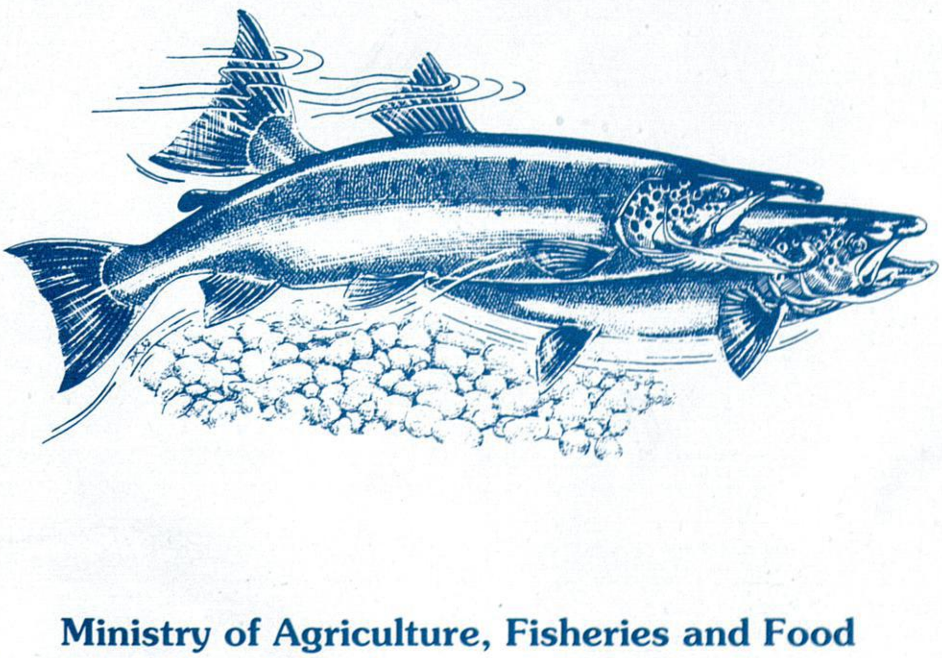
FACTORS AFFECTING EMIGRATING SMOLTS AND RETURNING ADULTS

Report of the Salmon Advisory Committee



Ministry of Agriculture, Fisheries and Food
Scottish Office Agriculture and Fisheries Department
Welsh Office Agriculture Department

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1. INTRODUCTION

The Salmon Advisory Committee was established by Fisheries Ministers in October 1986. Its membership is shown at Appendix A.

The terms of reference of the Committee are:

- "To examine and report on those matters relating to the conservation and development of salmon fisheries which are referred to it by Fisheries Ministers."

1.1 AIMS AND OBJECTIVES

Ministers have asked the Salmon Advisory Committee to examine the various influences on wild salmon stocks. These are numerous and varied, both in their nature and extent. We have therefore identified those human activities which may have significant and widespread effects on salmon and their environment, and we have pointed out where there is a reasonable expectation that we can make constructive and practical recommendations to alleviate undesirable effects.

The Committee recognised that the effects of many of these activities interact and that some affect more than one stage in the life cycle of the salmon. We also felt that the subject was too large to be addressed in a single report, and that a convenient and logical way to proceed was to consider the activities in terms of their impact on distinct phases of the life cycle. We therefore decided to produce two reports on the effects of human activities on Atlantic salmon, firstly covering the life stages from egg to pre-migrating smolt, and secondly emigrating smolts and returning adults.

The earlier report on this theme was published in May 1991 entitled "Factors Affecting Natural Smolt Production" and as it was the third report of the Committee, it is referred to subsequently as the Third Report. It dealt with human activities that affect the survival of juvenile salmon prior to their migration as smolts i.e. their early lives in fresh water and covered three main groups of factors: hydrology (e.g. river regulation and abstraction), water quality (e.g. pollution and acidification), and habitat (e.g. riparian management and gravel extraction). It contained a number of specific recommendations and also pointed to the need for a more integrated approach to all aspects of stream management, to include the creation of Buffer Zones between agricultural activity and the water course.

This report concentrates on activities which can affect the emigrating smolts and returning adults in fresh water and estuaries. In it we set out to highlight the importance of minimising adverse impacts upon the fish by explaining the possible consequences of various forms of human activity which can affect survival and seriously disrupt the natural movement of fish to and from the sea. In the past the upstream progress of adult salmon in many rivers has been impeded by man's activities, even to the extent of destroying the stocks in individual rivers. More recent efforts to improve water quality and open up access have greatly helped some rivers and resulted in the return of salmon to others, but the situation could easily be reversed and stocks would once more be lost.

We have endeavoured to avoid overlap between the two reports, and this report is concerned with life stages of the salmon in fresh water following the beginning of smolt emigration. It does not, for example, deal specifically with the late autumn downstream movements of parr which are known to occur in some rivers. Where these movements are a precursor to the smolt migration in the spring, it is likely that they will be affected by some of the factors addressed in this report. However, where they simply represent a redistribution mechanism for larger parr, they will be affected more by the factors covered in the earlier report. This report should, therefore, be read in conjunction with its predecessor, with the awareness that the factors impacting on salmon are subject to a continual process of change, which imposes the need for frequent review. This report thus assesses the problems facing smolts and returning adults as they are currently perceived.

2. INFLUENCES OF ENVIRONMENTAL FACTORS ON SMOLT EMIGRATION AND ADULT RETURN

2.1 SMOLTS

2.1.1 The process of smolting

The smolt stage of the Atlantic salmon is a period of morphological, physiological and behavioural change when the fish prepares for the sea water phase of its life cycle and subsequently migrates out to sea. The transformation from parr to smolt, referred to here as smolting, is initiated by environmental factors such as temperature and photoperiod operating through the endocrine system of the fish. Although the process of smolting is gradual and may have begun the previous winter, the actual migration of smolts generally occurs during the spring.

Much of our knowledge on smolting and smolt emigration has been derived from studies of hatchery-reared fish. Such information has to be treated with some caution when it is applied to fish in the wild, where additional factors come into play.

2.1.2 Effects of growth rate and size on smolting

Whether a parr will become a smolt and subsequently migrate to sea depends largely upon its achieving a certain size and physiological state. The growth of individual fish is related to environmental conditions and the availability of resources (e.g. food and cover). Hatchery populations of salmon parr develop both fast and slow growing groups during their first growing season. The larger fish will tend to continue growing during the autumn and winter and will normally become smolts the following spring. The remaining smaller fish will generally require a further year or more in fresh water. It is not clear to what extent the same applies in the wild, but fish which are dominant within a hierarchy in the river are likely to grow more quickly and become smolts sooner.

In British rivers the majority of smolts migrate after spending one, two or three years in fresh water. In rivers with abundant food resources and long growing seasons, such as southern chalk streams, many parr will become smolts after only one year. In rivers where food resources are scarcer, most parr will have to extend their stay in fresh water and migrate as older smolts.

Throughout their geographical range some fast growing male parr mature before becoming smolts and this delays their pattern of migration.

2.1.3 Behavioural and physiological changes associated with smolting

Salmon parr which had previously defended summer feeding territories against other parr move into deeper water in the autumn and winter and these may form loose aggregations with other parr. Weight per unit length decreases and the fish become more streamlined in shape. As smolting progresses the fin margins blacken and the fish become silvery in colour.

Increased enzyme activity in the gills permits the fish to osmoregulate successfully and to survive in a saline environment. Tolerance to higher salinities increases as the season progresses and coincides with the onset of the smolt migration. A physiological requirement to move to a saline environment may be one of the factors initiating downstream migration.

A number of endocrine changes also occur at the parr-smolt transformation, particularly an increase in the production of growth hormones by the thyroid, interrenal and pituitary growth glands. However the exact physiological role of these hormones during the smolting process is not fully understood.

2.1.4 Environmental influences on smolting

The smolting process is gradual, extending in some cases over six months, and as it progresses, the fish become more responsive to the environmental stimuli which will eventually initiate the downstream migration to the sea. Older smolts tend to migrate earlier in the spring, and, within each age class, larger smolts also migrate earlier. This suggests that the smolting process tends to start earlier or occurs more rapidly in the older and larger individuals.

The smolting process is influenced by water temperatures and photoperiod operating through the endocrine system. The annual cycle of growth, and the process of smolting in juvenile salmon have strong endogenous components which are synchronised by the photoperiod cycle. The change of day-length is the important photoperiod cue involved in the smolting process.

The role of temperature in the smolting process is to control the rate of physiological changes which are responding to the photoperiod. At elevated temperatures these changes occur more quickly.

2.1.5 Olfactory imprinting

Olfactory imprinting is the process by which the smells of particular chemical stimuli are learned and remembered. It is a relatively rapid process which takes place during sensitive periods in juvenile (parr and smolt) life and especially during migratory movements. The precise timing and duration of the various stages of imprinting are not known but the final stage is known to take place during the migration of smolts to sea. Returning adult salmon subsequently use imprinted olfactory information to identify their home streams at spawning time.

Two theories exist to explain the chemical basis of the substances that allow returning salmon to distinguish their home stream from others. The first is that each river system may have its own unique “bouquet” derived from the geology and vegetation of the surrounding drainage basin, and the second is that juveniles within a particular stream system may release population-specific pheromones. These theories are not mutually exclusive, and it is likely that pheromones are one part of the stream odour to which the salmon imprints.

