Ecology of the Atlantic Salmon

Salmo salar

Conserving Natura 2000 Rivers

Ecology Series No. 7

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Conserving Natura 2000 Rivers

This account of the ecological requirements of the Atlantic salmon (*Salmo salar*) has been produced as part of **Life in UK Rivers** – a project to develop methods for conserving the wildlife and habitats of rivers within the Natura 2000 network of protected European sites. The project's focus has been the conservation of rivers identified as Special Areas of Conservation (SACs) and of relevant habitats and species listed in annexes I and II of the European Union Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC) (the Habitats Directive).

One of the main products is a set of reports collating the best available information on the ecological requirements of each species and habitat, while a complementary series contains advice on monitoring and assessment techniques. Each report has been compiled by ecologists who are studying these species and habitats in the UK, and has been subject to peer review, including scrutiny by a Technical Advisory Group established by the project partners. In the case of the monitoring techniques, further refinement has been accomplished by field-testing and by workshops involving experts and conservation practitioners.

Life in UK Rivers is very much a demonstration project, and although the reports have no official status in the implementation of the directive, they are intended as a helpful source of information for organisations trying to set 'conservation objectives' and to monitor for 'favourable conservation status' for these habitats and species. They can also be used to help assess plans and projects affecting Natura 2000 sites, as required by Article 6.3 of the directive.

As part of the project, conservation strategies have been produced for seven different SAC rivers in the UK. In these, you can see how the statutory conservation and environment agencies have developed objectives for the conservation of the habitats and species, and drawn up action plans with their local partners for achieving 'favourable conservation status'.

Understanding the ecological requirements of river plants and animals is a prerequisite for setting conservation objectives, and for generating conservation strategies for SAC rivers under Article 6.1 of the European Habitats Directive. Thus, the questions these ecology reports try to answer include:

- What water quality does the species need to survive and reproduce successfully?
- Are there other physical conditions, such as substrate or flow, that favour these species or cause them to decline?
- What is the extent of interdependence with other species for food or breeding success?

For each of the 13 riverine species and for the *Ranunculus* habitat, the project has also published tables setting out what can be considered as 'favourable condition' for attributes such as water quality and nutrient levels, flow conditions, river channel and riparian habitat, substrate, access for migratory fish, and level of disturbance. 'Favourable condition' is taken to be the status required of Annex I habitats and Annex II species on each Natura 2000 site to contribute adequately to 'favourable conservation status' across their natural range.

Titles in the Conserving Natura 2000 Rivers ecology and monitoring series are listed inside the back cover of this report, and copies of these, together with other project publications, are available via the project website: www.riverlife.org.uk.

Introduction

A distinctive and recognizable fish, the Atlantic salmon is well known for its agility, strength and persistence in overcoming obstacles to reach spawning grounds upstream. It can leap from deep water about 3 m into the air to get over waterfalls and weirs. Adult males can reach up to 1.5 m in length and 36 kg in weight, while females are a maximum of about 120 cm and 20 kg. The usual life span is four to six years, but some individuals can live up to 10 years.

Erling Svensen/UWPhoto

Male Atlantic salmon can reach up to 1.5 m in length and 36 kg in weight. Females are smaller. The salmon is well known for its agility and persistence in leaping obstacles to migrate up rivers to spawning grounds.

Status and distribution

European distribution

The Atlantic salmon (*Salmo salar*) is listed in annexes II and V of the European Union's Habitats Directive as a species of European importance. Historically, the species was widely distributed in all countries whose rivers enter the North Atlantic. However, its current distribution has been restricted by anthropogenic effects, particularly man-made barriers to movement, and deterioration in water quality due to urban expansion and changes in agricultural practices. Consequently, the Atlantic salmon has declined or become locally extinct in many of the larger navigable rivers, such as the River Rhine (Mills 1991), and industrial rivers such as the Mersey (Hendry & Cragg-Hine 1997).

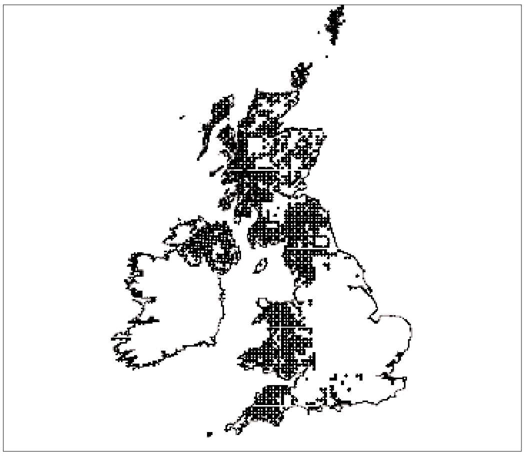
The current distribution ranges from Portugal to North America. It includes rivers in Spain, France, the UK, Ireland, Norway, Sweden, Finland and other countries draining into the Baltic, Iceland, Greenland, some Canadian provinces, and the northeast USA (Mills 1991, Maitland & Campbell 1992).

JNCC

Although present in most European countries on the Atlantic and Baltic coasts, the Atlantic salmon has become extinct from many rivers.

British distribution

The Atlantic salmon is widespread in some parts of the British Isles, and can be found in suitable river systems not affected by poor water quality or barriers to upstream migration. Virtually all Scottish rivers, except some lowland ones, are important for salmon. In England, Maitland (1972) notes the absence of salmon from central and southern regions. The main distribution gap in England and Wales is from rivers entering the sea between the Yorkshire Esk and the Itchen in Hampshire.



JNCC

The Atlantic salmon is widespread in Wales, Scotland and Northern Ireland, and has been reintroduced into some English rivers.

Recent improvements in water quality have allowed the species to return to some rivers from which they have been absent for most of the last century, such as the River Clyde and River Taff. In addition, several previously grossly polluted waterways, such as the Mersey and Trent, may soon be able to sustain populations. Salmon have been re-introduced to the Thames, but the population is being maintained by stocking, and completion of the life cycle has yet to be demonstrated.

There has been a steady decline in the overall abundance of salmon in British waters in recent years. Between 1983 and 1998 the total declared salmon catch (nets plus rods) in England and Wales declined from approximately 119,200 fish to about 43,200 fish (Environment Agency 1999). The situation is similar in Scotland, where the total catch has decreased steadily from about 500,000 fish in 1975 to approximately 180,000 fish per year in the mid-1990s (Scottish Office 1997).

However, commercial catches in Scotland have been affected to a considerable extent by the buy-out of netting stations, and only a fraction of the previous netting effort remains in many rivers, such as the Spey, Tay and Tweed. Parallel studies indicate that there has also been a significant reduction in stock abundance. This decline has occurred despite the absence of gross changes in catchment land use as have been experienced in England.

Life history

Salmon utilise rivers for reproductive and nursery phases, and the marine environment for adult development and rapid growth (Mills 1991), migrating from the Atlantic Ocean to fresh water to spawn in areas of rivers with clean gravel. This type of life cycle (spawning in fresh water, feeding and growing at sea) is termed 'anadromous'. It has the advantage of utilising relatively low-risk spawning sites in rivers and benefiting from the rich resources of the sea to enable rapid growth. A range of terms has been developed to describe the various life history stages (Table 1).

After hatching, the young fish develop in fresh water for two to four years before migrating to the sea to mature. Upon returning to the freshwater environment, both males and females undergo morphological changes to the teeth and jaws, and become darker in colour. This is particularly pronounced in the male, which develops a hooked lower jaw called a 'kype'.

Salmon spawn in autumn or winter in excavated depressions in the river substrate called 'redds'. The female produces around 1,100 eggs per kg of body weight; a small female grilse (see Table 1) of 2.3 kg will lay about 2,500 eggs, while a large MSW female (see Table 1) of 8 kg will lay about 8,800 eggs. Fertilisation success by the dominant male is high (Maitland & Campbell 1992). The redd is usually covered by materials dug out during the construction of a new one upstream, into which further eggs are shed. On completion of spawning, females drop downstream, while males may remain to spawn with further females.

