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Review Article

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Factors Affecting Atlantic Salmon Populations Adversely; Using the River Dee, Scotland, as an Example

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Abstract

The stocks of the Atlantic salmon (*Salmo salar*) in many rivers in North America and Europe have declined in recent years and are experiencing a crisis. Despite their high degree of legal protection, the quality of their aquatic environments within rivers and in the sea, including local coastal waters, appears to be deteriorating. Salmon survival, has declined both within the sea and within rivers. The status of the Atlantic salmon stocks is considered here, together with the adverse effects of different sources, and those steps that may need to be taken to improve the condition of the salmon. This paper is intended to assist management bodies in taking steps to resolve the problems that exist for salmon, both within rivers and in the sea. It makes particular use of information available on the River Dee in Scotland.

Introduction

A Brief Background on Salmon Life History

Atlantic Salmon [1] have been economically important fish in many countries, including Scotland, and they are found in many rivers connecting with the North Atlantic. They may enter their rivers from the sea in the spring, summer or autumn, and then breed within their river systems, both within the headwaters, and river tributaries (burns). Eggs are placed by the female within well-oxygenated loose gravel, and are then fertilized by a male, and the female then covers them with more gravel. The hatched fish, known as alevins, still have a yolk sac attached to their abdomen, and when the yolk sac has become absorbed the alevins move up into the water.

The juvenile fish then initially stay and feed in fresh water, their stages including the fry, parr (juveniles beginning to grow), and smolts (that eventually migrate downstream). The parr grow in freshwater for 2 to 3 years before transforming into smolts in the early spring. The parr feed mainly upon small invertebrates, insects and plankton. They later undergo a preparatory smolting process, involving morphological, biochemical, physiological and behavioral changes that pre-adapt them for life in the high salinity water found in the sea[10]. The smolts become silvery, like the adults, and after one or more years they move downstream to enter the sea. They are termed post-smolts as soon as they have entered the sea, and their migrations within the coastal environment can involve active directed swimming at speeds in excess of the prevailing water currents [35].

The post smolts can migrate thousands of miles north, to live in the North Atlantic, feeding on small pelagic marine invertebrates and fishes, and generally growing rapidly, when there are rich food resources available [31]. In recent years, the overall marine survival of Atlantic salmon, has declined for unknown reasons [27] Better understanding is needed of their mortality causes, and the changes in their migration patterns. The distribution of Atlantic salmon within the sea is shown in Figure 1. The American National Oceanic and Atmospheric Administration (NOAA) deal with salmon on their fisheries website, as they are responsible for the stewardship of the United States' ocean resources. NOAA have suggested that there are three main groups of Atlantic salmon: North American, European, and Baltic. They spawn in the coastal rivers of northeastern North America & Canada; Greenland, Iceland and Europe; and the shores of the Baltic Sea. After spawning, they migrate through various portions of the North Atlantic Ocean. The European and North American populations of Atlantic salmon may intermix while living in the ocean, and NOAA point out that they share summer feeding grounds off Greenland. Problems within the salmon populations in the sea may include poor marine feeding, migration difficulties, and perhaps poor survival.

The marine phase of the salmon's life may, in some cases, last little more than a year, some of them maturing and returning as grilse (one sea-winter fish), but many juvenile salmon remain in the sea for two or even more years. The mature adults then return to their rivers of origin to spawn [17,57], although a few may enter other rivers. The size of the returning adults may depend on how long they lived in the sea, and how well they were able to feed. The salmon may navigate through the sea using the earth's magnetic field [48, 52] and they possibly locate their rivers using their sense of smell. However, there is little information available on how they locate and identify their home rivers.

Once the salmon have entered their rivers, many of them then rest within favoured parts of their river, and in the autumn and winter they may go back to the part of the river where they were originally hatched [23,55]. As adults, they do very little feeding within the river, but eventually take part in spawning there, to generate new juvenile salmon. Having spawned, the adult salmon are weak, because they have not been feeding well within the river, and are susceptible to disease and predation, and many of them die.

Purpose of this Document

This document reviews the latest state of Atlantic salmon, highlighting major factors that have altered salmon numbers in the past few decades. Problems with the Atlantic salmon fisheries are common, although details of fisheries and specific problems may vary somewhat in different countries. Because of the variation in issues, it is impossible to review them in detail for each locale and this review focuses on specifics in the River Dee in Scotland, a country with a long and intimate relationship with the salmon industry, as a number of Atlantic salmon studies have been carried out within the Dee, some of them by Hawkins and his colleagues.

The Problem

For many years, fishing for adult salmon has taken place, both in coastal areas within the sea, and within rivers, and some of the salmon are eaten by

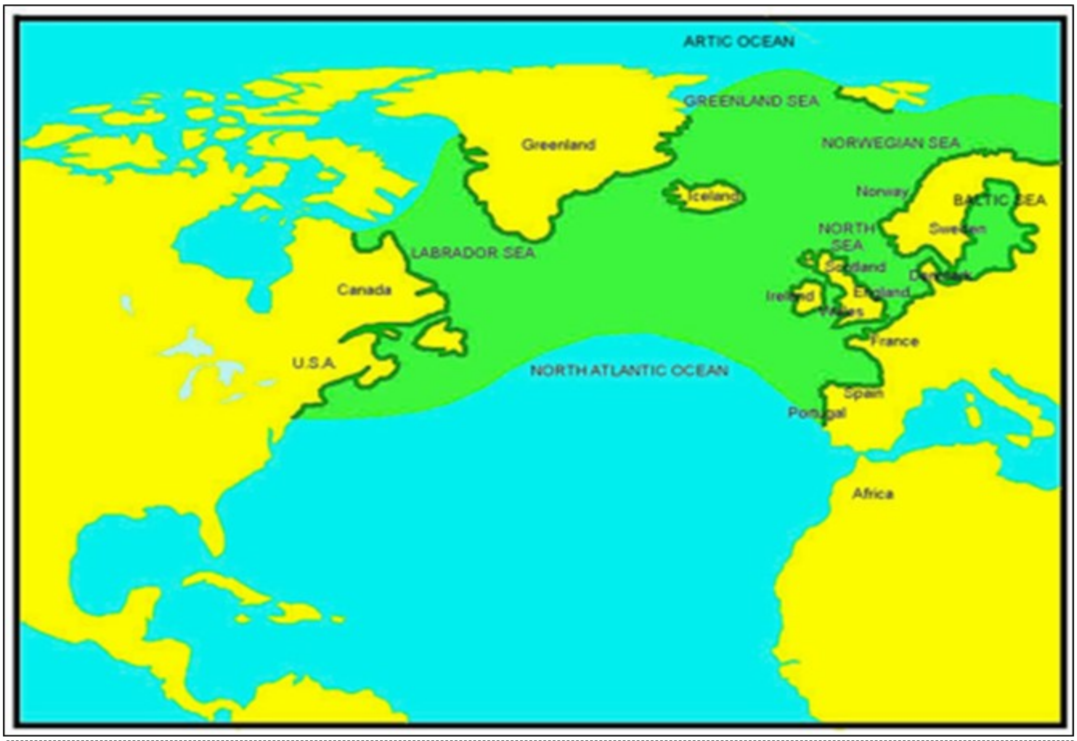

Figure 1. The distribution of Atlantic salmon within the North Atlantic Ocean. They enter the ocean from rivers in the adjacent countries, and later return to their rivers to spawn

humans. Nowadays, many Atlantic salmon are also farmed within Scottish coastal waters. Sea pens or cages were first used in the 1960's in Norway to raise fish to a marketable size. Scottish salmon farming started in the 1970's and is now a major part of Scottish aquaculture, which generates money and provides lots of jobs. The fish farms are mainly based on the west and north-west coast. The hatcheries import fertilized eggs to produce larval and juvenile fish, and these are initially reared in freshwater tanks, and are later placed in cages in coastal sea waters, where they are grown to reach a size when they can be harvested. Some of the farmed salmon escape from the marine farms and enter a few Scottish rivers, where some have been caught, but they have represented only a small percentage of the total Scottish salmon catch within rivers.