2.1.6 Initiation of smolt migration

Survival of smolts is particularly dependent upon the time when they enter the sea. Experiments on hatchery-reared Pacific salmon have shown that smolts emigrating during a fairly short time window show significantly higher return rates compared with smolts leaving earlier or later. There is also evidence, for example, that in certain rivers, a delay in the smolt run as a result of low flow conditions has resulted in reduced adult returns in Atlantic salmon. Timing of smolt migration is therefore of crucial importance and any factor, either natural or man-made, that alters it may affect survival.

The initiation of downstream migration of smolts is thought to be related to changes in water temperature, water flow and the development of a physiological requirement for the fish to move into sea water.

Fresh water discharge is considered to be one of the most important environmental cues initiating downstream movements of smolts after the physiological and morphological pre-adaptation during smolting. This is more evident in rivers that experience highly variable flows than in rivers such as chalk streams with more stable flows. Spates in certain rivers may not only act as an initiator of migratory behaviour but may also physically flush the fish downstream.

In many southern rivers, a general rule of thumb suggests that smolt migration tends to occur at temperatures above 10°C. However, in Scotland downstream movements from upper tributaries usually begin at much lower temperatures and it is possible that increased temperature is a less important stimulus than raised flows. A combination of an increase in temperature and river water discharge often results in the main smolt run in a river.

2.1.7 Smolt migration in fresh water

Much of the information on the timing and duration of the smolt migration has been derived from trapping and, more recently, telemetry studies and the tracking of individual fish.

Most smolt migration occurs between February and June depending upon the latitude of the river system. Smolt migration is predominantly nocturnal but on many rivers there are observations of movement during the day. This daytime movement may also be more common towards the end of the smolt run or under elevated flows. Nocturnal migration usually starts 1-2 hours after twilight and can continue throughout the hours of darkness. Migration represents an active behaviour pattern rather than passive displacement, and rates of movement can exceed 50km per day. Natural obstructions tend to cause little delay to downstream migrants, although groups of smolts may often be seen in the spring holding position in pools above obstructions during daylight hours.

2.1.8 Smolt migration through lakes

There is evidence to suggest that smolts having to pass through lakes during their seaward migration may experience problems in locating the lake outlet, especially if current velocity is very low. It is likely that fish from stocks that have to pass through lakes on their way from the nursery grounds to the sea may be adapted to this migratory pattern. Fish that are not similarly adapted may be delayed by the passage through almost stationary water and thus enter the sea at a time when conditions are less favourable for survival.

2.1.9 Smolt migration through estuaries

Tracking studies on one river in southern England showed that active migration through the estuary takes place predominantly at night but at all states of tide. Smolts reaching the saline limit at night tended to continue moving into the estuary; those reaching this point near dawn tended to hold position during the day, re-commencing their migration on the following night. As in fresh water, however, it is probable that migration also occurs during the day particularly towards the end of the smolt run and at times of increased fresh water flow. Adaptation for the saline environment occurs in the river, probably coinciding with, or just prior to, downstream migration. Movement from fresh to saltwater thus appears to require no period of adjustment. Residency within the estuary may vary with its length and topography and may differ between wild and hatchery-reared smolts. In shorter estuaries, passage is relatively rapid and may occur within a tidal cycle. Evidence suggests that migration is again the result of active swimming rather than passive tidal drift. Observations with hatchery-reared fish in extensive estuaries indicated distinct tidal rhythms of swimming speed, although this has not been shown in wild fish.

The estuarine and coastal phases of the smolt migration are thought to be a time of highest mortality, although nocturnal migration and migration at times when rivers are in spate may reduce the risks of predation. Little is known of the subsequent coastal movements of the smolts or of the high seas phase of migration, although they appear to leave coastal zones rapidly.

2.2 ADULTS

2.2.1 Timing of adult returns

The physiological processes associated with the onset of sexual maturity begin while the fish is still in the open ocean and these processes are controlled by both genetic and environmental factors. Surviving fish return to their home rivers after one or more sea winters, the proportions of fish returning at different sea ages varying between stocks of individual rivers. There is a tendency for males to mature earlier than females and thus return at a younger sea age.

Although spawning usually takes place between November and February, salmon return to rivers in Great Britain at all times of the year. However, there are usually peaks in the pattern of returns, in the spring and summer. The first peak consists entirely of salmon that have been at sea for two or more winters and tend to be larger fish, and the second mainly of one-sea-winter fish. In some rivers a few fish may return more than 12 months before they spawn.

2.2.2 Adult migration in coastal waters

Tagging studies and tracking of individual fish have shown that salmon returning to spawn make landfall at considerable distances from their home river. They then adopt a more or less directed migration pattern, often following the coastline quite closely. During this phase they appear to migrate independently of tidal flows or time of day.

As they move along the coast they adopt behaviour which helps them to detect the smell of their home river. This may involve swimming at a particular depth and making sorties close to or into estuaries. Salmon are often found in estuaries other than those to which they eventually return and some will even move well up into fresh water in the "wrong" river before eventually turning back. The number of fish which spawn in rivers other than their natal rivers is not known but the proportion is thought to be small.

2.2.3 Adult movements within estuaries

Fish have been seen to enter estuaries at all states of the tide but while in an estuary much of their movement may be passive, with the tidal currents. Some studies have shown fish making repeated movements in and out of estuaries over periods of days and even months. These movements may take the fish only a short distance beyond the estuary mouth or may extend the full length of the estuary. On some other rivers, salmon seem less likely to return to sea; having once committed themselves to the estuary, however, they may be more likely to hold position in the upper reaches of the estuary or lower reaches of the river. Thus the behaviour pattern of salmon is strongly influenced by the topography of the estuary and particularly by the availability of suitable holding areas. Salmon are able to make the transition from salt to fresh water very quickly, and there is no evidence that a period of acclimation at intermediate salinities is required.

Elevated temperatures in some cases above about 21°C appear to inhibit movements through the estuary. It has also been suggested that large differences between the sea and fresh water temperatures inhibit entry to rivers.

2.2.4 Adult movements in fresh water

Salmon usually move from the estuary into fresh water at night, although in elevated flow conditions they may also move during the day. Low river flows delay the movement of salmon past the tidal limit in most rivers.

Movements within the river tend to be strongly influenced by fresh water discharge, although the relative importance of discharge itself and other factors closely linked to it, such as turbidity and chemistry, are not known. Both low and very high flow may inhibit upstream movements.

The initial migration into fresh water will take some fish tens of kilometres upstream although others will stop quite close to the tidal limit. During the subsequent upstream movements, the fish travel predominantly at night and hold position during the day. Occasionally fish remain at the same location for several days before resuming upstream movements. When movements occur during the day, they are usually associated with increased river flow.

After this first phase of upstream migration, fish may stop at a particular location for weeks and even months and will show only limited upstream and downstream movements. Fish in such quiescent phases may be subjected to wide fluctuations in flow without changing location. Low temperatures reduce the ability of adult fish to negotiate major obstructions and as a result fish may hold position in pools below obstructions. It is known that salmon tend to avoid fast flowing water when temperatures are low.

Many fish will remain quiescent until they are ready to make their final migration to the spawning grounds in the autumn. However, some, particularly in larger rivers, will move up river in a series of steps, interspersed by quiescent periods. As the fish becomes physiologically ready to spawn in the autumn, it once again becomes responsive to environmental cues such as changes in flow. It then begins the final stage of its migration to look for spawning sites.

Salmon tend to be relatively easy to catch by rod and line while pausing during and for a period of days after the first phase of upstream movement, but become more difficult to catch during quiescent phases. They may then become easier to catch when they resume upstream movements prior to spawning. As a consequence of this, flow patterns supporting fish movements are very similar to those maximising angling catches. Fish rarely move long distances back downstream before spawning but where such downstream movements have been noted, they tend to be quite rapid.

2.2.5 Spawning location

In large rivers there is a tendency for fish returning early in the season to move greater distances upstream than fish returning later. There is evidence to suggest that a large proportion of adults return to the area of the river in which they originated. As the physiological readiness of fish to spawn increases they appear to be stimulated to move by smaller spates. However, elevated flows are important both for the entry of adults into spawning burns and for the subsequent movement to spawning sites. As result the full utilisation of head-water streams for spawning is dependent on flow, and condition of low flow during the spawning season may result in severe truncation of spawning distribution. The period of spawning is mainly between November and February although occasional observations of spawning activity have been observed outside these months.

Male fish may spawn with several females over a period of days and even weeks and may make extensive movements throughout the spawning area. In addition, males are able to detect the presence of females ready to spawn from considerable distances downstream and rapidly move up to join them.

2.2.6 Kelts

There are only very limited data on the post-spawning behaviour of salmon. However, tracking results suggest that females may move rapidly downstream into the main river, while males remain in the spawning area for long periods. Male salmon are more likely to die after spawning than females, although kelts may stay in the river for weeks or months reverting to a silver colour before moving out to sea.

Little is known about the factors controlling the survival of kelts on their downstream migration and once they return to the sea, although these are likely to be similar to some of the problems faced by smolts.

The proportion of any year's run of adult salmon returning to spawn for a second time is usually quite small (<5 per cent). However, there is evidence that it has been larger in the past and that it varies significantly between river systems.