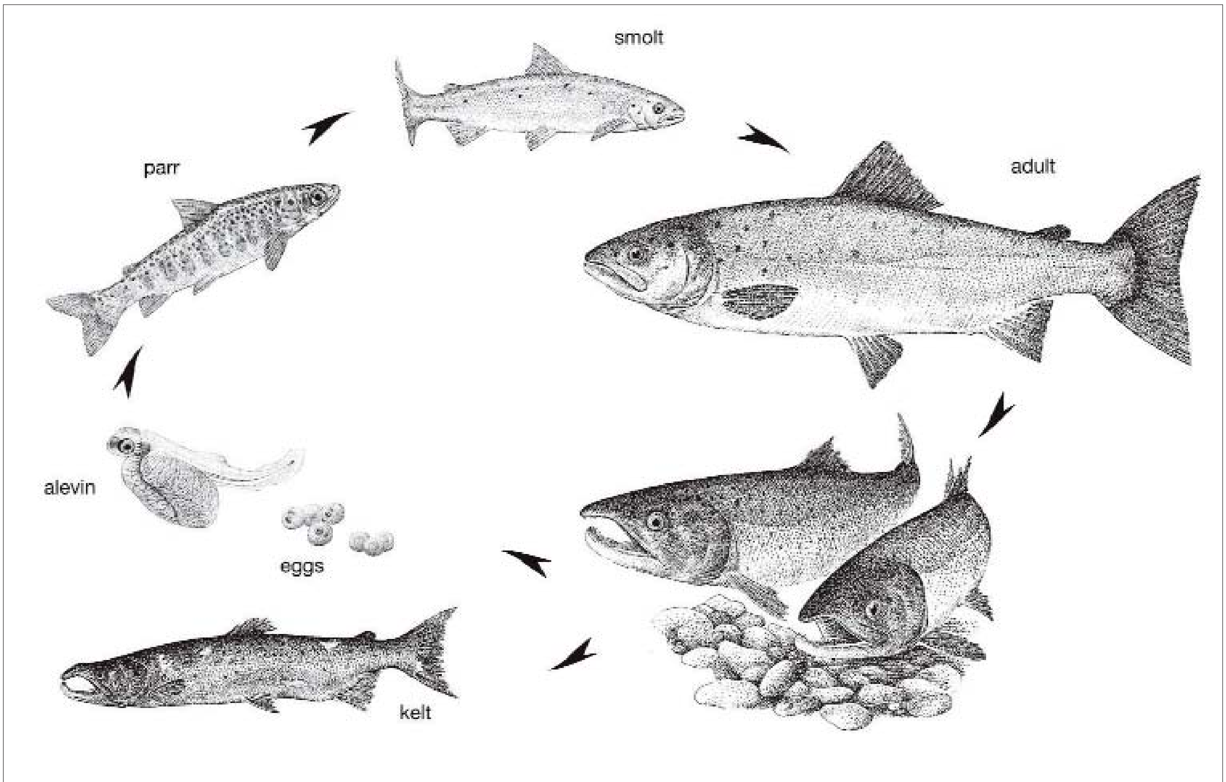
Table 1. Basic salmon life-stage terminology.

1	Alevin	From hatching to end of dependence on yolk sac for primary nutrition.
2	Fry	From independence of yolk sac to end of first summer.
3	Parr	From end of first summer to migration as smolt.
4	Smolt	Fully silvered juvenile salmon migrating to sea.
5	Post-smolt	From departure from river to end of first winter in sea.
6	Grilse	Adult salmon after first winter in sea.
	Multi-sea-winter (MSW)	Adult salmon after more than one winter in sea, commonly referred to as 'spring' fish when entering river before June.
7	Kelt	Spent or spawned adult.

As returning adults, neither males nor females feed in fresh water, and the migration and spawning process results in an approximate 40% loss in body weight (Belding 1934). The subsequent mortality rate of adults is high. Data from the River Conon over a six-year period show that the proportion of salmon descending as post-spawning kelts ranged from 20 to 36%. The proportion of salmon returning as previous spawners from a number of rivers in various countries is remarkably similar, being about 3 to 6% (Mills 1989).

The eggs remain in the redd throughout winter and hatch in spring. The incubation period for salmonid eggs is directly dependent on water temperature: at 3°C the incubation period is around 145 days, while incubation is about 40 days at 10–12°C (Drummond Sedgwick 1982). The incubation period can be expressed in terms of 'degree days', and is typically about 440 degree days. Thus, if the average water temperature is known, the likely time to hatching can be predicted.

The stability of the gravel during the incubation period is critical, as high flows during spate conditions



Sarah Wroot

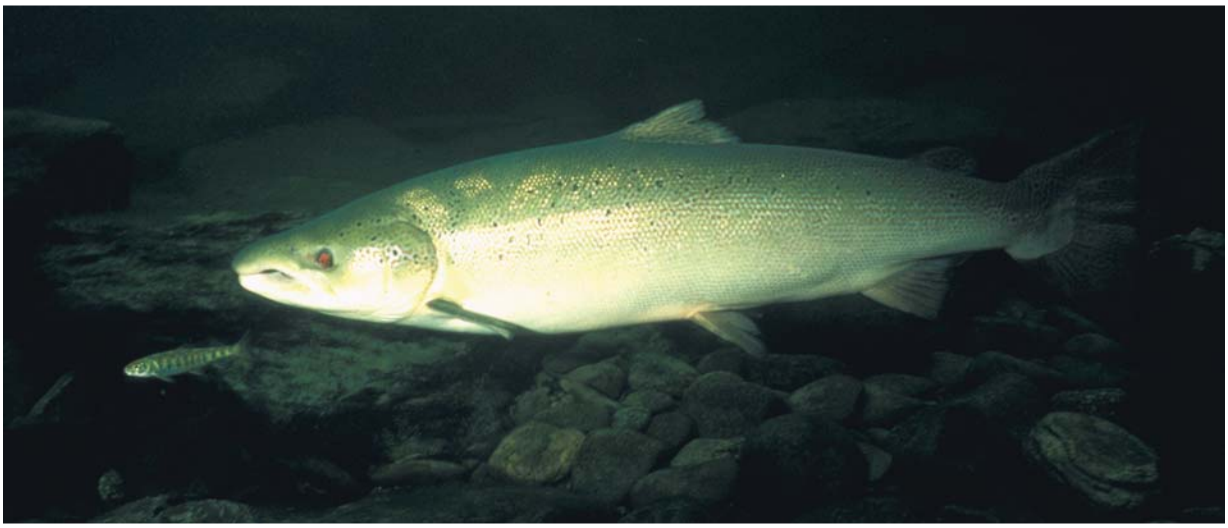
The Atlantic salmon has several life stages (beginning bottom right). The adult female lays eggs, which are fertilized by the male. The spent adults are then known as kelts, and while a few return to sea to spawn the following year, most die. The eggs hatch into alevins, dependent on their yolk sacs; then grow into fry, parr and smolt, when they first migrate to sea. Up to four years later, they return to their natal river to spawn.

Gilbert van Ryckevorsel

When they first hatch, young salmon are known as alevins. These stay in the redd, or nest, for up to two months, feeding on their yolk sacs. They then venture out as fry (above) to feed on small invertebrates.

Sue Scott

Salmon remain at the parr stage (above) for up to four years. Parr have distinct markings along their flanks, and measure only a fraction of the adult's size (below). They fiercely defend their feeding areas, and some males may become sexually mature before undergoing smoltification .



Gilbert van Ryckevorsel

can destroy the redd and kill the developing eggs. Empirical investigations by Crisp (1989) using colour-coded artificial eggs demonstrated that a spate of between 10 and 20 years' return period could wash out over 40% of eggs buried at 15 cm depth, and almost all eggs at shallower depths.

Newly hatched alevins remain within the redd, drawing nutrition from the yolk sac until they emerge to feed as fry. For the successful incubation of ova and subsequent emergence of fry it is essential that there is an adequate flow of water through the gravel. For this to occur the proportion of fine material in the gravel must be relatively low (Petersen 1978; MacCrimmon & Gotts 1986; Roche 1994).

Salmon fry and parr feed primarily upon invertebrates, particularly aquatic insect larvae such as mayfly, stonefly and caddis. Terrestrial insects caught on the surface of the water may also be taken, although this food source is more often utilised by trout (Mills 1964, Maitland 1965). Salmon nursery rivers do not necessarily provide large amounts of food during spring, although in some systems this can be a period of high growth, and mortality of fry at this time can be high (Maitland & Campbell 1992).

Salmon parr are territorial and will defend areas of the stream associated with feeding stations on or just above the substrate, from where they intercept drifting particles and forage the surrounding benthos (Stradmeyer & Thorpe 1987). Feeding motivation and foraging declines as the summer progresses (Metcalfe *et al.*, 1986), and in response to increased predation risk (Metcalfe *et al.* 1987).

Fry and parr densities vary considerably in natural streams (Mills 1991), and the limiting factor is often the availability of suitable habitat. Throughout the life cycle, each developmental stage utilises different habitats, and habitat availability will determine recruitment levels to the smolt stage. Salmon parr survival depends upon food availability and space, for which individuals compete (Kalleberg 1958). The availability of space is defined by habitat type within a river; this tends to limit population size and is termed the 'carrying capacity' (Egglishaw & Shackley 1982). Interactions with trout also affect utilisation of habitat by juvenile salmon. In summer months, juvenile trout are more aggressive than salmon of similar size, and their presence restricts salmon to the shallower and faster-flowing riffle areas of a stream, to which they are better adapted than trout (Kennedy & Strange 1986b).