Within their rivers the salmon need a good spawning habitat, with a suitable substrate to allow the successful deposition and hatching of their eggs. For the juvenile salmon, that are then born, there is a need for a diverse in-river habitat, to enable them to feed, grow, and protect themselves from predators. It must then be possible for the smolts to migrate downstream through the river, enter the sea, and then migrate successfully as post-smolts, to their northern feeding grounds. At sea, there must be lots of food to enable them to grow to maturity and obtain sufficient energy to later return through thousands of miles of the sea to their native rivers. Ideally, they need to be less exposed to predators within the sea, and they need to be able to find their home rivers without being adversely affected by coastal and estuarine human activities. Within their home rivers, once the adults have returned, there is a need for a suitable habitat for them to spend time within the river until they are ready to spawn. It must also be possible for them to move easily upstream, without encountering too many natural or human barriers.

Salmon within Scotland

The River Dee (Figure 2) is one of Scotland's finest salmon rivers, and the river and its tributaries (often described as burns) were designated as a Special Area of Conservation (SAC) under the European Union (EU) Habitats and Species Directive, as it provides valuable habitats for important populations of protected species including the Atlantic salmon, sea trout, European eel, freshwater pearl mussel, and otter. The protection of European Atlantic salmon has been discussed by Movik [42]. The River Dee flows 130 kilometers from the Cairngorm mountains to its river mouth at Aberdeen on the North Sea. Many tributaries enter the river as it passes east. Towns along the riverbank include Braemar, Ballater and Banchory, with Queen Elizabeth's Balmoral Castle between the former two towns.

Causes of the Changes in the State of Atlantic Salmon

Salmon in Scottish rivers, and also in other countries, are now declining, despite measures that have been taken to improve the salmon stocks. In Scotland, coastal netting fisheries, both in the sea and in estuaries, have now largely been closed down to protect the salmon entering rivers. In addition, fishers operating within rivers are sometimes encouraged to release the fish that they have caught, so that their numbers are not reduced. NatureScot (https://www.nature.scot/), has recently assessed the decline in salmon, and has pointed out on its website that salmon stocks are now failing to reach the level that would ensure their long-term survival. Their Marine Assessment online in 2020 provided a comprehensive assessment of Scotland's seas. In the mid-1980s there were between 8 and 10 million salmon swimming around the Atlantic close to Scotland. That number has now dropped to 2-3 million. It has been suggested that although there has been some evidence that the sea condition is improving, there have been problems for some of the fish species. It is possible that wild Atlantic salmon may become extinct in the future, because of habitat changes in their North Atlantic feeding areas, the coastal areas, and within the rivers themselves.

There appears to have been a marked increase in the mortality of salmon and other fishes in the sea, point-

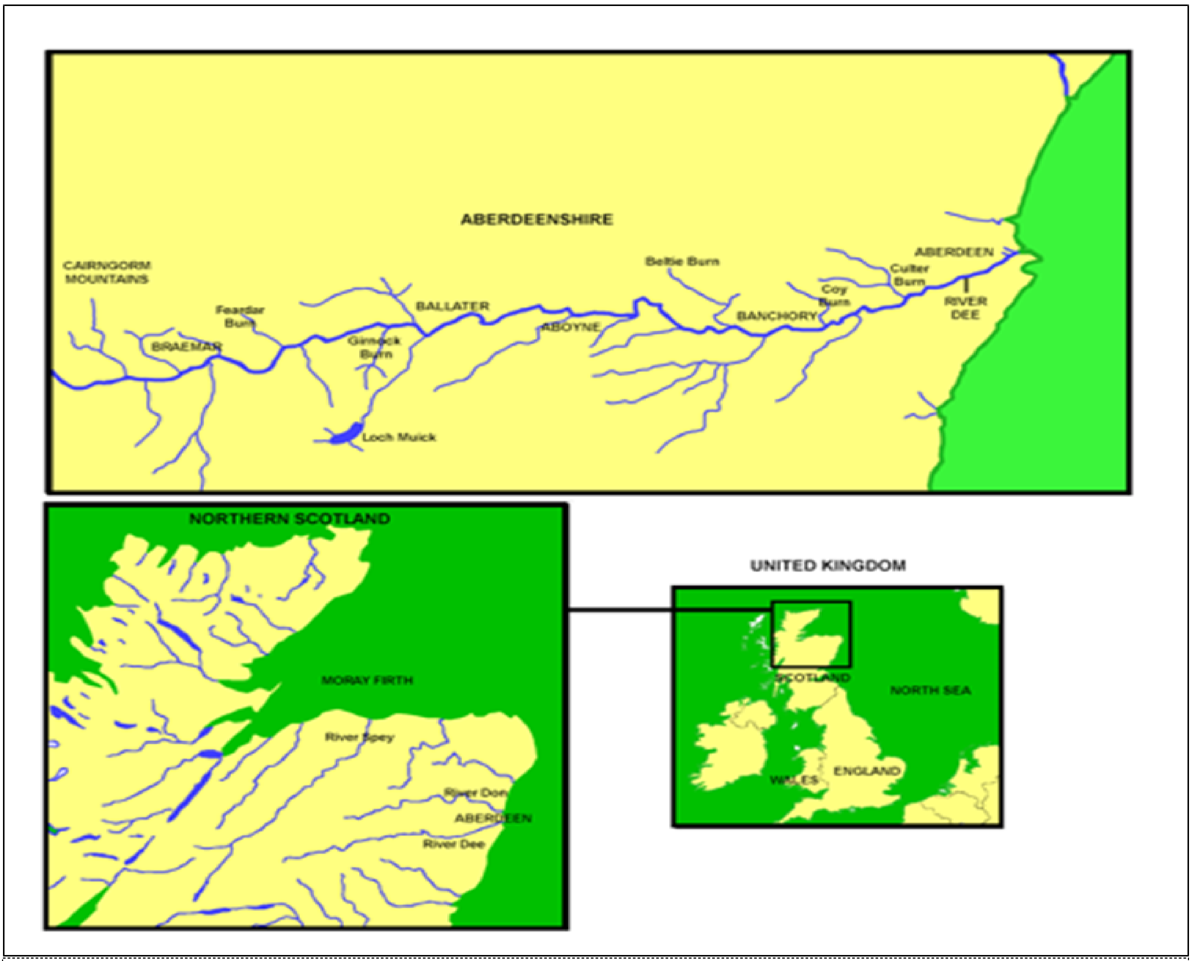

Figure 2. A map of Scotland showing the River Dee and many of its tributaries, together with some of the adjacent towns.

ed out by[40], with the return rates of salmon to rivers now at their lowest levels. Thus, it is necessary to determine the problems that are affecting salmon, especially in the sea. Climate change is having an adverse effect, with changes in the sun's intensity, large volcanic eruptions, and changes in naturally occurring greenhouse effects. The "greenhouse" effect is warming that results when the atmosphere receives heat radiating into the air space. Gases in the atmosphere, such as water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), trap heat: they allow direct sunlight to reach the Earth's surface, but absorb the heat that is radiated back. The natural occurrence of these gases in the atmosphere is in part responsible for the Earth's climate change. Human activities have caused changes in the natural cycles of some of these gases, for example through the burning of fossil fuels, and have also added man-made greenhouse gases. This increase in greenhouse gases in the atmosphere has led to significant changes in the Earth's climate since the start of the industrial revolution. [40] point out that the oceans are absorbing much of the carbon dioxide and excess heat resulting from a changing global climate. This absorption results in ocean acidification and increasing temperatures contribute to a loss of oxygen from the sea. These processes may have an adverse impact on marine life

It seems that climate change may result in changes in the water, both in the sea and in rivers. One of the main causes of climate change is the burning of fossil fuels such as oil, gas, and coal. When burning, the fossil fuels release carbon dioxide into the air, causing the planet to heat up. The sea levels have risen in recent years, owing to the melting of glaciers and ice-sheets, and thermal expansion in the oceans, where sea levels increase in volume as a result of the higher temperatures. [3] have pointed out that climate warming over several decades has been linked to changes in the large-scale hydrological cycle including: increasing atmospheric water vapour content; changing precipitation patterns, intensity and extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff into rivers. Over the 20th century, precipitation has mostly increased over land in some of the high northern latitudes, while decreases have dominated in southern areas. Water stored in glaciers and snow cover are expected to decline, reducing water availability.