2.3 WATER QUALITY

Good water quality is an essential requirement for the maintenance of a healthy salmon population. Salmon have the same basic water quality requirements at all stages of their life cycle, namely well oxygenated water, appropriate water temperature and pH, low levels of suspended solids and low concentrations of toxic chemicals. The national and European Community (EC) water quality standards for fresh water were listed in the Third Report. However, certain substances (e.g. heavy metals) have different effects in saline water and thus some different water quality standards are required for estuaries and coastal waters. Full lists of water quality standards are therefore provided in Appendix B.

2.4 DISEASES AND PARASITES

Smolts moving to sea and adults returning to spawn undergo major physiological changes in adapting to differences in salinity. This and the immunosuppressive and degenerative changes that occur during sexual maturation and following spawning can increase the potential susceptibility of the stock to many different infectious diseases and parasitic infestations. Although some fish pathogens are ubiquitous in the aquatic environment, the susceptibility of individual fish to infection will be a product of several factors. For example, minor skin abrasions may permit pathogens to establish infection on the skin, while wounds may allow invasion of deeper tissue. In addition, hatchery studies suggest that susceptibility to infection generally increases when fish are stressed. This may occur when there are sudden changes in water temperature, low levels of dissolved oxygen, poor water quality or overcrowding. Overcrowding, which can occur when fish congregate in pools, may also increase the risk of infection being transmitted among fish. Low levels of mortality from diseases may go undetected in wild populations and problems are generally only recognised when large numbers of fish are affected.

Certain named diseases are notifiable under the Diseases of Fish Acts 1937 and 1983 (Table 1). Although there are records of five of these occurring in farmed salmonids, only furunculosis, bacterial kidney disease (BKD) and infectious pancreatic necrosis (IPN) virus have been recorded in wild salmon in Great Britain.

Furunculosis has been recorded in returning adult salmon since the early part of this century and some mortalities of wild smolts have been attributed to this disease. However, it is not known if it has a significant effect on wild smolt numbers and its main impact is probably on kelt survival. It is, however, normal for a high proportion of salmon to die after spawning, and in some cases the infection may not be the primary cause of death.

BKD has been recorded in returning adult salmon since the 1930s but there have been no reports of the disease in wild salmonids in recent years. To date, BKD has not been recorded in wild smolts.

IPN is the only notifiable viral infection which has been recorded in wild salmon in Great Britain. Low incidences of infection have been recorded in wild smolts since the mid 1970's, but the current incidence of infection and its impact on stocks is not known. Although adult salmon may carry the virus and may transmit it to their progeny via infected ova, clinical signs of disease have not been detected in adult fish in the riverine environment.

TABLE 1: Notifiable diseases in Britain under the Diseases of Fish Acts 1937 and 1983

Disease	Causative Agent	Records of occurrence in Great Britain		
		Farmed salmonids	Wild salmon parr/smolts	Wild adult salmon
Bacterial diseases				
Furunculosis **(a)**	Aeromonas salmonicida	+	+	+
Bacterial kidney disease	Renibacterium salmoninarum	+	–	+
Enteric redmouth disease **(b)**	Yersinia ruckeri	+	–	–
Viral diseases				
Infectious pancreatic necrosis (IPN)	Birnavirus	+	+ (c)	+ (c)
Viral haemorrhagic septicaemia (VHS)	Rhabdovirus	–	–	–
Infectious haematopoietic necrosis (IHN)	Rhabdovirus	–	–	–
Spring viraemia of carp (SVC)	Rhabdovirus	–	–	–
Infectious salmon anaemia (ISA)	Unknown	–	–	–
Parasitic diseases				
Whirling disease	Myxobolus cerebralis	+	–	–
Gyrodactyliasis	Gyrodactylus salaris	–	–	–

(a) notifiable only in salmon
(b) notifiable in Scotland only
(c) causative agent isolated

The descriptive term Ulcerative Dermal Necrosis (UDN) has been applied to the clinical signs of fish suffering from a disease of unknown aetiology which caused major losses of adult salmon in many rivers in the 1960s and 1970s; very few juvenile fish were observed to be affected. It is widely believed that the same disease may have been responsible for similar heavy mortalities around the end of the last century. UDN was designated a notifiable disease in 1974, but its notifiable status was revoked in 1984.

Smolts and adults may be affected by other non-notifiable diseases. Some of these are restricted to fresh water while others only occur after entry into sea water. An example of the former is the fungal infection of the skin caused by *Saprolegnia sp.* which is probably the most commonly seen infection in wild fish. Such infections are common in fresh water but do not persist after entry into the sea. Fungal infections often begin on damaged areas of skin and may cause only minor physical damage, or may spread to cover large areas of the body including the gills in which condition the fish may be very visible. If the infection is extensive, if it becomes invasive or if secondary bacterial infection occurs, it is likely to be lethal.

Infestations by sea lice *(Caligus elongatus* and *Lepeophtheirus salmonis)* occur only in sea water. They have been a serious problem in salmon farms, and there have been reports of heavy infestations on wild sea trout in recent years. However, as yet there is no evidence that these parasites are a serious problem in wild salmon.

2.5 PREDATION

2.5.1 Predation on smolts

Predation of smolts during the fresh water and estuarine phases of the migration is well documented although little is understood of predators or predation pressures during the subsequent marine stage of the life cycle. The main predators of smolts are birds, other fish, otters and mink.

The main bird predators are considered to be cormorants, goosanders, mergansers and to a lesser extent shags, red throated divers, herons, gulls and terns. Although the majority of the smolt migration is nocturnal, movement and shoaling during the daylight hours may make them susceptible to predation although shoaling itself is a defence against predation. Levels of predation by different species will vary on a regional basis, but the following data indicate the possible scale of the losses.

In 1986, losses to goosanders and mergansers in the North Esk were estimated at between 10-25 per cent of the total smolt run. Between 21000-50000 smolts have been estimated to have been lost to goosanders in the Tywi catchment. These estimated losses must be treated with caution because of inadequate knowledge of the composition and population densities of fish stocks, smolt production, other causes of mortality and composition of the diet of goosanders in the Tywi catchment.

Predation losses to cormorants may vary from being insignificant in some rivers to 63-76 per cent of the run of wild smolts on the River Bush. Cormorants feed principally in the sea and in estuaries although there is increasing evidence that river sites and fresh water habitats are now being utilised.

Herons are known to prey on smolts but their impact on numbers is probably quite small because they tend to be territorially distributed and are restricted to shallow water. Predation by other birds such as gulls and terns can be described as opportunistic rather than specifically targeted.

Predation of smolts by fish species during the river stage of the migration is restricted mainly to pike, perch, trout (both brown and migratory trout), eels, and in certain areas, rainbow trout that have escaped from fish farms or have been deliberately stocked. The extent of predation will vary regionally and be related to the relative numbers of the species present. There are records of predation in the estuarine and marine environments by saithe, cod, pollack, bass and eels. Evidence suggests that some marine predators such as cod and saithe congregate in the estuaries during the smolt run and smolt mortality due to cod may be as high as 25 per cent. However, other studies on cod have not been able to show evidence of smolt predation.

Mammalian predators of smolts in fresh water include the otter and mink, although there are no reliable figures on rates of predation or its effects.

2.5.2 Predation on adults

The main predators on returning adult salmon, other than man, are common and grey seals and small cetaceans. These take fish in coastal waters but much of the recorded information refers to the removal of fish from nets. Seals also take salmon within the confines of certain estuaries and the lower reaches of rivers.

In some rivers mink and otters may also take salmon.

3. HUMAN ACTIVITIES AFFECTING EMIGRATING SMOLTS AND RETURNING ADULTS

3.1 INTRODUCTION

The Committee considered the human activities which affect salmon smolts and adults in their migrations in fresh water to and from the sea. Information on these activities was obtained from a number of experts, and the list is similar to but shorter than that in the Third Report because in this report only migration is considered. Smolt emigration takes place over quite a short time, but the distance travelled may be virtually the entire length of our longest river and during that time smolts are exposed to the range of activities which we have listed. Because the life stage in fresh water of returning adults and kelts is generally longer, they are subject to a wider range of human activities in their progression upstream.

The human activities covered in this section of the report are not placed in order of importance, but are set out in a sequence which recognises the stages of migration and the potential in each one for causing damage to the stock.

Again, as in our Third Report, we have adopted a common format for each of the factors so that these can readily be related one to another and to those which were previously considered.

3.2 ACTIVITIES AFFECTING WATER QUALITY

3.2.1 Definition and description

The wastes arising as a consequence of human activities which enter rivers and estuaries can be categorised as follows:

- oxygen demanding wastes e.g. domestic sewage, farm slurries, silage liquors, and effluents from fish farms and industry;
- plant nutrients e.g. nitrogen and phosphorus from domestic sewage, fish farms, industry and agricultural drainage;
- toxic substances including ammonia, heavy metals, insecticides, herbicides and other organic compounds such as disinfectants, anti-microbial drugs, growth promoting substances;
- silts, sludges, coal and china-clay washings, and sediments from land erosion and dredging activities;
- oils; and
- hot water from industry and power stations.

