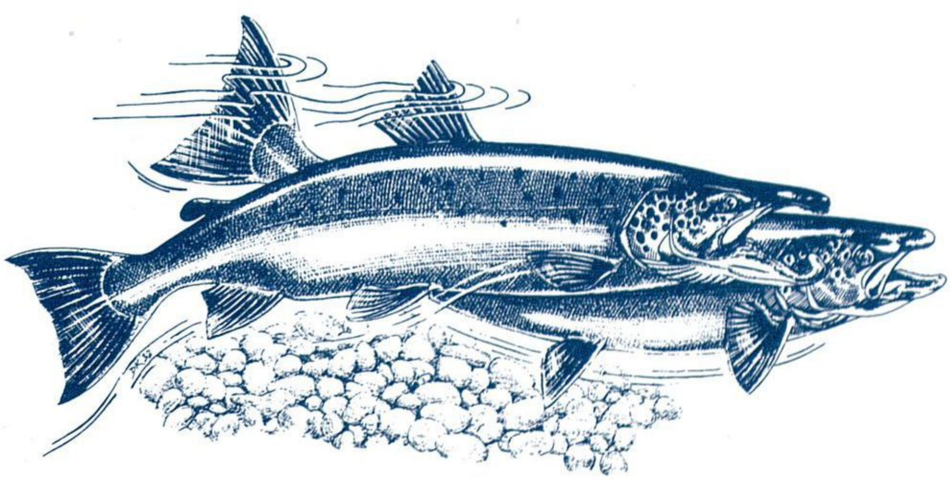
2.6.2.

THE EFFECTS OF PREDATION ON SALMON FISHERIES
Report of the Salmon Advisory Committee



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

CONTENTS

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 in Great Britain which are referred to it by Fisheries Ministers.'

As part of this remit Ministers have asked the Salmon Advisory Committee to examine influences on salmon fisheries including the effects of predators. We therefore decided to:

- identify significant predators of salmon in respect of which we believe that we might be able to offer advice relevant to the protection and development of salmon fisheries;

- review and comment on the current understanding of predation on salmon, and to advise on research needs.

The superscript numbers used throughout this report refer to the publications listed in numerical order in Appendix D.

2. PREAMBLE

In this report we define a predator as an animal which gains its main sustenance from killing and eating other animals. Salmon exist within a community of animals and are themselves predators. However, they are also preyed upon by a variety of other species throughout their life cycle. Predators may influence the production of smolts and their survival to return as adults, which will in turn affect net and rod fisheries and the number of salmon that spawn. We are well aware that factors other than predation may also influence the production and survival of salmon. For example, changes in water quality, stream flow and the nature of the river bed may affect very profoundly the capacity of a river system to support salmon. Such matters are, however, outwith the scope of this report.

It might be imagined that it would be a relatively simple task to determine the effects of predation on the salmon populations. All that might be required would be a list of predators of salmon, the species of prey that each of these predators eats, the proportions of these prey in the diet and the amount of food eaten. However, predator–prey relationships vary markedly from place to place and with season, and many predators are opportunistic, exploiting prey according to their relative availability and, for example, concentrating their efforts in circumstances where prey are especially accessible. The concept of the average diet of a predator species is therefore inappropriate and such knowledge is inadequate for determining the effect of predation on prey populations, especially local populations. Predators and their prey are constituents of complex food webs and the examination of a single link of a food chain, in isolation, within such a web cannot determine the full effect of a predator on the population of one of its prey species. However, as discussed later, in some circumstances assessments can be made of the impacts of predators on salmon fisheries.

Salmon are a valuable resource. The net and rod fisheries provide employment and attract angling tourists, often in areas where the economy is fragile and the fisheries a necessary part of it. It is therefore appropriate to protect the resource from serious damage by predators.

2.1 THE LIFE CYCLE OF THE ATLANTIC SALMON

The juvenile phase

The salmon breeds in fresh water in the late autumn and winter. The eggs, which are large and yolky, are deposited in a redd excavated by the female in clean gravel, fertilised by the male and subsequently covered over when spawning is complete. They overwinter in the interstices between the gravel. The young fish hatch in the spring and emerge from the gravel a few weeks later. The timing of development and emergence depends on the temperature. In Britain, the juveniles spend the first one to four, and exceptionally five, years of their lives in fresh water. Then they develop a silvery appearance and migrate downstream as smolts, eventually reaching the estuary and entering the sea. Some juveniles commence their downstream migration as parr in the autumn, but the main migration of smolts takes place in the spring. The parr are territorial, largely riffle-dwelling animals before their downstream migration. The young spawned in a particular year, known as a year-class, may initially be very numerous, but the death rate can be high and numbers quickly reduced.

At low densities in a favourable environment parr may develop into smolts at one or two years. Because of the influence of climatic and other factors upon growth, smolting occurs at later ages at higher altitudes and latitudes. Smolts originating from the upper reaches include a relatively higher proportion of older and smaller fish than those from lower reaches.

In any year, the smolt run from a particular tributary or part of a river normally consists of more than one year-class.

Salmon in the sea and subsequent return to freshwater

Much remains to be learned about the activities of salmon between entry to the sea as smolts and subsequent return to their native river as maturing adults. Salmon grow very rapidly in the sea and are believed to feed on small fish and crustaceans in the productive mixing zones which characterise parts of the boreal and subarctic oceans. The time spent at sea varies; some return as *grilse* after only one winter at sea, others return after several winters at sea as *multi-sea-winter* fish. The ratio of multi-sea-winter fish to grilse varies between rivers and also fluctuates between years. Multi-sea-winter salmon may return to rivers throughout the year, whereas most grilse return in the summer and early autumn.

2.2 POPULATION DYNAMICS

The term *population dynamics* is used to describe changes in the size of populations and the processes causing these changes. Predation occurs at all stages in the salmon's life cycle but is only one of many biological and physical factors which affect numbers. As a result of all of these factors, only a very small proportion of eggs will produce adult fish, even in the absence of predation.

Salmon produce relatively few eggs when compared with many other fish species but, because the eggs have a good supply of yolk, survival of embryos during the early stages of development in the gravel is normally high. Provided the eggs are well covered by gravel in the redd, egg survival is more dependent upon physical factors such as water temperature and flow than on predation.

Once the young fish emerge from the gravel and commence feeding, mortality rates may increase substantially. Not only do the young fish become more vulnerable to predation, but in the early period of residence in fresh water, the population may exceed the level that can be sustained by the available resources, such as food. This level, which is known as the *carrying capacity*, cannot be precisely quantified because it varies with environmental conditions and the size of the fish, but the effect is that some young salmon will die because they are unable to compete successfully with other juveniles for food or space. This mortality is said to be *density dependent*, because it is related to the number of fish per unit area (density). Under these circumstances, a fish that is killed by a predator may simply be replaced by one that might otherwise have failed to secure adequate food and space and consequently died. Furthermore, the loss of some fish may allow survivors to grow more rapidly, thus improving their chance of subsequent survival. These processes, by which populations are buffered against losses, are termed *compensation*.

Numbers of juveniles in a healthy population will be reduced to around the carrying capacity of the prevailing environment during the summer of their first year, and from this time on there will be relatively little density dependent mortality. Consequently, although some fish will continue to die or be killed, there will be less scope for compensation for these losses. However, because the habitat requirements of the parr change as they grow and the amount of available resources varies with the time of year, the carrying capacity will fluctuate throughout the year. In going through a period when resources are limiting, a year-class may be reduced to numbers well below the carrying capacity for later stages. Thus compensation varies throughout the freshwater phase, although it declines later in the year. It is therefore difficult to estimate precisely the effects of losses in fresh water on the number of adult salmon surviving.

Once the fish have become large parr, numbers have usually been so reduced that there is little possibility of any compensation occurring. Similarly, from the smolt to adult stages there are not thought to be extra salmon available to replace those taken by predators. Thus losses at these stages are likely to have a direct effect on the number of returning adults.

When spawning success has been poor, fewer fish will have to die for the population to be reduced to the carrying capacity. In such circumstances, there is less scope for compensatory mechanisms to operate.

Under normal circumstances, more adult salmon will return to a river to spawn than are required to maintain a stable population; this provides the surplus that can be exploited by fisheries. Any reduction in the numbers of returning salmon caused by predation will reduce this surplus and have a direct effect on both net and rod fisheries. Predation losses by themselves would have to be unusually severe to reduce the spawning numbers to the extent that it would have a long-term effect on the population.

Although this section provides a general description of population dynamics during the juvenile phases, insufficient is known about the detailed interactions. Further research is required to assess the circumstances under which predation on eggs and small parr may cause serious damage to fisheries.

2.3 IMPACT OF PREDATION

All salmon populations experience varying levels of predation at all stages in the life cycle. In order to be able to assess whether predation by a particular species is likely to have an effect on the fishery, it is necessary to have a detailed understanding of the population dynamics of salmon and to have some or all of the following information for that predator:

- numbers and population dynamics;
- distribution and foraging range;
- behaviour;
- diet; and
- potential indirect effects on prey.

Though predation occurs throughout the life of the salmon, the impact of predators is best considered in terms of their effects on the numbers of returning adults. These fish not only have economic value, in that they support the commercial and sporting fisheries, but they also provide the spawning fish needed to maintain the population.

For the purpose of this report, predation can be considered to fall into three categories:

- some predation will occur at stages in the life cycle when it will be compensated for by reductions in other forms of natural mortality and will not therefore affect the number of adult fish returning;
- some must be regarded as inevitable even where it results in some adult loss, since salmon are part of a complex food web;
- some will result in a more significant reduction in the number of returning adults and will be responsible for fishery interests suffering serious economic losses; in such cases management action to reduce predation may be appropriate.

In this report we are primarily concerned with the third category. As discussed above, heavy predation losses will significantly reduce the exploitable surplus and thus have serious effects on net and rod fisheries before the state of a population is greatly affected. Early detection of such predation is of great importance to the management of fisheries.

Predator–prey relationships can be complex and, in the absence of detailed information, it may be difficult to establish whether a predator is having a serious effect on a salmon population. Clearly the number of salmon killed by a predatory species depends both on the number of individual predators present and on the number of fish that each one kills. Thus a predator species that rarely takes salmon, if present in large numbers, could still have a major impact on a salmon population, and a small group of predators might have a significant impact if each killed a large number of fish. However, many species prey upon salmon only at particular life history stages or at certain locations or times of the year.

Although it is therefore difficult to generalise about the situations in which predators are likely to have a significantly adverse impact on fisheries, we feel that circumstances which should attract particular concern are:

- when the size of a predator population increases significantly;
- when the size of a salmon population is depleted;
- when predators occur in areas where salmon are concentrated or vulnerable; and
- when a predator species is known to kill salmon (or a particular component of salmon populations) in preference to other prey.

The abundance and distribution of a predatory species may be affected by changes in human activities or management. Clearly when a predator population grows, the number of salmon consumed is likely to increase. When a predator increases in numbers it may extend its distribution, and this may result in more salmon populations being affected.

Although, on average, salmon may not constitute a major part of the diet for any particular species of predator, where local concentrations of predators and salmon co-occur, a significant proportion of a salmon population may be killed. In some situations, human activities may also increase the vulnerability of fish to predation, and this may attract predators. For example, turbines in hydro-electric dams, in addition to causing direct mortalities on emigrating smolts, may damage or simply disorientate some of the fish which pass through. This may make them more susceptible to predation downstream of the obstruction.

Where predators have several prey species or prey of different sizes available to them, they are likely to be selective for particular groups. For example goosanders have been shown to take the smaller smolts, and at some sites cormorants take coarse fish rather than salmon.

Deliberate or accidental changes to part of the food web can also have effects on predation. For example, surplus live bait, taken to Loch Lomond for pike fishing and comprising several species, appears to have been the origin of the introduction of those species to the loch and its river system. Ruffe and dace in particular have thrived and provided an abundant food source for predators. Although the immediate and consequent impact of predation on salmon and trout may have decreased, the longer term effect of the introductions is difficult to predict.

There may also be indirect or secondary effects. For example, when salmon parr in captivity are exposed to a model trout (simulated predator) their feeding activity is reduced for a period of several hours. It is likely that, in the wild, salmon will modify their behaviour due to the presence or previous experience of predators. At present, insufficient information is available to assess the indirect effect of predators on salmon populations and we recommend that more research should be carried out on this subject.

3. PREDATORS

Appendix B contains a list of known predators on salmon, together with an indication of their relative importance. We believe that of the 36 species on the list, the following six are likely to be of most widespread significance to salmon populations in Great Britain:

- Cormorant
- Goosander } sawbill ducks
- Red-breasted merganser } sawbill ducks
- Otter
- Common seal
- Grey seal.

These species are known to prey upon salmon at stages in the life cycle during which compensatory mechanisms are unlikely to be operating. They are sufficiently abundant or consume enough salmon to have significant impacts on the populations even if only locally, and pose problems for which management solutions may be available.

Large numbers of other predators kill salmon; some (e.g. dippers, kingfishers) take salmon only at very early stages in the life cycle when there are likely to be compensatory mechanisms operating. Others such as pike, brown trout, mink, herons and gulls may be significant predators in some localised situations but do not generally have excessive effects on wild populations. Rainbow trout are also thought to be predators of salmon and, although little information is available, they may have significant effects where they are stocked or escape into salmon streams in large numbers. Although these species are not discussed further in this report, we recognise that they may cause problems in some instances and it may be necessary to consider management action. Further information on these predators is provided in Appendix B.

3.1 CORMORANTS *(Phalacrocorax corax)*

3.1.1 Population

In Europe cormorants have expanded their range and increased in numbers during the last few decades. Numbers in north-western Europe have risen from an estimated 10 000 birds in the 1960s to about 100 000 in the 1980s. The increase has been particularly marked in Denmark and The Netherlands, where most of the birds belong to the *sinensis* subspecies. Most cormorants breeding in the British Isles are of the *carbo* subspecies, although *sinensis* is now spreading in Britain.

Approximately 7000 pairs of cormorants breed in Britain, mainly in coastal colonies (Figure 3.1.1), and an additional 4700 in Ireland, where about 800 pairs breed in inland colonies[1]. Since Britain holds about one third of the world population of *carbo*, and since *sinensis* is specially protected in Britain as a species listed in Annex 1 of the EC Birds Directive, the national commitment to the conservation of cormorants cannot be ignored.

In the UK and Ireland numbers have changed in recent years (Figure 3.1.2)[2]. The largest increase (489%) has occurred in Ireland, whereas the numbers breeding coastally in Scotland have declined. There are, however, regional differences within Scotland; numbers have declined in Shetland, Caithness, the Western Isles and in south-west Scotland, but have increased on the east coast. The number of cormorants breeding in inland colonies in England have increased more than threefold between 1986 and 1992[3]. It is now estimated that 20 000 to 25 000 cormorants overwinter in the UK and Ireland, and there has been increasing use of inland waters for feeding and roosting (Figure 3.1.3)[4].

During the breeding season (March to July), adult cormorants are concentrated in the vicinity of their mainly coastal colonies, but the substantial populations of immature birds (they do not breed until three or four years old) are widely distributed in coastal and inland waters, as are the adults outside the breeding season. Table 3.1.1 provides a recent estimate of numbers wintering in coastal and inland areas of Britain[5].

Table 3.1.1: The numbers of cormorants wintering in Britain.

Region	Coastal	Inland	Total
Scotland	3 800	400	4 200
England	4 600	4 000	8 600
Wales	600	100	700
TOTAL			**13 500**

Figure 3.1.1: Distribution and size of coastal cormorant colonies (and grouped colonies), 1985–87.

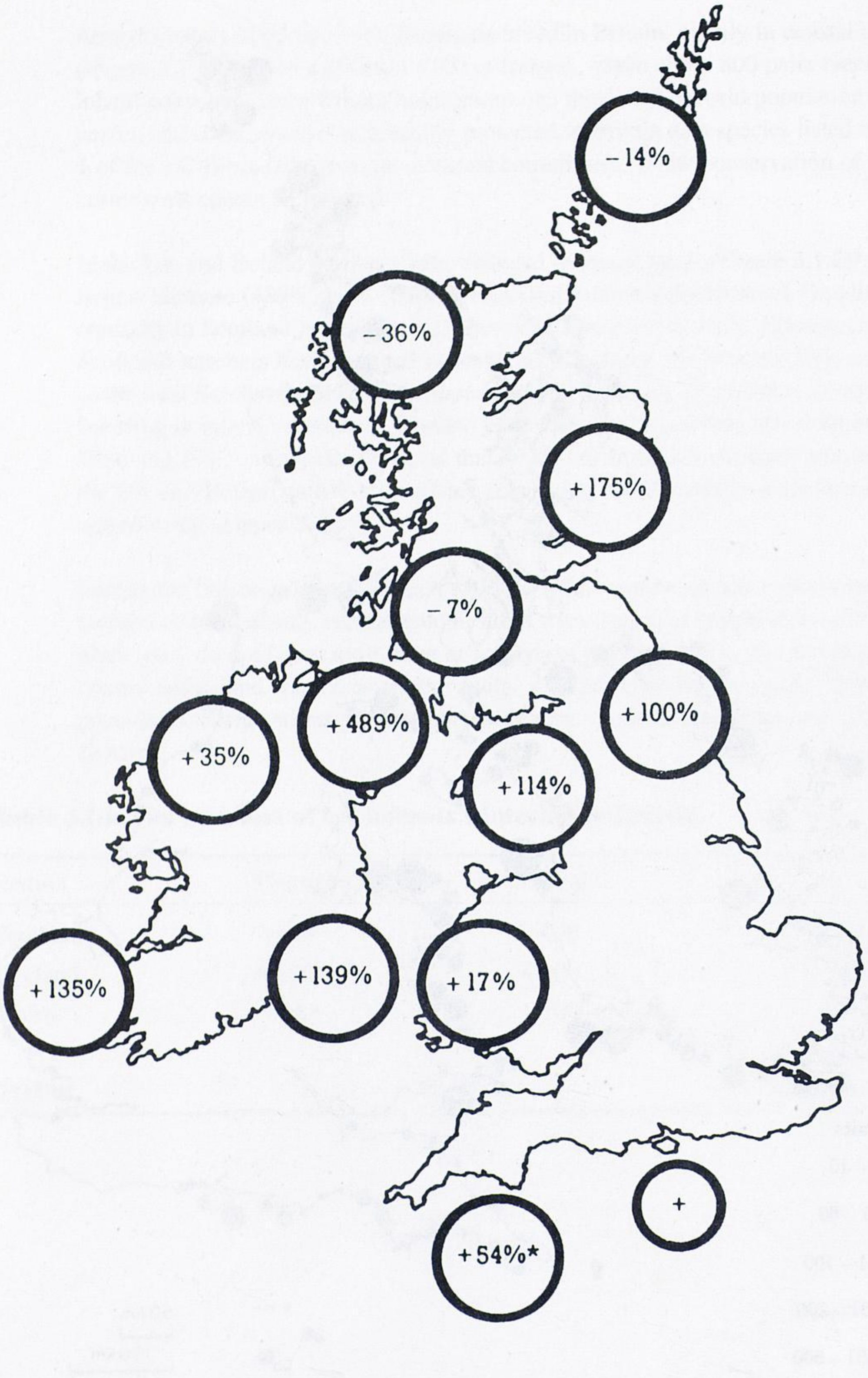


Figure 3.1.2: Regional changes in numbers of coastal breeding cormorants, 1969–87. No figure is given if more than 10% of a county/regional total was derived from counts made as individuals rather than pairs or where totals were less than 100 pairs. (*Cornwall not included.)

Figure 3.1.3: Overwintering cormorants in the UK and Ireland.

3.1.2 Interactions between cormorants and salmon

Cormorants are large birds, weighing 2–3 kg, with an estimated daily food intake of at least 340–520 g of fish[6]. A considerable number of dietary studies of cormorants in Europe have been undertaken using a variety of methods (examination of the stomachs of shot birds, regurgitates from nestlings, regurgitated pellets from adults, direct observation of feeding birds). These studies have shown that cormorants are opportunistic feeders which eat many species of marine and freshwater fish[7].