Water temperature may rise in northern rivers and lakes as the air temperature rises. Higher water temperatures and changes in extremes, including both floods and droughts, may affect water quality and increase many forms of water pollution, including sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salt, as well as thermal pollution, with possible negative impacts on fishes. This may also lead to lower levels of oxygen in the water, creating particular stress upon the fish, and other aquatic animals that rely upon oxygen. As temperatures rise, the flows of water in the rivers may change. Warming of the waters in the North Atlantic is believed to be taking place and may be a significant factor for some fish species. Low-lying coastal regions and estuaries are especially threatened by global warming and a concomitant rise in the sea levels. Warming of the sea is also affecting the supply of the food that salmon need. The food they consume in the sea allows the juveniles to grow into adults and enables them to travel long distances within the sea and then within their home rivers. A reduction in the size of salmon is said by NatureScot to be taking place, and it is suggested that egg production is also declining. It is thought that climate change is an especially critical factor, affecting the marine environment, with impacts upon both fish and plankton. Climate change is also causing changes to take place within the rivers themselves. It is anticipated by NatureScot that there may be severe droughts in Scottish rivers, mainly in the summer, because of climate change reducing the level of water available. In 2018, due to a long warm summer, low water levels on the

River Spey in Scotland (North of Aberdeenshire, entering the Moray Firth) led to especially low salmon catches. However, in the winters there have been some higher water quantities, as a result of rain and melting snow, resulting in flooding within and by the side of rivers.

However, in addition to climate changes, human activities in coastal waters and estuaries, and also within the rivers themselves, may also be affecting the salmon adversely. The harmful human activities include those that create underwater noise and water pollution, changes in riverbanks, drainage of water, water abstraction, fouled water entry from sewage processing centers and septic tanks. In the sea the problems may include shipping and fishing, exploration activities including seismic surveys, the development of offshore oil and gas facilities, and the construction of offshore wind farms. The potential impact of offshore wind farms on fishes and invertebrates has been reviewed by [19]. It is also possible that the new development of tidal energy schemes, using propellers mounted on the seabed, connected by cable to the shore, may also be harmful to salmon and other fishes.

Catches of Salmon

Overall, catches of salmon in the wider North Atlantic region have reduced in recent years (Figure 3). Reported catches for salmon in the North Atlantic from 1960 onwards indicate that harvests peaked in the mid-1970s at about 12,000 tonnes, but declined markedly to around 1,500 tonnes in recent years. This decline was partly due to the closure of many of the fisheries on the high seas and in coastal waters, which were intended to improve the state of the stocks within rivers.

Salmon fisheries in Scotland are now almost entirely focused on salmon that have returned to their home rivers, and which are caught predominantly by angling. It might have been expected that the closure of the fisheries at sea would have resulted in increases in the rod catches within the rivers. Indeed, the annual overall numbers of salmon caught by rod in Scotland did increase over the period 1952 to 2010 (Figure 4). However, since 2010 the reported angling catch has dropped each year until, in 2014, it was especially low (Figure 4). The reported rod catch recovered slightly in 2015 compared to 2014. In 2016, 98% of rod caught spring salmon were released, and also 90% of the total annual rod catch. The total reported rod catches (retained and released) of wild salmon for 2019 was 47,515. This was 97% of the previous average and was the fourth lowest since records began in 1952.

The proportion of the rod catch accounted for by catch and release was among the highest recorded. In 2019, 98% of rod caught spring MSW fish (taken before 1 May) were released, as were 92% of the annual rod catch. A proportion of fish released from the rod fishery may be re-caught and hence inflate the catch statistics by appearing in the reported data more than once.

The River Dee Catches

The characteristics of the salmon stocks determine the nature of the fishery. In particular, the Dee has been renowned amongst Scottish rivers for its excellent spring salmon fishing. However, the rod fishery has been especially strongly affected over the years by declines in the spring component of the catch. Many of the anglers visiting the Dee in the past did so in the spring, when salmon catches were especially high compared with other rivers. The numbers of visiting anglers have now declined, especially on the lower and middle parts of the river, where the dominance of the spring component of the stock has now been lost. In the lower parts, the development of stronger catches taken in the summer and autumn has not been sufficient to offset the fall resulting from lower spring catches.

Rod catches on the Dee (Figure 7) appear to have declined to a greater extent than catches on some other Scottish rivers over the last few years. Only 2,507 salmon were caught on the Dee in 2015. This was the poorest catch in over 60 years of records, and only 36% of the 5-year average of 6,973. The low catches were apparent for both the spring and summer/autumn periods, at 672 and 1,835 salmon, respectively. Salmon catches in 2016

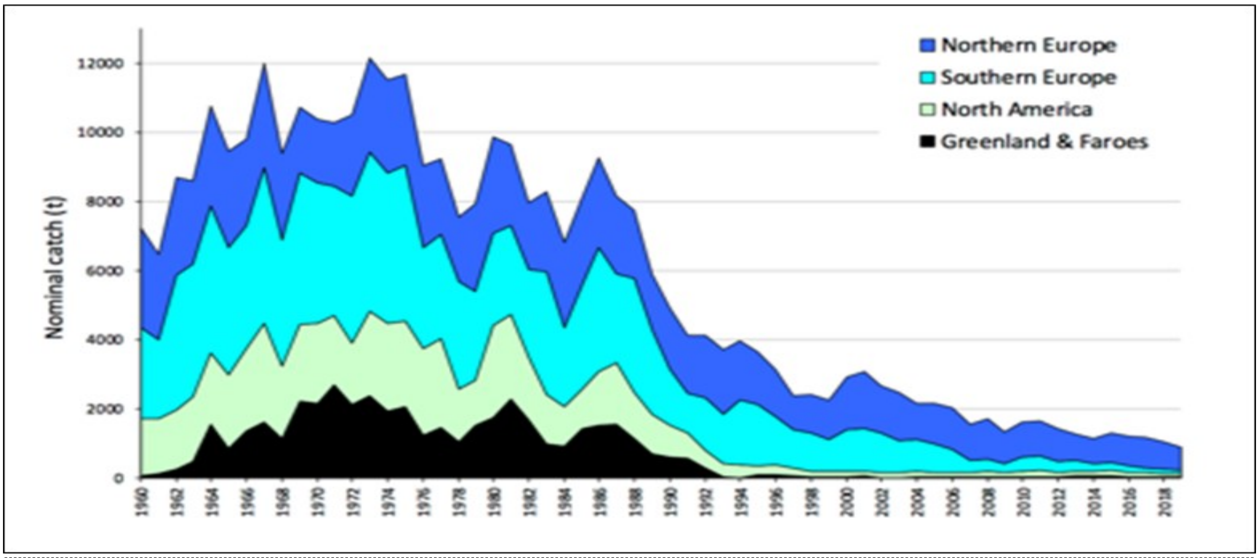

Figure 3. Total reported catches of Atlantic salmon (tonnes weight) in the fisheries within four North Atlantic regions from 1960–2019, as reported by the International Council for Exploration of the Sea [28].

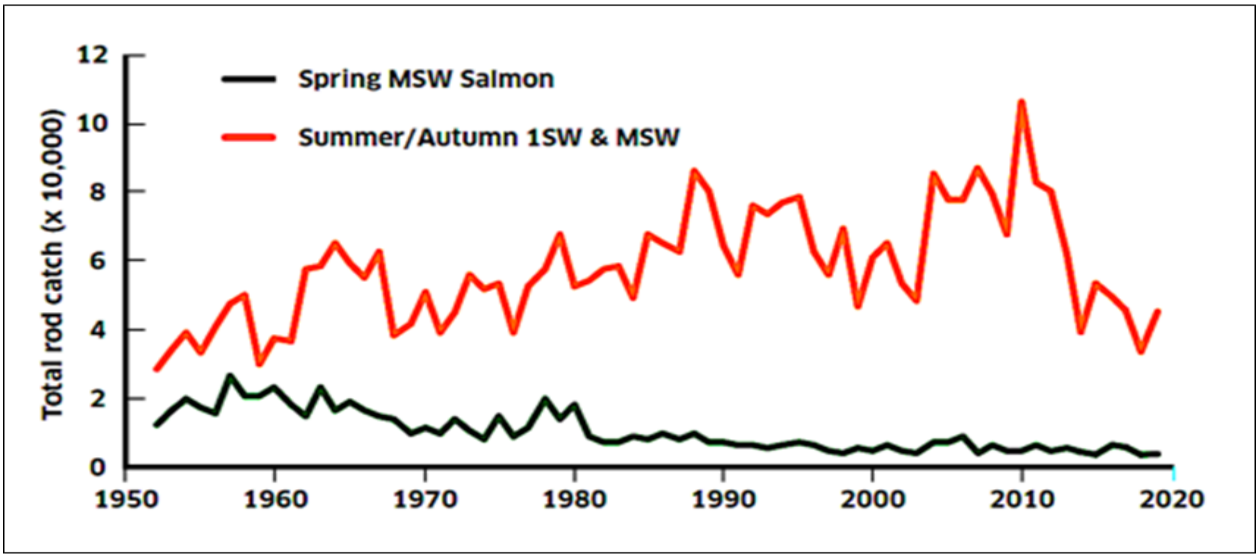

Figure 4. Total reported rod catches in Scotland from1952 to 2020, as presented by the Scottish Government, available as: salmon-fishery-statistics-2020-season.pdf, on the website https://www.gov.scot. The annual rod catches generally increased over the period 1952-2010, but then showed a decline. ISW are one-sea-winter salmon, whereas MSW are multi-sea-winter salmon.