Any wastes entering rivers, except those which are biodegraded, oxidised or absorbed onto sediments, become inputs to estuaries. All the wastes categorised above can cause serious deterioration in the quality of the waters to which they are discharged and thereby affect the well-being and survival of migrating smolts and returning adults. When deciding on the amount of any waste which is to be permitted to be discharged to a river or estuary the regulating authorities have regard for:

- the uses made of the receiving water;
- the standards required to protect those uses;
- the nature, quantity, concentration and rate of discharge of the waste;
- the rate of flow or amount of dilution afforded by the receiving waters;
- the nature and quantities of the other wastes discharged to the receiving waters; and
- the fate of the waste in the receiving water.

Acid deposition, although not involving direct discharges to rivers, does have serious effects on the receiving waters. Long term deposition of sulphur and nitrogen compounds arising from the burning of fossil fuels can increase the acidity of catchments onto which they fall. The process of acidification is exacerbated by coniferous afforestation.

The processes involved in the long term acidification of streams and lakes were described in our Third Report. The acid conditions produced may be directly toxic to salmon or may increase the solubility of metals such as aluminium which becomes highly toxic to fish at pH levels of 5-6. Most fish mortalities caused by acidification result from episodic decreases in pH. The acidic flushes are most common during periods of heavy rain and rapid run-off and may therefore occur at the time of smolt migration and upstream migration of the returning adults. Smolt migration in some northern rivers is likely to coincide with the spring thaw of snow which may have a low pH because of acidic deposition during the winter months.

All stages of the salmon's life-cycle in fresh water have similar water quality requirements and therefore the effects of such wastes on the survival of migrating smolts and returning adults are similar to those of juvenile fish and are described in the Third Report.

3.2.2 Scope of the problem

The Environment Committee of the House of Commons in its third report, published in May 1987, reviewed the pollution of rivers and estuaries. The report provides a comprehensive review of the state of rivers and estuaries in England and Wales, and of the nature of the water pollution problems affecting them.

Available evidence (Table 2) suggests that the water quality in rivers and estuaries in the United Kingdom is generally high. Some 88 per cent of the length of rivers included in the River Quality Survey of England and Wales is in quality Classes 1 and 2, the highest categories. In Scotland 99 per cent of the length is in these categories.

About 90 per cent of the length of estuaries included in the survey in England and Wales is in quality Classes A and B, the highest categories. In Scotland some 95 per cent is in these categories.

Although the overall situation reflected by these surveys appears satisfactory, concern must be expressed about the decline in quality between 1980 and 1990 in England and Wales of some 1400km of the length of rivers and some 60km of estuaries in the highest water quality class. According to the National Rivers Authority (NRA) the downgrading is due to the availability of more accurate data, the effects of two hot dry summers and discharges from sewage works, industry and farms. The effects of these discharges on receiving waters were discussed in our previous report. The improvement in quality in Scottish Rivers between 1980 and 1990 where more than 900km has been added to the Class 1 category is welcomed, and the work of the River Purification Boards (RPBs) in achieving this properly merits tribute.

Concern has been expressed that the classification systems presently used are too subjective and are not particularly sensitive to those changes in water quality which affect wildlife particularly in the high quality rivers. The systems of classification are being reviewed by the NRA and RPBs. The Department of the Environment (DOE) has issued proposals on water quality objectives for public consultation.

TABLE 2(i): River quality survey – England and Wales

(a) Freshwater Rivers/Canals*

		1980		1985		1990	
	Class	**Km**	**%**	**Km**	**%**	**Km**	**%**
1A	(Good)	13830	34	13470	33	12408	29
1B	(Good)	14220	35	13990	34	14536	34
2	(Fair)	8670	21	9730	24	10750	25
3	(Poor)	3260	8	3560	9	4022	9
4	(Bad)	640	2	650	2	662	2
	Total	40620		41400		42378	

(b) Estuaries*

		1980		1985		1990	
	Class	**Km**	**%**	**Km**	**%**	**Km**	**%**
A	(Good)	1870	68	1860	68	1805	66
B	(Fair)	620	23	650	24	655	24
C	(Poor)	140	5	130	5	178	7
D	(Bad)	110	4	90	3	84	3
	Total	2740		2730		2722	

*** Source: The Quality of Rivers, Canals and Estuaries in England and Wales. Report of the 1990 survey. NRA Water Quality Series No4 December 1991.**

TABLE 2(ii): River quality survey – Scotland

(a) Rivers, Lochs and Canals (Freshwater)*

	Class	1980* Km	%	1985* Km	%	1990*[(1)] Km	%
1	(Good)	45352	95	45695	96	46310	97
2	(Fair)	2035	4	1723	4	1199	3
3	(Poor)	260	<1	272	<1	238	<1
4	(Bad)	163	<1	132	<1	71	<1
	Total	47810	100	47822	100	47818	100

Source:* Water Quality Survey of Scotland 1990.
(1) 1990 data for same survey area as 1980 and 1985

(b) Estuaries

	Class	1980 Km	%	1985 Km	%	1990* Km	%
A	(Good)			315	66	293	64
B	(Fair)			112	24	144	31
C	(Poor)			17	4	22	5
D	(Bad)			28	6	2	<1
	Total			472	100	461	100

No estuaries designated in Tweed RPB area.
*** Source: Water Quality Survey of Scotland 1990.**
Source: RPB Indicators 1990

In assessing the performance of sewage treatment works it was found that some 14 per cent of effluents from those works in England and Wales which were sampled failed to comply with their discharge consents. In Scotland there is a slightly different approach to sampling and thus figures for failure are not comparable but in 1990 40 per cent of the plants failed on one or more occasions. The Water Services Plcs in England and Wales and the Local Authorities in Scotland are attempting to achieve compliance by the end of 1992.

During 1990 the NRA recorded 28,143 incidents 658 of which were regarded as major. In 1991 there were 29,372 reported incidents of which 22,469 were substantiated and 386 regarded as major. A major incident is described as one which has the following effects and includes all cases where legal proceedings are instituted:

- potential or actual persistent effect on water quality or aquatic life;
- closure of potable water, industrial or agricultural abstraction necessary;
- extensive fish kill;
- excessive breaches of consent conditions;
- extensive remedial measures necessary; and
- major effect on amenity value.

Discharges of sewage and sewage effluent, industrial effluent, farm wastes and oils and related products accounted for most of the major incidents reported. Details are presented in Table 3.

In Scotland 3208 incidents of pollution were reported to the RPBs in 1990. Of these 3208 incidents sewage accounted for 880, farm wastes 567, industrial discharges 758 and other issues 1003.

TABLE 3: Major incidents in England and Wales – Numbers Caused by Type

Cause	1990 (Reported)	1991 (Substantiated)
Sewage	131	96
Industry	109	83
Farming	239	99
Oil	87	69
Other	92	39
Total	658	386

Source: "Water Pollution Incidents in England and Wales – 1991". NRA 1992

Whilst the discharges of wastes to rivers and estuaries may not produce conditions which are immediately lethal to fish, the conditions may be such as to have chronic effects e.g. the growth rate and spawning success of the fish may be adversely affected. The discharges of wastes and their effect on the receiving waters may produce a barrier to the migration of smolts and adults. Waters of unsuitable oxygen content, temperature, ammonia, suspended matter and toxic metal content have all been reported as forming such barriers.

3.2.3 Possible solutions

The remedial measures recommended in our Third Report namely the establishment of riparian buffer zones and integrated management of catchments to protect and enhance juvenile salmon production will offer similar protection to migrating smolts and returning adults. The Committee therefore wish to emphasise the value of adopting such measures and continue to press for their application. In this respect the Committee is pleased to see that the NRA has established a programme of catchment management plans (two such plans namely the Ogwr catchment management plan and the Louth coastal catchment management plan have been issued for public consultation).

The flow of fresh water has a very significant influence on the distribution and concentration of dissolved oxygen and pollutants in individual estuaries. Efforts should be directed towards determining prescribed minimum flows of fresh water which will prevent adverse water quality conditions developing in estuaries as well as to seeking to reduce the discharge of pollutants.

We welcome the initiative of the NRA and DOE in publishing proposals for water quality objectives because we consider that such objectives and standards should lead to the formulation of appropriate emission standards to be applied to discharges. The regulatory authorities should police the discharges regularly and rigorously enforce compliance with the prescribed standards. Research is required to establish an appropriate standard for ammonia in estuaries. The Scottish Office Environment Department is exploring with the RPBs what arrangements would be appropriate for formal water quality objectives in Scotland.

The regulatory authorities should require all dischargers to provide means whereby accidental discharges of polluting matter are minimised. The recently introduced measures to control the storage of agricultural fuel oil, silage effluents and slurries will assist in this process.

Many estuaries still receive discharges of untreated or inadequately treated sewage and organic wastes from industries. The recently adopted EC Directive on Urban Waste Water Treatment which sets minimum standards for sewage treatment will ensure the ending of this practice with consequent improvement in estuarine water quality. The Directive requires that discharges to estuaries from municipalities with a population equivalent of 2000 or more are collected and given secondary treatment except in those waters where specified criteria are satisfied allowing the use of primary treatment only (less sensitive areas). If, however, the estuary is eutrophic (nutrient-rich) with blooms of algae, or might become eutrophic in the near future, then for discharges with a population equivalent of 10,000 or more treatment more stringent than secondary treatment will be required (sensitive areas). The Directive also requires that significant discharges of biodegradable wastes from specified industrial sectors shall comply with requirements appropriate to the nature of the industry concerned.