In some areas a significant seasonal difference in microhabitat use has been reported. Juvenile salmon leave the riffles in autumn as temperatures decrease, and spend the colder months in the deeper pools, re-appearing in shallower water in spring when temperatures reach 6 to 7°C (Rimmer 1984; Rimmer *et al.* 1985; Mills 1989; Bjorn & Reiser 1991). During the winter months juvenile salmon and trout are primarily nocturnal. However, Harwood *et al.* (2001) demonstrated that when salmon were in sympatry with trout they either remained primarily nocturnal, occupying shallower water than the trout, or became significantly less nocturnal, spending more time active during the day than when in allopatry.

Juvenile salmon remain at the parr stage for up to four years (usually two) before smoltification. In England and Wales one-year-old smolts are common and may predominate in some southern rivers, whereas three-year-old smolts are common in northeastern Scotland. Smoltification involves physiological, morphological and behavioural changes, which generally occur when the parr reaches 100–120 mm in length. However, a proportion of males will become sexually mature before developing into smolts, and are capable of fertilising the eggs of returning adult females (Maitland & Campbell 1992). These precocious male parr can constitute a large proportion of the male spawning population (Mills 1989).

The smolt is characterised by its silver livery. It migrates to the sea, usually between April and June. Downstream migration within the river is predominantly nocturnal and is often triggered by increases in flow. In estuaries migration is still primarily nocturnal, with a strong tidal component to the direction of migration, and with movement seawards occurring on ebb tides during the hours of darkness (Moore *et al.* 1995). Upon reaching the sea, salmon feed primarily upon fish such as capelin and sandeels, and crustacea (particularly euphausids and amphipods), and growth is rapid (Pyefinch 1952, Shearer & Balmain 1967).

The amount of time spent in the sea prior to the spawning migration varies from one winter (grilse) to four (MSW salmon). Since the early 1960s, the proportion of the adult run returning as grilse rather than as MSW fish has increased significantly, and 'spring' salmon in particular are much less common. This has led to considerable concern, as these early running fish are regarded as being particularly valuable. They are prized by anglers and fishery owners because their presence increases the length of the fishing season.

The decline in MSW salmon is also of concern for overall stock recruitment because MSW fish are larger in size and produce significantly greater numbers of eggs. Thus, egg deposition is reduced with a swing from MSW fish to grilse. This may be balanced to some extent by the expected higher marine survival from smolt to grilse. There is also concern that a component of the gene pool is being lost with the decline of the spring runs – although the exact relationships between environmental and genetic factors in determining age at maturity and time of return are not understood and require further investigation (Rogan *et al.* 1993).

When adults return to spawn in fresh water they home to their natal river, and possibly to that part of the catchment in which they originated, although straying does occur. Homing is thought to be possible due to the imprinting of olfactory cues characteristic of the natal waterway (Hasler & Wisby 1951, Hasler 1954). The imprinting process is thought to occur during smolt migration (Harden Jones 1968), although the substances involved as cues have not been identified.

The significance of such specific homing to natal habitats is that this trait has led to the development of genetically distinct sub-populations, possibly even within individual catchments (Youngson *et al.* in press). Genetic variation in populations of salmon in the rivers Teifi, Usk and Wye in Wales was investigated by O'Connell *et al.* (1995) using mitochondrial DNA and allozyme analysis. They concluded that there was a significant degree of genetic isolation between salmon populations, both within and between catchments, with only a small proportion of genetic migrants or strays (approximately 3%). Their conclusions gave support to the hypothesis that there is homing of salmon within catchments, and they suggested that the Teifi, Usk and Wye catchments should be managed as multi-stock salmon fisheries.

Gilbert van Ryckevorsel

Adult salmon returning to spawn can find the river in which they were born, possibly even the same area of the catchment. It is believed that smell plays an an important part, with smolts making note of the scents of their natal river as they begin their migration to the sea.

Population parameters

The status of the salmon stock in a catchment is primarily established by reference to two population parameters, adult and juvenile abundance. Adult abundance is most commonly assessed using catch statistics from rod (Prouzet & Dumas 1988) and net fishery catches (Environment Agency 2000a). In England and Wales these figures are compiled by the Environment Agency from mandatory catch returns. In Scotland annual catch figures are compiled by the Scottish Executive Environment and Rural Affairs Department (SEERAD) from returns made by the proprietors of net and rod fisheries.

The figures from a given river can be augmented with fish counter data, if available (Struthers & Stewart 1984), from trapping techniques, and in some cases redd counts (Gudjonnsen 1988). Juvenile densities are usually determined from electric fishing surveys, typically in headwater streams. In England and Wales this monitoring is normally carried out by the Environment Agency, and in Scotland by the local fisheries trusts and some of the district salmon fishery boards, currently co-ordinated by the Scottish Fisheries Co-ordination Centre. Juvenile statistics can be augmented with smolt data where traps are available, but these are few in number.

In order to establish the relative condition of fish populations in rivers in England and Wales, the National Rivers Authority (NRA), the forerunner of the Environment Agency, developed the National Fisheries Classification Scheme (NFCS) (NRA 1994a). For salmonids this is based on a juvenile database derived from over 600 survey sites. This scheme enables the comparison and classification or grading of a river system based on salmonid fisheries data. The classification of juvenile salmonid density makes use of 'absolute' bands ranging from 'good' (A) to 'poor' (E) (Table 2). This can be tempered to take into account habitat availability and produce a 'relative' classification based upon all sites of the same broad habitat type.

Table 2. Atlantic salmon abundance (fish per 100 square metres) associated with absolute classifications in the NFCS. Grades run from A to F (e.g. Grade A >86 and Grade B 45-86 0+ salmon 100 m^{-2}). Values represent the boundaries between grades.

	CLASS										
Species group	**A**		**B**		**C**		**D**		**E**		**F**
0+ Salmon		86		45		23		9		0	
>0+ Salmon		19		10		5		3		0	

No comparable system is presently available for Scotland. However, electrofishing surveys in the most productive Scottish rivers indicate that the densities of salmon frequently exceed the 'A' grade in England and Wales.

As an aid to understanding the observed status of a salmon population in a given stretch of river, the NRA designed a computer-based system called HABSCORE to measure and evaluate salmonid stream habitat features and to predict expected values of juvenile densities (Milner *et al.* 1993). Habitat features measured include stream width, depth, flow type, cover, substrate type, gradient, altitude, catchment area, distance from river mouth and chemical conductivity. Based on a series of empirical models, the software predicts estimates of the expected salmonid population and, by comparing these with field survey results, computes the degree of habitat utilisation. Its primary use is in the detection and assessment of environmental impacts by comparing observed and predicted salmonid densities. The methodology can also be used to identify sites where habitat is constraining salmonid populations, and can therefore be targeted for habitat rehabilitation. HABSCORE should be relevant to at least some Scottish rivers, although its predictive power is likely to be poorer because it was developed on rivers in England and Wales rather different in typical habitat features and climatic conditions than many Scottish rivers. With some modification the approach could possibly be adapted for Scottish rivers.

Habitat requirements

The principal in-stream physical habitat variables that determine suitability for juvenile salmon are water depth, water velocity, streambed substratum and cover (Heggenes 1990). Other habitat variables that can affect the suitability of a stream for juvenile salmon, and which are used in the HABSCORE model, are listed above.

Mills (1989) suggests favourable locations for salmon spawning are likely to occur where the gradient of a river is 3% or less. Preferred current velocity for spawning is within the range 25–90 cm s^{-1}, with a water depth in the range 17–76 cm (Hendry & Cragg-Hine 1997). Typical spawning sites are the transitional areas between pool and riffle where flow is accelerating and depth decreasing, where gravel of suitable coarseness is present and interstices are kept clean by up-welling flow (Petersen 1978, Bjorn & Reiser 1991). However, the ranges of hydrological conditions and grain-size composition in spawning gravels quoted in the literature vary considerably (Jones 1959; Ottaway *et al.* 1981; Beland *et al.* 1982; Bjorn & Reiser 1991; Kondolf & Wolman 1993).

Salmon fry and parr occupy shallow, fast-flowing water with a moderately coarse substrate with cover (Symons & Heland 1978, Baglinière & Champigneulle 1986). Deep or slow-moving water, particularly when associated with a sand or silt substrate, does not support resident juvenile salmonids (Wankowski & Thorpe 1979, Baglinière & Champigneulle 1986). Suitable cover for juveniles includes areas of deep water, surface turbulence, loose substrate, large rocks and other submerged obstructions, undercut banks, overhanging vegetation, woody debris lodged in the channel, and aquatic vegetation (Heggenes 1990; Bjorn & Reiser 1991; Haury *et al.* 1995).

The juxtaposition of habitat types is also important. The proximity of juvenile habitat to spawning gravels may be significant to their utilisation. In addition, adults require holding pools immediately downstream of spawning gravels in which they can congregate prior to spawning. A summary of typical habitat characteristics suitable for juvenile salmon is provided in Table 3.