The proportion of salmonids in the diet and the likely impact of cormorants on local salmon populations are very variable. The stomachs of cormorants shot under licence were examined at a number of freshwater sites in Scotland in winter and spring[8]. Stomachs containing food were received from the Rivers Tweed (41 stomachs), Nith (6), Tay (5), Deveron (19) and Beauly (7). The proportion, by mass, of juvenile salmon in the stomachs ranged from zero (Tay) to 18.9% (Beauly). In general, the proportion of salmon in the diet increased from south to north, possibly reflecting a decrease in the availability of alternative prey. The juvenile salmon ranged in length from 6 to 16 cm; more than half were smolts, or parr about to smolt. Cormorants also eat large salmonids; single post-spawning adult salmon were found in stomachs from the Deveron (estimated fish weight 1.0 kg) and the Beauly (1.5 kg).

Studies on two Irish rivers indicate that cormorants may prey heavily on salmonids during the smolt run. On the River Bush, the numbers of feeding birds were counted and the stomach contents of cormorants shot upstream (six stomachs) and downstream (four stomachs) of a smolt release point were examined[9]. It was estimated that cormorants could have taken 13–26% of the smolts released from the hatchery and 51–66% of the wild salmon smolt run. Predation by cormorants on salmon and sea trout smolts at Newport, County Mayo, was assessed by direct observation of feeding birds[10] and it was concluded that cormorants ate 5.8–13.1% of the migrating smolts.

3.1.3 Conclusions and recommendations

The diet of cormorants varies considerably between rivers and possibly with the time of year. In some places cormorants feed on coarse fish, but in others they may eat sufficient salmonids to have significant impacts on fishery interests. Although adult salmon have been recorded in cormorant diets, such occurrences are likely to be rare and the major impact of these birds will be on the parr and smolt stages.

Further information is required on the growth of cormorant populations in Great Britain. Studies should also be carried out on the factors affecting the movement of cormorants to inland areas and their selection of feeding and roosting sites in order to assess whether they may be discouraged by manipulating the habitat. Research is required on foraging behaviour, the extent to which cormorants congregate around estuaries at the time of smolt runs and whether predation on emigrating smolts continues into the sea. The use of radio tracking should be considered to investigate effects of various scaring techniques on the movements of birds.

Protection of large parr and smolts from predation by cormorants should be considered on stretches of river where cormorants congregate at the time of the smolt run, and especially on rivers where salmon populations are known to be depleted. Scaring, habitat modification, such as the removal of roosting sites, and other non-lethal methods should be the preferred way of reducing predatory impact at particular sites. Shooting may be necessary if other methods are not practicable or have failed to reduce the effects of excessive predation.

Work also needs to be carried out on the diet of cormorants on more rivers in Great Britain along with studies at different times of year and in situations where there are different choices of prey.

3.2 GOOSANDERS *(Mergus merganser)* AND MERGANSERS *(Mergus serrator)* (SAWBILL DUCKS)

3.2.1 Population

Goosanders breed in fresh water habitats, typically upland rivers. They were first recorded breeding in Britain (Perthshire) in 1871[11], and much of the spread and increase has occurred since the 1950s. The breeding area now includes much of Scotland, northern England and Wales, where breeding was first recorded in 1968–72 (Figure 3.2.1). Further major expansions are considered unlikely[7]. The number of goosanders breeding in Britain has increased during the last two decades and currently stands at approximately 2700 pairs[1]. They do not breed regularly in Ireland. The overall increase has resulted from a marked rise in numbers breeding in northern England and Wales. The situation in Scotland is less clear-cut; numbers have increased in some areas and decreased in others. Mature goosanders (two years and older) move to their breeding rivers in spring. Only the females incubate, and as early as April or May the adult males leave the breeding grounds and move north to moult, becoming flightless, on estuaries and shallow coastal waters. Most European males moult in north Norway. By late October moulted adults return and join the fledged young in their winter range which includes most of Great Britain (Figure 3.2.2)[7].

Red-breasted mergansers breed in both fresh water and marine coastal habitats. In the 1870s, they bred in many parts of northern and western Scotland, but the range has now expanded to include the rest of Scotland, northern England (where breeding was first recorded in 1950) and Wales (1953)[11]. The British breeding population is still concentrated in western Scotland, but there are well-established populations in the Lake District and in north Wales (Figure 3.2.3). There has recently been further colonisation in northern England and southwards in Wales. The numbers of mergansers breeding in inland sites in Scotland and Wales appear to have decreased. However, the size of the British breeding population at present is not known because the most recent survey of sawbills was restricted to freshwater sites and would have missed the mergansers breeding on the coasts[1]. Extrapolation from counts in 1988/89 gives a minimum estimate of 2150 pairs, with an additional 750 pairs breeding in Ireland, but it is not known what proportion breed in riverine habitats. An estimated 6000-10 000 individuals overwinter, mainly coastally (Figure 3.2.4) in Britain.

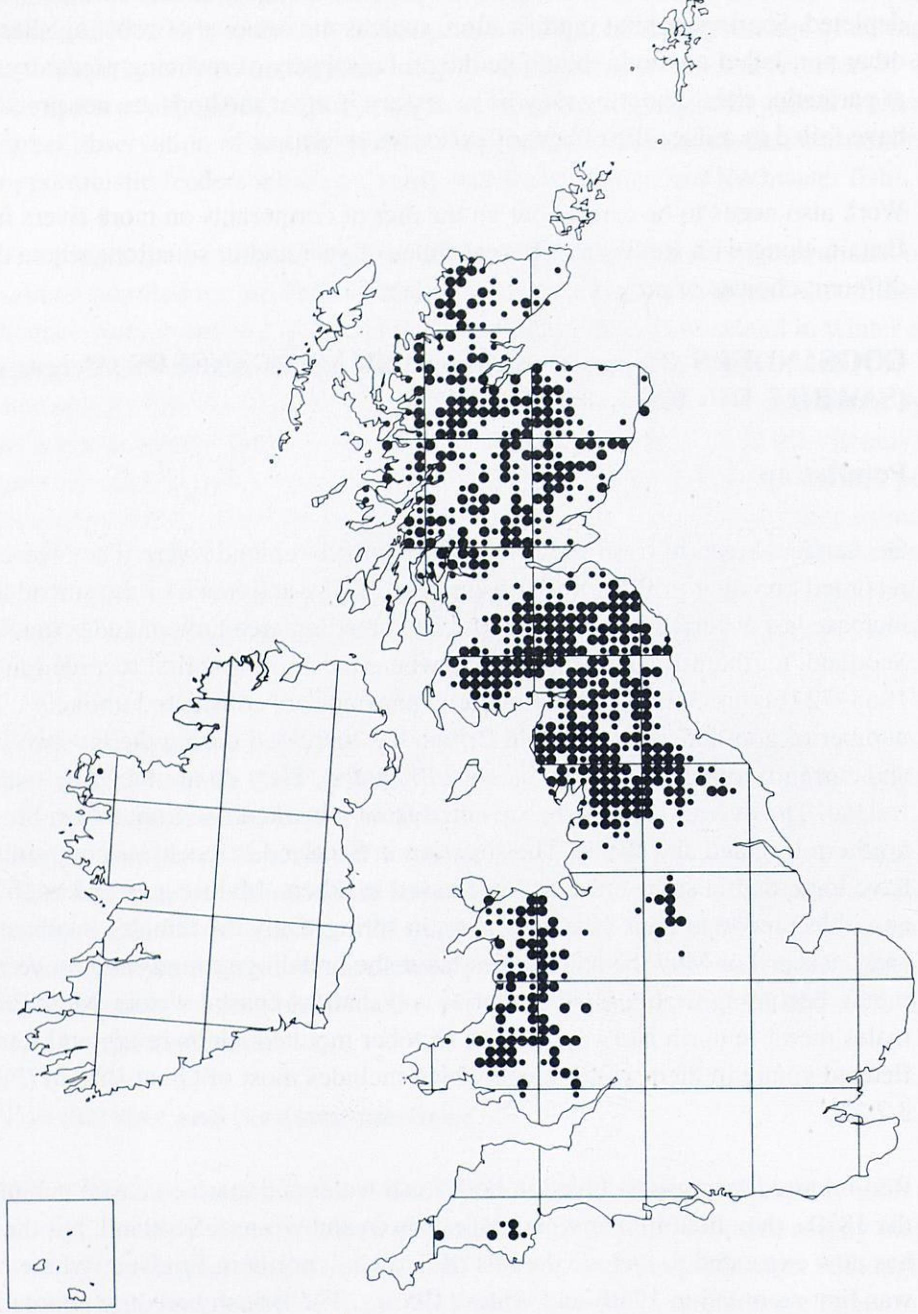


Figure 3.2.1: Goosanders: distribution and breeding.

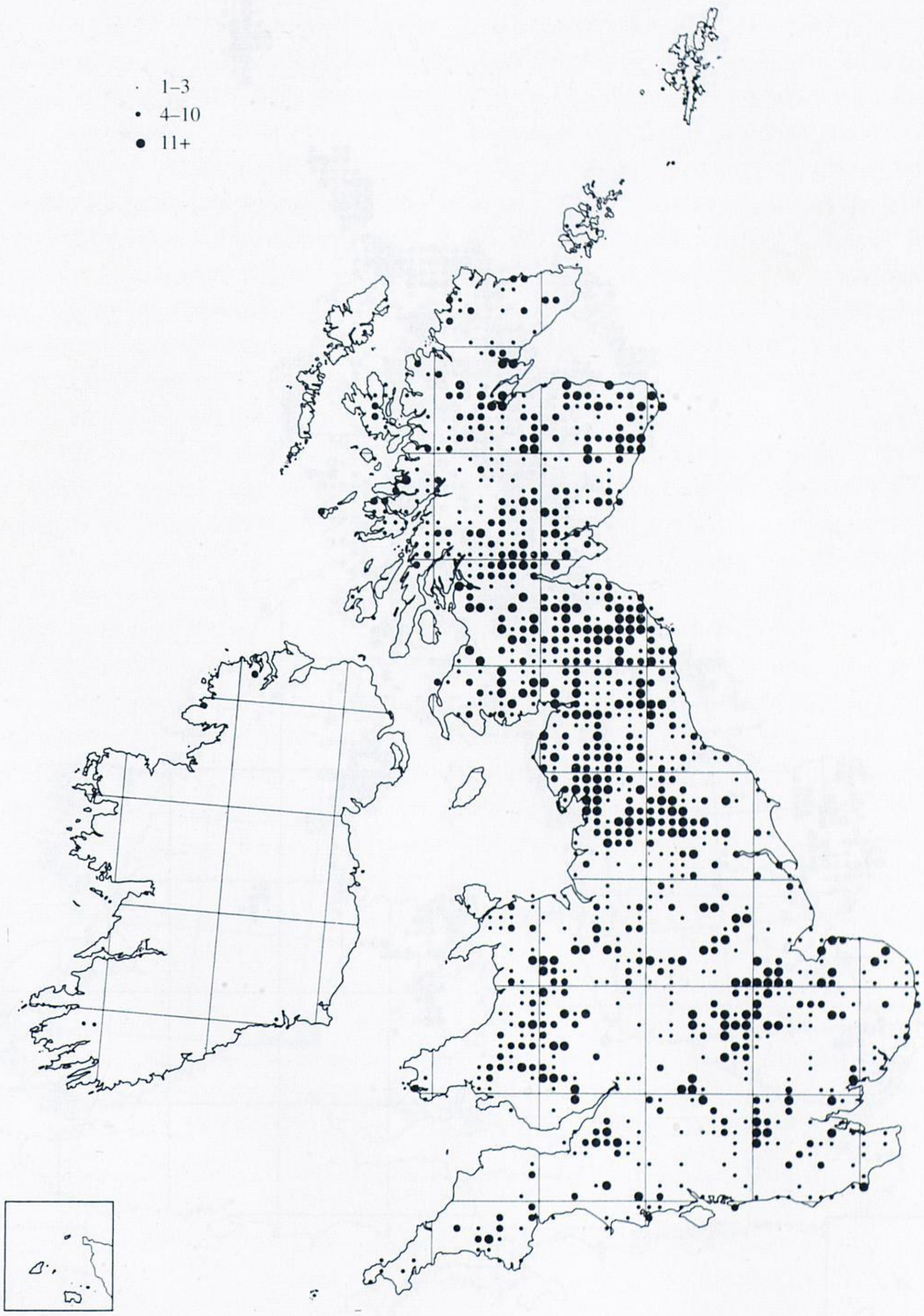


Figure 3.2.2: Goosanders: winter distribution.

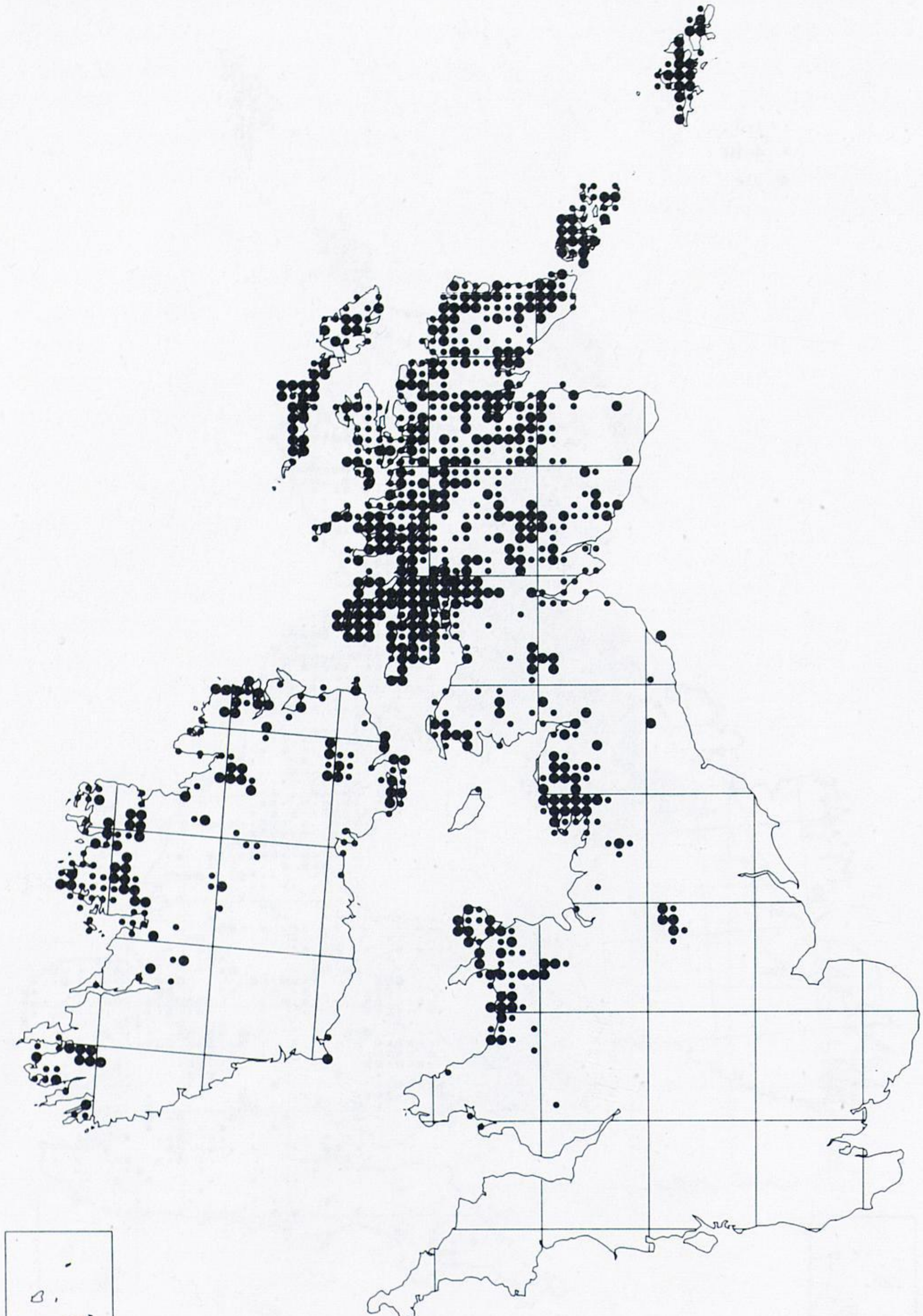


Figure 3.2.3: Breeding distribution of mergansers.

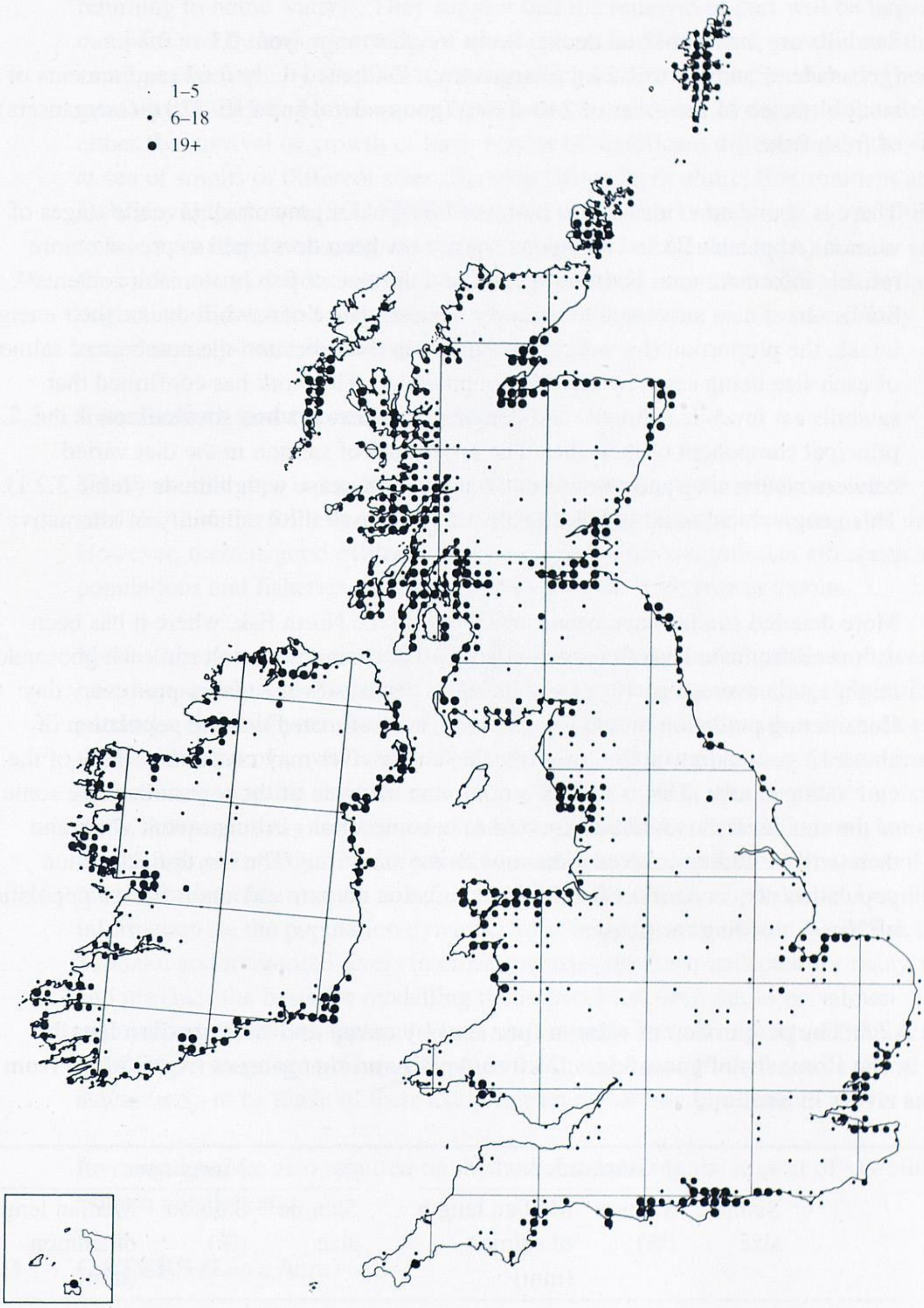


Figure 3.2.4: Red-breasted merganser: winter distribution.

3.2.2 Interactions between sawbills and salmon

Sawbills are medium-sized ducks. Body weights range from 0.9 to 2.1 kg (goosanders) and 0.9 to 1.2 kg (mergansers). Estimated daily food requirements of adult birds are of the order of 240–520 g (goosanders) and 210–320 g (mergansers) of fresh fish.