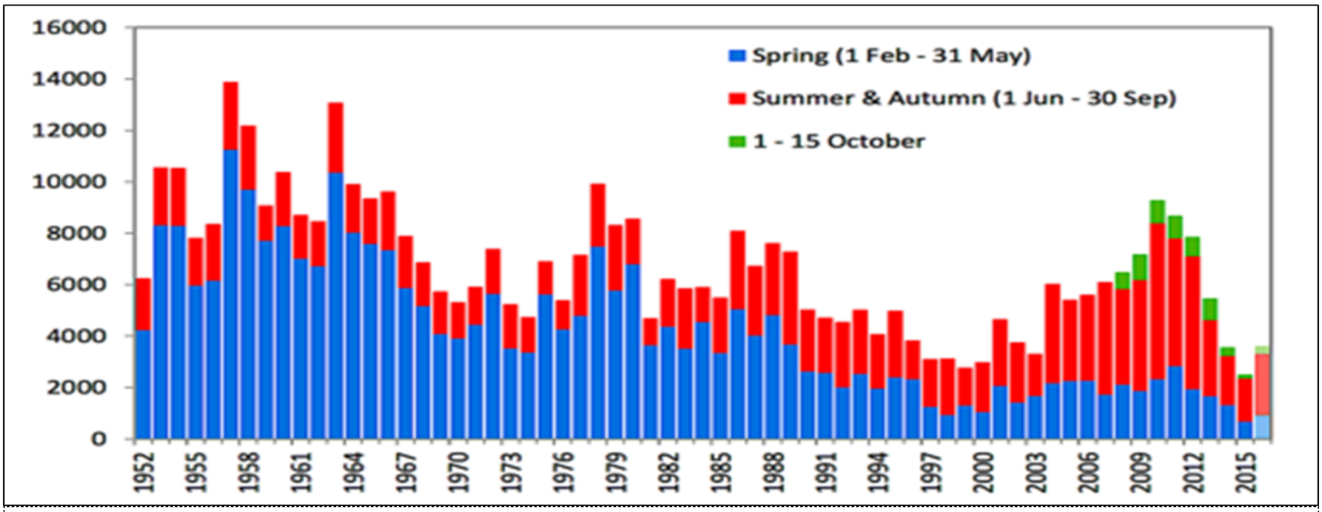

Figure 5. Salmon rod catches for the River Dee, 1952 – 2016 (Marine Scotland Science data), as presented by the Dee Board. The River Dee salmon fishing season commences on the 1st of February and finishes on the 15th of October each year. Note that the October catch is taken over only 2 weeks, whereas the Spring and the Summer/ Autumn periods are each 16 weeks.

showed some recovery, reaching more than 3,600, but this was still well below the five-year average of 5.617. Catches remain low at present.

Since 2010, there has been a general decline in both spring, and summer/autumn catches on the Dee. It is thought that additional, local, or regional factors may be affecting the Dee stocks. Recent work by Marine Scotland Science (MSS) found evidence of a local (North East) trend; whereby rod catches on the Dee, Don, and some other rivers, have all recently declined, showing a different pattern to other Scottish rivers.

The recent fall in the angling catches appears to indicate a wider decline in salmon within the North Atlantic, which seems to be the result of a number of factors. These may include climate change within the northern oceans, and higher numbers of competing species at sea (especially herring and mackerel), which may be reducing the food available to salmon. The growth of the herring, mackerel and blue whiting fisheries may also be affecting salmon survival by taking salmon as a by-catch. There have also been increases in the populations of predators that consume salmon; including birds, otters, seals, whales, and dolphins. There are currently large numbers of dolphins and other predators in the coastal waters close to Scottish rivers, and the salmon are often heavily preyed upon. It is also possible that coastal and in-river developments may be affecting the migrations of both smolts and adult salmon, through the generation of underwater noise, changes in the electromagnetic fields, increases in the number of barriers, the generation of pollutants, and increases in silt and other contaminants.

Catches are not necessarily the most accurate indicators of salmon stock size. Some catches may go unreported. In addition, catches may change with the number of anglers that are fishing - the level of fishing effort. The introduction of catch and release may also result in some salmon being caught more than once, affecting the relationship between catches and salmon abundance. It is particularly valuable to have independent measures of the numbers of salmon returning to the river, and especially the installation of fish counters.

The Behavior of Salmon

Studies have been carried out on the movements of returning adult salmon in North Sea coastal waters [24,34] within estuaries [51, 52, 56, 62] and within rivers [23,36]. The returning multi-sea-winter adults may arrive at the Scottish coast and enter the estuary of the Dee as early as February and March, and may subsequently be found within the main part of the River Dee throughout the spring, summer and autumn. Radio-tracking experiments on adult fish returning early in the year to the River Dee have shown that such fish may spend very long periods, several months at a time, holding positions within the main stem of the river [23]

Within the sea

The sea stage has been viewed as a feeding migration [45], with the salmon moving into productive marine feeding grounds in the subarctic. There is hardly any information available on the juvenile migratory routes [34]. However, post-smolts of unknown river origin were examined by [49] and they migrated northwards off the western coast of Scotland along the continental shelf edge, apparently making use of the dominant ocean currents. It is possible that the post-smolts use near-shore areas at the commencement of their marine migrations, and they may be especially vulnerable to human activities close to the shore, but there are currently no data on the migratory routes or geographical distribution of post-smolts within the North Sea.

[24] described observations on the movements of salmon on their return to coastal waters off the east of Scotland. Adult salmon caught at a coastal netting station were tagged with acoustic transmitters, released back into the sea, and their subsequent movements followed by means of a hydrophone receiver fitted to a small boat. Several of the salmon then entered a river, and their movements within the estuary were plotted. It was noted that the salmon approached their river mouths by moving

against the water flowing from the river. In stemming the river, the behavior of the fish changed from swimming with the tidal current to swimming against the flow of the river. Some of the salmon entered the river rather gradually, spending some time in the sea off the river mouth.

[34] have reviewed the migratory routes used by Atlantic salmon, sea trout and European eel in Scottish coastal waters. They concluded that there is currently no information on the swimming depths utilized by adult salmon in Scottish coastal waters; there is substantial uncertainty as to the mechanisms and routes by which adult salmon move around the Scottish coast to the proximity of their natal rivers; and there is limited information on the timing of migration for both juvenile and adult fish for specific locations on the Scottish coast. The resolution of available data is insufficient to assess the likely proximity of salmon to any particular projects or development areas. They concluded that in order to assess the potential impact of specific developments there is a need for additional detailed local information on salmon migration and behavior.

The water current issuing from a river is thought to be an important guide to the salmon migrating into it [26]. The importance of olfactory cues to migrating salmon has been clearly demonstrated by [6]. [53] presented evidence that the homing of adult Atlantic salmon may be largely dependent upon pheromones released by other individuals in the river. [7], on the other hand, has suggested that the level of natural chemicals in waters is important in guiding sockeye salmon to their home tributaries.

Four grilse and two salmon caught in nets were tagged with acoustic transmitters and tracked in the sea [52]. The movement of the salmon was greatly affected by the tidal flow, but subtraction of the tidal flow from such movements produced a set of swimming courses, indicating the salmon's ability to set and maintain a particular directional course. The salmon maintained a relatively constant swimming direction, independent of the speed and direction of the tide, perhaps related to orientation to the earth's magnetic field.