3.3 ABSTRACTION

3.3.1 Definition and description

Water is abstracted from rivers for a wide range of uses including public water supply, industrial needs, cooling purposes, hydro-electric generation (considered in detail in Section 3.4), irrigation and fish farming (considered in detail in Section 3.6). In some cases the water is returned a short distance downstream e.g. fish farming, while in other cases it is effectively lost to the river, although some may be indirectly returned e.g. via sewage treatment works.

Abstraction can affect salmon smolts and adults in two ways:

- depletion of flows may affect migration and even survival downstream; and
- smolts (and kelts) may be entrained with the abstracted flow or held against intake screens.

3.3.2 Scope of the problem

Water abstraction is a widespread practice, with hardly a river in Great Britain entirely unaffected.

The NRA issues over 14,000 licences for abstraction from non-tidal surface waters in England and Wales, and more are being added as previously-exempt abstractions are being issued with Licences of Entitlement under the terms of the Water Resources Act 1991. Many of these are for small volumes but of the order of 500 are for volumes in excess of 10 Ml/day. The total volume of abstraction covered by these licences is of the order of 38,000 Ml/d. By no means all the licensed volumes are actually abstracted throughout the year – typically an uptake of about 50 per cent to 60 per cent occurs as an annual average. The approximate breakdown by use of the water actually abstracted (both surface water and ground water) is shown in Table 4. In addition, there are many very large abstractions from estuaries, mainly for power station cooling.

TABLE 4: Allocation of abstracted water, England and Wales, 1989.

Utilization		Approximate %
Public Water Supply		
Unaccounted for		14
Non-potable		2
Potable: WC	12	
Bath/Shower	6	
Clothes Wash	5	
Outside	1	
Misc.	13	
Total potable		37*
Total Public Water Supply		**53**
Private Water Supply		
Electricity Supply Industry		35
Other industry		11
Agriculture		1
Total Private water supply		**47**
Total		**100**

* **Approx. 9% metered, 28% un-metered.**
\# **Fish farms producing for human consumption excluded – except from licensing requirement.**

Sources: Waterfacts 1990 (Water Services Association).
Digest of Environmental Protection and Water Statistics 1989 (DOE).

In Scotland the right to abstract water from surface and underground sources is generally founded in common law. Abstraction of water for public water supplies and for hydro-electric development is controlled by the Water (Scotland) Act 1980 and the Electricity Act 1989 respectively. The promoters of a public water supply or a significant hydro-electric development must consult statutory bodies and seek an Order which is open to public objection. In the past the water compensation provisions in such Orders have in some cases proved inadequate to safeguard salmon stocks in the affected waters. With the passing of the Natural Heritage (Scotland) Act 1991, Purification Boards will be able to apply to the Secretary of State for a Control Order for the purpose of licensing irrigation abstractions.

It is well established that upstream migration of adult salmon is stimulated by elevated flows following rain or snow melt, though both water quantity and chemistry appear to be implicated. Releases of stored water from reservoirs have often been less effective than equivalent natural freshets in this respect. Fish are less likely to migrate on normal river flows, but the total number of fish migrating under such flows may be significant because these conditions occur for a greater proportion of the time. Many fewer fish move at low flows. While small abstractions have little impact on fish movement, large takes or the cumulative effect of several medium takes may remove a major part of the flow. Hydro-electric diversions may be particularly thirsty in this respect, but abstraction for water supply can be significant especially on smaller rivers. Fish farms and other temporary abstractions can leave a depleted section of river that may be a severe deterrent to movement or may even be totally impassable. While operating rules (licence conditions) may rightly protect very low flows (e.g.. no abstraction below Q95 flows), taking a significant proportion of somewhat higher flows, including minor freshets, may have a significant effect on fish movements. For example, two licensed abstractions on the River Tavy representing a total loss to the river (ie. none returned) can remove over 200 Ml/d from a natural flow of 450 Ml/d. Such a natural flow is often associated with significant movements of salmon, being over six times the Q95 flow.

Smolt emigration is also greatly enhanced by elevated flows, but evidence from several studies shows that fish will emigrate even in the absence of freshets. However, such emigration is delayed and this can have an impact on marine survival. Thus flow depletion by abstraction can also have an impact on smolt migration and possibly survival.

Section 14 of the Salmon and Freshwater Fisheries Act 1975 requires, with certain exceptions, that the proprietor of any undertaking in England and Wales taking water via an artificial channel for the purposes of a water or canal undertaking, or for developing water power, shall install Ministry-approved gratings to prevent the passage of migratory fish. This legislative provision appears to have been virtually ignored, as MAFF records indicate the existence of only seven such screens, all approved more than thirty years ago under the 1923 Act. Few NRA licences stipulate any requirement for intake screening, and no record exists of the numbers of intakes that are in fact screened. In any event, many screens are unsatisfactory in design, siting and state of repair. The NRA may also install gratings on intakes exempt from the requirement for the proprietor to close under Section 14, but it is then responsible for their upkeep and the effectiveness of their operation. Very few such gratings have been installed. In Scotland, Schedule G of the Salmon Fisheries (Scotland) Act 1868 requires the owners of mill dams only to maintain adequate screens at lade intake to preclude the entrance of adult salmon. This schedule is outdated for it contains no requirement to provide smolt screens. The Salmon Act 1986 contains powers to make provisions for safeguarding both migrating adult salmon and smolts but no regulations have been made.

A further, and often unrecognised, problem associated with abstraction is the transfer of water from one catchment to another. In some cases all flows, except extreme floods, are transferred to another part of the system, which is seriously detrimental to the depleted rivers and appears to provide little benefit to the rivers which have an increased flow. The examples of transfer between catchments which occur as a result of hydro-electric projects in Scotland are usually near the headwaters and cause depletion in flows which impact on both downstream and upstream migration.

3.3.3 Possible solutions

Depletion of flows

Several studies of salmon migration throughout the UK using radio tracking and electronic fish counters are providing invaluable data concerning the relationship between fish movement and river flow, and other environmental variables. This information properly interpreted will allow development of appropriate operating rules for abstraction, including protection of very low flows, and of flows and events associated with significant migrations. Possibilities include "sparing" of minor spates, and daytime only abstraction as appropriate.

From the studies so far conducted it is apparent that river systems vary considerably with respect to critical factors, including river flow, for salmon migration. Care must therefore be exercised when using information about one river when preparing a scheme for another river, and for major projects a detailed Environmental Impact Assessment, including field observations, is essential and should be mandatory.

Fish drawn into intakes

Recent advances in the design and installation of intake screens mean that it is now relatively easy to render most intakes harmless to smolts and kelts. These advances include not only physical screens that allow ready avoidance by fish, but also behavioural deflection systems that encourage fish to remain away from the influence of the intake. A review of screening requirements and technology currently being undertaken on behalf of the NRA is considered timely and dissemination of the findings is recommended. Widespread application of the best available technology is strongly recommended. While it is sometimes costly to install and maintain effective fish protection mechanisms, the destruction of salmon smolts at intakes is totally unacceptable. Although the mechanism exists in England and Wales to require installation of effective screens on new abstractions, the situation regarding existing abstractions is complex and confused. A review of the relevant legislative arrangements is recommended, as they appear totally inadequate. In Scotland new regulations on fish passes and screens for all stages of migrating salmon are urgently required and are long overdue.

3.4 DAMS AND WEIRS

3.4.1 Definition and description

Salmon rivers, often with large flows and steep gradients, have been particularly attractive for the purposes of generating power. Problems arise for fish from five sources:

- obstruction to upstream migration is often not adequately alleviated by fish passes;
- downstream migrants may be entrained with the flow through the plant and be damaged passing through the turbines or water wheels;
- upstream migrants may be attracted to tailwater flows;

- depletion of flows between the abstraction point and the return may discourage migration; this is covered under Section 3.3; and
- passage of smolts through impoundments above dams may be delayed; this is covered under Section 2.1.8.

3.4.2 Scope of the problem

Various Acts of Parliament have set out the requirements for fish passes to be incorporated in dams or weirs to facilitate the passage of fish. Many obstructions in salmon rivers now incorporate fish passes, but in some rivers where there were no salmon because of high levels of pollution, it was not deemed necessary to provide passes when dams were built. The water quality in many of these rivers has now improved to such an extent that salmon are once more able to migrate upstream, but are restricted in access because of the dams. The problem is often further compounded by the difficulty in tracing ownership of, and responsibility for, such dams which may have been built to provide water to a mill which has gone out of business long ago. In these cases there may be no-one who can be identified to bear the cost of the construction of a pass.

There is considerable evidence of poor operation of some fish passes. Some are badly sited; some appear to have inadequate flows, while others are unable to cope with variations in river flows; some are in locations which attract poaching; and others fail to attract fish. Thus, while fish passes have been installed in many man-made obstructions, their effectiveness in providing for the unhindered migration of salmon has often been shown to be unsatisfactory.