Cover for adult salmon waiting to migrate or spawn can be provided by overhanging vegetation, undercut banks, submerged vegetation, submerged objects such as logs and rocks, floating debris, deep water and surface turbulence (Bjorn & Reiser 1991). Woody debris has been found to provide a significant amount of instream cover for salmon (House & Boehne 1985). If the holding pools and

Sue Scott

Adult salmon waiting to spawn may take refuge beneath overhanging vegetation, rocks and woody debris. The salmon pictured above in the River Shee, Scotland, is resting beneath a log.

Table 3. Summary of typical habitat characteristics of juvenile salmon (Hendry & Cragg-Hine 1997).

Fry and underyearling parr	
Water depth	≤ 20 cm
Velocity	50 to 65 cm s^{-1}
Substrate type a. Summer b. Winter	Gravels and cobbles (16–64 mm) Cobble up to boulder (64–256 mm)
Yearling and older parr	
Water depth	20–40 cm
Velocity	60–75 cm s^{-1}
Substrate	Cobble up to boulder (64–256 mm)

spawning areas have little cover, the fish present will be vulnerable to disturbance and predation. Bjorn & Reiser (1991) suggest that proximity of cover to spawning areas may be a factor in the selection of spawning sites by some salmonid species.

Water quality

Salmon require very good water quality, typical of that found in upland streams and spring-fed chalk streams. The EU Freshwater Fisheries Directive (EU 1978; NRA 1994b) reflected these requirements in defining standards of water quality for the protection of salmonid fisheries (Table 4), typically more stringent than those applied to cyprinid waters. However, the recently adopted Water Framework Directive requires dischargers to take account of the impact of the discharge on the ecology of receiving waters. The new directive is a more integrated and powerful regulatory tool for pollution control than those previously available, and should bring a further level of water-quality improvement to all waters affected by discharges.

Table 4. Water quality parameters for salmonids (set by EU Freshwater Fisheries Directive in NRA 1994b).

Temperature (°C)	–	<25°C (98 %-ile)
Dissolved oxygen (mg l^{-1})	>9 (50 %-ile) >7 (100 %-ile)	>9 mg (50 %-ile)
pH	–	6–9
Suspended solids (mg l^{-1})	<25 (annual average)	–
Biochemical oxygen demand (mg O l^{-1})	<3 (95 %-ile)	–
Nitrites (mg l^{-1})	<0.01 (95 %-ile)	–
Non-ionised ammonia (mg l^{-1})	<0.005 (95 %-ile)	<0.025 (95 %-ile)
Total ammonia (mg l^{-1})	<0.04 (95 %-ile)	<1.0 (95 %-ile)

The General Quality Assessment (GQA) used in England and Wales (River Classification Scheme in Scotland) is based on biological data and defines salmonid waters as being of grade A or B. These are streams typified by the presence of high-scoring (Biological Monitoring Working Party, BMWP) pollution-intolerant invertebrate taxa such as mayfly and stonefly nymphs.

Water quantity

General flow requirements

The major requirements are that spawning and nursery areas are accessible to adult salmon, and that there are adequate holding areas to provide shelter for these large fish. In addition, summer flows must be sufficient to maintain adequate depth and velocity in juvenile rearing areas. During these low summer and autumn flow periods, natural freshets that temporarily increase base-flows are of great importance in providing the stimulus to initiate migration of adults into freshwater reaches (Hendry *et al.* in press).

Flow requirements for entry to rivers and upstream migration

Upstream migration of salmon primarily occurs at higher river flows, and is typically triggered by increases in flow. The actual flows required to encourage migration in a particular river vary in different parts of the river and at different times of year, being typically lower as the spawning season approaches. Using data derived from telemetry studies on radio-tagged salmon in rivers in southwest England, Solomon *et al.* (1999) found that the threshold flow required to induce salmon to enter a river from the sea varied from 101% to 284% of the Q95 (the flow exceeded for 95% of the time). The percentage of the Q95 required to provide a threshold migration flow at the tidal limit tended to be higher in smaller rivers, and as fish moved further upstream the percentage of the Q95 needed in individual rivers to maintain migration also increased. A possible consequence of river regulation is that freshets may be insufficient in magnitude or frequency to provide adequate migration opportunities for salmon.

To quantify precisely the flows used for migration in any particular river, it is necessary to have data from telemetry tracking studies or from fish counters. In the absence of such empirical data on fish movement in relation to flow in a particular river, the approach developed by the former Lancashire River Authority to predict likely migration flows can be used (Stewart 1973). Studies of fish movement using counters on a range of rivers in northwest England indicated that salmon commenced upstream migration when the flow reached a level of 0.084 cumecs (cubic metres per second, or $m^3 s^{-1}$) per metre of channel width. Peak migration occurred at a flow of 0.2 cumecs per metre width.

Flow requirements to negotiate barriers

Bjorn & Reiser (1991) discuss the ability of salmon to negotiate barriers to upstream migration. They conclude that leaping conditions at falls are ideal when the ratio of the height of the fall to the depth of the pool below is 1:1.25. Salmon can surmount obstacles 2–3 m high, providing there is an adequate pool in front of the obstruction. Bjorn & Reiser (1991) mention the role of debris dams in preventing or delaying upstream migration, but warn that removal should only be undertaken with care to avoid sedimentation of downstream spawning and nursery areas. As previously noted, woody debris is extremely important in providing habitat for juvenile salmon, as well as for a host of other species, while contributing to overall stream diversity. Other more permanent structures such as bridge culverts are arguably much more significant in terms of their impact on upstream migration. On the River Tweed for example, several hundred man-made obstacles of this type were recently identified in the catchment (Campbell pers. comm.). The Scottish Executive is preparing a guidance manual on the subject: *River Crossings and Migratory Fish: Design Guidance*.

Environment Agency

Salmon migrating upstream can leap obstacles up to 3 m high, as long as there is an adequate pool in front.

Flow requirements for juveniles

The minimum flows required to provide adequate depths and velocities in juvenile rearing areas can again be estimated by using an approach suggested by the Lancashire River Authority (Stewart 1973). Observations on northwest rivers indicated that a flow of 0.03 cumecs per metre of channel width could be regarded as a 'survival' flow. A flow of this magnitude also represents an 'inactivity' flow for adult salmon, which do not attempt upstream migration at such river levels.

Various authors have stressed that the critical water velocity is the snout (nose) or focal velocity – the actual velocity at the precise location of the fish (Bird *et al.* 1994) – and preferred water velocity for juvenile salmon increases as individuals grow (Heggenes 1990). Juveniles can tolerate a relatively wide variety of depths and substrates, but water velocity near the stream bed is the dominant physical factor influencing selection of microhabitat (Morantz *et al.* 1987, De Graf & Bain 1986). Morantz *et al.* (1987) considered that selection of habitat near the stream bed where velocity is low is best associated with nearby faster velocities. Such selection can provide high 'profitability', since the availability of drift food is good but the energy required to hold station is relatively low. Wankowski & Thorpe (1979) suggested that the ability of larger fish to maintain position in faster currents fulfilled to some extent their increased food requirement, as they would receive more drift food. As a general principle, a naturally diverse channel structure will produce a range of diverse flow conditions to which juvenile salmon have become adapted.

Substrate requirements

Substrate composition and flow are intimately connected in rivers. In general, the faster the water velocity, the coarser or more compacted the substrate. Conversely, fine substrates are associated with low velocities. Thus, in a typical riffle/pool sequence, the coarser substrate will be found in the fastest water at the top of the riffle, while the substrate in the slow-flowing deep pool will contain a high proportion of fine material. The distribution of different substrate types within a river is typically determined by the velocities prevalent during spate conditions.

Nursery and juvenile habitat

Pebbly riffles without boulders (substrate particle size predominately 16–64 mm diameter) could be considered to be prime nursery habitat for salmon less than 7 cm long (Symons & Heland 1978). As fry grow, their preference for deeper and swifter parts of riffles increases, and by the time they reach

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Young salmon require different substrates according to their size, beginning with shallow riffle areas with pebbles. As they grow, they prefer deeper, faster-flowing water with cobbles or boulders. The River Shee in Scotland (above) provides prime salmon habitat for all life stages.

8–9 cm in length, 80–90% choose areas with cobble/boulder habitats (substrate size > 64 mm) with depths greater than 300 mm. In-stream cover provided by varied substrate size is important for juvenile salmon. Mills (1989) suggested that this provides obstruction to vision between neighbouring parr and reduces territorial aggression. Coarse substrates also provide shelter from high flow velocity, which can be utilised as feeding stations adjacent to faster drift food currents. In chalk streams where substrate size is generally smaller, macrophytes (particularly *Ranunculus spp.*) provide most of the visual barriers between territories and velocity shelters.