River Entry

Salmon may return to Scottish rivers in any month of the year to spawn, including the early part of the winter. Most of the grilse return in late summer and early autumn, but multi-sea-winter fish may also return in large numbers in the winter and spring, when they form the basis of important rod fisheries. Ten fish were captured within the estuary of the River Dee, and were tracked upstream using radio transmitters [23]. During their upstream migrations the salmon often stopped moving and took up residence at a number of locations, which was perhaps surprising, given that the the water levels were consistently high and variable. During these periods of residence in the river, the fish appeared to resist any stimulus to move. Such fish, entering the river early in the year, may spend many months in particular pool locations without feeding, living on their body reserves. Later, towards their spawning periods, their behavior changes, and they once more set off upstream. The observation that a long period of residence in the river is spent at a particular location may provide the clue to understanding why salmon may enter rivers so early in the year. There may be selective pressure for fish, and especially females, to arrive early to occupy the best holding positions, perhaps resisting competition from other individuals. Thus, the early arrivals may secure favorable positions below suitable spawning sites. Some of the tracked fish appeared to spawn in the main part of the river, where there were clean areas of appropriate substrate. Others moved upstream or entered tributaries to spawn.

There are waterfalls in some parts of the rivers and tributaries travelled through by Atlantic salmon as they move upstream. The salmon sometimes have to jump upwards, as well as swimming through the waterfalls.

In some estuaries, the river temperature may affect the entry of salmon. [1] showed that the returns of salmon to a trap above the head of tide on the River Thames were negatively correlated with water temperature during the summer months. However, [51] examined the movements of salmon within the estuary of the River Dee, and the movements of returning adult salmon were not inhibited by temperature conditions in that estuary. [18] Suggested that the early entry into the Dee by salmon was related to the abundance of suitable holding locations within the river itself. In shorter rivers, late migration might be the only option because of the lack of suitable holding positions.

Upstream counts of adult salmon in a tributary entering the River Dee, the Beltie Burn, during autumn and winter were examined over a 13-year period using an optical fish counter[54]. The salmon mainly entered the tributary at a particular time of year, peaking in early December. Environmental factors had a large influence. Entry of salmon was initiated by high flow rates. However, a change in flow from one day to the next did not result in a response from salmon. Rather, they reacted only after more than a day of flow increase. There was no consistent threshold level of flow that triggered tributary entry. The upstream passage of salmon was reduced at low temperatures (below 3°C). The numbers of salmon migrating upstream showed a gradual increase as the temperatures increased up to 11°C, but then sharply decreased at higher temperatures. Female salmon migrated earlier than males, by about 2 weeks on average.

[61] described the spawning behavior of salmon within another tributary of the River Dee, the Girnock Burn. Individual fish were followed by means of radio tracking and by visual observation from the banks of the burn. A trap close to the mouth of the burn intercepted adult salmon ascending to the burn. The timing of capture of fish at the trap confirmed that water flow in the burn played an important part in stimulating entry and ascent of this tributary. The males moved more extensively than females, swimming between several of the spawning areas within the tributary. The females went straight to their spawning areas, and tended to remain there, although some of the tagged females were observed to spawn at two different locations.

Individual females were joined by males over varying distances, often from considerable distances downstream, thereby precluding dependence on auditory or visual cues. It is possible that the males are attracted to the females by olfactory stimuli – the sense of smell. Within their spawning areas the females cut into the substrate gravel, an area termed the redd, to lay their eggs that were then fertilized by a male. Their first excavations proved to be exploratory. The activities of the fish did not always appear to result in the deposition of eggs. The females often simply produced a limited excavation, a few centimeters deep, below the normal stream bed level. There was no evidence of any initial attempt at egg burial, until activity was resumed at these sites later in the spawning period.

Female salmon tend to spawn at their natal location, where the riverbed's gravel is in a favorable condition, and the males then mate with them wherever they find a female wanting to do so. The major period of redd cutting activity within the main spawning areas was observed in November and December. It took place in areas of loose gravel where the flow of water was strong. Spawning usually took place at night. The female initially excavated a small depression in the bed of the stream, the start of the redd, by turning over on her side and vigorously flexing her body and caudal fin, thereby actively displacing the finer sand and gravel down stream. Male fish, either singly or in numbers, previously lying down stream of the redd site, moved upstream and gathered by the side of the female, the individual males reacting aggressively to the intrusion of other males into the immediate area. During the excavation period, the female repeatedly moved into the pit, dipping her body so that her vent was close to the base of the pit. Eventually, the female dipped down into the redd depression, and on holding this position was joined by one of the attendant males. Both fish then quivered alongside one another with their jaws gaping. As the eggs were placed in the substrate the large males released their sperm into the location of the eggs within the substrate. In some cases, the parr may also go up to the spawning areas and release sperm into the substrate where the female has deposited its eggs, so that a few eggs may be fertilized by parr, although most of them are fertilized by the larger males that have returned from the sea. The eggs dropped into the crevices in the substratum were seen to be surrounded by a cloud of milt. Subsequently the female proceeded to an area of undisturbed gravel just upstream of the eggs, turned upon her side and, flexing her body and caudal fin, displaced sediment which was then washed down stream onto the eggs, burying them. Having excavated a redd, spawned, and completed the burial of eggs, females sometimes remained on the redd for several hours, lying on the gravel with limited fin movements. However, more commonly, the females turned and moved downstream with a combination of both active swimming and passive displacement, with sufficient movement of the body to keep the fish in the main current. The females often descended to the nearest deep pool, remaining there for varying periods of time. Attendant males often remained in the area of the redd, and attempted to court other females in the vicinity.

Subsequent return to the main lower parts of the River Dee by the females was often associated with an increase in water discharge within the burn. In contrast, most males remained within the burn until they became physically incapacitated or died. [23] confirmed that males moved more extensively and frequently than the females, within rivers and their tributaries. It has also been shown that female Atlantic salmon in a Canadian river move less than males regardless of river temperature or discharge, whereas the males engage in more extensive movements except at elevated temperatures and discharge rates [14]. There appears to be a strong commitment on the part of the males to engage in sexually orientated activities over the spawning period, until the physical state of the male fish deteriorates, when activity is progressively reduced and it eventually dies. Most of their life has been spent in saltwater, where they feed, and the adult salmon do very little feeding when they return to their home rivers. They have a negative buoyancy in fresh water, and when they die, which many of the males do, their carcass sinks to the riverbed.

It is especially important to ensure that appropriate substrates are present in the rivers and tributaries, close to the original spawning grounds, to ensure that salmon are able to spawn there.

Salmon Changes in the River Dee

Monitoring Adult Salmon

At the end of December 2015, the Dee experienced extreme weather conditions as Storm Frank hit the area, causing extensive flooding. The Dee burst its banks at a number of locations and torrents of water tore through the river, damaging the river banks and bridges, displacing rocks and sediments and almost certainly damaging the spawning redds of salmon. This has been described as a one in 500-year event, however, the Scottish Environment Protection Agency (SEPA) has predicted that the impact of climate change will result in "milder and wetter winters, hotter and drier summers, more extreme weather events, and rising sea levels". If there is more extreme weather and especially more extreme winter rainfall in Scotland in the future, then it may affect the state of salmon stocks. There is little that can be done directly to prevent such damage, except to ensure that the environment in the Dee is protected against damage from human activities and that salmon stocks remain in a healthy and active state within the river.

The counts of adult salmon moving upstream into the Beltie Burn, monitored by [54] have shown a decline in recent years (Figure 6). It is evident that fewer salmon are returning to the River Dee to spawn. The effects of various environmental factors on the numbers of fish entering the Beltie Burn have been examined over the period 2000 to 2013 using statistical modelling. In particular, the numbers of fish entering were compared with the time of year, water flow in the main stem of the River Dee and in the burn itself, and water temperatures. The statistical analysis revealed that salmon are primed to enter the Beltie Burn at a particular time of year – beginning in September/October. Even if the right flow and temperature conditions exist in the river earlier in the year, salmon do not enter the tributary in large numbers. Migration into the Beltie may peak as late as the end of November to early December in some years, depending on the environmental conditions.