Many of the large Scottish river systems are extensively harnessed for hydro-power, while others have water exported to feed schemes in neighbouring catchments. River systems affected include the Tay, Spey, Conon, Awe, Shin, Ness, and Beauly, with numerous smaller schemes on a wide range of rivers. Following the setting of an attractively high premium tariff rate, a number of new private generating schemes using run of the river heads have been installed in Scotland and many others are currently under consideration. Although some of these schemes must meet the outdated provisions of Schedule G of the 1868 Act, new regulations on fish passes and screens are required immediately to protect migrating smolts and adults. In England and Wales, there are minor schemes on most salmon rivers, utilising the head of often just a few feet created by weirs. It is not possible to enumerate the schemes as most NRA regions are unable to identify hydro-electric abstractions among the many thousands of abstraction licences they issue; further, many schemes (for domestic use) were exempt from licensing until 1989, and Licences of Entitlement for such schemes are still being issued. In Wales, however, the total volume of licensed abstractions from fresh waters for hydro-electric power is 13,680 Ml/d, which exceeds all other abstractions combined.

Fish passing through turbines are at risk from mechanical damage by collision with fixed or moving parts, pressure changes and shear (turbulence). For low-head stations it is likely that mechanical damage is the predominant risk. The risk varies with the equipment type and operating conditions, but field observations and theoretical modelling both suggest mortality of smolts of the order of 3-20 per cent for a wide range of installations (Table 5). Mortality of larger fish (e.g. kelts) is likely to be very much higher and may even be total.

TABLE 5: Summary of results of studies on juvenile salmon mortality in axial flow turbines (Kaplan and Bulb)

	Dam	Head m	Rpm	Runner D(i)	V(ii)	Fish	Mortality %
1	Foster	30.8	257	2.54	34.2	Chinook Salmon 12 cm	11.2
2	Bonneville	19.5	75	7.6	29.8	Chinook Salmon 8-12 cm	11-15
3	Essex	8.8	128.6	3.7	24.9	Atlantic Salmon Smolts	2 (A)
4	Ice Harbour					Coho Salmon 1+	10-19
5	Tobique Narrows	22.9	225	2.64	31.1	Atlantic Salmon Smolts	12-14 (B)
6	T W Sullivan	12.5	240			Steelhead Trout + Chinook Salmon	7.7-10.5
7	Big Cliff	30	163.6	3.76	32.2	Chinook Salmon 10cm	4.5-2
8	Big Cliff	30	163.6	3.76	32.2	Chinook Salmon fingerlings 1+	9-21 (C)
9	Rock Island	12	85.7	7.0	31.4	Coho Salmon (c) + Steelhead Trout(s)	7(c), 3.5(s)
10	Waterville	18		3.07		Chinook Salmon	13
11	Waterville	18		3.07		Rainbow fingerlings	2.5-7.5
12	Gold Hill	7				Chinook Salmon + Steelhead Trout	8.1
13	Mc Nary	26	85.7	7.11	32.6	Chinook Salmon	11
14	Tusket	8	225	2.37	27.9	Atlantic Salmon Smolts	11.5 (D)
15	Holyoke	15.5	129	4.32	29.2	Atlantic Salmon Smolts	12.8-13.1
16	Foster	30.8	257	2.54	34.2	Chinook Salmon	6.1
17	Bonneville	19.5	75	7.6	29.8	Chinook Salmon	3.9
18	Wells	20				Steelhead Trout	16
19	Invergarry	53.4				Atlantic Salmon Smolts	13.2-19 (E)

Notes. (i) D = runner diameter, m (ii) V = peripheral velocity, m/sec. (A) Numbers small – one fish killed out of 50. (B) 16-24 including delayed mortality up to 8 days. (C) Higher figure at unusual operating condition. (D) 16.5 including delayed mortality up to 7 days. (E) Figures for 50% load and above.

Source: Solomon D J 1988
Fish Passage Through Tidal Energy Barrages Published by Dept of Energy Contractors Report ETSU TID 4056

It has also been observed at a number of N. American hydro-electric stations that predation of temporarily disorientated smolts in the tailrace, and other delayed mortality associated with turbine passage may exceed the losses which occur within the machinery.

The screening of intakes is discussed in Section 3.3. Many mechanical screens can cause significant damage to fish which come into contact with them. Siting is critical too, with a requirement for an easily accessed safe alternative for passage. Accepting that smolts had difficulty in finding safe passage through hydro installations by smolt chutes and fish passes, the North of Scotland Hydro Electric Board (now Scottish Hydro Electric PLC), adopted a policy of not attempting to prevent passage of smolts through stations of less than 30 metres head, on the grounds that losses and delay were less than those caused by screening; kelt screens have been fitted on all stations.

Adult salmon migrating upstream may be attracted to station tailraces, representing often greater and faster flow than the main river. At best this may cause delay to migration; if fish are able to overhaul the current and if screens are not fitted, fish may swim into the plane of the turbine runner and be killed. Siting of screens is important; they should be located so that the appropriate alternative route, e.g. the main channel or fish pass is readily located with minimal delay.

The formation of long lakes by the construction of dams is likely to alter the pattern of smolt migration, as the smolts must negotiate the length of the lake rather than utilising the flow of the river. This slows down their progress and may result in their entry to salt water later than the main migration, resulting in lower survival.

3.4.3 Possible solutions

A review of fish pass design and performance is now required because of the need to overcome complex problems in the design of future passes, and in the improvement of existing passes. In addition there is a need to build passes at some of the more difficult natural obstructions which may require a new approach to pass design.

There is a requirement for assessment of the losses of smolts and problems for upstream migrating adults due to power generating activity on individual rivers, followed by application of ameliorating action where appropriate. Measures could include shutting down operations at critical periods, e.g. at night in April, to protect smolts, and installation of effective screens or deterrent equipment.

The technology of excluding fish from intakes and diverting them efficiently to safe alternative routes has developed significantly in recent years – intake screening is discussed further in Section 3.3. Excluding fish from outfalls is relatively straightforward, using physical bar screens, electric screens or other barriers. The appropriate recommendations regarding screening in Section 3.3 apply here. New regulations are required to ensure that all hydro-electric intakes are screened effectively.

The assumption that losses of smolts associated with passage through low-head generating stations is low and can be overlooked is neither accepted nor acceptable without further full evaluation of both immediate and delayed mortality.

3.5 TIDAL BARRAGES

3.5.1 Definition and description

Tidal barrages are generally built for one or more of three purposes:

- to create a difference of water level from which power can be generated;
- to enhance the amenity of the area upstream by controlling water level; and
- to exclude very high tides and provide protection upstream against flooding.

Where a tidal barrage is built, it will affect all smolts leaving the river and all adults returning. Fish may be affected by:

- delay or obstruction to migration past the barrier or through the impoundment above the barrage;
- damage caused by passage through turbines; or
- the effects of reduced water quality above or below the barrage.

3.5.2 Scope of the problem

The barrages which are built for power generation raise many problems such as fish passage through turbines, mechanical damage due to collisions, pressure changes within turbines and hydraulic shear. These problems are compounded by the range of conditions under which the turbines have to operate to cater for the varying head within the tidal cycle. They will also be greatly increased where the turbines are used for pumping water during flood tides.

Mechanical damage will occur with some fish due to collision with the fixed and, more particularly, with the moving, parts of turbines. While mortality rates are likely to be limited with smolts, they could be very severe with adult fish. Even with optimal efficiency there are likely to be areas of harmful low pressure within a turbine, and at lower efficiency, which is associated with head variation these areas will increase in both severity and extent. In this way the proportion of fish likely to be harmed will increase. This is also the case with hydraulic shear, where zones within the turbines, which could be harmful, will increase in extent with lower efficiencies.

The passage of fish through turbines is clearly a problem which may be unacceptable because of the mechanical damage which occurs. The problem is exacerbated by the likelihood that fish may make a number of passages through the barrage before continuing with their migration.

Amenity barrages are less likely to cause physical damage to salmon, simply because they do not incorporate turbines, while flood protection barriers will be used very infrequently and are unlikely to delay migration for more than a few tides.

The passage of fish through barriers is dependent on the provision of effective fish passes, but very little is known about the behaviour of adult fish entering fresh water from the sea from which to establish the parameters of pass design. Tidal flow reversals and the natural movement of the fish will accentuate the problem of ensuring the provision of proper facilities for the fish in the situation where behaviour patterns are changing from those appropriate for the marine environment to those appropriate to the river.

The creation of large bodies of brackish water, or the formation of long lakes in previous tidal estuaries will produce, for migrating salmon, conditions about which little is known as these have not been the subject of study. The evidence from other examples of the formation of new lakes in river systems suggests that the construction of tidal barrages may be detrimental to the migration process, particularly in relation to the downstream movement of smolts. There are fears that the construction of barrages will cause a reduction of water quality because of the reduction of water flow into and out of an estuary. The construction of a barrage will raise concerns about water quality. Oxygen content, turbidity, concentration of pollutants and sedimentation upstream and downstream of the barrage will all change. The impoundment of nutrient rich (eutrophic) water together with its increased transparency, and, under conditions of low fresh water flow, a longer period of retention could create conditions suitable for excessive growths of algae, including possible blooms of potentially toxic blue-green algae.

If a barrage can be located at a point where it will exclude pollutants there is the possibility of improving the water quality inside a barrage so that it provides a positive benefit. Tidal barrages can be acceptable only if the effluent treatment upstream is of a sufficiently high standard.

3.5.3 Possible solutions

The need to exclude fish from turbines is paramount and systems of screening or diversion will be necessary. These screens will have to adopt the standards used for screening turbines in more conventional hydro-power locations and be located in both the upstream and downstream intakes to the turbines.