There is abundant evidence that both sawbill species prey on all juvenile stages of salmon (Appendix B) and techniques have now been developed to provide more reliable information on both the species and the size of fish in stomach contents[12]. Studies have also attempted to quantify the abundance of sawbill ducks, their energy intake, the proportion (by weight) of salmon in their diet and the numbers of salmon of each size being eaten by the duck populations. The work has confirmed that sawbills eat juvenile salmon[13] and demonstrated that at some sites salmon is the principal component of their diet. The proportion of salmon in the diet varied between rivers, sites and seasons and tended to increase with latitude (Table 3.2.1). This geographical trend is presumably a reflection of the availability of alternative prey.

More detailed studies have been carried out on the North Esk, where it has been estimated from studies of energy budgets[14] that during the smolt run each goosander might eat an average of 10–11 smolts and a further 48–52 smaller parr every day. Considering predation on the smolts alone, it is estimated that the population of about 12 goosanders on the lower reaches of the river may consume 3–16% of the emigrating smolts. This is clearly a minimum estimate of the impact because some of the smaller fish would be expected to become smolts in subsequent years and there will be additional predation outwith the smolt run. The North Esk salmon population also experiences additional predation on parr and smolt from a population of 56–64 breeding mergansers[15].

Table 3.2.1: The proportion of salmon (per cent by mass) and their median lengths (mm) in the stomachs of goosanders (March/April) and mergansers (April/May) from various rivers in Scotland.

River	Goosander			Merganser		
	Sample size	Salmon (%)	Median length of salmon (mm)	Sample size	Salmon (%)	Median length of salmon (mm)
Beauly	9	60	98			
Deveron	11	54	88			
Abdn. Dee	13	28	78			
North Esk	14	26	91	53	61	73
South Esk	7	19	96	41	48	76
Tay	8	26	75	26	26	66
Tweed	151	23	99			
Border Esk	29	17	84			
Nith	12	8	75			

Some have argued that sawbills have little impact on the numbers of salmon returning to home waters[7]. They suggest that the removal of parr will be largely compensated by lower mortality of the survivors and increased growth, and that the small smolts eaten by sawbills are those which would have suffered the highest mortality in the sea. However, we have found no evidence of density dependence in either the survival or growth of large parr or of significant differences in the survival at sea of smolts of different sizes (Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) Freshwater Fisheries Laboratory). As sawbills tend to select smaller smolts, a greater absolute number of fish has to be taken to satisfy the birds' energy requirements. In addition, the birds may take more fish at the beginning of the smolt run and may thus tend to kill those smolts more likely to return as early-running multi-sea-winter salmon.

3.2.3 Conclusions and recommendations

There are still gaps in our knowledge of the diet and population dynamics of sawbills[7] and the full effect of these species on salmon populations remains unclear. However, there is good evidence that both species have significant effects on some populations and fisheries when these birds prey on large parr or smolts.

Most of the recent information on the diet comes from a small number of rivers, based upon only a few stomach samples, and sampling has been largely restricted to particular times of year. We therefore fully support the continuation of studies to analyse the diet of sawbill ducks from rivers around Britain and at various times of the year and to refine estimates of the numbers of salmon that are eaten by these birds. Although there is some information on the effects of predation on young smolts and parr, further investigation is needed on the population dynamics of juvenile salmonids in order to refine models of the effects of predation. Detailed information on the population dynamics of salmon from the River North Esk in Scotland and monitored rivers in other countries has been collected for many years and provides the basis for modelling the impact of sawbill ducks on salmon populations. Judicious applications of such models, with the incorporation of information on geographic variations in the diets of sawbill ducks, will allow assessments to be made of their likely impact on salmon elsewhere.

Investigations are also required on methods for reducing the impact of sawbills on salmon populations.

3.3 OTTERS *(Lutra lutra)*

3.3.1 Population

Otters are now widely distributed in Scotland and Wales (Figure 3.3.1); in some areas they are being reintroduced and in others habitats are being improved. In England, otters are most numerous in the south-west and the counties bordering mid-Wales, whilst occurring in lower numbers in the north, south and east of the country and being absent from much of central England[16]. They occupy their home ranges throughout the year.

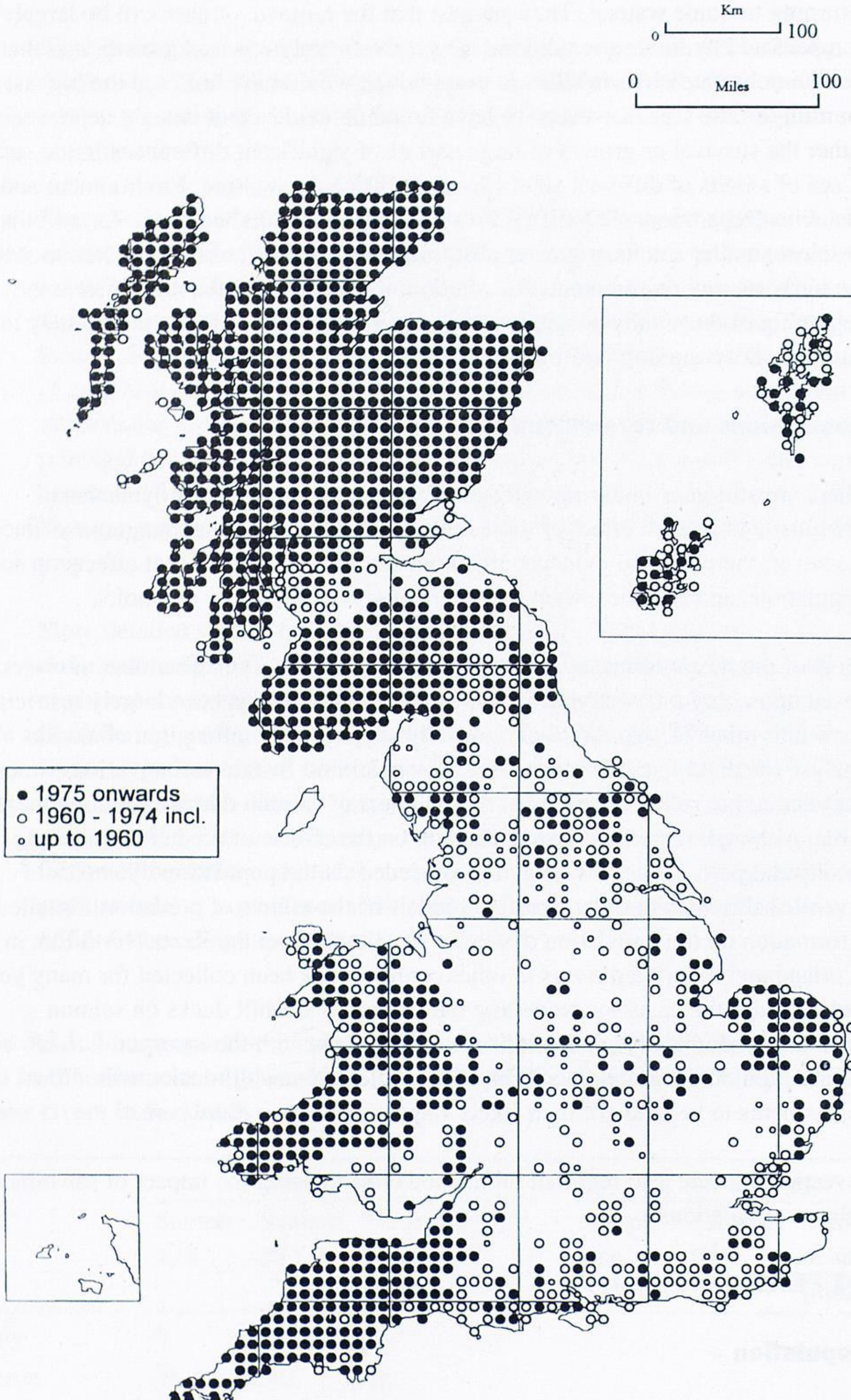


Figure 3.3.1: Distribution of otters. Taken from the *Atlas of Mammals in Britain* by the Institute of Terrestrial Ecology. (This map was prepared by the Biological Records Centre, ITE Monks Wood, from data supplied by the Mammal Society using Dr A. Morton's DMP software.)

Otters occupy a wide range of habitats (lakes, rivers, streams, coasts) and individual animals may alternate between marine and freshwater sites. The home ranges of individual otters and population densities vary considerably depending on the availability of suitable feeding, resting and breeding sites. Numbers are difficult to calculate since otters are secretive, largely nocturnal and far ranging. A density of one otter per kilometre of coastline has been estimated in Shetland, and seven or eight breeding females along 98 km of waterways in Perthshire[16], although densities are often much lower.

3.3.2 Interactions with salmon

Otters range in weight from 6 to 17 kg (male 10 kg, female 7 kg) and are reported to consume 15% of their body weight each day. Although they feed on a wide variety of prey, including mammals, birds, amphibians, crustaceans and insects, their preferred prey is fish. In general, otters select slow-swimming and/or small fish. Eels are a favourite prey in fresh water, whereas in coastal waters at Shetland they feed mainly on species such as eel, pout and gunnel. Both juvenile and adult salmonids are also eaten, however, and may constitute a large part of the diet in places or at times when other prey are less available[17,18,19].

There are three principal difficulties in trying to assess the impact of predation by otters on salmon. Firstly, few of the published reports on otter diet distinguish between salmon and trout. Secondly, many of the records of otters eating salmon are unpublished; for example, otters have been seen feeding on hatchery-reared salmon smolts at a release site in south-east Kintyre (Greenstreet, *pers comm*), and smolt tags have been recovered from spraints and otters killed near smolt traps elsewhere in Scotland (Mills, unpublished). Thirdly, much of the research on predation by otters is confined to predation on adult salmon and thus excludes predation on juveniles which may be equally significant[20,17]. Kruuk *et al.* (1993)[19] analysed the diet of otters feeding in streams running into the Rivers Dee and Don, where salmon were taken in preference to trout, and otters were eating a large proportion of the available biomass of one-year-old salmon and trout.

Recent information on predation by otters on adult salmon in north-east Scotland indicates that, although predation on large salmonids (greater than 30 cm) was recorded throughout most of the year, there was marked seasonal variation with the heaviest predation being during and immediately after the spawning season (November–January)[18,19]. In one study, 122 fish carcasses were collected, 111 (91%) of which were salmon. Of the salmon, 63 (56%) were judged to have been killed by otters with the remainder having died from other causes. The salmon killed by the otters were large, with a median length of 71 cm; they were also in good condition, indicating that diseased fish were not selected. The majority of the fish which appeared to have been killed by otters were found in shallow riffles, whereas those fish that had died of other causes were in pools or in midstream. More male than female salmon were eaten, probably as a result of the males being more active and remaining on the spawning grounds for longer. Observations of a radio-tagged otter indicated that each night one salmon was killed with approximately 1 kg of each fish being eaten and the rest abandoned. In one of the burns in the study area, 116 redds were counted and 55 fish kills by otters recorded. On this basis, it was estimated that otters may have killed about 23% of the salmon which had spawned in the burn.

It has been suggested that, despite the substantial numbers of apparently healthy fish taken, the overall effects of predation by otters were relatively small[18]. The reasons for this were: (i) the majority of the kills were in January, after spawning had taken place; (ii) although some of the salmon killed had not yet spawned, the majority of kills were males which are capable of mating with several females and whose loss thus has less impact on breeding success than the loss of an equivalent number of females; (iii) although some of the post-spawning salmon might have survived to spawn again, the proportion of previous spawners in Scottish rivers rarely exceeds 5%.

3.3.3 Conclusions and recommendations

Otters eat a wide variety of freshwater and coastal fish species. They remain resident in rivers throughout the year and therefore have the potential to harm salmon populations where otters and salmon are abundant. Both juvenile and adult fish are taken. Recent studies on Deeside (north-east Scotland) have shown that otters consume considerable numbers of parr at times when there is little or no capacity for compensation. Otter predation on juvenile salmon therefore has the potential to reduce the number of smolts which reach the sea. Smolt production may also suffer when otters prey upon depleted populations of adult salmon in systems where the numbers of eggs deposited at spawning time are insufficient to make full use of the spawning and nursery habitats available in the river.

Further research is required on the numbers of otters on salmon rivers throughout Great Britain, on their impact on juvenile and adult salmon populations and on the assessment of methods of reducing the impact of otters on salmon populations.

We acknowledge and appreciate the protected status of the otter and the interest in the recovery of its populations, but recommend that due consideration should be given to the potential effects on salmon populations before otters are reintroduced to an area or their populations are enhanced. Where otters are thought to be having a damaging effect on the spawning population in a stream or tributary, consideration should be given to methods of reducing predation.

3.4 GREY SEAL *(Halichoerus grypus)* AND COMMON SEAL *(Phoca vitulina)*

3.4.1 Population

Grey seals have been sighted around most of the coast of Great Britain (Figure 3.4.1). Their seal numbers are estimated by counting the pups born at each of the major breeding sites each year and then calculating the all-age population by means of a statistical model which incorporates, in addition to the pup counts, data on fecundity, the age at which females start to breed, longevity and the ratio of males to females. Pup counts have been made for many years and they indicate that the British grey seal population has been increasing. Over the last decade, numbers have grown at a rate of 7% per annum and in the last six to eight years the population has doubled. The most recent estimates indicate that the total population numbered 115 000 at the start of the 1993 pupping season. Of these, 105 600 (92%) were associated with breeding sites in Scotland and 9400 (8%) with sites in England and Wales (J. Harwood, *pers comm*). If the present rate of increase is maintained, the population will double again within the next six to seven years. Grey seals have been recorded on the majority of the British coastline, but are especially abundant in the North and Western Isles and west coast of Scotland and in south Wales (Figure 3.4.1). The major breeding colonies are in those areas, but also on the Farne Islands and Isle of May on the east coast. Their distribution at sea is less well known, but tracking studies have shown considerable movements. Very few seals have been observed from oil installations in the North Sea (P. Doyle, *pers comm*).

Common seals have been surveyed less frequently and systematically than grey seals, so less is known about their numbers, trends in their numbers and their distribution. They occur all round the Scottish coast and eastern and southern England (Figure 3.4.2). Until 1984, common seal abundance was estimated by making boat surveys of the number of animals hauled-out in July, at the end of the pupping season. From 1984 onwards, aerial surveys were made in August. These surveys counted approximately twice as many seals as did the boat surveys in the same region in July. Virtually all the likely common seal haul-out sites in Britain have been surveyed from the air since 1988, although it was not possible to survey the entire area in any one year. Surveys of hauled-out seals provide an estimate of the minimum size of the population; behavioural studies indicate that total population numbers may be 20–60% higher. In 1993, the minimum size of the British common seal population was approximately 28 300, of which about 26 500 (94%) were in Scottish waters. The 1988 outbreak of phocid distemper virus caused heavy mortality in some areas. For example, the numbers of common seals in the Wash, the largest concentration in English waters, fell by 50% and remained stable at that level until recently. However, mortality in Scottish waters is generally believed to have been much lower. Thus the numbers in the Moray Firth decreased by only about 15% in 1988/89 and are now higher than before the epidemic.

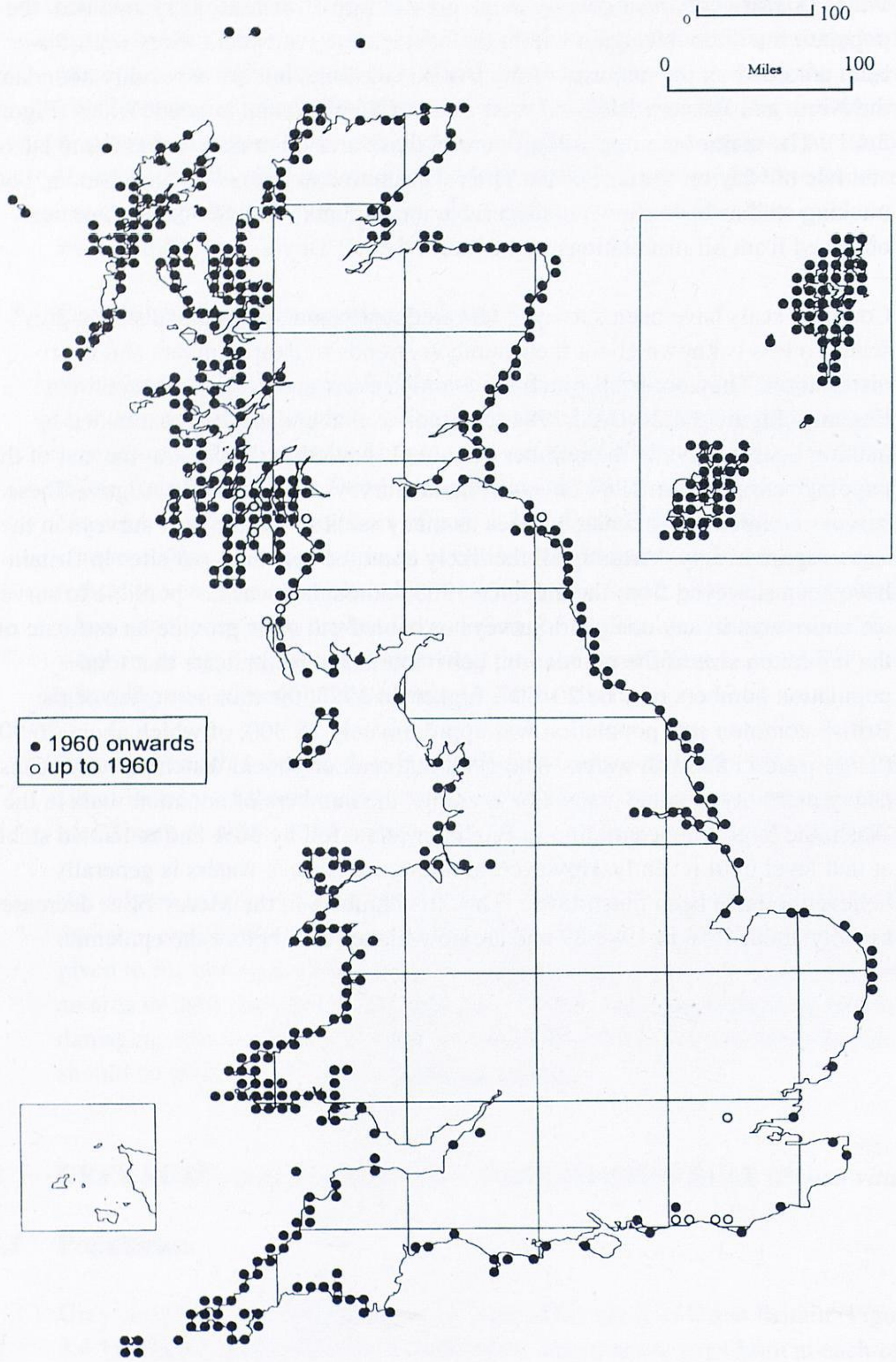


Figure 3.4.1: Distribution of the grey seal on the coast of Britain. Each dot represents at least one sighting on the British coast. Taken from the *Atlas of Mammals in Britain* by the Institute of Terrestrial Ecology. (This map was prepared by the Biological Records Centre, ITE Monks Wood, from data supplied by the Mammal Society and the Sea Mammal Research Unit using Dr A. Morton's DMAP software.)