Entry into the Beltie Burn was triggered by water flow. However, it was rising water levels in the main stem of the River Dee that initially triggered entry into the tributary, rather than flow in the Beltie Burn itself. Salmon entered the Beltie when spate conditions existed in the main stem of the River Dee, even when there is no increase in flow within the tributary itself. Tributary entry was also influenced by temperature. Salmon did not enter the Beltie Burn at temperatures below three degrees or above twelve degrees Celsius. Within that range, the higher the temperature the more likely they were to enter, provided the water levels in the main stem of the river were sufficiently high. The optimum temperature for entry was around eleven degrees Celsius.

The numbers of upstream-migrating salmon entering the Beltie Burn each year varied greatly, depending on the environmental conditions. It was largely water flow and temperature that determined the migration pattern, influencing the numbers of salmon entering the tributary in a given year. In those years when the autumn period was especially cold and dry, entry was delayed and the total numbers of salmon entering the Beltie were reduced.

parison of the annual numbers of salmon entering the Beltie with the numbers entering other Dee burns, the Girnock and Baddoch, showed only poor correlations, which tends to confirm that the numbers entering a particular tributary each year are controlled by local environmental conditions. There may also be differences in the migratory patterns of different sub-stocks of salmon within the Dee. There is also a lack of correlation between the numbers entering the Beltie Burn, and other tributaries, and the recorded annual rod catches. This suggests that counter or trap data from a single tributary cannot be used to assess the abundance of salmon within the river as a whole.

The study on the Beltie Burn initiated by the Middle Dee Project, a group of river proprietors and anglers, confirmed the value that can accrue from work undertaken by volunteers and representatives of local communities. It underlines the importance of “Citizen Science”; where members of the public may participate in scientific research in collaboration with professional scientists.

Additional optical counters have been deployed by the Dee Board. An optical counter (VAKI) was placed on the Feardar Burn in the upper part of the Dee in 2001. Quite large counts were obtained from this small tributary, casting doubt on the validity of the much smaller numbers of salmon passing through the fish trap on the nearby Girnock Burn. However, maintenance of the counter proved to be a problem because of the remoteness of the site, and operation of the counter was discontinued.

More recently, VAKI counters have been placed by the Dee Board on the Coy Burn and the Culter Burn. In both cases the counters were placed at the top of fish ladders, intended to allow salmon passage through dams across the burns. A Denil fish pass and counter was installed on the four-metre-high Coy dam on Crathes Castle Estate in 2008. Numbers of salmon and sea trout ascending the Coy burn were variable, and very low over the years, but in 2014 were the highest recorded to date with a total of 43 salmon and 69 sea trout. The fish pass on the Culter Burn has opened up 76 miles of habitat that was previously inaccessible to migratory salmon and sea trout. The Culter counter recorded 43 salmon and 69 sea trout ascended the fish pass during 2014, its first year of operation (coincidentally the same number of fish passing through the Coy fish pass). However, in general the numbers of salmon passing through both the Coy and Culter counters has been relatively small. The dams on the Coy and the Culter have been present for many years, and these burns have not been producing large numbers of juveniles for long periods because the upstream entry of adult salmon has been blocked.

From the standpoint of monitoring salmon passage on the Dee it would be especially useful to place VAKI or similar counters on unobstructed spawning tributaries at a number of diverse locations, in order to compare the numbers returning to different tributaries from year to year.

Fry Surveys

Fry densities at different sites on the Dee have been examined by the Dee Board. Electrofishing surveys have been carried out to look at fish densities in different parts of the catchment and have investigated how the numbers of fish may have changed over time. The first comprehensive juvenile stock assessment using the collected data was made in 2015 and a similar assessment was then carried out in 2016, when salmon fry abundances at each site were estimated by Marine Scotland Science, based on the numbers of fish caught by electrofishing, using a capture probability model. Numbers were compared to a reference density, or national benchmark, based on expected fry densities at a site with similar habitat characteristics. The benchmark is what could be considered as indicative of a healthy catchment. Fry densities at some sites within the Dee catchment in 2016 were found to be considerably below the benchmark, with many sites containing less than 10% of the fry numbers associated with a healthy fry population. In contrast, fry densities in 2012 – which were expected to be high due to high spawner abundance in 2011 – were close to the benchmark and showed the catchment had been close to maintaining maximum fry production in that year. Fry densities in 2016 were also substantially below those in 2015, in terms of the number of sites attaining the national benchmark.

Fry numbers are generally highest where there is good habitat for fry. Such areas may become filled to full capacity with fry, resulting in some of the fry then having to move to poorer habitats. It is important in conducting fry surveys to examine areas of poor habitat as well as areas of good habitat, as such poor areas may contribute to the total numbers.

Although juvenile densities on some parts of the Dee may still be healthy, it seems that densities are greatly reduced on some of the tributaries. This may be the result of fewer adults spawning in these tributaries, but it may also be attributed to local environmental degradation; through poor farming and forestry practices, the release of contaminants into the river, and perhaps in some cases the presence of construction developments in close proximity to the river and its tributaries. It is clearly necessary to investigate the causes of these low fry densities on certain tributaries. The Board is doing valuable work in carrying out fry surveys.

Salmon Smolt

Migrations

Mortality during the smolt and early post-smolt migration may be especially significant. Whether a salmon parr will become a smolt, and migrate to sea, or remain in fresh water, is based on the individual growth rate and the energetic status in the late summer and autumn of the year before it migrates [38]. The smolts move down in groups, sometimes swimming faster than the water current [10].

It has been pointed out by [37] that the timing of estuarine and ocean migration is very critical for the survival of the juvenile salmon. Travelling downstream and through estuaries may expose the smolts to visual predation risk and different timing strategies can have a strong influence on the chance of surviving. The behavioral timing decisions affecting estuarine survival are influenced by riverine characteristics, in particular water visibility. This survival difference between rivers is plausibly attributed to differences in visual predation risk. In small, clear, rivers most salmon avoided migrating during daylight hours and the survival of fish migrating at night was twice that of fish migrating in daylight. In vulnerable habitats (small, clear rivers) salmon smolts may time their downstream and estuarine

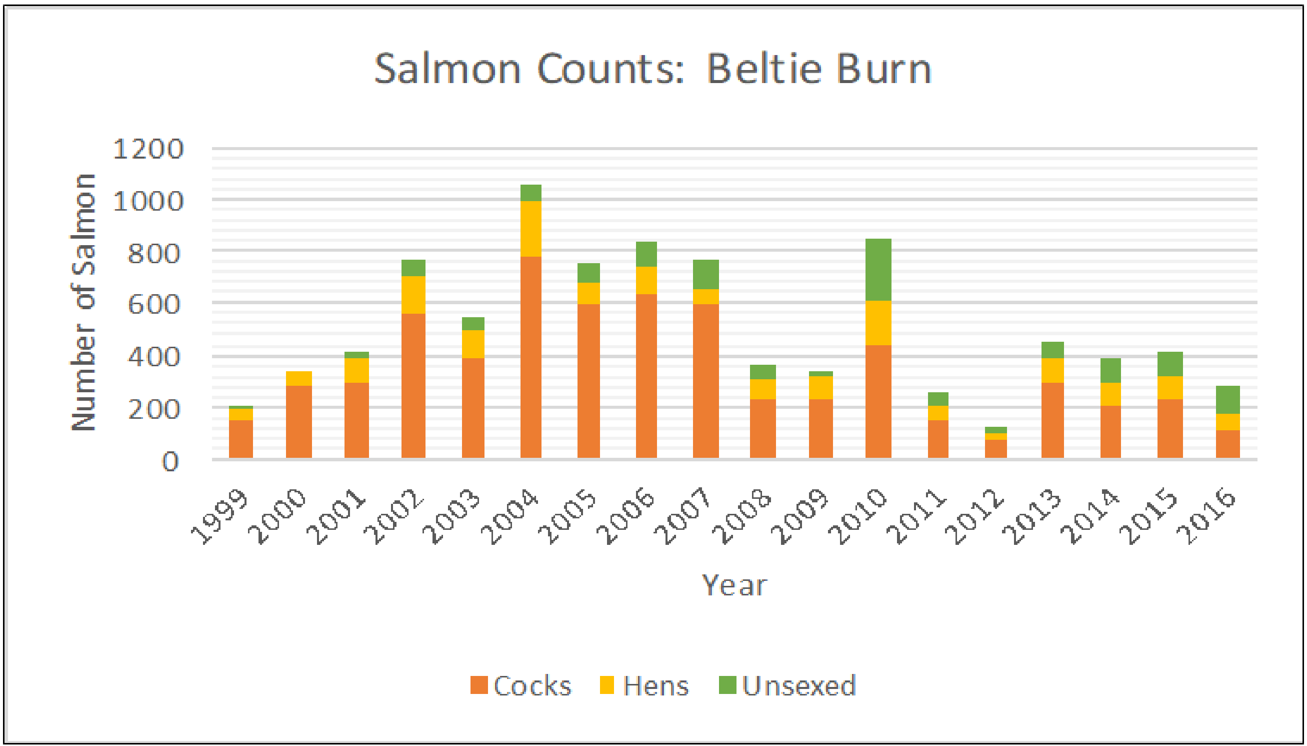

Figure 6. Numbers of salmon moving upstream into the Beltie Burn, data from the Middle Dee Project optical fish counter 9 [54].