There is a requirement for research into a range of environmental issues, including the behaviour of fish at tidal barrages. This would cover aspects of migration and movements, vertical distribution of fish in the water, and fish reaction to light or sound barriers which might be used instead of physical screens. Research is also needed into the behaviour of smolts and adults in long impoundments containing brackish water.

3.6 FISH FARMING

3.6.1 Definition and description

Many fresh and sheltered tidal waters are being used for the intensive farming of salmonids.

Problems for emigrating smolts and returning adults may arise from:

- local changes in flow regime;

- reductions in water quality;
- entrainment in fish farm intakes;
- the transmission of diseases and parasites;
- the attraction of migrating fish to farm installations; and
- escape of farmed fish and their entry into wild population (possible genetic interactions are not covered in this report).

3.6.2 Scope of the problem

The farming of salmonids has expanded substantially over the last two decades. In 1990, 1,000 tonnes of Atlantic salmon smolts and some 15,000 tonnes of rainbow trout were produced in fresh water in the UK. Approximately 12 million salmon smolts were reared in freshwater tanks and a further 13 million in cages moored in freshwater lochs. The water for tank rearing is normally obtained by diversion or pumping from a watercourse but, at a few sites, groundwater is the primary source. Trout are reared in freshwater ponds or raceways, freshwater tanks, or in cages moored in fresh or salt water.

Intakes to fish farms are potential traps for smolts and kelts although, as indicated elsewhere in the report (Section 3.3), the technology exists to apply adequate protection by screening. However there is no requirement in the legislation for fish farms to place gratings on their intakes in England and Wales and although the NRA may install screens, it is then responsible for their upkeep and operation. The problem is equally serious in Scotland. Abstraction may also obstruct the movements of migrant salmon by reducing river flows between intake and outflow points. The amount of water abstracted may also be affected by the requirement to meet discharge consents.

Although water of good quality is essential for the maintenance of cultured fish, the extent to which fish farm effluents influence the behaviour of migrating smolts is not known. If such influences occur, they could be caused either directly from changes in BOD, pheromone or other complex organic outputs, or indirectly via changes to the river or lake bed.

The use of disinfectants, pesticides and antimicrobials is commonplace to combat disease. Solids from waste feed and fish faeces can cause serious local problems. Solids are washed into rivers or build up below cages and it is now common practice to move cages to new sites periodically to avoid this build-up. Charr and trout are known to gather around moored cages and to grow faster as a result of the availability of waste food. The impact of cages on migrating smolts and adults is unknown.

Farmed fish can suffer from most of the diseases that affect wild fish. Research suggests that outbreaks of certain diseases (e.g. furunculosis) in farmed fish may result in large numbers of pathogens being released into the aquatic environment. It is unknown if this has any significant impact on wild fish. Certain serious diseases (e.g. VHS, IHN) which are endemic in parts of mainland Europe have not been recorded in the UK, probably due in large part to the Diseases of Fish Acts which have proscribed the importation of live salmonid fish from other countries since 1937. EC Directives will change the legislation in 1992 and unless the UK gets "Approved Zone" status (which is being sought – surveys are being carried out throughout the UK in support of our VHS/IHN free claim) we will be unable to prevent importation of live salmonid fish from areas in the EC where these diseases are endemic. Other countries have some ominous parasites and diseases e.g. *Gyrodactylus salaris* and infectious salmon anaemia.

3.6.3 Possible solutions

Descending smolts and ascending adults are potentially vulnerable to fish farming activities through direct effects on freedom of migration. Information should therefore be collected on the extent to which fish farm intakes are adequately screened and the degree to which flow is reduced between intakes and outflows.

Research also needs to be undertaken on the behaviour of wild smolts and adults in the vicinity of fish farms to see whether local changes in such conditions as flow and water quality influence migratory movements. The first priority is to look in detail at the behaviour of ascending adults because the spawning migration is more discontinuous and directed than the downstream migration of smolts.

Although it is well known that captive farmed populations may suffer serious losses from pathogens and parasites, little is known about their transmission between farmed and wild populations. Additional work is required to guide the application of existing regulatory measures and, perhaps also, to prepare for the contingency that, at some future date, live salmonid fish may be imported into the UK from other EC states.

3.7 RIVER MANAGEMENT

3.7.1 Definition and description

This section covers a number of activities which affect the physical nature of the river and its banks and which have not been addressed elsewhere in this report. These activities include changes in land use, drainage, flood prevention, bank maintenance, afforestation and vegetation clearance. The problems created by these activities fall into five categories:

- loss of cover for smolts or adult fish;
- obstructions to migrating fish;
- loss of holding pools for adult fish prior to spawning;
- loss of spawning areas as a result of gravel extraction or siltation; and
- depletion of flows.

3.7.2 Scope of the problem

Many of the activities covered by this section were also discussed in the Committee's Third Report.

Their impact on emigrating smolts and returning adults, however, is likely to be slightly different from that on resident juveniles. For example, the main impact of the mismanagement of bankside vegetation on juveniles was thought to be loss of production in the stream. The effect on smolts and adults is likely to be the loss of suitable cover of holding areas, and of protection from predators.

Various types of cut vegetation can also block narrow stream channels. In forestry plantations thinnings may be left on the land and, if they fall into spawning burns, can form impassable obstructions. Similarly, if bankside vegetation is discarded into the river or weed is not removed after cutting it can often block fish passes. It is rare for larger timber to be deliberately discarded into the river, but if it is left close to the river bank, it may be washed away in a flood and create a major obstruction further downstream.

Land drainage and flood prevention works may involve dredging or removing natural topographical features or boulders from the river. These features provide important holding areas for adult salmon, and the resultant clear channels are unlikely to offer good resting sites. Such channelisation may therefore affect the distribution of adult fish prior to spawning.

Work such as land drainage and afforestation will increase the rate at which rainfall will run off the catchment, resulting in shorter periods of more intense flooding during wet weather, and serious depletion of flows during dry weather. Both of these conditions impact on salmon migration, and the likely scenario is that the more intense flooding will attract adult fish into streams, which cannot support them, or their progeny, during periods of depleted flow.

Adult salmon will select areas for spawning where the gravel appears favourable. Thus, siltation from drainage, which may cause compaction of spawning gravels, and activities such as gravel removal will affect the distribution of spawning fish in the river; this will reduce the production of juvenile fish. Engineering works such as pipe laying or road or bridge building may also introduce silt or disturb the river bed, and such activities may occasionally disrupt fish movements. Culverts and pipes carrying streams under new roads may also impede returning adults from important spawning burns due to high water velocities and the creation of shallow slipways.

3.7.3 Possible solutions

Many of the problems covered by this section were addressed by the Committee's recommendations for Integrated Catchment Management and Riparian Buffer Zones discussed in the Third Report. A wide range of competing interests impinge upon the river environment and full account must be taken of their different effects. A number of guides for riparian management already exist but people need to be made more aware of the effects of certain activities on the fauna and flora of the stream and the interactions between different activities.

More research is required on the behaviour of salmon during the resting phase of their upstream migration in order to establish how to provide holding areas for adult fish which are compatible with good flow characteristics of the river. In England and Wales trash screens are required on new fish passes approved by MAFF, but further work is required on the use of more open passes, such as the Larinier pass, to reduce the problem of blocking.

Although there are mechanisms for consultation between river managers and other interests about engineering works on or close to rivers, bank protection and flood prevention, there is a need for greater control on these activities in some areas. There is great scope for the impacts of such activities on fish stocks to be reduced and, in some cases, for them to be used to enhance the river habitat. For example, such works should be carried out at times when the impact on fish stocks will be minimised.

3.8 SPECIFIC RECOMMENDATIONS CONTAINED IN SECTION 3

3.8.1 Water quality

(a) Integrated Catchment Management and Riparian Buffer Zones are important and necessary measures to protect migrating fish and plans for such measures should be established and implemented with some urgency.

(b) Prescribed minimum flows of freshwater into estuaries should be determined in order to prevent adverse water quality conditions developing. The well-being of migratory fish should be protected by the establishment of Statutory Water Quality Objectives and their associated Water Quality Standards. These objectives and standards must be used to formulate appropriate standards for effluents, and the Regulatory Agencies should enforce compliance with the prescribed standards.

(c) Research is required to establish an appropriate standard for ammonia in estuaries.

(d) All dischargers of polluting wastes should be required to provide means whereby accidental discharges can be contained, and should have approved contingency plans to deal with any incident.

3.8.2 Abstraction

(a) Environmental Impact Assessments should be carried out for all major abstraction schemes to determine whether a consent to abstract should be granted and to define any conditions which might apply.

(b) The best available technology on screening should be applied to all abstraction and discharge points in salmon rivers and a review of the relevant legislative powers is recommended to ensure that this is adopted on existing facilities.

3.8.3 Dams and weirs

(a) Orders should be made as soon as possible to set modern statutory requirements for fish passes at all types of dams and for screens to protect all stages of migrating salmon at all intakes and outlets.

(b) There is a general need to assess the performance of existing fish passes, to improve the design of new passes, and to provide these at dams in rivers which have recently become suitable for salmon. The responsibility for the provision of an effective pass rests with the owner of a dam and where no owner can be identified, the fishery authority for the river should have power either to remove the dam or to construct a pass with approval from the Secretary of State.