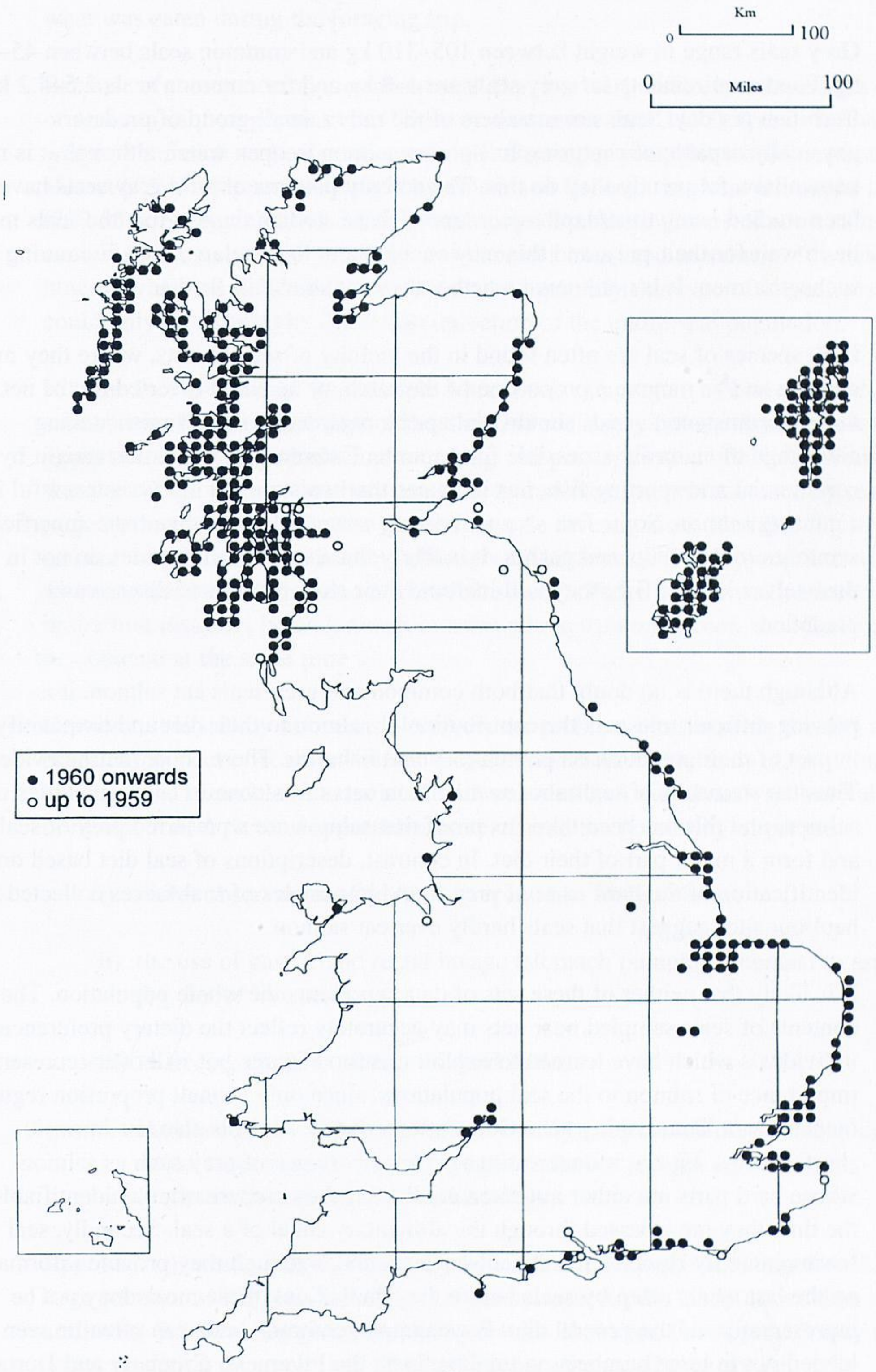


Figure 3.4.2: Distribution of the common seal on the coast of Britain. Each dot represents at least one sighting on the British coast. Taken from the *Atlas of Mammals in Britain* by the Institute of Terrestrial Ecology. (This map was prepared by the Biological Records Centre, ITE Monks Wood, from data supplied by the Mammal Society and the Sea Mammal Research Unit using Dr A. Morton's DMAP software.)

3.4.2 Interactions between seals and salmon

Grey seals range in weight between 105–310 kg and common seals between 45–130 kg. Food requirements for grey seals are 4–8 kg and for common seals 2.5–4.2 kg of fresh fish per day. Seals are members of the rather small group of predators physically capable of capturing full-grown salmon in open water, although it is not known how frequently they do this. The activity patterns of wild grey seals have been studied using time/depth recorders[21]. These studies suggest that the seals may lie in wait for their prey, and this may enable them to take large, fast-swimming fish such as salmon. It is not known whether they eat smolts in British waters.

Both species of seal are often found in the vicinity of salmon nets, where they may damage and/or remove a proportion of the catch, or take fish diverted by the net. In these circumstances, seals should perhaps be regarded as opportunists, taking advantage of an easily accessible food source. Examination of salmon caught by commercial and sporting fisheries indicates that seals are not always successful in capturing salmon. Some fish escape, bearing wounds which range from superficial scratches to deep cuts and gashes. It is likely that even if such injuries do not in themselves kill the fish, they will increase their susceptibility to disease and predation.

Although there is no doubt that both common and grey seals eat salmon, it is proving difficult to assess the contribution of salmon to their diet and to quantify the impact of their predation on populations and fisheries. There is conflicting evidence. Thus the stomachs of seals shot near salmon nets often contain large quantities of salmon, and this has been taken as proof that salmon are a preferred prey of seals and form a major part of their diet. In contrast, descriptions of seal diet based on the identification of the hard parts of prey found in samples of seal faeces collected at haul-out sites suggest that seals hardly ever eat salmon.

It is likely that neither of these sets of data represents the whole population. The gut contents of seals sampled near nets may accurately reflect the dietary preferences of individuals which have learned to exploit this food source but will over-represent the importance of salmon to the seal populations, since only a small proportion regularly feeds near or from fishing nets. Conventional faecal analysis also has intrinsic shortcomings. Firstly, it underestimates the importance of prey such as salmon whose hard parts are either not eaten at all, or if they are, are often unidentifiable by the time they have passed through the alimentary canal of a seal. Secondly, seal faeces can only be collected at haul-out sites and, although they provide information on the last meals eaten by seals before they hauled-out, these meals may not be representative of the general diet. For example, common seals can often be seen hauled-out in large numbers on tidal banks in the Inverness, Cromarty and Dornoch Firths, adjacent to several major salmon rivers. However, radio-tracking indicates that these seals frequently travel tens of kilometres to forage in the open sea of the Moray Firth and that they may be away from their haul-out sites for several days at a time. Radio-tracking and satellite-tracking have shown that grey seals are even more mobile, some individuals travelling to feeding areas located hundreds of kilometres from haul-out sites. Because food passes through the alimentary canal of a seal very rapidly, the remains of meals eaten more than a few hours before hauling-out will be voided at sea, and the prey found in faecal samples on shore may not truly represent what was eaten during the foraging trip.

Because of these uncertainties about seal diet, it is very difficult to assess the effects of seals on salmon populations. There are now more than 143 000 seals in British waters, so if each seal eats only one adult salmon per year, this would amount to almost 60% of the number caught by all salmon fisheries in Great Britain in 1993 (239 551). Seals could thus have a major impact on the numbers of adult salmon even if such a very small proportion of their diet consisted of salmon. It would, however, be very difficult to demonstrate and quantify this type of impact, and it could only be reduced by draconian reduction of the entire seal population.

In some local situations, for example where seals congregate in a river mouth, salmon may form a larger part of the diet, and seals may have a significant local impact on emigrating smolts and returning and post-spawning adults. We consider that these local interactions between seals and salmon are best assessed by research projects on a local scale, rather than large-scale investigations intended to provide a general description of seals' diet (although the latter may be an appropriate way of assessing the impact of seals on whitefish stocks). These local investigations should, in the first instance, be undertaken in areas where data on salmon abundance could be obtained at the same time.

However, it is still by no means clear how the problem of estimating the diet and the predatory impact of seals on salmon populations should be addressed, even on a local scale. The problems associated with conventional faecal analysis have already been mentioned. Several approaches have offered the possibility of progress:

(i) direct observation of seals in river mouths and estuaries;

(ii) the use of gastric and rectal lavage (stomach pumping, enemas) to assess the diet of live seals;

(iii) analysing the gut contents of dead seals;

(iv) improving the efficiency of dietary analysis by developing techniques to detect trace remains of prey species in faeces and gut contents (e.g. mitochondrial DNA methodology).

Approach (i), which is non-lethal, may be a suitable way of estimating the taking of large salmon, which seals usually eat at the surface. A pilot study undertaken in north-east Scotland has given promising results. However, this approach may not detect predation on smolts and small grilse, because small prey are generally swallowed whole, underwater.

Approaches (ii) and (iii) may increase the frequency with which salmon remains are detected, because the contents of stomachs and intestines are less degraded than faecal matter. In common with faecal sampling, these techniques provide information on only the last one or two meals eaten by the seal, but this may be an advantage if the object is to investigate local predation. Both approaches have disadvantages. Although lavage (which is non-lethal) offers the opportunity to collect serial samples from an individual, it would be difficult, and probably extremely costly, to capture enough seals on a regular basis, and it would be hard to obtain a sample of the population that was not weighted in favour of young or sick animals, which are easier to catch. The main disadvantage of conventional stomach sampling is that it may be necessary to kill a rather large number of seals because a high proportion of seals shot on land have empty stomachs. Although it is possible to shoot seals in the water, dead seals often sink and can only be retrieved by taking special measures, such as employing divers. We see merit in developing approaches to enhance the detection of prey remains (approach (iv) above), provided that they can be developed to the point where large numbers of faecal/gut samples can be screened rapidly.

On the question of interaction between seals and fisheries generally, the European Parliament has commissioned a study into the interaction between fisheries and grey seals which will be reported in 1997.

3.4.3 Conclusions and recommendations

In view of the potential for seals to have significant and widespread effects on salmon stocks and fisheries, the priority for research is to identify the circumstances where they are most likely to cause damage. It seems likely that seals can have unacceptable impacts where they congregate in groups in or near estuaries during runs of adults or smolts. Research is particularly required on the effects of seals on salmon in such situations. In this context further information is needed on the foraging ranges and behaviour of individual seals.

While recognising the limitations of data on diets, we see merit in seeking improved methods for the analysis of faecal and gut samples to determine what is eaten.

There is likely to be a need for local control of seals in order to protect runs of adult salmon, and possibly smolts, on some estuaries. More information is therefore needed on the effectiveness of different control methods. Studies should also be carried out on the factors causing seals to congregate in particular areas, and the development of methods to discourage this behaviour.

If the number of grey seals continues to increase at the present rate it seems inevitable that management measures to stabilise or reduce the population will be needed. We strongly support the continuation of work to develop and evaluate methods of seal management, including methods such as contraception (see paragraph 5.5).

4. PREDATOR CONTROL LEGISLATION

The principal predators of salmon are fish, birds and mammals. All are at least to some extent protected by the Wildlife and Countryside Act 1981.

4.1 BIRDS

The EC Directive on the conservation of wild birds (79/409/EEC) published in April 1979 relates to the conservation of all species of birds living free in the wild state in the European territory of the Member States to which the Treaty of Rome applies. It covers the protection, management and control of these species and sets down rules for their exploitation. The Directive applies not only to birds, but also to their eggs, nests and habitats.

In Great Britain the Directive is implemented under the Wildlife and Countryside Act 1981, which makes it an offence to kill most birds except under licence. Depending on the area within Great Britain, the licensing authority is the Ministry of Agriculture, Fisheries and Food (MAFF), the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) or the Welsh Office Agriculture Department (WOAD). Each licensing authority may issue licences to kill birds to prevent serious damage to fisheries (there is no statutory definition of what constitutes serious damage). The Act requires the relevant Ministers to consult from time to time with the statutory nature conservation agencies – English Nature, Scottish Natural Heritage and the Countryside Council for Wales – about the exercise of their licensing powers.

Licences are issued to shoot cormorants, herons, goosanders and mergansers to prevent serious damage to fisheries. Applicants are required to provide evidence in support of their claim that serious damage is occurring or is expected. Licences are only issued when there is no other satisfactory solution for preventing damage to the fishery. The licences can be issued at any time of the year, but do not usually permit birds to be shot during their breeding seasons. This can leave the May and June component of the smolt runs unprotected. Licences are only issued to prevent serious damage to fisheries, not as a means of culling the bird populations. The Act provides that certain persons, including fisheries authorities and owners of salmon fisheries, may kill birds for various purposes, including the prevention of serious damage to fisheries (this exemption does not apply to some rare birds which are specially protected).

4.2 FISH

In Scotland, the principal lawful method for taking freshwater fish is by rod and line, but there are provisions that the owner, and persons acting on his behalf, may take brown trout by net in lochs (provided that all the proprietors agree) and that any other freshwater fish can be taken in any inland water by net or trap. These provisions have been used by individual proprietors and by District Salmon Fishery Boards to gill-net pike in order to reduce predation on salmon smolts. The Secretary of State has a power to authorise otherwise illegal methods of killing freshwater fish for the purpose of protecting, improving or developing particular stocks of fish. Under this provision, poison has been used in the past to eliminate the pike population in some lochs (although this has been to protect trout rather than salmon fisheries).

Predatory freshwater fish can be removed by the National Rivers Authority (NRA)* in England and Wales at any time of the year, or subject to NRA byelaws, by fishery owners during open season providing that the method is permitted under legislation. Owners or occupiers of several fisheries where salmon or trout are specially preserved may also remove eels, freshwater fish or rainbow trout at any time of the year.

In the sea there is generally a public right of fishing and any method may be used unless it has been proscribed. There are no specific legislative provisions relevant to the control of predatory fish.

4.3 MAMMALS

Otters are protected under the Wildlife and Countryside Act 1981 and may not be killed except under licence. The Act provides that certain persons, including fisheries authorities and the owners of salmon fisheries, may kill otters for various purposes including the prevention of serious damage to fisheries. Two licences, each to kill a single otter, have been issued by SOAEFD since 1981; neither otter was killed. No such licences have been issued in England or Wales.

Feral mink may be killed using any method not prohibited by the Wildlife and Countryside Act 1981.

The Conservation of Seals Act 1970 makes it an offence to kill grey or common seals during specified periods which cover their breeding seasons. The grey seal close season is from 1 September to 31 December inclusive and for common seals the close season is from 1 June to 31 August inclusive. There are two exceptions to this ban. Firstly, a fisherman may kill a seal to prevent it causing damage to his fishing net or tackle, or to any fish in the net, provided that the seal was near the net or tackle. Secondly, the Secretary of State, after consulting the Natural Environment Research Council, may grant a licence authorising a person to kill seals for a variety of purposes, including the prevention of damage to fisheries, the reduction of a population surplus for management purposes and the use of a surplus as a resource. Three licences were issued in 1994 for the protection of fisheries. Since 1977, no licences have been granted for the culling of seals. In May 1985 the Secretary of State for Scotland announced that there would be no cull of grey seals in Scotland until numbers reached a level at which culling would be justified.

All cetaceans (whales, porpoises and common and bottlenose dolphins) are now afforded complete protection under the Wildlife and Countryside Act 1981, reinforced by an amending Order in 1988. Any cetacean accidentally caught in any net must be returned alive to the water.

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* It should be noted that with effect from 1 April 1996 the duties and functions of the National Rivers Authority (NRA) were taken over by the Environment Agency.

5. METHODS OF REDUCING PREDATION

There are several means of attempting to reduce predation and the effectiveness of any method or combination of methods will depend upon particular circumstances.

5.1 PHYSICAL PROTECTION

It may be possible to provide some form of physical protection to salmon at locations or periods of their life cycle when they are particularly vulnerable. An example of such vulnerability is the disorientation of emigrating smolts that have passed through turbulent outfalls. In such cases netting or floating coverboards would decrease the opportunities for avian predators. Apart from such easily identified situations, physical protection is not considered practical for wild fish populations.

5.2 RELOCATION

Smolts may be transported downstream to bypass areas where they are thought to be particularly vulnerable to predation; this procedure can increase their overall survival rate[22]. This may be expensive and is not always practicable.

Predators may be relocated to areas where the impact on salmon fisheries will be less, but there are few situations where this would be practical.

5.3 ALTERNATIVE FOOD SOURCES

The provision of alternative food sources might be an appropriate remedy where the location and identity of the predator and the timing of the predation are known. For example, otters preying on spawning adults might be diverted by the provision of a more readily accessible source of food. Considerable expense would be involved in the provision of appropriate alternative food, in many cases at remote locations. The method could also result in predators becoming dependent on the alternative food sources. Considerations of practicality and the difficulties of co-ordination indicate that this method could only be used in special circumstances.

5.4 SCARING

Predators may be dispersed from locations where salmon are particularly vulnerable to predation. Methods are usually based upon acoustic or visual devices or combinations of both.

Some use has been made of acoustic devices on marine and estuarial nets to disperse seals, but this practice has not proved generally successful. Shotguns fired close to predators, especially sawbills, will usually disturb the birds sufficiently for them to move away, at least temporarily. However, especially on wide rivers, birds sometimes become accustomed to this activity. For seals it has been suggested that individuals may learn to associate the sound of scaring devices with the presence of food and thus be attracted.

Visual factors include the prominent presence of man as well as models of the predator or a natural enemy of the predator. Herons, being territorial feeders, may be deterred from preying in particular locations due to the presence of other herons, even if they are artificial. Similarly, inflatable killer whales have been observed to disperse seals.

Scaring must be regarded as a short-term remedy which may do little other than relocate the problem elsewhere and, as predators become accustomed to the method used, will become ineffective.

5.5 CONTRACEPTION AND STERILISATION

The control of predator numbers may be possible by non-lethal methods, such as contraception and sterilisation.

Research is being undertaken in Canada into the use of contraceptives fired into grey seals in a hard lipid bullet. The contraceptives used are antibodies which prevent the development of either eggs or sperm. Problems remain with regard to how such contraceptives would be administered to the British seal population. In some circumstances similar methods can also be used to sterilise animals permanently.

There have been occasional attempts to use steroid contraceptives in long-acting doses to grey seals, but these have produced equivocal results and the problems of administering the large injection necessary means that this is unlikely to prove practical.

There would be merit in refining techniques for the contraception and sterilisation of predators sufficiently for use in population control, especially as populations could thus be maintained at reasonably predictable levels. Research on this topic is of relevance to a wide range of other problems and might be particularly significant where the populations of certain species have experienced a very rapid increase.

5.6 SELECTIVE KILLING

It is sometimes possible to identify, within a population of a predator species, certain individuals whose predation may have a disproportionately large impact on salmon populations. The term 'rogue' seal is often used to describe individual seals which prey on salmon already entrapped in nets. These seals can cause high mortalities; however the removal of one such individual often leads to early replacement by another.

As stated in paragraph 5.4, selective killing may also be used to reinforce scaring techniques.

The principle of selective killing may also be applied to the choice of a particular stage in the life cycle of the targeted species. The killing of breeding females will usually have greater effect than the killing of males but the value of selection may also depend upon the practicality of targeting any particular component of the predator population.

5.7 CULLING

In this report we define culling as the killing of a proportion of a population with the objective of stabilising or substantially reducing the population size. Culling may be appropriate where predator populations are large and have a continuing and rapid rate of growth.

Culling of predators may not be solely to protect a particular species of prey but may also have other objectives such as the protection of other prey species and the improvement of habitat or condition of the remaining predators.

For culling to be effective, it must be carried out over an area large enough to ensure that the reduction in numbers is maintained for an appropriate period. A high level of organisation is required in terms of choice of locations and timings, and the culling should be carried out by using the most appropriate humane method. Delays in reducing numbers to a target figure will probably result in a requirement to cull an increasing number in order to achieve that target figure.

5.8 ERADICATION

Whereas culling is based upon the killing of a proportion of a population, eradication refers to the removal of the maximum number, with total elimination being considered possible. Total eradication of a species within Great Britain could be achieved by a deliberate policy of extermination, by over-exploitation, or by the introduction of a disease, either natural or engineered. Although the eradication of a species might have widespread and unforeseen effects on the biological community, it can be argued that the eradication of any recently introduced species may not only be harmless but may be beneficial to the community (for example, the successful eradication of musk rat and coypu). The widespread distribution of mink, which is not a native species, originates entirely from escapes and releases from captivity. The species has no beneficial effect within the biological community and is therefore an appropriate candidate for eradication in the wild.

6. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL CONCLUSIONS

We have have addressed the problem of predation exclusively as it affects salmon fisheries and populations. In this context the impact of predators is best considered in terms of the effect that the removal of fish at different stages in the life cycle will have on the number of adult salmon that are available to the net and rod fisheries and on the number of spawners. We acknowledge that some predation must be regarded as natural and inevitable, but conclude that in certain circumstances predation can result in a significant reduction in the exploitable surplus of salmon populations and thus have serious economic effects on fisheries. Even more seriously, it may affect the viability of the population.

Some predation occurs at stages when it will be compensated for by reductions in other forms of natural mortality and will not therefore affect the number of adult salmon. However, as the young fish grow, such compensation decreases and losses to predation are more likely to have direct effects on adult numbers. In addition, if spawning success has been poor, the ability of the population to compensate for early losses may be further reduced. As a priority, research should concentrate on those aspects of predation for which there is little or no likelihood of compensation and this should be borne in mind in relation to our recommended research for each predator species.

