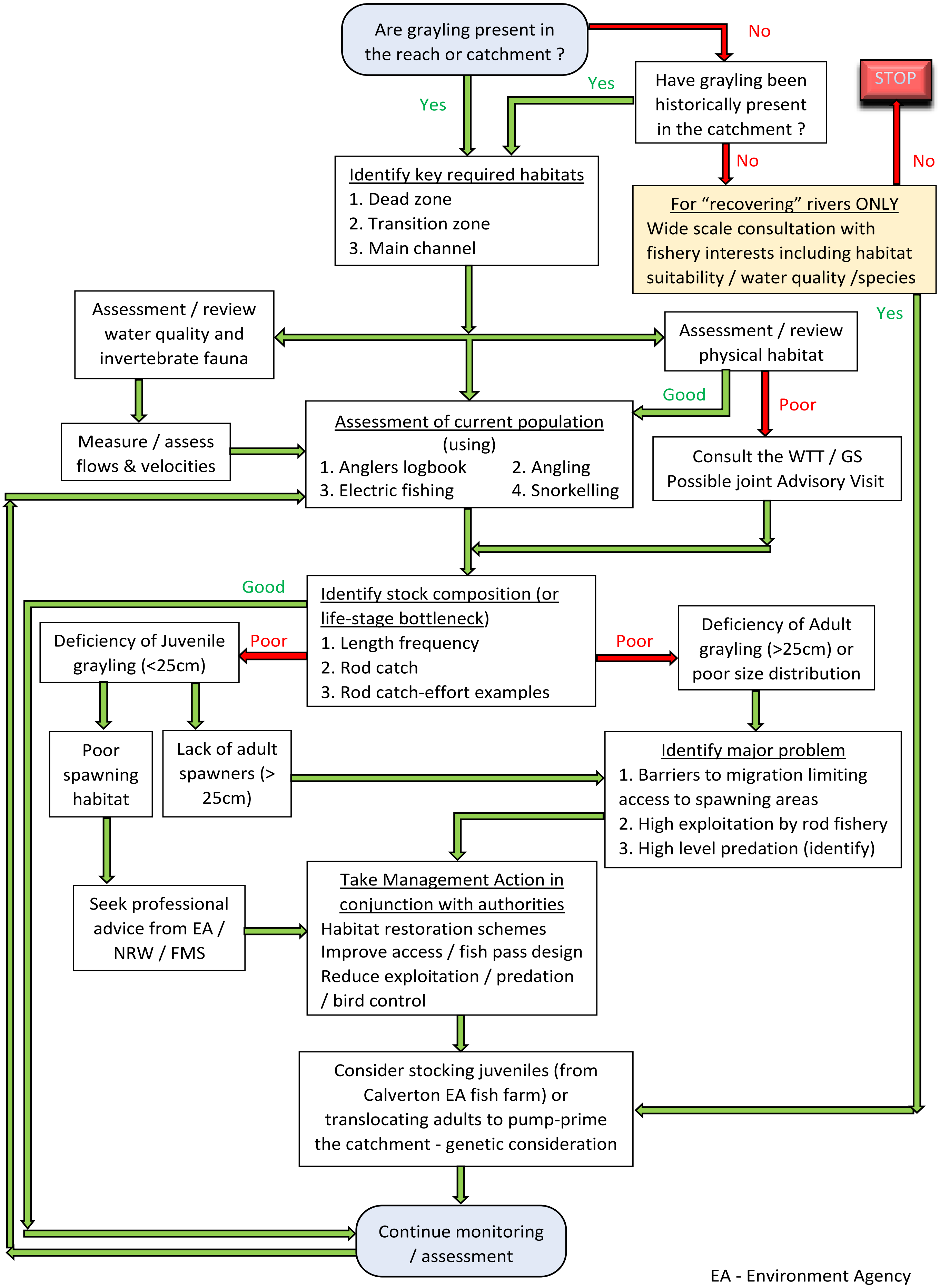
This form is appropriate for use by keen amateur and fisheries professional. It can help in assessing suitable physical habitat, water quality, identifying declining grayling populations as well as potential life-cycle and habitat bottlenecks. It could also be used as a precursor to contacting The Grayling Society / Wild Trout Trust for a joint Advisory Visit (AV).

http://www.wildtrout.org/content/advice-and-practical-help

Basic River Requirements	**Tick**
pH range between 6.5-9.0 (ideally around pH 7)	
Summer and winter water temperatures between 4-18°C	
Maximum water temperature of less than 25°C	
Dissolved oxygen (DO) greater than 5-7mg/l	
Ammonia less 0.2mg/l	
Gradient of the zone akin to 5.7m km^{-1}	
River wider than 5m	
BMWP score greater than 71 (ideally 100+)	
Spawning / recruitment requirements	**Tick**
Depth of water (March to mid May) over the spawning riffles / gravels 10-50cm	
Flow (March to mid May) over the spawning riffles / gravels 23-91.7cm s^{-1}	
Gravel 2-8cm in diameter	
Depth of spawning gravel >5cm	
Gravel clean of fine sediment	
Fry Requirements	**Tick**
Sand / silt / gravel bed substrate	
“Dead zones” with depth range from 45 to 90cm and velocity <10cm/s	
Water depth 10-90cm	
Velocity between 6-50cm s^{-1}	
Chironomid (non-biting midge) larvae & pupae or dipteran (true fly larvae) present	
Juvenile Requirements	**Tick**
Water depth between 45-90cm	
Flow velocity <10cm s^{-1}	
Juvenile depth 40-60cm velocity <10-110cm s^{-1}	
Copepods, oligochaetes, chironomid larvae and pupae present	
Adult Requirements	**Tick**
Depth ranging between 20-400cm with preference of 75-165cm with increased age	
Water velocity 20-50cm s^{-1}	

Diverse habitat with pebble / cobble / boulder substrate	
Feeding areas free of in-river vegetation	
Deep-water refuges from predators	
Monitoring / Assessment	**Tick**
Juvenile grayling present (<25cm) consisting of >35% of the population (rods or e/f)	
Adult grayling present (>25cm) consisting of >35% of the population (rods or e/f)	
Balanced population structure (including at least four year classes)	
Assess impacts and threats (negatives for a healthy grayling population)	**Tick**
River stocked with grayling, brown trout or coarse fish	
River stocked or have resident rainbow trout	
River section within 2km of the following:	
➢ Sewage Treatment Works	
➢ Industrial run off	
➢ Agricultural run off	
➢ Road run off	
➢ Fish farm effluent/discharge	
➢ Water cress farm effluent/discharge	
➢ Mine water discharge	
➢ Potential barriers to migration within 1km	
High exploitation (kill rates) by anglers	
Significant avian predator abundance or visitation (cormorant or goosander)	

Appendix III. Simple Flow Chart to Assist with Grayling Conservation



EA - Environment Agency
NRW - Natural Resources Wales
FMS - Fisheries Management Scotland

Underwater photographs supplied by Jack Perks
http://www.jackperksphotography.com/ https://www.facebook.com/JackPerksPhotography

Notes

Grayling Research Trust

The Grayling Society

THE FISHMONGERS' COMPANY

Cyfoeth Naturiol Cymru
Natural Resources Wales

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grt@graylingsociety.net

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