Spawning gravels

The composition and mean grain size of gravels used by salmon for spawning varies markedly, but typically consists of a mix of cobbles (grain size 22–256 mm), pebbles (2–22 mm) and finer material (< 2 mm) (Hendry & Cragg-Hine 1997). For successful incubation of ova and subsequent emergence of fry it is essential that there is an adequate flow of water through the gravel. It is therefore important that the content of fines less than 2 mm in grain size should be low, and certainly less than 20% by weight. The minimum permeability (1000 cm hr^{-1}) for successful emergence of fry corresponds to a sand (< 2 mm) content of 12–15% (Peterson 1978, Roche 1994). Where the fines content of gravels has been increased by excessive inputs of silts and fine sand, for example from severely eroded banks, suitability for spawning is likely to be reduced.

Milan *et al.* (2000) present the findings of a range of studies from rivers and streams known to provide salmonid spawning grounds, showing the maximum level of fine sediment that allows 50% emergence of fry. The top 30 cm of river substrate are critical, and are the most sensitive to changes in physical character. The most stringent criteria therefore represent a level of less than 10% for fines below 0.83 mm to allow 50% emergence of fry.

Channel structure

Adequate habitat diversity of the type provided by the typical riffle/pool sequence is important for both

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Overhanging vegetation is important for providing cover for both adult and juvenile salmon. It is also a source of coarse woody debris, which provides habitat for the invertebrates on which salmon feed.

juvenile and adult salmon. The pools provide the deeper holding areas required by adults, the riffles provide the fry and parr habitats, and suitable spawning sites are provided at the point where pool shallows become a riffle and water velocity increases.

In natural situations, pool/riffle sequences typically repeat at intervals of five to nine channel widths. However, many river channels have been extensively modified for land drainage and flood defence, and the characteristic pool/riffle sequence with its attendant habitat diversity has often been lost. River sections modified in this way might therefore be considered for restoration to a more natural habitat, thus enhancing production of juvenile salmon (Hendry & Cragg-Hine 1997).

O'Grady (1993) studied the effects of deciduous bankside vegetation on salmonid stocks in Irish rivers. He found that mean juvenile salmon density in heavily shaded areas was only 19.4% of that found in comparable but more open zones with dappled shade. He attributed this reduction to the loss of aquatic plant cover such as epiphytic algae, mosses and aquatic macrophytes, as a consequence of the 'tunnelling' effect and heavy shading of the river bed by dense growth of bankside scrub. O'Grady recommended only selective clearance of overgrown scrub, leaving partial shading to prevent over-proliferation of aquatic macrophytes, which may choke rivers, particularly in lowland and chalk streams with elevated nutrient levels.

The need to maintain bankside vegetation is further emphasised by Bjorn & Reiser (1991) who warn against over-zealous removal of riparian vegetation cover, as this may result in excessive warming in summer by increased exposure to the sun, particularly in small streams. Riparian vegetation is also important in providing overhead cover and food for juvenile salmon and other species, maintaining the integrity of the banks and reducing erosion. Ultimately it is also a source of coarse woody debris and will contribute to overall stream diversity.

Substantive threats

Although salmon runs vary considerably in size from year to year, both within and between individual rivers, salmon stocks are currently thought to be under threat in both the freshwater and marine phases. In fresh waters the gradual degradation of juvenile and spawning habitat is giving cause for concern (MAFF & NAWAD 2000). Land use, in particular intensive agriculture, is thought to be having the greatest effect (Hendry *et al.* in press).

In the marine phase there is concern over recent declines in post-smolt marine survival rates. Several potential reasons have been put forward, including the following:

- Changes in sea surface temperatures with reduced areas of suitable habitat and hence increased intra-specific competition (Friedland & Reddin 1993).
- Fish farming, resulting in localised increases in sea lice, affecting outgoing smolts (Whelan 1993).
- Industrial fishing, which can affect marine-phase salmon both indirectly via over-exploitation of their food source (e.g. sand eel fishery), or directly by post-smolts being inadvertently netted as by-catch.
- Increased predation by seals (Scottish Office 1997).

The relationships between changes in the marine environment, marine survival rates and salmon populations are not clearly understood. In response to declining numbers of adult fish returning to rivers in many countries, a precautionary approach has been adopted and international effort has resulted in increased controls on the exploitation of North Atlantic high seas fisheries. The Faroese fishery has ceased to operate since 1991, and the West Greenland fishery is operating at a subsistence level (Scottish Office 1997). The Scottish Salmon Strategy Task Force reports that an estimated 20% of the combined salmon catch from these two fisheries comes from UK rivers (Scottish Office 1997).

There are many factors that can adversely affect salmon populations in fresh waters. These are discussed below.

Exploitation

UK salmon stocks are exploited in a number of ways:

- High seas interceptory net fisheries (mixed stock).
- Coastal drift nets (mixed stock).
- Coastal fixed nets (Scotland and Northern Ireland).
- Estuarine commercial nets (single stock).
- Recreational estuarine nets (Haaf nets on Solway).
- Heritage nets (coracle fishermen, Wales).
- Estuarine putchers (mixed stock, Severn Estuary).
- Rods.
- Poachers.

All of the above impact salmon stocks to a greater or lesser degree, depending on local circumstances.

High seas fisheries are outside the control of UK legislation, requiring international co-operation. Reductions in catch are usually funded by quota buy-outs (for example, the Faroes and West Greenland fisheries) and have been achieved on stock conservation grounds. The Irish drift net fishery is thought to take as much as 15% of the salmon stock from west coast rivers in England and Wales and up to 20% of the stock from southern English rivers (MAFF and NAWAD 2000). No current proposal for a buy-out of the Irish drift net fishery exists, although future developments have not been ruled out.

Both photos by the Environment Agency

Salmon are exploited in rivers, estuaries and the sea. Most forms of exploitation can be controlled by legislation, but high seas fisheries have to be policed by international cooperation.

In domestic waters, Atlantic salmon stocks from Scottish rivers contribute 80% of the northeast drift net fishery catch. This fishery is the most significant in England and Wales, and is currently subject to an accelerated buy-out part-funded by the government and with support from the North Atlantic Salmon Fund (UK). Other net fisheries in England and Wales are being bought out by local agreements reached between fishery owners and local netsmen, either individually or collectively – for example, the Solway Haaf and the Clwyd drift net fisheries.

However, the situation is complicated in England and Wales by the fact that the fisheries are generally a public right and cannot be bought or sold. The agreements reached involve the fishermen who hold licences of entitlement agreeing not to fish, and being compensated appropriately. The situation in Scotland is different: fishing rights are private and transferable, and considerable progress has been made by the Atlantic Salmon

Guy Mawle/Environment Agency

Many anglers in the UK operate a voluntary catch-and-release policy for salmon. In Scotland, district fishery boards can restrict salmon fishing for conservation reasons, and make catch-and-release mandatory.

Conservation Trust and the North Atlantic Salmon Fund (UK) in negotiating the acquisition of netting rights, which are then not exercised. Buy-out of nets is also being negotiated in Northern Ireland with support from the North Atlantic Salmon Fund (UK). For those nets that remain, local closed seasons and gear/technique restrictions control fishing effort. In England and Wales, net limitation orders restrict the numbers of licences issued, but normally these can only be reduced after the holding of a public inquiry.

Salmon may also be taken as bycatch in commercial fisheries for other species, although this cannot be reliably quantified. There is concern that the increased industrial fishing for species such as sand eels may be having a significant impact on the availability of food sources for salmon during their marine phase.