In general, predation on smolts and large parr is not well compensated for. A better understanding is needed of the situations where predation on earlier stages may have significant direct and indirect impacts on salmon populations or cause serious loss to fisheries. **Further research into the early life history and population dynamics of salmon is therefore required to identify the circumstances under which predation on eggs and small parr is not compensated for and causes serious damage to fisheries and salmon populations**.

Although many predatory species are known to kill salmon, detailed information on the numbers of salmon taken is available for only a very few species and in a limited range of circumstances. For example there is as yet no effective way of accurately determining the number of salmon lost to seals.

We believe that the predator species likely to have the most widespread effects on salmon fisheries and populations in Great Britain are cormorants, sawbills, otters and seals. Further information is required on numbers, distribution and diet of these predators and on their impacts on salmon. As studies will be expensive and difficult to conduct, it is important to identify those future research requirements which are of top priority. Other predators such as pike, brown trout, mink, heron and gulls may have significant effects in some localised situations, but do not generally have excessive impacts on salmon populations. However, we recognise that these predators and others in Appendix B may cause problems in certain circumstances, and it may be necessary to take management action.

It is important to try to achieve a balance between conflicting interests, and, in situations where predation levels become excessive and have a detrimental effect on the exploitable surplus, some form of control will be required. **In the absence of precise data on predator-prey interactions, decisions on the impact of predation, and on measures to reduce it, will have to be made on the basis of the best available information and interpretation.**

The eight methods of reducing predation outlined in **Section 5** range from the complete physical protection of prey to the eradication of the predator. In terms of practical management, attempts to reduce predation may involve the use of one of these methods alone or in combination with another. **We consider it most important to record the action taken and, where practicable, to monitor the results of that action; and we encourage the dissemination of this information.**

Control of predator species is covered by the Wildlife and Countryside Act 1981, which allows that licences may be issued 'for the purposes of preventing serious damage to fisheries'. There is no clear statutory definition of 'serious damage', but it is recognised that it includes economic considerations. It is not necessary for it to result in a decline in a salmon spawning population for it to be regarded as serious. A significant reduction in the exploitable surplus of the returning adult fish may not affect the spawning success of the population while still having a major impact on the viability of net and rod fisheries. Evaluation of serious damage should be made on a case-by-case basis taking account of the estimated extent of the impact on the spawning population, the exploitable surpluses and the economics of the fishery operation.

Predator control programmes need to be assessed on a case-by-case basis. However, there is also a need for some co-ordination of programmes which would allow the status of the predator population on a wider scale to be taken into consideration. Co-ordination would also help to ensure that a consistent approach is adopted and that beneficial actions in one area do not have adverse effects in another.

6.2 CORMORANTS

Although adult salmon have been recorded in cormorant diets, this is rare and the major impact of these birds is on the parr and smolt stages. The diet of cormorants varies considerably between rivers and with the time of year, but evidence suggests that in some places they eat sufficient salmon to have a significant impact on fisheries.

Action should be taken to protect large parr and smolts from predation by cormorants where predation is or is likely to be excessive or where salmon populations are at low levels. Scaring and habitat modifications, such as the removal of roosting sites, should be considered to reduce impacts at particular sites. Shooting will be necessary if other methods are impracticable or have failed to reduce the predation. Whatever action is taken should be recorded and, where practicable, the consequences monitored; and we encourage the dissemination of this information.

Priorities for research:

- to assess further the diet of cormorants on more rivers in Great Britain, carrying out studies at different times of year and in situations where there are different choices of prey;
- to assess the extent to which cormorants congregate around estuaries at the time of smolt runs, and whether predation on emigrating smolts continues into the sea;
- to carry out studies on the factors affecting the movement of cormorants to inland areas and their selection of feeding and roosting sites in order to assess whether they can be discouraged by manipulating the habitat;
- to acquire further information on the growth and distribution of cormorant populations in Great Britain;
- to examine, with a view to improving efficiency, the effects of various scaring techniques on the distribution of cormorants.

6.3 SAWBILL DUCKS

There is good evidence that sawbills have a significant effect on some salmon fisheries when they prey on large parr or smolts. Action should therefore be taken to protect large parr and smolts from predation by sawbills where this is or is likely to be excessive or where salmon populations are at low levels. Non-lethal scaring methods should be considered to reduce impacts at particular sites. **Shooting will be necessary if other methods are impracticable or have failed to reduce the predation. Whatever action is taken should be recorded and, where practicable, the consequences monitored; and we encourage the dissemination of this information**.

Most of the recent information on the diet of these species comes from a small number of rivers, many of which have yielded only a few stomach samples, and sampling has been largely restricted to particular times of year. **We therefore fully support the continuation of studies to analyse the diet of sawbill ducks from rivers around Great Britain and at various times of the year, and to refine estimates of the numbers of salmon that are eaten by these birds**.

Detailed information on the population dynamics of salmon from the River North Esk in Scotland, and monitored rivers in other countries, has been collected for many years and provides the basis for modelling the impact of sawbill ducks on salmon populations in these rivers. **The judicious application of such models with the incorporation of the information on geographic variations in the diet and numbers of sawbill ducks will allow assessments to be made of their likely impact on salmon stocks and fisheries elsewhere**.

Priorities for research:

- to assess the effect on salmon populations of predation on juvenile fish;
- to acquire further information on the movements, distribution and foraging behaviour of sawbill ducks in Great Britain;
- to investigate non-lethal methods for reducing the impact of sawbills on salmon fisheries.

6.4 OTTERS

Otters eat a wide variety of freshwater and marine fish species. They are resident in rivers throughout the year and, where abundant, have the potential to harm salmon populations where salmon predominate in the fish fauna.

We acknowledge and appreciate the interest in the recovery in otter populations, but **recommend from a fisheries perspective that there should be a presumption against the deliberate reintroduction of otters to salmon rivers. This should be borne in mind when formulating any national strategy**.

Where otters are thought to be having a serious effect on the salmon population of a river, **consideration should be given to methods of reducing predation**.

Priorities for research:

- to further assess the impact of otter predation on juvenile salmon populations and returning adult fish;
- to assess methods of reducing the impact of otters on salmon populations;
- to establish the numbers of otters on salmon rivers throughout Great Britain.

6.5 SEALS

It is known that both common and grey seals prey on salmon, although it is difficult to assess the contribution of salmon to their diet and to quantify the impact of their predation on populations, exploitable surpluses and the economics of rod and net fisheries. However, there is reliable evidence of local problems, and there is a need for local control of seals in order to protect runs of adult salmon, and possibly smolts, on some estuaries. **More information is therefore needed on the effectiveness of different control methods. Studies should also be carried out on the factors causing seals to congregate in particular areas and at particular times, and on the development of methods to discourage this behaviour**.

Given the substantial and continuing increase in numbers of seals in recent years and the potential for damage to salmon, management action should be seriously considered. **Bearing in mind the particular public sensitivities attached to the use of lethal methods, urgent consideration should be given to the development**

and use of non-lethal methods of control. However, until successful non-lethal methods are identifiable, we support the use of killing in instances where it can be demonstrated that salmon populations, exploitable surpluses and the economics of operation of a fishery are seriously damaged.

Priorities for research:

- to assess the impact of seal predation on populations of adult salmon passing through estuaries where seals congregate;
- to develop improved methods for the analysis of faecal and gut samples to determine what is eaten;
- to evaluate all methods of seal management and the effects of their implementation on seal populations and their predation on salmon.

* * * * * *

In compiling this report we have been grateful for the assistance of a number of organisations and individuals. We recognise that this is a controversial and sensitive subject, but believe that our report provides an analysis of the problem and that the conclusions and recommendations indicate a way forward.

APPENDIX A

MEMBERSHIP OF THE SALMON ADVISORY COMMITTEE

Chairman: Professor G M Dunnet*

Mr G H Bielby	Dr L Laird
Mr C G Carnie	Mr I Mitchell
Mr R M Clerk	Mr M Owens
Mr J H Ferguson	Mr D R Paton
Mr D Heselton	Dr D J Solomon

* Professor Dunnet was Chairman of the Salmon Advisory Committee from its inception in 1987 until his death in September 1995. This report was prepared under his chairmanship. The new Chairman is Mr R M Clerk.

PREVIOUS REPORTS BY THE SALMON ADVISORY COMMITTEE

- *Information on the Status of Salmon Stocks* published in September 1988 (Ref. No. PB 2021 Price £3).
- *The Effects of Fishing at Low Water Levels* published in March 1990 (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).
- *Factors Affecting Emigrating Smolts and Returning Adults* published in May 1993 (Ref. No. PB 1270, Price £4).
- *Run Timing of Salmon* published in June 1994 (Ref. No. PB 1797, Price £4.95).

Copies of these reports may be obtained from: MAFF Publications, London SE99 7TP.

APPENDIX B

PREDATORS OF ATLANTIC SALMON, *Salmo salar**

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INTRODUCTION

This report summarises what is known regarding the mortality inflicted on Atlantic salmon by predators. Table B1 lists the documented evidence for predation on Atlantic salmon worldwide. The stage of the life-cycle preyed on, the likely impact on the population and the area where the observations were made are tabulated, along with literature references. This table is as comprehensive as possible. However, because of the limited time available to search the literature, some documented examples of predation may have been overlooked. The large majority of the documented cases of salmon predation involve parr, smolt, post-smolt and adult stages of the life-cycle, yet considerable mortality occurs at the egg, alevin and fry stages. It would appear that the major predators on these stages have still to be identified, and may include invertebrate as well as vertebrate species.

In Section B1 of this report we have briefly reviewed the literature, species by species, regarding those predators listed in Table B1 likely to affect salmon stocks in UK waters. In Section B2 we have summarised the literature concerning those predators listed in Table B1 which are scarce or absent in the UK and are therefore unlikely to effect UK salmon stocks.

In Table B2 we have listed a selection of piscivorous predators which Atlantic salmon are likely to encounter at some stage of their life-cycle, and for which we have been unable, as yet, to find reliable documented evidence of salmon predation. These predators are briefly discussed in Section B3 of the text.

Following a short discussion, in which we point out the scarcity of reliable data on salmon predators, we have provided a reference list and related bibliography.

B1 PREDATORS OF ATLANTIC SALMON IN UK WATERS

B1.1 Introduction

Table B1 lists all those predator species for which we have been able to find definite records of predation on salmon. This section deals with those predators which we feel are likely to have an impact on the UK Atlantic salmon stock. For each species we have summarised the information available and have attempted to assess the level of impact, how localised or widespread such impacts are likely to be, and we have identified the vulnerable stage, or stages, of the salmon's life-cycle.

* Not to be quoted without permission of the authors.

B1.2 Fish

B1.2.1 Greenland shark *Somniosus microcephalus*. A salmon of 120 cm was found in the stomach of a Greenland shark caught in the north-west Atlantic (Bigelow and Schroeder, 1948). Templeman (1967) mentions similar incidental records.

B1.2.2 Porbeagle shark *Lamna nasus*. Incidental observations only are available. Two salmon (3 and 4 kg) were recovered from a porbeagle caught 2 km off St Cyrus, Kincardineshire (Rae, 1966). Adult salmon were also found in porbeagle sharks caught in the north-west Atlantic (Templeman, 1967).

B1.2.3 Sharks. A number of incidental records of salmon being found in the stomachs of unidentified sharks are listed in Wheeler and Gardner (1974).

B1.2.4 Skate *Raja batis*. Rae (1965a) records two incidents of skate caught in the Moray Firth, Scotland, having eaten grilse.

B1.2.5 Brown/Sea trout *Salmo trutta*. Small brown trout, 230–320 mm in length, were considered by Piggins (1962) to be a 'serious' predator of salmon smolts in Ireland. Mills (1964) also observed trout to be a threat to smolts in Ross-shire, and also noted that they consumed salmon fry between April and November. There is some indication from Norwegian work that sea trout consume smolts as they enter the sea (Hvidsten and Møkkelgjerd, 1987).

B1.2.6 Pike *Esox lucius*. The diet of pike appears to depend upon seasonal variation in the availability of various prey. Juvenile salmon are therefore most vulnerable during the smolt run when mortality inflicted by pike may vary between 10 and 20% (Mills, 1964; Mann, 1982; Larsson, 1985). Mann (1982) demonstrated that smaller pike (30–40 cm) preyed more heavily upon salmon smolts than larger pike. He suggested that control measures involving the culling of larger pike might in fact be detrimental to salmon stocks, since numbers of small pike were controlled through cannibalism by larger pike.

B1.2.7 Eel *Anguilla anguilla*. There is some evidence from Ireland that small eels prey on salmon alevins. (Piggins, 1958, 1962).

B1.2.8 Halibut *Hippoglossus hippoglossus*. A 2 kg grilse was found in the stomach of a 40 kg halibut caught in the North Minch (Rae, 1965a).

B1.2.9 Cod *Gadus morhua*. There are several incidental records of salmon post-smolts being found in the stomachs of cod caught around the Scottish coast (Rae, 1966, 1967, 1969a). On the Norwegian coast cod have been shown to gather off river estuaries at the time of the smolt run, inflicting mortality as high as 25% on emigrating smolts (Hvidsten and Møkkelgjerd, 1987; Hvidsten and Lund, 1988). The impact of cod, and other predators such as saithe (see below), on smolts at river estuaries may in fact have been higher than 25%. Retaining smolts in tank barges and releasing them well offshore increased the numbers of smolts surviving to return as adults by over 100%; suggesting that predators which normally had an impact of over 50% on smolt numbers had been avoided (Jensen, 1979; Gunnerød *et al.*, 1988).

B1.2.10 Saithe *Pollachius virens*. Like cod, saithe are thought to gather off river mouths on the west Norwegian coast. Smolts have been recorded in their stomachs and may be quite frequent in the diet, although the impact of saithe as a cause of smolt mortality has not been assessed (Hvidsten and Møkkelgjerd, 1987; Hvidsten and Lund, 1988).

B1.2.11 Pollack *Pollachius pollachius*. Irish data suggest that shoals of pollack move into estuaries to intercept migrating smolts and these may have a significant impact on smolt numbers (Piggins, 1962).

B1.2.12 Whiting *Merlangius merlangus*. There is one incidental record of a whiting containing a salmon post-smolt (Kennedy, 1954).

B1.2.13 Ling *Molva molva*. A 50 cm salmon was found in the stomach of a ling caught off Faroe Bank (Rae, 1971).

B1.2.14 Bass *Dicentrarchus labrax*. Smolts were recorded being taken by bass at the mouth of the River Blackwater, Youghal, Ireland (Kennedy, 1954).

B1.3 Birds

B1.3.1 Cormorant *Phalocrocorax carbo*. Cormorants are opportunistic feeders, exploiting the available fish species within the limits of their fishing ability and feeding range. Salmon, mainly parr and smolts taken while still in freshwater, tend to form only a small fraction of their total diet (Mills, 1965; Pearson, 1968; West *et al.*, 1975). On occasion, however, heavy predation may occur, particularly on migrating smolts, resulting in smolt mortality as high as 70% (Kennedy and Greer, 1988). Such impact is likely to occur only at a local level, dependent upon the proximity of cormorant colonies and/or roost sites to salmon rivers.

B1.3.2 Shag *Phalacrocorax aristotelis*. Shags feed predominantly close inshore in the marine environment (Cramp and Simmons, 1977) and are therefore likely to prey only upon post-smolts. Predation has been documented (Pearson, 1968; Rae, 1969) although impact levels were light. However, shag numbers may build up at river mouths, coincident with smolt runs, providing an opportunity for more significant predation at a local level (Greenstreet *et al.*, 1993).

B1.3.3 Red-throated diver *Gavia stellata*. Mainly marine except during the breeding season. There are no records of salmon predation in the UK, but in the Baltic there is some indication that red-throated divers can take significant numbers of migrating smolts if smolts are present in large numbers (Valle, 1985). This predator may be of importance in respect of hatchery-reared smolt plantings or releases.

B1.3.4 Red-necked grebe *Podiceps griseigena*. Red-necked grebes occupy estuarine and sheltered coastal waters in winter (Lack, 1986). There is one record of predation from the lower reaches of the River Beauly; a shot bird contained two smolts, two parr and three fry (Mills, 1960).

B1.3.5 Red-breasted merganser *Mergus serrator*. Red-breasted mergansers tend to occupy the lower reaches of rivers in spring and summer and move to estuaries and the inshore marine environment during the rest of the year (Carter and Evans, 1986). Thus it is only in spring and summer that salmon are particularly vulnerable to merganser predation. Juvenile salmon made up 42.5% of the prey items found in the stomachs of 148 mergansers sampled throughout Scotland (Mills, 1962) and 60% of 609 fish found in the stomachs of 56 mergansers sampled on the North Esk (Feltham, 1990). Shearer *et al.*, (1987), modelling the effect of sawbill predation on the salmon stocks of the North Esk, estimated that 20 000 to 60 000 smolts might be consumed and calculated that controlling sawbill numbers (almost all mergansers) could result in a 35% increase in the numbers of adult salmon returning to the river. However, the model made several assumptions which have recently been shown not to hold true. Shearer *et al.*, (1987) assumed that during the smolt run smolts were the sole salmon component of the mergansers' diet. However, Feltham (1990) showed that only 22% of young salmon consumed by mergansers were smolts; even during the smolt run, parr made up the bulk of juvenile salmon taken. In addition, mergansers selectively consumed the smaller smolts, those perhaps likely to be more vulnerable in the sea. Thus it is likely that the model overestimated the impact of mergansers on smolt mortality, but it took no account of the impact of mergansers on parr mortality. Mergansers are widely distributed (Carter and Evans, 1986) and are therefore likely to have an extensive impact on UK salmon stocks.

B1.3.6 **Goosander** *Mergus merganser*. In Canada, juvenile salmon, from fry to the smolt stage, have been found to contribute up to 85% of the diet of goosander* (White, 1936; Anderson, 1986). Control of goosander numbers resulted in up to five-fold increases in juvenile salmon production, albeit in conjunction with artificial stock enhancement (Elson, 1962; Anderson, 1986). Salmon predation by goosanders in the UK is also well documented (Mills, 1962, 1964). In late spring and summer goosanders occupy the upper reaches of rivers and their tributaries, while in the non-breeding season they tend to inhabit lochs and reservoirs (Carter and Evans, 1986). Salmon have been observed in the diet (up to 86% by number) of goosanders throughout the year, but may be less important during the winter (Mills, 1962). Salmon fry and small parr appear in the diet of ducklings within weeks of hatching and larger fish are taken with increasing duck size (Mills, 1962; Marquiss and Feltham, 1991). Goosander diet appears to reflect the relative abundance of prey available, thus salmon feature more strongly where they are abundant and where they are the dominant species in the fish assemblage (Mills, 1962, 1964). Goosanders are highly mobile and are able to respond quickly to variation in prey abundance (Wood, 1985), suggesting that concentrations of salmon, such as occur during the smolt run, may be more vulnerable to predation. However, predation on smolts is not clearly documented in the UK, although tags fitted to hatchery-reared smolts have been recovered in shot goosanders (Mills, 1964). Marquiss and Feltham (1991) observed that fry and parr were the main salmon life-cycle stages preyed on; smolts were rarely taken. Goosanders are widely distributed (Carter and Evans, 1986) and are therefore likely to have an extensive impact on UK salmon stocks.

B1.3.7 **Heron** *Ardea cinerea*. There are few records of heron predation in the literature, although smolt tags have been recovered from heronries. Impact on salmon in the Burrishoole River was assessed as less than 10% (Piggins, 1962). Herons may have

* In Canada *Mergus merganser* is known by the common name 'merganser'. Thus Canadian work on 'mergansers' refers to the birds known in the UK as 'goosanders'.

some impact on smolts migrating down unprotected fish-ladders or over weirs. Smolts, fitted with acoustic tags, migrating down a release ladder suffered 11% losses through heron predation (Greenstreet, unpublished, a). Up to 600 tags fitted to smolts on the River North Esk have been recovered at local heronries in one year (J. C. MacLean, SOAEFD, Montrose, *pers comm*). An average of approximately 7000 smolts are tagged on this river each year and a recovery rate as high as 600 (and many tags probably go unrecovered) suggests that herons may cause moderate smolt mortality on rivers where they are numerous.