migration so as to reduce their exposure to visual predation risk during daylight hours, whereas in less vulnerable habitats the preference for nocturnal travel may be less pronounced. Smolts migrating downstream later in the season may be less selective with respect to diurnal travel preferences, because delaying their timing of ocean entry even further may have consequences in terms of reduced marine growth. Temperature increases from climate change are especially predicted to accelerate the timing of downstream migration and ocean entry, which may increase the survival of juvenile salmon from small coastal rivers, but decrease the survival of salmon from much larger rivers.

[60] stated that the timing of the smolt migrations is very important in determining marine survival. They pointed out that estuaries and river mouths are the sites of the highest mortalities, with predation being a particular cause. The mortality rates varied greater in estuaries than in rivers and marine areas, probably reflecting the huge variation among estuaries in their characteristics. They added that behavior and survival during migration may also be affected by pollution, fish farming, sea lice (*Lepeophtheirus salmonis*), hydropower developments, and other anthropogenic activities that may be directly lethal, delay migration or have indirect effects by inhibiting migration. Thorstad *et al* confirmed that water discharge and temperature may affect both the smolting process and the timing of the downstream migration. They suggested that the main natural cause of mortality during the smolt and initial post-smolt migration seems to be predation by various birds, mammals, freshwater and marine fishes. Although predation may be the direct cause of mortality, there may also be other indirect contributors to the ultimate mortality perhaps including diseases.

The declining numbers of adult salmon returning to the Dee in recent years, while juvenile stocks may have remained relatively stable in some areas, suggests that additional mortality may be occurring between the smolt and adult return stage, both in the sea and in the river itself. Within the river, it is likely that predation by birds, mammals and larger fishes may remove some of the smolts. It is also possible that smolts may be injured by poor conditions within their rivers. As a first step in investigating when and where this mortality occurs within the river, an acoustic tracking study on salmon smolts was carried out in 2016 by the River Dee Board. Between the years 2016-2019, thousands of smolts were trapped to assist with better understanding of smolt production and to find out more about the perils they face in the early stages of their migration to the sea. In 2019, the fourth and final year project, 134 smolts were tagged. Some were tagged as pre-smolts but the majority were tagged as smolts. The aims of the 2019 study were to: 1) identify effect of tagging time on losses; 2) identify differences in migration timing between the two tagged groups; 3) assess losses between areas of intensive and background piscivorous bird control; 4) compare timing of smolt presence in Aberdeen Harbour between 2016 and 2019; and 5) make a comparison of fish tagged at the Baddoch smolt trap between the years 2017 and 2019.

In 2016, smolt losses occurred in the river and none in the harbour. Results from 2017 indicated that most losses (70%) occurred in the upper to middle catchment. This high loss of tags, indicating mortality, raised concerns over piscivorous bird predation losses in the upper and middle parts of the river. Therefore, in 2018 additional receivers were installed in the river to more precisely define where losses were highest. However, in-river losses in 2018 were low, and instead high losses occurred in Aberdeen Harbour. From a comparison between the three years of tracking fish from the Baddoch burn down to Aberdeen Harbour, it was concluded that: in the upper river (up to 41 miles downstream from the Baddoch burn), tag losses are similar across years and are higher than in the lower river; and that tag losses in Aberdeen Harbour are generally low, but at risk of being very large under certain conditions, such as occurred in 2018. It was concluded that the tracking has shown substantial losses of smolts in the river, with predation considered to be the primary cause of these losses.

There are a number of problems in carrying out such experiments. The capture of smolts in the tributaries can be difficult, especially at high water flows, where the captured smolts may be carried past the trap and are also at risk of being damaged. It is probable that some of the migrating smolts are not captured, and that the counts obtained may therefore underestimate the number of smolts moving downstream. The tagging of the smolts with acoustic transmitters may also impair their health and change their behavior. In addition, the tag signals may not always be well detected by the receivers placed in the river and estuary. The results of this study should perhaps be regarded as provisional, although the work is valuable in providing additional information on factors affecting the Dee salmon stocks.

Possible Changes affecting Fishes like the Salmon

Human Activities

Salmon can be adversely affected by the loss, degradation and transformation of marine and freshwater habitats. Features which can affect the salmon badly are human activities that create noise and pollution, changes in land use, drainage, water abstraction, water entry from sewage works. In many river locations, detrimental changes are taking place that cause the environment for salmon to deteriorate. The presence of in stream obstacles is one of the major factors that can affect the movements of salmon and the sustainability of salmon within rivers. The presence of hydropower generators may involve the presence of dams that restrict the upstream movements of fishes, and turbines that may damage fishes moving downstream. In some cases, salmon cannot successfully enter burns, where spawning areas may have declined, or been blocked off, and nursery areas for juvenile salmon may have been damaged. Salmon spawn in areas of the river and its tributaries where there is spawning gravel. Heavy levels of silt on the substrate can make it especially difficult for the salmon to spawn.

Other fishes may also be adversely affected by human activities within rivers. There has been recent interest in the effects of human activities upon the movements and migrations of eels, as well as on other fishes, largely because of concern regarding the diminishing status of their populations at various locations within their geographic range [5,33,50,58]. Hydroelectric structures on rivers, and in particular their turbines, pose particular problems for downstream-migrating fishes, including salmon, trout and adult eels [2]. Elongate fishes like eels are especially vulnerable to injury and mortality from turbines [13], and so there is especially strong interest in protecting out-migrating adult silver eels on the way to their spawning grounds in the sea. In many watersheds, the numbers of eels have diminished greatly in recent years [9]. For example, the recent long-term abundance index of American eels (*Anguilla rostrata*) at the Saunders eel ladder in the upper St. Lawrence River is about 8% of the abundance observed in the mid-1980s[8]. The abundance of the European eel (*Anguilla anguilla)* has also declined throughout its range, with the abundance of juvenile European eels arriving at the coast reduced by more than 95% since the 1980s [41,47] have explored the need to develop guidance systems that use acoustic cues, and perhaps other stimuli, to influence the movements of fishes close to river turbines.

Climate Change

Climate changes are affecting salmon and other fish in the sea and in rivers. The food of salmon in the sea is especially being affected. The growing juvenile salmon in the sea consume zooplankton and small fishes. Zooplankton are the animals that dwell in the sea. And while many of the zooplankton can move voluntarily within their small surrounding areas, they are collectively subject to the water motion in their larger surroundings. Climate change is resulting in more water entering the sea, and increases in the seawater temperature leading to lower levels of oxygen. These changes may affect the prey of the salmon detrimentally, as well as the salmon themselves.

Increasing sea temperatures are predicted to decrease the body size of marine organisms [29] This work confirms that the mean length-at-age of adult fish has declined in many sea areas. The trend of decline in adult length is inversely correlated with bottom sea temperatures. However, the mean length-at-age of juvenile fish has concurrently increased, correlated positively with rising temperature, suggesting that the juveniles have a faster growth rate due to increased temperatures. It is evident that that global warming is affecting the size of marine fish species, presumably including the salmon. The effects of these changes require investigation.

Interference with Salmon Sensitivity

Salmon have a range of senses, and like humans they have sight, smell, taste, hearing and feeling.