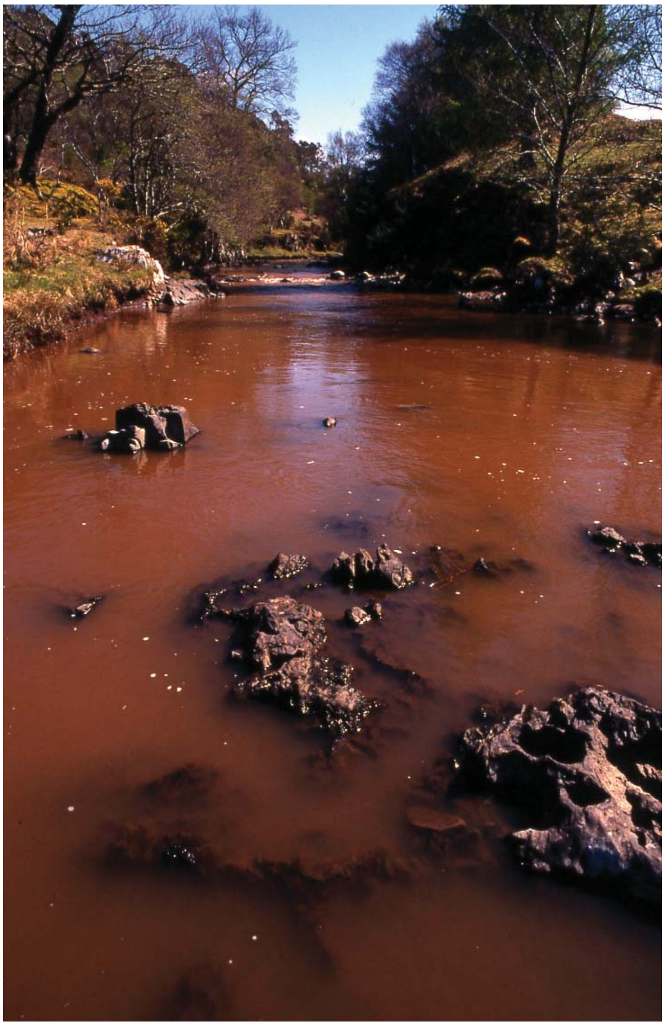
Rod exploitation is largely controlled by a combination of close season and bait or lure restrictions, and by restricting angler numbers based on the beat system under the control of riparian interests – for example, in Scotland there is no angling for salmon on Sundays. In addition, new bylaws have recently been introduced in England and Wales to protect the vulnerable spring fish component of the run, catch and release being mandatory before June 16th.

There is a strong and rapidly developing catch-and-release philosophy among anglers for both salmon and sea trout. During the 2002 fishing season, 50% of the salmon caught by anglers in England and Wales were released (Environment Agency/CEFAS 2003). In Scotland in 1999, 28.6% of the spring salmon caught by anglers were released (Salmon and Trout Association 2001). Furthermore, the recently enacted Salmon Conservation (Scotland) Act gives the district salmon fishery boards and the Scottish First Minister the power to impose conservation measures to limit effort on specific rivers. District salmon fishery boards or other parties can apply to the First Minister for such action, which could include method or effort restrictions and mandatory catch and release.

Illegal fishing (poaching) remains a problem on many salmon rivers, although the Salmon Act 1986 (which applies to England, Wales and Scotland) resulted in a reduction in this criminal activity due to harsh penalties. Smaller, remote rivers are particularly vulnerable to poaching, which can take a relatively high proportion of the stock. Techniques used include gill-netting, foul-hooking with rod and line, snares and poisoning.

In the context of stock management, in England and Wales Salmon Action Plans (SAPs, see Appendix 1) offer a framework within which the level of exploitation can be assessed relative to the size of the stock (Environment Agency 1996). For instance, the estimated total number of salmon eggs laid in a specific catchment on any given year should exceed the conservation limit for that river. Compliance against the conservation limit has been set at the 20 percentile, which means that the target should be exceeded for four years in five. The Centre for Environment, Fisheries and Aquaculture Science (CEFAS) has now published management targets for all rivers, which are basically the conservation limit value +20%. However, an assessment of compliance is complicated since performance is examined in blocks of three years, which is the shortest period in which a failure can be measured. The pass/fail criteria are tempered by biological considerations, such as the impact of a single year-class failure on egg deposition over the following years. In Special Areas of Conservation, additional consideration needs to be given to setting conservation limits, reflecting the ability of the catchment to support salmon under conditions of low anthropogenic impacts (Environment Agency 2003b).

Arguably, exploitation could be curtailed if the stock falls below its conservation limit for a prolonged period greater than two years in three. Due to economic considerations under such circumstances, mandatory catch and release could be considered for rod fisheries, while other forms of exploitation that deliberately set out to kill fish (i.e. netting) would have to cease until stock levels recovered to a point at which exploitation was sustainable. However, current exploitation does not allow rapid cessation of netting activity in England and Wales.



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Siltation as a result of disturbance, such as forestry or bank construction, can seriously impact salmon. Fine silt can smother eggs, choke fish and disrupt feeding behaviour.

The UK Environment Agency and CEFAS have recently set management targets for all salmon rivers in England and Wales. These are the stock levels that managers should aim to achieve – i.e. over and above the conservation limit (Environment Agency/CEFAS 2003).

In Scotland, the need for a target-based approach as advised by the North Atlantic Salmon Conservation Organization (NASCO) is accepted. However, the detail of how this will be achieved must be sensitive to a range of local factors. These include issues such as the significance of local sub-catchment populations that need further investigation before egg deposition targets can be reliably applied. The specific approach to be followed in Scotland has yet to be developed. Salmon stock conservation in Northern Ireland is under review, and the development of a system comparable to Salmon Action Plans based on spawning targets is likely (A Waterman pers. comm., GJA Kennedy pers.comm.).

Gravel composition and siltation

Hydrological conditions in rivers can be radically altered by activities such as regulation for flood protection and abstraction for water supply (Hendry & Cragg-Hine 1998). Land-use change through intensive agriculture and urbanisation can also result in marked effects on flow regimes and increased requirement for flood-prevention measures. These man-induced changes in flow and flood dynamics can alter both the size composition of gravels available for spawning and the depth to which gravels are reworked and redds disrupted (Milner *et al.* 1981).

Siltation of spawning gravels is a particularly common risk owing to disturbance in river catchments by activities such as forestry and mining, arable cultivation and intensive livestock-based agriculture (Herbert *et al.* 1961, Neill & Hey 1992). Under natural conditions, most spawning rivers in the UK would have suspended concentrations of sand, fine silt and clay of less than 5 mg l^{-1} during low flows and may be essentially clear-water rivers (Hendry & Cragg-Hine 1997).

High concentrations of suspended solids in the water may physically choke fish or disrupt feeding behaviour (Barrett *et al.* 1992). The fines smother salmonid eggs by preventing intra-gravel currents (Moring 1982, Thibodeaux & Boyle 1987), and by clogging the interstices at the surface of the riverbed. This prevents or disrupts alevin emergence (Phillips *et al.* 1975, Hausle & Coble 1976) and reduces the fitness of the fry and parr, and hence their ability to cope with the natural pressures faced within the riverine environment (MacCrimmon & Gotts 1986, Olsson & Persson 1988).

Flow regime

Both high and low flows are likely to be affected by climate change in the future, with wetter summers and drier winters predicted. Low flows occur naturally during periods of drought, but may be exacerbated by human activities such as river regulation, abstraction, water transfers, large-scale forestry, agriculture and urbanisation. Low flows may result in elevated water temperatures and low dissolved oxygen during summer periods, causing salmon kills (Brooker *et al.* 1977), especially among the 0+ cohort (Cowx *et al.* 1984). Additional impacts include loss of spawning areas, a reduction in wetted perimeter, loss of juvenile rearing habitat (De Graf & Bain 1986) and increased competition via a reduction in the number of territories available (Cowx *et al.* 1984, Giles *et al.* 1991). In addition, flows may be insufficient to draw adult fish into the river or to provide plunge pools of sufficient depth beneath obstacles to allow adult salmon to pass.

The movement of gravels during natural or controlled high flows can cause the erosion of spawning beds and the downstream drift of salmon eggs and alevins (Crisp 1995). This will usually result in high egg and alevin mortality rates. As a general rule, eggs buried at depths of 5 cm will be scoured away during floods, while there will be significant loss at 10 cm depth, and up to 40% loss at 15 cm depth (Crisp 1989). Eggs laid by small salmon are therefore particularly vulnerable to being washed out of redds during high flow. With the decline in the proportion of MSW fish in many river systems, the larger proportion of spawning fish are grilse, and hence the population may be more at risk from the effect of higher flows on egg survival. The severity of this flow-mediated damage is likely to vary with the different river types: erosive upland streams are likely to be more susceptible than lower-energy chalk streams.

Obstructions to migration

These can include temporary natural features such as coarse woody debris blocking the whole channel, and engineered structures such as dams, weirs, fords and culverts, which are of much greater significance. The structures associated with fish farms can also form a barrier to migration. The location of obstructions in relation to upstream spawning areas is obviously an important consideration.

However, there is a general presumption against attempting to modify natural obstacles such as waterfalls. Coarse woody debris is also an extremely valuable component of the physical stream habitat, providing vital in-stream diversity for fish and other wildlife. It is only in extreme conditions that the whole channel will become blocked and impassable to migrating salmon.

Pollution

Salmon are susceptible to deteriorating water quality as a result of both direct point-source discharges and diffuse or non-point-source pollution arising from land-use practices or industrialisation (Hendry *et al.* in press). Industrial contaminants such as heavy metals and organic chemicals are now largely reduced and controlled through the introduction of new and more stringent pollution and water quality regulations (NRA 1990). Similarly, point discharges from sewage treatment works have come under more stringent control and received significant investment over the last 10 years. Future investment will continue and will be extended to reduce the risks from expanding urbanisation via improved infrastructure design and increased discharge standards. The implementation of the Water Framework Directive is likely to instigate further improvements that will have wider benefits for salmon.