B1.3.8 Blackheaded gull *Larus ridibundus*. Blackheaded gulls have been seen feeding on juvenile salmon, and smolts made up 53% of the prey items found in the stomachs of 19 blackheaded gulls shot on the River Bran, Ross-shire (Mills, 1964). Predation from blackheaded gulls may only occur near their breeding colonies and may therefore be a local phenomenon. However, breeding colonies of these gulls occur on or near many of the major Scottish salmon rivers.

B1.3.9 Herring gull *Larus argentatus*. Herring gulls were observed taking migratory hatchery-reared smolts in south-west Scotland. However, those smolts taken were unhealthy, appearing darker in colour and moribund (Armstrong, 1989 unpublished). Impact on healthy smolts may only be light.

B1.3.10 Common gull *Larus canus*. Most literature regarding salmon predation by gulls suggests that common gulls are the most frequent predator (e.g. Reitan *et al.*, 1987). Of prey items taken from the stomachs of 16 common gulls shot at the nest in Ross-shire, 46% were juvenile salmon (Mills, 1964). The presence of smolt tags in gull pellets indicates that young salmon are vulnerable right up to, and including, the smolt stage of their life-cycle. Common gull colonies are not numerous and are discretely located so predation would only occur at the local level and is unlikely to be heavy.

B1.3.11 Sandwich tern *Sterna sandvicensis*. There are incidental records of tags fitted to smolts in the River North Esk being recovered at the nests of sandwich terns on the Sands of Forvie National Nature Reserve, Aberdeenshire, 80 km to the north (J. C. MacLean, SOAEFD, Montrose, *personal communication*). It is not known whether the smolts were captured in the North Esk or intercepted further north, thus the geographical extent of any impact is difficult to determine. Some 65 tags were recovered between 1978 and 1987, but the actual impact of sandwich terns on smolt numbers is difficult to assess.

B1.3.12 Gannet *Sula bassana*. Post-smolts (juvenile salmon from the time they leave the river as smolts until the onset of wide annulus formation on the scales at the end of the first winter in the sea; Allan and Ritter, 1977), made up less than 1% of the diet of gannets off Newfoundland (Montevecchi *et al.*, 1988). Post-smolts have been recorded in the diets of gannets in the Clyde (Wanless, 1984), but so infrequently as to suggest that any impact on post-smolt mortality would appear to be light. However, in one incident involving the release of 1200 salt water adapted smolts into the mouth of the River Lussa in south-east Kintyre, the numbers of gannets feeding off the river mouth quickly built up and an estimated 300–400 post-smolts were consumed (Greenstreet, unpublished).

B1.3.13 Hooded crow *Corvus corvus cornix*. There is one record of a bird observed taking smolts at a trap on the River Meig, Ross-shire (Mills, 1960).

B1.4 Mammals

B1.4.1 Otter *Lutra lutra*. Otters appear to be highly dependent on fish. They show a preference for slower-moving species, such as eels and other coarse fish, and these make up the bulk of the diet where they are available. Only in rivers where salmonids are the most numerically abundant prey, species do salmon and trout constitute a significant fraction of the diet. Fish varying in length from 6 to 45 cm may be consumed (Wise *et al.*, 1981). Salmonids occur most frequently in the diet of otters in autumn and winter when alternative, more preferred prey, such as eels are less abundant (Jenkins *et al.*, 1979; Wise *et al.*, 1981). This suggests that otters may prey most heavily on parr and returning adults, rather than on smolts. Carss *et al.* (1990) observed that salmon occurred most frequently in the diet of otters on the River Dee, Aberdeenshire, in January, and that apparently healthy adult males were the most frequent prey. Large numbers of these fish may have been taken, but since most had already spawned, and repeat spawners made up only around 5% of the spawning population, the impact on the spawning stock was probably slight. Family groups of otters have been seen feeding heavily on emigrating hatchery-reared smolts at the bottom of a release ladder in south-east Kintyre, as well as on returning adult fish (Greenstreet, unpublished). Smolt tags have also been recovered from otters killed at smolt traps elsewhere in Scotland (Mills, unpublished). Otters are relatively rare, but are widely distributed. Their impact on salmon stocks will depend on a variety of local conditions.

B1.4.2 Mink *Mustela vison*. Mink take less fish than otters, in general preferring mammalian and avian prey (Akande, 1972; Day and Linn, 1972; Dunstone and Birks, 1987). Those fish taken tend to be the slower-moving coarse fish species or tidal rock pool fish (Day and Linn, 1972; Dunstone and Birks, 1987) Salmonids only feature strongly in the diets of mink feeding on rivers where salmon and trout make up the bulk of the fish biomass, e.g. in Scotland (Akande, 1972) and English chalk streams (Chanin and Linn, 1980). Even then it would appear that salmonids are mainly taken in winter when alternative terrestrial prey, such as rabbits, are less abundant (Wise *et al.*, 1981). Only trace salmonid remains were found in the scats of coastal living mink (Dunstone and Birks, 1987). In all the above-mentioned studies, salmon and trout were not differentiated among the prey remains, but both species were available in the study areas and it therefore seems likely that salmon were included within the diets of the animals studied. Like otter, mink are likely to be a problem at a local level.

B1.4.3 Grey seal *Halichoerus grypus*. Grey seals are known to take salmon from nets and are frequently seen taking salmon in rivers and estuaries (Harwood, 1984). However, quantifying their impact on salmon stocks is proving to be extremely difficult. Between 1958 and 1971, 609 grey seals were dissected by the Department of Agriculture and Fisheries for Scotland (DAFS) and salmon remains were found in approximately 25% (Rae, 1968, 1973). Salmon was estimated to constitute anything between 20% and 80% of the diet of grey seals (Lockie, 1962; Rae, 1960, 1973), indicating significant impact on salmon stocks (Parrish and Shearer, 1977) along with other collateral damage to the salmon fishing industry (e.g. Rae, 1960; Rae and Shearer, 1965). Through the 1980s the Natural Environment Research Council's Sea Mammal Research Unit (SMRU) studied the diet of grey seal by identifying otoliths found in faecal samples collected at breeding and haul-out sites. Their results differed considerably from the earlier studies of Rae *(op. cit.)*. The SMRU studies indicated that grey seal diet varied both seasonally and geographically in response to variation in local prey availability. It appeared that sandeels were the most important prey species. No salmonid remains were found in any of the faecal samples examined by SMRU, who estimated that salmon predation may constitute less than 1–2% of the total diet (McConnell *et al.*, 1984; Prime and Hammond, 1985, 1990; Hammond and Prime, 1990). In captive feeding experiments otolith recovery from faecal samples was found to be unrepresentative of actual food intake (Boyle *et al.*, 1990). Identification of skeletal remains in addition to otoliths generally improves diet description using faecal sample analysis (Pierce *et al.*, 1991a). Despite this however, in a more recent study, faecal sample analysis failed to identify salmon in the diets of grey seals (Pierce *et al.*, 1990b) whereas analysis of digestive tract samples suggested that salmon may have contributed 4% or more of the prey biomass (Pierce *et al.*, 1989), particularly of grey seals taken near salmon nets (Pierce *et al.*, 1991c).

B1.4.4 Common seal *Phoca vitulina*. The problems in determining the diet of grey seals apply equally to common seals. Rae (1968, 1973) examined the stomach contents of 253 common seals between 1958 and 1971. Between 5% and 8% contained the remains of salmon, leading Rae to conclude that common seals were a predator of salmon, but that they had less impact on stocks and caused less damage to the fishery than grey seals. Analysis of faecal samples indicated that salmon formed a small part (1–11%) of common seal diets in the Moray Firth over summer and in early autumn (Pierce *et al.*, 1990b, 1991b), while examination of digestive tract samples suggested that near to fishing nets salmonids were frequently taken (17% of tracts), but they were absent in samples taken away from nets (Pierce *et al.*, 1991c).

B1.4.5 Bottlenose dolphin *Tursiops truncatus*. Bottlenose dolphins have been observed attacking salmon in the Moray Firth (P.M. Thompson, unpublished).

B2 ADDITIONAL PREDATORS OF ATLANTIC SALMON AFFECTING STOCKS OUTSIDE UK WATERS

B2.1 Introduction

In this section we have summarised the literature concerning those predators listed in Table B1 which were not discussed in Section B1, and which we do not consider to have any impact on the salmon stocks of the UK.

B2.2 Fish

B2.2.1 Burbot *Lota lota*. Burbot are a major predator of Baltic salmon in Sweden. Impacts on hatchery-reared smolts as high as 30% have been recorded and losses of wild smolts may be as high as 35% (Larsson, 1977, 1985).

B2.2.2 Garfish *Belone belone*. There is one record of garfish as a predator of Baltic salmon (Carlin, 1954).

B2.3 Birds

B2.3.1 Double-crested cormorant *Phalocrocorax auritus*. Apparent increases in double-crested cormorant populations coincided with declining return rates of hatchery-reared Atlantic salmon smolts released into Passamaquoddy Bay, New Brunswick. However, an investigation into cormorant diets suggested that their depredation rate accounted for less than 1% of the smolts released (Kehoe, 1987).

B2.3.2 Caspian tern *Hydroprogne caspia*. At least 2% of Baltic salmon smolts released into two rivers in northern Finland were consumed by caspian terns (Valle, 1985).

B2.3.3 Belted kingfisher *Megaceryle alcyon*. Salmon fry and parr constitute up to 80% of the diets of kingfishers feeding on salmon rivers. Kingfisher diet appears to reflect the relative abundance of the various prey species available. Juvenile salmon were more prevalant in the diet in areas where they constituted the major part of the fish biomass in the river (White, 1936, 1937, 1953; Elson, 1962).

B3 POTENTIAL PREDATORS OF ATLANTIC SALMON

B3.1 Introduction

Any piscivore encountering Atlantic salmon of a size it is capable of eating is likely at some time or other to include Atlantic salmon in its diet. The seriousness of any impact will depend on many factors, including for example: predator abundance, salmon abundance and the availability of alternative prey species. Table B2 provides a list of mainly piscivorous predators that Atlantic salmon are likely to encounter. The possibility exists that predators on this list may have an impact on salmon numbers under particular circumstances and at specific locations. However, we have been unable to find any reference in the literature to predation on Atlantic salmon by any of these species. Table B2 is therefore a list of additional possible predators; there is no conclusive evidence, that we are aware of, that any of these species is in fact a salmon predator. Some caution, and research, will therefore be required before implicating any of the predators on this list.

B3.2 Fish

In fresh water it is likely that several predators of juvenile salmon have yet to be ‘discovered’; some of these may be fish. Freshwater piscivorous fish, such as perch, may take fry and small parr, but where perch diet has been examined, juvenile salmon were absent. Indeed, because perch may help to control trout numbers, their removal may in fact be detrimental to salmon stock management (Mills, 1964). Lampreys and lamperns may cause damage to parr which could result in death. On occasion lampreys have got into hatcheries and parr have been found with characteristic wounds from the sucker discs (Greenstreet, personal communication) and this may occur in the wild. Adult lamprey (*P. marinus*) may attack adult salmon in the sea (Wheeler, 1978).

As marine fish increase in size their diets tend towards increased piscivory (Daan, 1973, 1981; Robb and Hislop, 1980), thus salmon post-smolts may be at risk from any piscivorous predator two to three times their size or more. The number of potential marine fish predators of post-smolts is therefore too numerous to be listed in full, but Table B2 contains a few candidates. Some of the bigger carnivorous species, such as members of the shark family, may also attack adult salmon. This is an area where data are lacking, and it is difficult to conceive of an adequate method of rectifying this shortcoming The spurdog was assessed to be the most likely predator of hatchery-reared salmon smolts leaving the River Lussa in south-east Kintyre. However, despite an intensive sampling programme, predation by spurdogs was not confirmed (Morgan *et al.*, 1986).

B3.3 Birds

Sea eagles and ospreys are piscivorous birds of prey whose UK distributions are almost entirely confined to Scotland. Osprey numbers have built up to around 50 pairs and some 70 sea eagles have been reintroduced into the wild on the Island of Rhum following the extinction of both species in the UK in the early 1900s. Ospreys are present in Scotland between the months of April and September inclusive, feeding mainly on fresh-water, although they may also visit estuaries. Salmonids make up the bulk of the diet, although pike and perch (*Perca fluviatilis*) also feature. Fish of around 0.5 kg make up the bulk of the diet, although fish of up to 2 kg may be taken (Brown, 1976). Thus trout are likely to be the salmonid most frequently taken, but small grilse may also be vulnerable (Brown and Waterston, 1962). Pictures of ospreys with salmonid prey of 0.5 to 1.5 kg abound in the popular literature (e.g. Brown, 1979).

Sea eagles are rare in the UK, those present being the result of the Nature Conservancy Council reintroduction scheme on Rhum (Love, 1983). They remain more common along the Norwegian, Icelandic and Greenland coasts where they feed predominantly in the marine environment. A variety of fish species have been recorded in the diet, including gadids, flatfish, dogfish, lumpsuckers (*Cyclopterus lumpus*). Most fish caught weigh between 0.5 and 3 kg. Sea eagles do feed in fresh water habitats where pike, perch, eels and other coarse fish species are taken (Brown, 1976; Love, 1983). Anecdotes refering to sea eagles watching over falls where salmon jump exist in the literature (e.g. Ussher and Warren, 1900, quoted in Love, 1983) and salmon may occur in the diets of Norwegian sea eagles (Willgohs, 1961). In America, related bald eagles (*H. leucocephalus*) and Steller's eagle (*H. pelagicus*) feed on Pacific salmon kelts (Brown and Amadon, 1969).

The black-throated diver breeds in the UK on large lochs in the north-west of Scotland (Sharrock, 1976). These birds are piscivores, feeding on small fish, and small salmonids may be vulnerable. However, because black-throated divers are so restricted to lochs, trout are more likely to be taken than salmon. Although black-throated divers winter on estuaries and coastal waters (Lack,1986), they are unlikely to be able to cope with anything larger than a smolt. Great northern divers also winter around the UK coast and can take small cod and herring (Lack, 1986), and so could potentially cope with post-smolts. However, since the numbers of divers around the coast are least at the time of the smolt run (Webb *et al.*, 1990), these species are unlikely to pose much of a threat to salmon in the marine environment.

Slavonian grebes breed in Scotland, but their preference for small, shallow, acidic fresh water lochs (Sharrock, 1976) suggests that they will encounter few juvenile salmon. Little grebes occupy more eutrophic water and breed in a greater diversity of fresh water habitats (Sharrock, 1976). They take small fish and may therefore pose a threat to salmon fry. Both species are more coastal in winter (Lack, 1986), but are unlikely to be a threat to salmon in the sea.

The kingfisher breeds mainly in England, Wales and Ireland and is only rarely found in Scotland (Sharrock, 1976). In winter it remains on fresh water habitats, but has a more coastal distribution (Lack, 1986). Its diet consists almost entirely of small fish up to 8 cm (Boag, 1982), so salmon fry and small parr may be included.

B3.4 Mammals

Apart from the incidental observations of Atlantic salmon being attacked by bottle-nose dolphins mentioned above, we have been unable to find definite records of Atlantic salmon in the diets of any member of the whale families. Porpoises were accused of being an enemy of salmon in the sea (e.g. Berry, 1935; MacIntyre, 1934). However, examination of the stomachs of 52 porpoises taken mainly from inshore waters on the east coast of Scotland between the months of November and March 1959 to 1965 failed to confirm predation on salmon. Herring and sprat were the dominant prey species, although whiting and cod were also frequently taken (Rae, 1965b). Other possible predators in the North Atlantic include white-beaked, white-sided and Risso's dolphins. Of the three, the white-beaked seems to have the most piscivorous diet, taking a variety of demersal and pelagic fish species (van Bree and Nijssen, 1964). White-sided and Risso's dolphins feed primarily on cephalopods (Mitchell, 1975), although white-sided dolphins also frequently take pelagic fish such as herring (Sergeant and Fisher, 1957).

Other toothed whales (Odontoceti) in the North Atlantic which may prey on Atlantic salmon include the killer, long-finned pilot, white and sperm whales. The diet of 95 killer whales off the Norwegian coast consisted almost entirely of herring, although one had taken a cod (Christensen, 1982). Cephalopods, birds and marine mammals are also known to be important foods (Nishiwaki and Handa, 1958). Two reviews of the general biology and ecology of killer whales suggest that they are opportunistic feeders and may be important predators of Pacific salmon (*Oncorhynchus* sp.) in Alaskan waters (Leatherwood and Bowles, 1984; Matkin and Leatherwood, 1986). Long-finned pilot whales feed mainly on squid off Newfoundland, but took Atlantic cod on occasion (Sergeant, 1962). In European waters scad (*Trachurus trachurus*) and flatfish were included in addition to the squid (*Ommastrephes sagittatus*) (Mitchell, 1975). Around the Faroe Islands cephalopods formed the bulk of the diet; fish occurred rarely but the two species most frequently taken were greater argentine (*Argentina silus*) and blue whiting (*Micromesistius poutassou*) (Desportes and Mouritsen, 1988). White whales (*belugas*) take a wide spectrum of shallow water prey including decapod crustaceans, cephalopods and schooling fish (Mitchell, 1975). However, in Alaskan waters white whales may also feed on Pacific salmon adults and post-smolts (Seaman and Burns, 1981). Sperm whales feed almost entirely on cephalopods; specimens 19 m in length have been recorded. Fish have occasionally been observed in stomach contents including a shark (*Cetorhinus*) of

3 m. This suggests that sperm whales are quite capable of taking a salmon should they encounter one, however sperm whales are predominantly deep water feeders (Berzin, 1972).

The baleen whales (Mysticeti) use their baleen plates to filter feed and therefore feed predominantly on crustacea, cephalopods and small pelagic fish, such as capelin (*Mallotus villosus*). However, adult cod, saithe, haddock and herring have been found in the stomachs of minke whales caught off the Norwegian coast and in the North Atlantic (Jonsgard, 1982; Nordø *et al.*, 1990), suggesting that at least this species is capable of taking larger fish.

Seals are generally opportunistic foragers feeding on whatever is most available to them (Anon, 1986). Atlantic salmon migrate through regions occupied by hooded, harp, ringed and bearded seals, in addition to the grey and common seal discussed above (Bonner, 1989). While all four species appear capable of feeding on fairly large fish, such as cod (Anon,1986; Nilssen *et al.*, 1990), we have found no record of Atlantic salmon occurring in their diets.

B4 DISCUSSION

Whilst preparing this report we were surprised to discover how little well-documented information on the predators of Atlantic salmon is available in the scientific literature (although we acknowledge that we may have missed a number of key references and would be glad to be informed of any serious omissions). We unearthed much anecdotal information, but few factual reports. Even the well-documented records often consisted of isolated instances of predation, or reports of predation on hatchery-reared and/or tagged fish, which might be expected to be more vulnerable to predators than wild salmon.

Another problem that we encountered was how to define predation. For example, a number of species of birds (including ducks, swans and even dippers) and fish (including salmonids and eels) have been accused of eating salmon eggs at redds. However, since it seems likely that the majority of eggs eaten in such circumstances were incompletely buried and would not have survived, should this be classed as predation? Similarly, a number of birds and mammals will prey on diseased fish or descending kelts, whose viability is questionable.

There is an obvious need for considerably more well-planned research before the effects of predation on any of the life stages of the Atlantic salmon can be objectively assessed.

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B6 REFERENCES AND RELATED BIBLIOGRAPHY

Akande, M. (1972) The food of feral mink (*Mustela vison*) in Scotland. *J. Zool. Lond.*, **167**, 475–479.

Allan, I.R.H. and Ritter, J.A. (1977) Salmonid terminology. *J. Cons. Int. Explor. Mer.*, **37**, 293–299.

Anderson, J.M. (1986) Merganser predation and its impact on Atlantic salmon stocks in the Restigouche River system, 1982–1985. *Atlantic Salmon Federation Special Publication*, **13**, 66 pp.

Anon. (1986) Seals and sealing in Canada. *Rep. Roy. Commn.*, **3**, 679 pp.

Armstrong, R. (1989 unpublished) The impact of seabird predation on the release of hatchery-reared salmon smolts. Results of 1988 field season. *Internal Report to DAFS, Freshwater Fisheries Laboratory*.

Barrett, R.T., Røv, N., Loen, J. and Montevecchi, W.A. (1990) Diets of shag, *Phalaxcrocorax aristotelis*, and cormorants, *P. carbo*, in Norway and possible implications for gadoid stock recruitment. *Mar. Ecol. Prog. Ser.*, **66**, 205–218.