(c) Mortalities of smolts, returning adults and kelts at hydro-power stations should be reported promptly by the operator to the fishery authority. If the mortality rate at any life stage is deemed by the fishery authority to be too high, it should be the duty of the operator to remedy the situation.

3.8.4 Tidal barrages

(a) The recommendations on intake and outlet screening which are applicable to abstraction and to dams and weirs are even more important in relation to tidal barrages.

(b) Research is needed into the behaviour of both smolts and adults at tidal barrages.

(c) Fish passes in tidal barrages are a new concept which requires detailed investigation.

3.8.5 Fish farming

(a) The recommendations on intake and outlet screening which were made earlier particularly apply to fish farms.

(b) There is a need to look at the behaviour near fish farms of ascending adults to see whether local conditions created by farms influence migratory movement.

(c) The transmission of disease requires further research in order to ensure that regulations are adequate and can be applied where necessary.

3.8.6 River management

(a) Research into the behaviour of adult salmon is needed in order to achieve a better understanding of the resting phases during the upstream migration of adults.

(b) There is a need for greater control of engineering works in or adjacent to rivers and estuaries so that they are carried out by methods and at times when their impact on salmon can be minimised.

4. GENERAL RECOMMENDATIONS

4.1 INTRODUCTION

This report is concerned with the stages of migration in freshwater and estuaries. It is important to ensure that these migrations can take place with as little hindrance as possible, recognising man's impact on the environment of rivers and the conditions of the water through which the fish must pass.

Four themes have emerged as general topics in the preparation of this report and we recommend that each of them should be addressed. These are:

- water quality;
- river flows;
- fish pass design; and
- protection of fish at intakes and outfalls.

4.2 WATER QUALITY

We are happy to note and comment positively on the general improvement in water quality in many of our rivers and estuaries, but there are still serious problems in the lower reaches of some rivers and there has been some deterioration in quality between 1985 and 1990 in England and Wales. These problems usually occur near the tidal limit which is often the location of an industrial town whose history goes back to the development of a harbour where very high levels of pollution were common. Implementation of the Urban Waste Water Treatment Directive will assist in achieving the improvement of these rivers.

The problem of passage through a polluted estuary is more serious for smolts than for adults for two reasons. Firstly, their downstream migration is not necessarily related to flood conditions which might provide acceptable levels of dilution and thus of water quality and, secondly, they are more sensitive than adult fish to pollutants and poor water quality. However, adults are also very much at risk and we recommend that appropriate water quality objectives with their associated stringent water quality standards should be applied to those rivers and estuaries where serious pollution problems occur.

4.3 RIVER FLOWS

The requirements for water to meet the needs of public water supply, industry and other users have resulted in a level of depletion in some salmon rivers which now has a serious impact on migration. This depletion is exacerbated by patterns of land use which aggravate the extent of droughts and the peaks of floods creating conditions when opportunities for adults to migrate upstream are limited.

APPENDICES

A. MEMBERSHIP OF THE SALMON ADVISORY COMMITTEE

Chairman: Professor G M Dunnet

Mr G H Bielby	Dr L M Laird[2]
Mr C G Carnie	Dr P S Maitland[1]
Mr R M Clerk	Mr I Mitchell
The Hon Edward Davies[1]	Mr M J Morgan[1]
Mr J H Ferguson	Mr M Owens
Mr N W Graesser[1]	Mr D R Paton
Dr M M Halliday[1]	Dr J D Pirie[1]
Mr D Heselton	Dr D J Solomon
Mr A V Holden[1]	

[1] **up to 2 February 1993**
[2] **with effect from 3 March 1993**

PREVIOUS REPORTS BY THE SALMON ADVISORY COMMITTEE

- 'Information on the Status of Salmon Stocks' published in September 1988 (Ref No UR 145, price £3).
- 'The Effects of Fishing at Low Water Levels' published in March 1989 (Ref No PB 0176, price £3).
- 'Factors Affecting Natural Smolt Production' published in May 1991 (Ref No PB 0535, price £3.95).
- 'Assessment of Stocking as a Salmon Management Strategy' published in September 1991 (Ref No PB 0641, price £1.50).

Copies of these reports may be obtained from:

MAFF Publications, London, SE99 7TP.

B. ENVIRONMENTAL QUALITY STANDARDS

The national standards listed below are for general ecosystem conservation, not specifically for salmonid conservation. They do, however, apply to rivers and estuaries containing salmon populations. They are derived from EC directives and national standards (see source references below) some of which have not yet been finalised.

All standards are in µg/l unless otherwise stated. Values are given as annual averages (An.av.), maxima (Max.) or percentiles (e.g. 95%) for total (T) or dissolved (D) concentrations.

SUBSTANCE	FRESH WATER			SALT WATER		
	An.av.	Max.	95%	An.av.	Max.	95%
Ammonia unionised (T)	15		21	21		42
Arsenic (D)	50			25		
Azinphos-methyl (T)	0.01	0.04		0.01	0.04	
Benzene (T)	50			50		
Biphenyl (T)	25					
Boron (T) (mg/l)	2			7		
Carbon-tetrachloride (T)	12			12		
Cadmium (T)	5					
(D)			estuary	5		
			open sea	2.5		
Chloroform (T)	12[a]		5	12[a]		5
Chloronitrotoluenes (T)	10					
Dichlorobenzene (T)	20			20		
1,2-Dichloroethane (T)	1000[b]			1000[b]		
Dichlorvos (T)	0.001			0.04	0.6[c]	
DDT (T)	0.025			0.025		
para para DDT (T)	0.01			0.01		
"Drins" Total (T)	0.03			0.03		
Aldrin (T)	0.01			0.01		
Dieldrin (T)	0.01			0.01		
Endrin (T)	0.005			0.005		
Isodrin (T)	0.005			0.005		
Endosulfan (T)	0.003	0.3		0.003	0.3	
Fenitrothion (T)	0.01	0.25		0.01	0.25	
Flucofuron (T)			1			1
HCH (T)	0.1			0.02		
HCB (T)	0.03			0.03		
HCBD (T)	0.1			0.1		
Inorganic tin (T)	25			10		
Iron (D)	1000			1000		
Malathion (T)	0.01	0.5		0.02	0.5	
Mercury (T)[d]	1		estuary	0.5		
			open sea	0.3		

[a] EC values
[b] EC proposed annual average EQS = 10µg/l
[c] max. after 24h.
[d] or 0.3 mg/kg in a sample of wet fish flesh

SUBSTANCE	FRESH WATER			SALT WATER		
	An.av.	Max.	95%	An.av.	Max.	95%
Monochlorobenzene (T)	5			5		
Organotin TBT (T)		0.02			0.002	
& TPT (T)		0.02			0.008	
PCP (T)	2			2		
PCSDs (T)			0.05			0.05
Permethrin (T)			0.01			0.01
Phosphorus (T)	200					
Simazine/Atrazine (T)	2	10		2	10	
Sulcofuron (T)			25			25
Sulphide (T)	0.25	2.5[e]			10[e]	
Tetrachloroethylene (T)	10			10		
Toluene (T)	50	500		40	400	
Trichlorobenzene (T)	1[f]			1[f]		
Trifluralin (D)	0.1	1		0.1		
(T)		20			20	
1,1,1-Trichloroethane (T)	100	1000		100	1000	
1,1,2-Trichloroethane (T)	400	4000		300	3000	
Xylenes (T)	30			30		

[e] 24hr average
[f] EC proposed annual average EQS = 0.4 µg/l

The following substances have standards for freshwater that depend upon the water hardness:

SUBSTANCE		FRESH WATER Hardness (mg/l $CaCO_3$)			SEA WATER
		<50	50-150	>150	
Chromium (D)	aa	2	10	20	5
Copper (D)	aa	1	6	10	5
Lead (D)	aa	4	10	20	10
Nickel (D)	aa	8	20	40	15
Zinc (T)	aa	8	15	50	10
Vanadium (T)	aa	20(hardness <200)		60(hardness >200)	100

OTHER DETERMINANDS:

The following standards are applicable to salmon fishery conservation and are derived from EC directives and national standards (see source references below).

Dissolved oxygen	Min.	7 mg/l		50% >9 mg/l
BOD	95%	3 mg/l		
Residual chlorine	95%	5 μg/l at pH6		
Temperature	98%	<21.5°C		
	98%	<10°C for breeding of coldwater species		
	98%	<1.5°C increase in affected waters		
pH	An.av.	6.5-8.5) fresh water	–) sea water	
	95%	6.0-9.0) fresh water	6.0-8.5) sea water	

C. SOURCE REFERENCES

Council directive (78/659/EEC) on the quality of fresh waters needing protection or improvement in order to support fish life.

Official Journal of the EC No. L222/1 1978

ENDS (1992) Dangerous substances in water. A practical guide. Environmental Data Services Ltd., 64pp, London.

Water Environment. The implementation of EC directives on pollution caused by dangerous substances discharged into the aquatic environment.

DoE Circular 7/89 1989, Welsh Office Circular 16/89.

Zabel, T.F (1991) Standards for dangerous substances in surface waters (ES9378). Final report to the Department of the Environment, Jan. 1987-Mar. 1991. Report No. DOE 2687-M,9pp + appendices, Water Research Centre, Medmenham.

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