Farm wastes have also become much more of an important issue over recent decades, as European policy has encouraged an intensification of agriculture (NRA 1992). This has been accompanied by changes in practice resulting in accumulations of potentially damaging pollutants such as livestock slurry and silage liquor. The problem is further compounded by storage and disposal procedures for the ever-accumulating volume of farm wastes (MAFF 1991).

Non-point-source pollutants include nutrients used as fertiliser in agriculture and forestry. For example, afforestation will increase the output of fertilisers such as nitrate and phosphate during initial site preparation, and again during clear-felling operations when soils are disturbed (Binkley & Brown 1993). There is also some evidence from Northern Ireland of an increase in water acidity and toxicity owing to peat drainage, which may have impacted salmon populations (Bayfield 1991).

A further, widespread example of non-point-source pollution is that of acidification from industrialisation and land-use practices. Power generation and fossil fuel combustion in industrial nations results in releases of gaseous oxides of sulphur and nitrogen (Schofield 1976, Schindler 1988). Nitrous and sulphurous oxides act in various ways, both directly from the atmosphere (acid rain) and catchment runoff (sulphate particulate transfer), and indirectly via internal catchment processes (soil acidification), to cause the process known as acidification (Mason 1998). Particulate deposition can lead to dramatic drops in pH values, as episodic heavy rain and snowmelts can flush settled particulates into the river system. This process is further accentuated by the ability of vegetation to scavenge and accumulate pollutants (Mason 1998). Coniferous forests in upland regions have been shown to increase rain acidity by an average factor of eight during its passage down the trunks of trees (Mills 1989).

Increased acidity increases the mobility of toxic metals, particularly aluminium. Eggs and alevins are highly sensitive to acidification and cannot tolerate a pH of much less than 4.5. Older parr stages are also susceptible, even to short duration acid events (Mills 1989). However, local geology can have a buffering effect, for example in limestone catchments.

Large quantities of organic fine sediment or woody logging-debris can reduce oxygen levels by increasing the biochemical oxygen demand (BOD). The effect of BOD is exacerbated by increased water temperature, which reduces the solubility of oxygen and increases microbial activity. Furthermore, increased macrophyte growth as a consequence of eutrophication can lead to oxygen sags due to the respiratory phase during darkness. It is generally recognised that oxygen concentrations should not fall below a single-day mean of 8 mg l^{-1} for spawning fish, although 5.0–6.5 mg l^{-1} is acceptable to adult fish at other times (Binkley and Brown 1993).

One of the most worrying pollution impacts on salmonid streams to have emerged in recent years is the effect of the comparatively new synthetic pyrethroid (SP) sheep dips on stream invertebrates. SP sheep dips are many times more toxic to aquatic invertebrates than the organophosphate (OP) products previously used, and even small amounts can eliminate many of the invertebrate organisms on which young salmon feed, even when direct mortality of fish has not been observed. Recent evidence from the Environment Agency suggests that inadequate disposal has seriously affected several thousand kilometres of upland stream in England and Wales. Invertebrate populations are sometimes wiped out over several kilometres during each incident, leaving little or no food for juvenile salmonids (Millband 1997). The Scottish Environment Protection Agency (SEPA) estimates that, by 2010, the major threat to the freshwater environment will be agricultural pollution, and at present the greatest single threat is SP sheep dips. Many kilometres of river within the River Tay catchment were severely damaged by SP dips during 1999 and 2000.

The new EC Groundwater Regulations, enforced from 1 January 1999, are designed to prevent pollution of groundwater through the control of certain dangerous substances, including sheep dips (Protection of groundwater against pollution caused by certain dangerous substances – 80/68/EEC). The substances to be controlled fall into two lists. List I substances are the most toxic and include pesticides, sheep dip, solvents, hydrocarbons, mercury, cadmium and cyanide.

Aquaculture

There has been a substantial growth in salmon farming in the sheltered inland and inshore waters of west Scotland, and the Western and Northern Isles (Scottish Office 1997). Salmon smolts, brown and rainbow trout are reared in freshwater lochs and land-based sites associated with adjacent watercourses. Farmed fish can impact upon wild populations of Atlantic salmon in several ways. Farmed stocks harbour disease and parasites that can infect wild salmon populations. In particular, sea lice have been identified as being of considerable concern by the Scottish Salmon Strategy Task Force (Scottish Office 1997), which commented that the highest levels of infestation in wild fish were in areas used for salmon farming.

Erling Svensen/UWPhoto

Wild salmon are at risk of contracting parasites and diseases from farmed fish, particularly in Scotland. Farmed salmon also compete with wild fish and may reduce their genetic fitness if they breed with them.

In addition, farmed fish can escape and compete with wild salmon populations, both spreading disease and competing for resources. Escapees will probably not be genetically suited to the local environment and, if allowed to breed with the wild population, the genetic fitness of indigenous offspring can be reduced. Escaped male salmon are often larger than wild fish, making them more attractive to females and more successful in spawning, even though they are less fit genetically. Excess feed and fish waste from farm cages can severely pollute the surrounding waters. This is of particular concern in poorly flushed and nutrient-poor waters, where nutrients from food and faeces, and antibiotics used during the rearing process, can accumulate.

Stocking

Stocking includes both the introduction of Atlantic salmon and other fish species. The introduction of salmon can be a useful fisheries management tool, but may mask the real reasons for declining salmon

Tony Wells

Salmonids such as brown trout stocked for angling can impact wild salmon by predation, competition and introduction of disease.

stocks and is not sustainable in the long term. Restocking following pollution events has been regarded as an essential technique to re-establish populations. However, other species of conservation interest, such as the bullhead and lamprey, are not usually stocked. Where possible, depopulated areas should be allowed to re-colonise naturally with fish from unaffected regions within the river/catchment.

The Environment Agency has recently developed a consistent and nationally applicable Fish Introductions Policy, in which conservation interests are specifically addressed. The guidance (Environment Agency 2003b) states that Section 30 consents, which authorize fish stocking, should not be granted if any features of ecological or conservation value could be compromised by the proposed introduction, whether the intention is to stock salmon or other fish species. In the case of Section 30 consent applications involving Sites of Special Scientific Interest (SSSIs) (SACs are not directly mentioned), English Nature and the Countryside Council for Wales (CCW) must be consulted, and no Section 30 consent should be given without their agreement. The Environment Agency, English Nature and CCW have established a common framework for salmon stocking in relation to other salmon management approaches (Environment Agency 2003b).

In Scotland, permission to stock salmon must be obtained from the district salmon fisheries boards, where they exist. However, no nationally agreed policy on fish introductions has yet been established.

Stocked fish may impact upon Atlantic salmon through a variety of mechanisms, the most significant being as follows:

- Mortality of ova resulting from over-cutting of redds by later-spawning fish, e.g. spring-spawning rainbow trout.
- Predation on eggs, fry, parr and smolt stages.
- Reduced availability of juvenile rearing areas due to aggressive territorial behaviour.
- Competition for food.
- Disease and parasite introduction.
- Contamination of gene pool if non-native salmon introduced.
- Reduction in genetic diversity (hatchery stock rapidly lose genetic diversity through inbreeding and unintentional selection for strains that survive well in hatchery conditions).
- Increased attractiveness to predators, particularly if stocking is to compensate for poor habitat.

The most significant risk to salmon fry from stocking is an increase in competition for food and territory (Aprahamian *et al.* in press). This risk is primarily associated with the introduction of non-adult salmonids. Competition for territory between introduced juvenile trout and salmon fry and parr may result in the restriction of salmon to shallow and fast-flowing reaches (Kennedy & Strange 1986b). As such, salmon would be unable to occupy all available habitat, and overall production would be reduced. Additional competition for food is likely to occur between early juvenile stages of trout and salmon (Kennedy & Strange 1986a, Harwood *et al.* 2001).

Stocked adult salmonids and chub can also pose a potential threat through increased predation. Adult brown and rainbow trout may prey on salmon fry and small parr (Mills 1964, Welton *et al.* 1997). Predation on eggs and alevins is not normally significant, as these stages are buried within the substrate. However, bottom-feeding fish such as barbel, which can occur in the faster flowing reaches, may be able to prey on eggs and alevins. Where stocking with salmon ova is taking place there is a potential risk that disturbance of the receiving gravel might damage existing spawning redds. Over-cutting of salmon redds might occur where rainbow trout from spring-spawning stock are attempting to spawn in areas previously used by salmon (Welton *et al.* 1997).

Widespread salmon stocking has taken place for a variety of reasons, including mitigation, restoration and enhancement exercises. However, the issue of Atlantic salmon genetic integrity and the potential impact of stocking has received much attention in recent years. Reduced levels of genetic variability are often associated with artificially reared fish (O'Connell *et al.* 1995). Genetic heterogeneity has been recorded in a hatchery stock where parr that smolted after one year were found to be genetically distinct from those that smolted after two years, although both groups were derived from a common pool of broodstock (Crozier 1998). If wild populations interbreed with stocked fish, they may suffer a loss of adaptive or productive potential, and individual development characteristics specific to that catchment may be altered.