Berry, J. (1935) British mammals and birds as enemies of the Atlantic salmon *(Salmo salar). Rep. Avon Biol. Res.* 1934–35, 31–64.

Berzin, A.A. (1972) *The Sperm Whale.* Keter Press, Jerusalem. Translated from Russian.

Bigelow, H.B. and Schroeder, W.C. (1948) Fishes of the western North Atlantic – sharks. *Mem. Sears Found. Mar. Res.*, **1**, 59–546.

Boag, D. (1982) *The Kingfisher.* Blandford Press, Poole, Dorset, 120 pp.

Bonner, W.N. (1989) *The Natural History of Seals.* Helm, Bromley, Kent, 196 pp.

Boyle, P.R., Pierce, G.J. and Diack, J.S.W. (1990) Sources of evidence for salmon in the diet of seals. *Fish. Res.*, **10**, 137–150.

Brown, L. (1976) *British Birds of Prey.* Collins, London, 400 pp.

Brown, L.H. and Amadon, D. (1969) *Eagles, Hawks and Falcons of the World.* Country Life/Hamlyn, Feltham.

Brown, P. (1979) *The Scottish Ospreys: From Extinction to Survival.* Heinemann, London, 190 pp.

Brown, P. and Waterston, G. (1962) *The Return of the Osprey.* Collins, London.

Brown, R.F. and Mate, B.R. (1982) Abundance, movements and feeding habits of harbour seals, *Phoca vitulina*, at Netarts and Tillamook Bays, Oregon. *Fish. Bull.*, **81**, 291-301.

Browne, J., Eriksson, C., Hansen, L-P., Larsson, P-O., Lecomte, J., Piggins, D.J., Prouzet, P., Ramos, A., Sumari, O., Thorpe, J. E. and Toivonen, J. (1983) COST project 46/4 on ocean ranching of Atlantic salmon: pp. 16–94. final report. In *Action COST* **46** *Mariculture: Rapport Final.* Comm. des Comm. Europ., Brussels.

Calderwood, W.L. (1931) *Salmon Hatching and Salmon Migrations.* Arnold, London, 95 pp.

Carlin, B. (1954) Tagging of salmon smolts in the River Lagan. *Rep. Inst. Freshwater, Res. Drottningholm,* **36**, 57–74.

Carss, D.N., Kruuk, H. and Conroy, J.W.H. (1990) Predation on adult Atlantic salmon, *Salmo salar* L., by otters, *Lutra lutra* (L)., within the River Dee system, Aberdeenshire, Scotland. *J. Fish Biol.*, **37**, 935–944.

Carter, S.P. and Evans, P.R. (1986) Goosander and merganser studies in Scotland. *Final Report to the Nature Conservancy Council on contract* **HP3-03-208/9**.

Chanin. P.R.F. and Linn, I. (1980) The diet of feral mink *(Mustela vison)* in southwest Britain. *J. Zool. Lond.,* **192**, 205–223.

Christensen, I. (1982) Killer whales in Norwegian coastal waters. *Rep. Int. Whal. Commn.,* **32**, 633–642.

Coull, K.A., Jermyn, A.S., Newton, A.W., Henderson, G.I. and Hall, W.B. (1989) Length/weight relationships for 88 species of fish encountered in the north-east Atlantic. *Scot. Fish. Res. Rep.,* **43**, 81pp.

Cramp, S. and Simmons, K.E.L. (eds) (1977) *The Birds of the Western Paleartic.* Oxford University Press, Oxford.

Daan, N. (1973) A quantitative analysis of the food intake of North Sea cod *Gadus morhua. Neth. J. Sea Res.,* **6**, 479–517.

Daan, N. (1981) Feeding of North Sea cod in round fish area six in 1980; preliminary results. *ICES Document,* CM 1981/G:73.

Day, M.G. and Linn, I. (1972) Notes on the food of feral mink, *Mustela vison,* in England and Wales. *J. Zool. Lond.,* **167**, 463–473.

Desportes, G. and Mouritsen, R. (1988) Diet of the pilot whale, *Gobicephala melas,* around the Faeroe Islands. *ICES Document,* CM 1988/N:12.

Dunstone, N. and Birks, J.D.S. (1987) The feeding ecology of mink *(Mustela vison)* in a coastal habitat. *J. Zool. Lond.,* **212**, 69–83.

Elson, P.F. (1962) Predator–prey relationships between fish eating birds and Atlantic salmon. *Bull. Fish. Res. Bd. Can.,* **133**, 1–87.

Feltham, M.J. (1990) The diet of red-breasted mergansers *(Mergus serrator)* during the smolt run in NE Scotland: the importance of salmon *(Salmo salar)* smolts and parr. *J. Zool. Lond.,* **222**, 285–292.

Greenstreet, S.P.R., Morgan, R.I.G., Barnett, S. and Redhead. P. (1993) Variation in the numbers of shag, *Phalaxcrocorax aristotelis,* and common seals, *Phoca vitulina,* near the mouth of a small Atlantic salmon, *Salmo salar,* river at the time of the smolt run. *J. Anim. Ecol.,* **62**, 565–576.

Gunnerød, T.B., Hvidsten, N.A. and Heggberget, T.G. (1988) Open sea releases of Atlantic salmon smolts, *Salmo salar,* in central Norway, 1973–83. *Can. J. Fish. Aquat. Sci.,* **45**, 1340–1345.

Hammond, P.S. and Prime, J.H. (1990) The diet of British grey seals, *Halichoerus grypus.* In *Population Biology of Sealworm* (Pseudoterranova decipiens) *in Relation to its Intermediate and Seal Hosts* (W.D. Brown, ed.), *Can. Bull. Fish. Aquat. Sci.,* **222**, 243–254.

Harkonen, T.J. (1987) Seasonal and regional variations in the feeding habits of the harbour seal, *phoca vitulina*, in the Skagerrak and the Kattegat. *J. Zool.*, **213**, 535-543.

Hartt, A.C. (1980) Juvenile salmonids in the oceanic system: the critical first summer. In *Salmonid Ecosystems of the North Pacific* (W.J. McNeil and D.C. Himsworth, eds) pp. 25-37. Oregon State University Press, Corvallis, Oregon, USA.

Harwood, J. (1984) Seals and fisheries. *Mar. Poll. Bull.,* **15** (12), 426–429.

Horwood, J.W. and Cushing, D.H. (1978) Spatial distributions and ecology of pelagic fish. In *Spatial Pattern in Plankton Communities* (J.H. Steele ed), Plenum Press, New York and London, pp. 355-384.

Hvidsten, N.A. and Lund, R.A. (1988) Predation on hatchery-reared and wild smolts of Atlantic salmon, *Salmo salar* L., in the estuary of the River Orkla, Norway. *J. Fish Biol.,* **33**, 121–126.

Hvidsten, N.A. and Møkkelgjerd, P.I. (1987) Predation on salmon smolts, *Salmo salar* L., in the estuary of the River Surna, Norway. *J. Fish Biol.,* **30**, 273–280.

Jenkins, D., Walker, J.G.K. and McCowan, D. (1979) Analysis of otter *(Lutra lutra)* faeces from Deeside, NE Scotland. *J. Zool. Lond.,* **187**, 235–244.

Jensen, K. W. (1979) Salt water releases and salt water adaptation of smolts of Atlantic salmon. *ICES Document,* CM 1979/M:8.

Jobling, M. (1987) Marine mammal faeces samples as indicators of prey importance – a source of error in bioenergetics studies. Sarsia, **72**, 255–260.

Jonsgard, A. (1982) The food of minke whales *(Balaenoptera acutorostrata)* in northern North Atlantic waters. *Rep. Int. Whal. Commn.,* **32**, 259–262.

Kehoe, F.P. (1987) The effect of double-crested cormorant predation on the Salmon Genetics Research Program (SGRP) *SGRP Tech. Rep.,* **66**, 29 pp. Atlantic Salmon Federation, St Andrews, NB, Canada.

Kennedy, M. (1954) *The Sea Angler's Fishes.* Hutchinson, London, 524 pp.

Kennedy, G.J.A. and Greer, J.E. (1988) Predation by cormorants *(Phalacrocorax carbo* L.) on the salmonid populations of an Irish river, Northern Ireland, UK. *Aquacult. Fish. Management,* **19**, 159–170.

Keyes, M.C. (1968) The nutrition of pinnipeds. In *Behavior and Physiology of Pinnipeds* (R.J. Harrison et.al., eds). Appleton – Century – Crofts, New York pp 359–396.

Lack, P. (1986) *The Atlas of Wintering Birds in Britain and Ireland.* T. and A. D. Poyser, Calton, 447 pp.

Larsson, H.-O. (1977) The influence of predation after release on the result of salmon smolt planting. *ICES paper* 1977/M44.

Larsson, H.-O. and Larsson, P.-O. (1975) Predation pa nyutsatt odlad smolt i Lulealven 1974. English summary: Predation on hatchery-reared smolts after release in River Lule 1974. *Swed. Salmon Res. Inst. Rep.,* **9**.

Larsson, P.-O. (1985) Predation on migrating smolts as a regulating factor in Baltic salmon, *Salmo salar* L., populations. *J. Fish Biol.,* **26**, 391–397.

Leatherwood, S. and Bowles, A.E. (1984) Killer whales *(Orcinus orca)* in southeast Alaska, Prince William Sound and Shelikof Strait: a review of available information. *Rep. Int. Whal. Comn.,* **34**, 521–530.

Lindroth, A. (1955) Mergansers as salmon and trout predators in the River Indalsalven. *Rep. Inst. Freshwater Res. Drottningholm,* **36**, 126–132.

Lockie, J.D. (1962) Grey seals as competitors with man for salmon. In *Exploitation of Natural Animal Populations* (E. D. LeCren and M. W. Holdgate, eds) pp. 316–322. Blackwell Scientific Publications, Oxford.

Love, J.A. (1983) *The Return of the Sea Eagle.* Cambridge University Press, 240 pp.

Mann, R.H.K. (1982) The annual food consumption and prey preferences of pike *(Esox lucius)* in the River Frome, Dorset. *J. Anim. Ecol.,* **51**, 81–95.

Markussen, N.H. and Ryg, M. (1990) Energy requirements for maintenance and growth of captive harbour seals, *phoca vitulina. Can. J. Zool.,* **68**, 423–426.

Marquiss, M. and Feltham, M.J. (l991) Sawbill ducks and salmon. *ITE Final Report to SOAEFD.*

Matkin, C.O. and Leatherwood, S. (1986). General biology of the killer whale, *Orcinus orca*: a synopsis of knowledge. In *Behavioural Biology of Killer Whales* (B.C. Kirkevolde and J.S. Lockard, eds) pp. 35–68. Alan R. Liss Inc., New York.

McCabe, G.T. Jr., Long, C.W. and Park, D.L. (1979) Barge transportation of juvenile salmonids on the Columbia and Snake Rivers. *Mar. Fish. Rev.,* **41**, 28–34.

McConnell, B.J., Prime, J.H., Hiby, A.R. and Harwood, J. (1984) Grey seal diet. In *Interactions between Grey Seals and UK Fisheries*. Report by Sea Mammal Research Unit, NERC, to DAFS, pp.148–186.

MacIntyre, D. (1934) Sea enemies of salmon. *Salm. Trout Mag*., **74**, 38–42.

Menzies, W.J.M. (1925) *The Salmon: Its Life Study*. Blackwood, Edinburgh, 210 pp.

Mills, D.H. (1960) Hooded crow and red-necked grebe as predators of salmon. *Scottish Birds*, **1** (9).

Mills, D.H. (1962) The goosander and red-breasted merganser as predators of salmon in Scottish waters. *Freshwater Salm. Fish. Res*., **29**, 10 pp.

Mills, D.H. (1964) The ecology of the young stages of the Atlantic salmon in the River Bran, Ross-shire. *Freshwater Salm. Fish. Res*., **32**, 58 pp.

Mills, D.H. (1965) The distribution and food of the cormorant in Scottish inland waters. *Freshwater Salmon Fish. Res.* **35**, 16 pp.

Mitchell, E. (1975) Report of the meeting on smaller cetaceans, Montreal, 1–11 April 1974. *J. Fish. Res. Bd Can*., **32**, 889–983.

Montevecchi, W.A., Cairns, D.K and Birt, V.L (1988) Migration of post-smolt Atlantic salmon, *Salmo salar*, off northeastern Newfoundland, as inferred by tag recoveries in seabird colony. *Can. J. Fish. Aquat. Sci*., **45**, 568–571.

Morgan, R.I.G., Greenstreet, S.P.R. and Thorpe, J.E. (1986) *First Observations on Distribution, Food and Fish Predators of Post-smolt Atlantic Salmon,* Salmo salar, *in the Outer Firth of Clyde*. ICES, CM 1986/M:27.

Nilssen, K.T., Grotnes, P.E. and Haug, T. (1990) The effect of invading harp seals (*Phoca groenlandica*) on local coastal fish stocks of north Norway. *ICES*, CM 1990/N:11.

Nordø, E.S., Mathiesen, S.D. and Blix, A S. (1990) Food selection and energy uptake in minke whales (*Balaenoptera acutorostrata*). *Rep. Int. Whal. Commn*., **40**, 593–594.

Nishiwaki, M. and Handa, C. (1958) Killer whales caught in the coastal waters off Japan for recent 10 years. *Sci. Rep. Whales Inst. Tokyo,* **13**, 85–96.

Parrish, B.B. and Shearer, W.M. (1977) Effects of seals on fisheries. *ICES*, CM 1977/M:14, 1–4.

Payne, P.M. and Selzer, L.A. (1989) The distribution, abundance and selected prey of the harbour seal, *Phoca vitulina concolor,* in southern New England. *Mar. Mammal* Sci., **5**, 173–192.

Pearson, T.H. (1968) The feeding biology of sea-bird species breeding on the Farne Islands, Northumberland. *J. Anim. Ecol*., **37**, 521–552.

Pervozvanskiy, V.Ya., Bugaev, V.F., Shustov, Yu.A. and Shchurov, I.L. (1988) Some characteristic features of ecology of the pike, *Esox lucius*, from the salmon River Keret (the White Sea Basin). *J. Ichthyol*., **28**, 136–140.

Piggins D.J. (1958) Investigations on predators of salmon smolts and parr. *Annu. Rep. Salmon Res. Trust Ireland Inc,* Appendix I, 12 pp.

Piggins, D.J. (1962) Predation of brown trout, certain birds and marine fish upon salmonid fishes. *Rep. Challenger Soc.,* **3** (14), 25 pp.

Piggins, D.J. (1964) *Annu. Rep. Salmon Res. Trust Ireland Inc.* 17 pp.

Piggins, D.J. and Mills, C.P.R. (1985) Comparative aspects of the biology of naturally produced and hatchery reared Atlantic salmon smolts (salmo salar L.) *Aquaculture*, **45**, 321–333.

Pierce, G.J., Diack, J.S.W. and Boyle, P.R. (1989) Digestive tract contents of seals in the Moray Firth area of Scotland. *J. Fish Biol.*, **35** (Suppl. A), 341–343.

Pierce, G.J., Boyle, P.R., Diack, J.S.W. and Clark, I. (1990a) Sandeels in the diet of seals: application of novel and conventional methods of analysis to faeces from seals in the Moray Firth area of Scotland. *J. Mar. Biol. Assoc. UK*, **70**, 829–840.

Pierce, G.J., Boyle, P.R and Thompson, P.M. (1990b) Diet selection by seals. In *Trophic Relationships in the Marine Environment, Proc. 24th Eur. Mar. Biol. Symp.* (M. Barnes and R.N. Gibson, eds), pp. 222–238. Aberdeen University Press.

Pierce, G.J., Boyle, P.R and Diack, J.S.W. (1991a) Identification of fish otoliths and bones in faeces and digestive tracts of seals. *J. Zool. Lond.*, **224**, 320–328.

Pierce, G.J., Thompson, P.M., Miller, A, Diack, J.S.W., Miller, D. and Boyle, P.R. (1991b) Seasonal variation in the diet of common seals (*Phoca vitulina*) in the Moray Firth area of Scotland. *J. Zool. Lond.*, **223**, 641–652.

Pierce, G.J., Boyle, P.R. and Diack, J.S.W. (1991c) Digestive tract contents of seals in Scottish waters: comparison of samples from salmon nets and elsewhere. *J. Zool. Lond.* **225**, 670–676.

Prime, J.H. and Hammond, P.S. (1985) The diet of grey seals in the North Sea assessed from faecal analysis. In *The Impact of Grey and Common Seals on North Sea Resources,* Final Report by Sea Mammal Research Unit, NERC, to the EC, pp. 84–99.

Prime, J.H. and Hammond, P.S. (1990) The diet of grey seals from the south-western North Sea assessed from analysis of hard parts found in faeces. *J. Appl. Ecol.*, **27**, 435–447.

Rae, B.B. (1960) Seals and Scottish fisheries. *Mar. Res.*, 1960 (No. 2), 39 pp.

Rae, B.B. (1965a) Salmon in halibut stomach. *Scott. Fish. Bull.*, **24**, 33.

Rae, B.B. (1965b) The food of the common porpoise (*Phocaena phocaena*). *J. Zool.*, **146**, 114–122.

Rae, B.B. (1966) Salmonids in fish stomachs. *Scott. Fish. Bull.*, **25**, 33.

Rae, B.B. (1967) The food of cod in the North Sea and on west of Scotland grounds. *Mar. Res.*,1967 (No. 1), 67 pp.

Rae, B.B. (1968) The food of seals in Scottish waters. *Mar. Res.*, 1968 (No. 2), 23 pp.

Rae, B.B. (1969a), Salmonid in cod stomach. *Scott. Fish. Bull.*, **31**, 29.

Rae, B.B. (1969b) The food of cormorants and shags in Scottish estuaries and coastal waters. *Mar. Res.*, 1969 (No. 1), 16 pp.

Rae, B.B. (1971) Salmon from ling's stomach. *Scott. Fish. Bull.*, **35**, 35.

Rae, B.B. (1973) Further observations on the food of seals. *J. Zool. Lond.*, **169**, 287–297.

Rae, B.B. and Shearer, W.M. (1965) Seal damage to salmon fisheries. *Mar. Res.*, 1965 (No. 2), 39 pp.

Rees, E.I.S. (1965) The feeding range of shags. *Br. Birds,* **58**, 508–509.

Reitan, O., Hvidsten, N.A. and Hansen, L.P. (1987) Bird predation on hatchery-reared Atlantic salmon smolts, *Salmo salar* L., released in the River Eira, Norway. *Fauna Norv. Ser. A,* **8**, 35–38.

Robb, A P. and Hislop, J.R G. (1980) The food of five gadoid species during the pelagic 0-group phase in the northern North Sea. *J. Fish Biol.*, **16**, 199–217.

Roffe, T.J. and Mate, B.R. (1984) Abundance and feeding habits of pinnipeds in the Rogue River, Oregon. *J. Wildl. Manage.*, **48,** 1262–1274.

Ruggerone, G.T. (1986) Consumption of migrating juvenile salmonids by gulls foraging below a Columbia river dam. *Trans. Am. Fish. Soc.*, **115**, 136–742.

Scarnecchia, D.L. (1984) Forecasting Yields of two sea winter Atlantic salmon (*Salmo salar*) from Icelandic rivers. *Can. J. Fish. Aquat. Sci.,* **41**, 1234–1240.

Seaman, G.A. and Burns, J.J. (1981) Preliminary results of recent studies of belukhas in Alaskan waters. *Rep. Int. Whal. Commn.,* **31**, 567–574.

Sergeant, D.E. (1962) The biology of the pilot or pothead whale *Globicephala melaena* (Traill) in Newfoundland waters. *Bull. Fish. Res. Bd Can.*, **132**, 84 pp.

Sergeant, D.E. and Fisher, H.D. (1957) The smaller Cetacea of eastern Canadian waters. *J. Fish. Res. Bd Can.,* **14**, 83–115.

Sharrock, J.T.R. (1976) *The Atlas of Breeding Birds in Britain and Ireland.* T. and A.D. Poyser, Calton, 479 pp.

Shearer, W.M., Cook, R.M., Dunkley, D.A., MacLean, J.C. and Shelton, R.G.J. (1987) A model to assess the effect of predation by sawbill ducks on the salmon stock of the River North Esk. *Scott. Fish. Res. Rep.*, **37**, 1–12.

Soikkeli, M. (1973) Tagged salmon smolts in the diet of the caspian tern. *Laxforskningsinst. Medd.*, **3**, 3 pp.

Taylor, E.B. and McPhail, J.D. (1985) Burst-swimming and size-related predation of newly emerged coho salmon, *Oncorhynchus kisutch. Trans. Am. Fish. Soc.*, **114**, 546–551.

Templeman, W. (1967) Atlantic salmon from the Labrador Sea and off West Greenland, taken during A. T. Cameron cruise, July–August 1965. *Res. Bull. Int. Comm. Northwest Atlantic Fish.*, **4**, 5–40.

Thompson, P.M. and Harwood, J. (1990) Methods for estimating the population size of common seals, *Phoca vitulina. J. Appl. Ecol.*, **27**, 924–938.

Thompson, P.M. and Miller, D. (1990) Summer foraging activity and movements of radio-tagged common seals (*Phoca vitulina* L.) in the Moray Firth, Scotland. *J. Appl. Ecol.,* **27**, 492–501.

Thompson, P.M., Fedak, M.A., McConnell, B.J. and Nicholas, K.S. (1989). Seasonal and sex-related variation in the activity patterns of common seals (*Phoca vitulina*). *J. Appl. Ecol.,* **26**, 521–535.

Thompson, P.M., Pierce, G.J., Hislop, J.R.G., Miller, D. and Diack, J.S.W. (1991) Winter foraging by common seals (*Phoca vitulina*) in relation to food availability in the inner Moray Firth, NE Scotland. *J. Anim. Ecol.,* **60**, 283–294.

Trayler, K.M., Brothers, D.J., Wooler, R.D. and Potter, I.C. (1989) Opportunistic foraging by three species of cormorants in an Australian estuary. *J. Zool. Lond.,* **218**, 87–98.

Ussher, R.J. and Warren, R. (1900) *The Birds of Ireland.* Gurney and Jackson, London.

Valle, E. (1985) Predation of birds on salmon and sea trout smolts and post-smolts. *ICES*, CM 1985/M:22.

van Bree, P.J.H. van and Nijssen, H. (1964) On three specimens of *Lagenorhynchus albirostris* Gray, 1846 (Mammalia, Cetacea). *Beafortia,* **11**, 85–93.

Wanless, S. (1984) The growth and food of young gannets on Ailsa Craig. *Seabird*, **7**, 62–70.

Webb, A., Harrison N.M., Leaper, G.M., Steele, R.D., Tasker, M.L. and Pienkowski, M.W. (1990) *Seabird Distribution West of Britain.* Report to the Nature Conservancy Council, Peterborough.

West, B., Cabot, D. and Greer-Walker, M. (1975) The food of the cormorant *Phalocrocorax carbo* at some breeding colonies in Ireland. *Proc. Roy. Irish Acad.*, **75**, 285–304.

Wheeler, A. (1978) Key to the *Fishes of Northern Europe.* Warne, London, 380 pp.

Wheeler, A. and Gardner, D. (1974) Survey of the literature of marine fish predators on salmon in the North-east Atlantic. *J. Inst. Fish. Management.*, **5** (3), 63–66.

White, H.C. (1936) The food of kingfishers and mergansers on the Margaree River, Nova Scotia. *J. Biol. Bd Can.*, **2**, 299–309.

White, H.C. (1937) Local feeding of kingfishers and mergansers. *J. Biol. Bd Can.*, **3**, 323–338.

White, H.C. (1939) The food of *Mergus serrator* on the Margaree River, NS. *J. Biol. Bd Can.*, **4**, 309–311.

White, H.C. (1953) The eastern belted Kingfisher in the Maritime Provinces. *Bull. Fish. Res. Bd Can.*, **97**, 1–44.

Willgohs, J.F. (1961) *The White-tailed Eagle,* Haliaeetus albicilla *(Linne)* in Norway. Norwegian Universities Press, Bergen.

Wise, M.H., Linn, I.J. and Kennedy, C.R. (1981) A comparison of the feeding biology of mink *Mustela vison* and otter *Lutra lutra. J. Zool. Lond.*, **195**, 181–213.

Wood, C.C. (1985) Aggregative response of common mergansers (*Mergus merganser*): predicting flock size and abundance on Vancouver Island salmon streams. *Can. J. Fish. Aquat. Sci.*, **42**, 1259–1271.

Table B1: Documented predators of *Salmo salar*

Table B1.1: Fish

Predator species	Stage	Country	Impact*	References
Greenland shark	Adult	NW Atlantic		Bigelow and Schroeder, 1948
Somniosus microcephalus	Adult	Greenland		Templeman, 1967
Porbeagle shark	Adult	UK		Rae, 1966
Lamna nasus	Adult	Greenland		Templeman, 1967
'Sharks'	Adult	UK		Calderwood, 1931
	Adult	UK		Menzies, 1925
Skate *Raja batis*	Grilse	UK		Rae, 1965a
Brown/sea trout	Smolt	Ireland	Moderate	Piggins, 1958
Salmo trutta	Smolt	Ireland	Moderate	Piggins, 1962
	Smolt/fry	UK	Heavy	Mills, 1964
	Post-smolt	Norway	Light	Hvidsten and Møkkelgjerd, 1987
Pike	Smolt/parr	UK	Light	Mills, 1964
Esox lucius	Smolt	UK	Moderate	Mann, 1982
	Smolt	Sweden	Moderate	Larsson, 1985
	Smolt	Russia	Moderate	Pervozvanskiy *et al.*, 1988
Eel	Alevin	Ireland	Light	Piggins, 1958
Anguilla anguilla	Alevin	Ireland	Light	Piggins, 1962
Halibut *Hippoglossus hippoglossus*	Grilse	UK		Rae, 1965a
Cod	Post-smolt	UK		Rae, 1966
Gadus morhua	Post-smolt	UK		Rae, 1967
	Post-smolt	UK		Rae, 1969a
	Post-smolt	W Europe	Light	Browne *et al.*, 1983
	Post-smolt	Norway	Moderate	Hvidsten and Møkkelgjerd, 1987
	Post-smolt	Norway	Moderate	Hvidsten and Lund, 1988
Saithe *Pollachius virens*	Post-smolt	Norway		Hvidsten and Møkkelgjerd, 1987
	Post-smolt	Norway	Moderate	Hvidsten and Lund, 1988
Pollack *P. pollachius*	Post-smolt	Ireland	Moderate	Piggins, 1958

continued

Table B1.1: Fish (cont.)

Predator species	Stage	Country	Impact*	References
Whiting *Merlangius merlangus*	Post-smolt	UK		Kennedy, 1954
Ling *Molva molva*	1 sea winter fish	Faroe Bank		Rae, 1971
Bass *Dicentrarchus labrax*	Smolt	Ireland	Light	Kennedy, 1954
Garfish *Belone belone*	Post-smolt	Baltic		Carlin, 1954
Burbot	Smolt	Sweden	Moderate	Larsson and Larsson, 1975
Lota lota	Smolt	Sweden	Moderate	Larsson, 1977
	Smolt	Sweden	Moderate	Larsson, 1985

Table B1.2: Birds

Predator species	Stage	Country	Impact*	References
Cormorant	Parr/smolt	UK	Light	Mills, 1964
Phalocrocorax carbo	Parr/smolt	UK	Light	Mills, 1965
	Parr/smolt	Ireland	Light	Piggins, 1958
	Parr/smolt	Ireland	Light	Piggins, 1962
	Parr/smolt	Ireland	Light	Piggins, 1964
	Smolt	UK	Light	Pearson, 1968
	Parr/smolt	Ireland	Light	West *et al.*, 1975
	Smolt	UK	Heavy	Kennedy and Greer, 1988
	Smolt	Norway	Light	Barrett *et al.*, 1990
Double-crested cormorant *P. auritus*	Post-smolt	Canada	Light	Kehoe, 1987
Shag	Post-smolt	UK	Light	Pearson, 1968
Phalocrocorax aristotelis	Post-smolt	UK	Light	Rae, 1969b
Red-throated diver *Gavia stellata*	Post-smolt	Finland	Light	Valle, 1985
Red-necked grebe *Podiceps griseigena*	Fry-smolt	UK		Mills, 1960
Red-breasted merganser	Parr	Canada	Heavy	White, 1937
Mergus serrator	Parr	Canada	Heavy	White, 1939
	Parr/smolt	UK	Heavy	Mills, 1962
	Parr/smolt	UK	Heavy	Feltham, 1990
	Parr/smolt	UK	Heavy	Marquiss and Feltham, 1991

continued

Table B1.2: Birds (cont.)

Predator species	Stage	Country	Impact*	References
Goosander	Fry/parr	Canada	Moderate	White, 1936
Mergus merganser	Parr/smolt	Sweden	Moderate	Lindroth, 1955
	Parr	Canada	Heavy	Anderson, 1986
	Parr	Canada	Heavy	Elson, 1962
	Fry-smolt	UK	Heavy	Mills, 1962
	Fry-smolt	UK	Moderate	Mills, 1964
	Smolt	Canada	Implied	Wood, 1985
	Smolt	Finland	Light	Valle, 1985
	Fry/parr	UK	Heavy	Marquiss and Feltham, 1991
Heron	Parr/smolt	Ireland	Light	Piggins, 1962
Ardea cinerea	Smolt	UK	Moderate	Greenstreet, unpublished
	Smolt	Scotland	Moderate	J.C. MacLean, pers. comm.
Blackheaded gull	Parr/smolt	UK	Light	Mills, 1964
Larus ridibundis				
Herring gull	Smolt	UK	Light	R. Armstrong, 1989, unpublished
Larus argentatus				
Common gull	Smolt	Norway	Moderate	Reitan *et al.*, 1987
Larus canus	Parr/smolt	UK	Light	Mills, 1964
Gull sp.	Smolt	Finland	Moderate	Valle, 1985
Sandwich tern	Smolt	Scotland	Light	J.C. MacLean, pers. comm.
Sterna sandvicensis				
Caspian tern	Post-smolt	Finland	Light	Valle, 1985
Hydroprogne caspia	Post-smolt	Finland	Light	Soikkeli, 1973
Gannet	Post-smolt	UK	Light	Wanless, 1984
Sula bassana	Post-smolt	Canada	Light	Montevecchi *et al.*, 1988
	Post-smolt	UK	Moderate	Greenstreet, unpublished
Hooded crow	Smolt	UK		Mills, 1960
Corvus corvus				
Belted kingfisher	Fry/parr	Canada	Moderate	White, 1936
Megaceryle alcyon	Fry/parr	Canada	Moderate	White, 1937
	Fry/parr	Canada	Moderate	White, 1953
	Fry/parr	Canada	Moderate	Elson, 1962

Table B1.3: Mammals

Predator species	Stage	Country	Impact*	References
Otter	Parr	Scotland	Moderate	Jenkins *et al.*, 1979
Lutra lutra	Parr/adult	England	Moderate	Wise *et al.*, 1981
	Adult	Scotland	Moderate	Carss *et al.*, 1990
	Smolt/adult	Scotland	Moderate	Greenstreet, unpublished
Mink	Parr/smolt	Scotland	Light	Akande, 1972
Mustela vison	Parr	England	Light	Chanin and Linn, 1980
	Smolt	Scotland		Dunstone and Birks, 1987
	Parr	England	Light	Wise *et al.*, 1981
Grey seal	Adult	UK	Light	Lockie, 1962
Halichoerus grypus	Adult	UK	Moderate	Rae, 1960
	Adult	UK	Moderate	Rae, 1968
	Adult	UK	Moderate	Rae, 1973
	Adult	UK	Moderate	Rae and Shearer, 1965
	Adult	N Atlantic	Light	Anon, 1986
	Adult	UK	Light	Pierce *et al.*, 1989
	Adult	UK	Light	Pierce *et al.*, 1991c
Common seal	Adult	UK	Light	Rae, 1960
Phoca vitulina	Adult	UK	Light	Rae, 1968
	Adult	UK	Light	Rae, 1973
	Adult	UK	Light	Pierce *et al.*, 1990b
	Adult	UK	Light	Pierce *et al.*, 1991b
	Adult	UK	Light	Pierce *et al.*, 1991c
Bottle-nose dolphin	Adult	UK		P.M. Thompson, unpublished
Tursiops truncatus	Adult			

* Impact has been assessed in one of two ways, either according to the proportion of a salmon life-cycle stage (e.g. smolts) taken, or by the proportion of the predator's diet consisting of salmon. 'Heavy' indicates 50% consumption, or more, of the salmon stage concerned, or 50%, or more, of the predator's diet. Similarly, 'moderate' indicates percentage values between 10% and 50% and 'light' less than 10%. In the remaining cases, although predation on salmon has been recorded, no quantitative assessment of impact can be made.

Table B2: Potential predators of *Salmo salar*

Table B2.1: Fish

Predator species	Salmon stage vulnerable to attack
Lamprey *Petromyzon marinus*	Fry and small parr in freshwater, adults in sea
Lamperns *Lampetra fluviatilis* *L. planeri*	Fry and small parr
Perch *Perca fluviatilis*	Fry and small parr
Tope *Galeorhinus galeus*	Post-smolt
Spurdog *Squalus acanthias*	Post-smolt
Bluefin tunny *Thunnus thynnus*	Post-smolt
Mackerel *Scomber scombrus*	Post-smolt
Greenland halibut *Reinhardtius hippoglossoides*	Post-smolt and small adult

Table B2.2: Birds

Predator species	Salmon stage vulnerable to attack
Sea eagle *Haliaeetus albicilla*	Post-smolt to adult
Osprey *Pandion haliaetus*	Smolt and grilse
Black-throated diver *Gavia arctica*	Fry and parr
Great northern diver *Gavia immer*	Post-smolt
Slavonian grebe *Podiceps auritus*	Fry
Little grebe *Tachybaptus ruficollis*	Fry
Kingfisher *Alcedo atthis*	Fry and parr

Table B2.3: Mammals

Predator species	Salmon stage vulnerable to attack
Porpoise *Phocoena phocoena*	Post-smolt and adult
White-sided dolphin *Lagenorhynchus acutus*	Post-smolt and adult
White-beaked dolphin *Lagenorhynchus albirostris*	Post-smolt and adult
Risso's dolphin *Grampus griseus*	Post-smolt and adult
Long-finned pilot whale *Globicephala melaena*	Post-smolt and adult
Sperm whale *Physeter catodon*	Post-smolt and adult
Killer whale *Orcinus orca*	Post-smolt and adult
White whale *Delphinapterus leucas*	Post-smolt and adult
Minke whale *Balaenoptera acutorostrata*	Post-smolt and adult
Ringed seal *Phoca hispida*	Post-smolt and adult
Bearded seal *Erignathus barbatus*	Post-smolt and adult
Harp seal *Phoca groenlandica*	Post-smolt and adult
Hooded seal *Cystophora cristata*	Post-smolt and adult

APPENDIX C

GLOSSARY OF SCIENTIFIC NAMES

Cormorants	*Phalacrocorax carbo*
	Phalacrocorax sinensis
Dace	*Leuciscus leuciscus*
Eel pout	*Zoarces viviparus*
Eels	*Anguilla anguilla*
Feral mink	*Mustela vison*
Goosanders	*Mergus merganser*
Gunnel	*Pholis gunnellus*
Mergansers	*Mergus serrator*
Otters	*Lutra lutra*
Red-breasted mergansers	*Mergus serrator*
Ruffe	*Gymnocephalus cenuus*
Seals (common)	*Phoca vitulina*
Seals (grey)	*Halichoerus grypus*

APPENDIX D

SOURCE REFERENCES

1. Gibbons, D.W., Reid, J.B. and Chapman, R.A. (1993) *The New Atlas of Breeding Birds in Britain and Ireland: 1988–1991*. T. & A.D. Poyser, London.
2. Lloyd, C., Tasker, M. and Partridge, K. (1991) *The Status of Seabirds in Britain and Ireland*. T. & A.D. Poyser, London.
3. Walsh, P.M., Sim, I. and Heubeck, M. (1993) *Seabird Numbers and Breeding Success in Britain and Ireland, 1992*. Joint Nature Conservation Committee, Peterborough (UK Nature Conservation, No. 10).
4. Kirby, J.S. and Sellers, R.M. Trends in the numbers and distribution of cormorants in Great Britain. *Proc. 3rd Eur. Cormorant Conf.* Gdansk, Poland 13–17 April 1993.
5. Sellers, R.M. (1991) *Breeding and Wintering Status of Cormorant in the British Isles. Proc. Workshop 1989 on cormorants* Phalacrocorax carbo. M.R. van Eerden and M. Zilstra, (eds). Rijkswaterstaat Directive Flevoland, Lelystad, 30–35.
6. Voslamber, B. (1988) Visplaatskenze, fourageerwijze en voedselkenze van aalscholvers *Phalacrocorax carbo* sinensis in het Ijsselmeerebied in 1982. *Flevobericht 286*. Rijksdienst voor de Ijsselmeerpolders, Lelystad.
7. Marquiss, M. and Carss, D.N. (1994) *Avian Piscivores: Basis for Policy*. National Rivers Authority, R and D Project Record 461/8N&Y.
8. Carss, D.N. and Marquiss, M. The diet of cormorants in Scottish freshwaters in relation to feeding habitats and fisheries. *Proc. 3rd Eur. Cormorant Conf.* Gdansk, Poland 13–17 April 1993.
9. Kennedy, G.J.A. and Greer, J.E. (1988) Predation by cormorants, *Phalacrocorax carbo* (L.), on the salmonid populations of an Irish river. *Aquaculture and Fish. Management*. **19**, 159–170
10. MacDonald, R.A. (1988) The cormorant *Phalacrocorax carbo* in relation to salmon fisheries. *Ibis*, **130**, 590.
11. Sharrock, J.T.R. (1976) *The Atlas of Breeding Birds in Britain and Ireland*. T. and A.D. Poyser, London.
12. Feltham, M.J. and Marquiss, M. (1989). The use of first vertebrae in separating, and estimating the size of, trout (*Salmo trutta*) and salmon (*Salmo salar*) in bone remains. *J. Zool. Lond.* **219**, 113–122.
13. Feltham, M.J. (1990). The diet of red-breasted mergansers (*Mergus serrator*) during the smolt run in NE Scotland: the importance of salmon (*Salmo salar*) smolts and parr. *J. Zool. Lond.* **222**, 285–292.
14. Feltham, M.J. (1995). Consumption of Atlantic salmon smolts and parr by goosanders: estimates from doubly-labelled water measurements of captive birds released in two Scottish rivers. *J. Fish Biol* **46**, 273–281.
15. Carss, D.N. and Marquiss, M. (1992). Avian predation at farmed and natural fisheries. *Proc. 22nd Ann. Inst. Fish. Management Study Course*. Aberdeen, 10–12 September 1991.
16. Corbet, G.B. and Harris, S. (eds), (1991). *The Handbook of British Mammals*. Blackwell Scientific Publications, Oxford, 588 pp.

17. Wise, M.H., Linn, I.J. and Kennedy, C.R. (1981). A comparison of the feeding biology of mink *Mustela vison* and otter *Lutra lutra*. *J. Zool. Lond.* **195**, 181–213.

18. Carss, D.N., Kruuk, H. and Conroy, J.W.H. (1990). Predation on adult Atlantic salmon, *Salmo salar* L., by otters, *Lutra lutra* (L.), within the River Dee system, Aberdeenshire, Scotland. *J. Fish Biol.* **37**, 935–944.

19. Kruuk, H., Carss, D.N., Conroy, J.W.H. and Durbin, L. (1993) Otter (*Lutra lutra* L.) numbers and fish productivity in rivers in north-east Scotland. *Symp. Zool. Soc. Lond.* **65**, 171–191.

20. Jenkins, D., Walker, J.G.K. and McCowan, D. (1979). Analyses of otter (*Lutra lutra*) faeces from Deeside, NE Scotland. *J. Zool. Lond.* **187**, 235–244.

21. Thompson, D. and Fedak. M.A. (1993). Cardiac responses of grey seals during diving at sea. *J. Exp. Biol.* **174**, 139–154.

22. Mills, D.H. and Shackley, P.E. (1971). Salmon smolt transportation experiments on the Conon River System, Ross-shire. *Department of Agriculture and Fisheries for Scotland, Freshwater and Salmon Fisheries Research*, **40**.

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