Youngson *et al.* (in press) highlight compelling evidence of locally adaptive genetic variation in salmon stocks. From a management perspective, the precautionary approach should therefore be applied, based on the assumption that salmon exist in locally adapted populations. Practical management guidelines developed by Aprahamian *et al.* (in press) include the following:

- Where possible, obtain broodstock from the sub-catchment or catchment to be stocked with juveniles.
- If local broodstock not available, obtain from a geographically near or ecologically similar stream.
- Use a sex ratio close to 1:1.
- Do not compromise wild populations in donor catchments by removing fish for broodstock.
- Do not use hatchery brood stock due to a high degree of domestication.
- Source adults from throughout the spawning run.
- Residency time in the hatchery should be kept to a minimum.
- Stocking should be carried out over several years.
- Results should be monitored.

Management guidance specific to SAC rivers in England and Wales is provided in Environment Agency 2003b.

Predation

Predation of salmon is a natural phenomenon, fish, birds and mammals having co-existed in an ecological balance over the millennia. The recent expansion of the otter population may lead to increased predation pressure upon salmon (Scottish Office 1997), but this is unlikely to be significant. In rivers where salmon predominate, otters will feed on parr and smolts but will also take hen fish prior to spawning. There is considerable concern over the impact of piscivorous birds, which are recognised as increasing in number nationally (Wernham *et al.* 1999). MAFF (Feltham *et al.* 1999) and the Scottish Office (Marquiss *et al.* 1998) have produced recent reviews of bird predation upon both Atlantic salmon and other fish species, which acknowledge that significant impacts are possible. However both of these reviews highlight the difficulty of assessing predation impact, since this requires accurate estimates of salmon population density and predator feeding rates.

Marquiss *et al.* (1998) report on fishery proprietor concerns in Scotland regarding predation of Atlantic salmon by sawbill ducks, including goosander (*Mergus merganser*) and the red-breasted merganser (*Mergus serrator*), as well as the great cormorant (*Phalacrocorax carbo*). The authors conclude that under some circumstances, fish-eating birds can consume large numbers of Atlantic salmon. Goosander and merganser were found to take the most fish, with large parr and smaller than average smolts being the most common prey. Feltham *et al.* (1999) reviewed the impact of cormorant and goosander predation upon both coarse fish and salmonid fisheries. The authors concluded that predation impact was likely to be fishery-specific, but could significantly reduce stock levels. For instance, it was estimated that goosander broods removed approximately 6–21 % and 22–60% of juvenile salmonids on the rivers Ribble and Hodder, despite juvenile salmon comprising only 7–14% of their diet by mass.

Where there is evidence of serious damage to specific fish populations, a licence can be obtained to shoot a specified number of birds, but only after all other efforts to deter predation have failed. DEFRA (formerly MAFF), NAWAD and the SEERAD all have licensing systems in place with procedures for progressing applications that include gathering evidence of the degree of impact caused by piscivorous birds.

Conclusions

The development of representative long-term datasets on all salmon life stages is essential for the adequate management of the species. In addition, data on the quantity and quality of the habitat required for various life stages will greatly enhance the ability to understand population fluctuations and the environmental drivers that influence salmon stocks.

Gilbert van Ryckevorsel

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Appendix 1
Salmon management in the United Kingdom

England and Wales

Salmon rivers in England and Wales are managed on a river-by-river basis using a specifically designed methodology – salmon action plans (SAPs) (Environment Agency 1996), which will be developed for each of the principal salmon rivers by 2002. Each SAP will review the status of the stock and fisheries on a particular river, identify the main issues limiting performance, and draw up a list of costed options to remedy perceived problem areas.

A new concept introduced by SAPs is that of setting a target for spawning to assess stock and fishery performance. These allow a more objective assessment of the status of a given river's stock. SAPs therefore provide a common framework for the delivery of salmon management strategies throughout England and Wales. The Environment Agency is currently revising the guidance on how SAPs, spawning targets and compliance monitoring are developed. The revision will include details on the process and mechanisms for reviewing and refining SAPs, which are scheduled for individual re-assessment on a five-yearly basis.

There has been some debate about the level at which the spawning target is set. The target is currently defined as the 'conservation limit' , which is a reference point on the stock-recruitment curve for salmon known as the MBAL (minimum biologically acceptable level). This is the level of spawning that maximises the sustainable catch – thus, if exploitation increases above the sustainable catch, then although catch will temporarily increase, stock will eventually reduce.

From a conservation perspective it is debatable whether a single target based on MBAL is sufficient. In the recent Review of Salmon and Freshwater Fisheries Legislation (MAFF and NAWAD 2000), a recommendation was made that several egg-deposition targets ought to be set, including a true 'conservation target'. This was defined as the level of egg deposition below which the stock was considered to be at threat and should be a trigger to reduce or remove, albeit temporarily, exploitation.

However, the review group recommendation on this point was that compensation should not be paid if the reduction in exploitation was enforced on conservation grounds. The government supported this recommendation; hence it might be anticipated that the current situation will be reviewed in the near future. Therefore, the setting of a true conservation target on SAC rivers below which exploitation is not permitted (no fish to be killed) should be a priority.

Scotland

Local management of salmon stocks in Scotland is undertaken by the district salmon fisheries boards, which have statutory powers to carry out works for the protection and improvement of fisheries, and for the increase of salmon and the stocking of waters in their district with salmon. In several areas local fisheries trusts have been set up that work alongside a board to advise on best practice and provide support for specific resource management and enhancement projects. Advice on fisheries management matters is also provided by the Freshwater Fisheries Laboratory at Pitlochry.

The Scottish Fisheries Co-ordination Centre was established in recognition of the need for collaboration and information exchange between the various bodies currently involved at local and national level. The principal function of the centre is to promote a two-way flow of information on management issues. Information collected at local level is collated and integrated into national databases by the centre and then fed back to support international, national and local management decisions.

Under the recently enacted Salmon Conservation (Scotland) Act, the district salmon fishery boards can apply to the First Minister for the power to impose conservation measures to limit exploitation on specific rivers. Such action could include method or effort restrictions and mandatory catch and release. Although the need for a target-based approach, as advised by the North Atlantic Salmon

Conservation Organisation (NASCO) and adopted by the Environment Agency in England and Wales, is accepted in Scotland, the specific approach to be followed has yet to be developed. Issues such as the significance of local sub-catchment populations need further investigation before reliable egg-deposition targets can be applied.

Northern Ireland

A salmon management plan has been under development in the Fisheries Conservancy Board area of Northern Ireland since 1999, supported by funding from the European Union. The two project staff have mainly been working on GIS-based habitat surveys of salmon rivers and the development of a network of fish counters. The habitat surveys are being used to build up a database to identify areas requiring rehabilitation, and to form the basis for developing appropriate spawning and egg deposition targets.

The purpose of the fish counter programme is to provide a means of monitoring adult salmon runs to determine if spawning targets are being met, and counters have now been installed on three rivers. Application is to be made for further funding from the EU to enable the programme to be expanded so that the NASCO requirement for a target-based approach to stock management can be fully met.

In the River Foyle area a fishery management scheme based on spawning requirements (originally implemented many years ago by the former Foyle Fisheries Commission) is in operation. The legislation here allows the Loughs' Agency (successor body to the commission) to close down the commercial fisheries if escapement into the river, as measured at a fish counter in the lower reaches, has failed to reach a pre-determined target by a set date.

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Life in UK Rivers was established to develop methods for conserving the wildlife and habitats of rivers within the Natura 2000 network of protected European sites.

Set up by the UK statutory conservation bodies and the European Commission's LIFE Nature programme, the project has sought to identify the ecological requirements of key plants and animals supported by river Special Areas of Conservation.

In addition, monitoring techniques and conservation strategies have been developed as practical tools for assessing and maintaining these internationally important species and habitats.

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SNIFFER

The Atlantic salmon is a distinctive, immediately recognizable fish, displaying incredible athleticism and persistence. Its long migrations between the sea and freshwater spawning grounds are well-documented.

However, despite its important historical role in the cultures and economies of Western Europe, salmon numbers are suffering a widespread decline. In several rivers on the Atlantic seaboard, the salmon has now become extinct due to a range of impacts, including water pollution, barriers to migration, commercial fishing and the siltation of spawning grounds.

This report describes the ecological requirements of the Atlantic salmon in a bid to assist the development of monitoring programmes and conservation strategies that are vital for its future.

Information on Conserving Natura 2000 Rivers and Life in UK Rivers can be found at
www.riverlife.org.uk

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