Salmon use their sensory systems to gather information on their surroundings and such systems are crucial for migration, survival and reproduction. Their activities are based on what they can observe, hear, smell or feel. Their behavior takes place in response to some particular stimuli.

Salmon hearing may be especially damaged by the effects of underwater noise. Sound travels faster through water than in air, and it travels further than other stimuli through the ocean and is used by marine animals, including invertebrates, fishes and marine mammals, to examine the marine environment and to interact within other animals. Ocean soundscapes are changing, because of: major declines in the abundance of sound-producing animals; increases in anthropogenic (human-generated) noise; and changes in the contributions of geophysical sources, such as sea ice and storms, owing to climate change. It is said that the soundscapes within the oceans are fundamentally different from that of preindustrial times, with anthropogenic noise negatively impacting marine life [11]. Shipping and fishing, resource exploration including seismic surveys, and infrastructure development, including the development of offshore oil and gas facilities and the construction of wind farms, have increased the sounds generated by human activities, whereas the sounds of biological origin may have been reduced as a result of fishing and habitat degradation. Climate change is also affecting natural sounds. Changes in the soundscape can affect marine animals at many different levels, including their behavior, physiology, and, in some cases, their actual survival.

Hearing by the salmon is especially important for navigation, avoidance of predators and the location of prey. The hearing abilities of salmon were first examined by[20]. Salmon are especially sensitive to low frequency sounds (below 380 Hz) and they are sensitive to particle motion rather than sound pressure. Their hearing is likely to be masked by anthropogenic aquatic noise and substrate vibration. A number of noise measurements were made in the River Dee, and it was found that the low frequency natural noise levels (below 100 Hz) were greater in the river than in most places in the sea. It was considered that there would be some impairment of hearing in a fast-flowing river, or close to heavy sources of water noise like the entry of a tributary, a water-fall, or sources of anthropogenic noise, including vehicles close to the river, motorized vessels within the river, and other human sources of underwater sound (including splashing of the water, or shouting on the river bank). Russian investigations have shown that salmonid fishes are themselves active sound producers [43], with some of the sounds produced during spawning. [44] suggested that drum beats were produced by muscles overlying the swim bladder at its anal end, and other sounds, including croaking, resulted from the intake of air into the swim bladder, while rumbling followed the ejection of gas at the anus, and clicking accompanied closure of the jaws. A number of aquatic animals that may serve as prey to the salmon in the sea may also produce sounds. The localization of female salmon, that are ready to spawn, by male salmon may be especially important. It is evident that anthropogenic (human) noise has the potential to prevent fish calls being detected, and may also affect the discrimination of such sounds. Fishes may also obtain biologically important information about their environment by examining the acoustic scene that surrounds them.

Underwater noise, from both natural and anthropogenic sources, has increased across the biosphere, creating changes to ecosystem health. Sounds are important to animals in both terrestrial and aquatic environments and detrimental effects have been shown across a wide range of taxa. [22] have described the various anthropogenic sound sources and their potential effects upon fishes. It was concluded that the extent to which sound affects the structure and functioning of fish populations and ecosystems is of considerable importance, although such effects have yet to be fully established. Despite the ever-growing changes to human activities in rivers and coastal waters, the adverse effects of sounds have largely been ignored. It is important to evaluate the effects of underwater noise upon the Atlantic salmon, and then to take steps to minimise the noise levels.

Rivers are often naturally noisy, as a result of water flow and turbulence. Anthropogenic sound sources associated with construction works on rivers and lakes will add to the background noise. Sources may include pile driving, dredging and trenching, concrete mining, the deposition of rock fill, and the operation of land-based and water-based construction machinery. At hydroelectric dams and other installations, sound may also be generated through the running of the turbines and the opening and closing of sluices, lock gates, and screens. The use of boats within rivers and estuaries can also generate noise.

Sound travels almost 4.5 times faster in water than in air. However, propagation of sound in shallow water environments like rivers can be very complex as a result of the presence of many discontinuities and complex topography. It is often difficult to predict or model sound transmission. Propagation of low-frequency sounds may be especially constrained in shallow waters. However, low-frequency sounds generated within the substrate, including the riverbed, may travel considerable distances and affect fishes and invertebrates [21]. The energy from substrate and interface waves can be reradiated into the water and may be detectable by salmon and other fishes. It is important to recognize that all fish, including salmon, respond to the particle motion accompanying passage of a sound rather than the fluctuations in sound pressure. Only a few species of fish can also detect sound pressure. Measuring or estimating the sound fields to which fish are exposed therefore poses formidable difficulties[20] showed that salmon are sensitive to particle motion, and respond mainly to low frequency sounds. [32] later examined juvenile Atlantic salmon and several species of Pacific salmon and concluded that frequencies in the infrasound range (5 to 10 Hz) were the most efficient for evoking both awareness reactions and avoidance responses.

The responses of salmon to very low-frequency sounds need to be taken into account. [12] showed that the frequency response of a number of species of fish extended well below the lower limit of 20 to 30 Hz usually examined in hearing studies. Cod, salmon, and a few other species were found to respond to sound frequencies extending down to below 1 Hz (infrasound). Tests on the behavior of juvenile salmon performed in a large tank showed that the fish produced spontaneous avoidance responses to sounds at 10 Hz, but not to sounds at 150 Hz. Tests on down-river migrating salmon smolts were also performed. Over a stimulation period of 170 minutes, only 6 smolts passed an operating 10-Hz sound source, whereas 338 smolts passed during a silent period of the same duration. Stimulation at 150 Hz had no evident effect on the migration of salmon smolts. There have, however, been relatively few recent studies on the detection of infrasound by salmon, despite the interesting results from these early experiments.

In a range of experiments, [16] examined auditory and tissue effects upon juvenile Chinook salmon. Noise from a simulated tidal turbine noise was presented for 24 hours at an SPL of 159 dB re 1 μPa. This was believed to represent a worst-case exposure scenario for juvenile salmon. After exposure, the fish were assessed for tissue damage and for changes in hearing sensitivity. Some of the treated fish appeared to show significant levels of injury compared with controls. In other experiments, juvenile Chinook salmon were exposed to pile driving signals that had been recorded in the field during actual pile driving installations. The distributions of results from experimental treatments of 1,920 and 960 pile driving strikes showed a statistically significant correlation between the injury and the sound level. It would seem that salmonids only show significant levels of damage and injury when they are exposed to impulsive sounds at very high SPLs. However, there is a lack of data on the effects of exposure to very high levels of vibration, where particle motion levels are high. Shaking the fish may be more damaging, especially to the auditory system, than exposing it to sound pressure fluctuations. Within Alaskan rivers the Chinook salmon returning to their natal rivers to spawn are becoming more scarce and smaller each year, since 2007. There appear to be a number of factors that affect Chinook survival in both their natal river and ocean waters. However, it has been shown that sound produced by boats with outboard motors has been especially harmful to migrating and spawning Chinook salmon [30].

Adverse Effects of Human Coastal Activities

Many human activities are taking place in the sea that may affect salmon adversely. Numerous offshore wind farm development projects are currently taking place. Ecological interactions can occur during pre-construction site assessments, the construction of offshore wind farms, during the wind turbine operations, and if the wind farms are being removed. Pile driving and vessel noise can affect the behavior of salmon adversely, and especially their movements, and migratory patterns. Pile driving during wind farm installation, and other coastal construction work, can damage some fish and invertebrate species and the noise can interfere with the ability of fishes to evade predators and detect coastal locations.

Entry Problems Within Rivers

Salmon and trout adults can have considerable difficulty in entering smaller spawning tributaries and burns when autumn rainfall is low. This has been shown, for Scotland, by the long-term study on Salmon spawning in the Girnock Burn on the Aberdeenshire Dee. The first information relating the numbers of Salmon managing to enter this tributary to the amount and pattern of water flow was given in[25]. This was then updated and extended by [59], demonstrating the same point in more detail – that unless flows of the right quantity occur at the right time, entry of spawning salmon can be restricted.

Rivers often contain barriers that influence the flow of water downstream, and the movements of fishes upstream. Dams, weirs, bridges and other structures have adverse effects upon the salmon. Such barriers may be built in rivers to control or divert water flow, or to raise water levels, or to accommodate river crossings. The barriers and their effects in European rivers have been described in detail by [4]. Within Europe, the main barriers are the result of agricultural activities, river-road crossings, structures built to control or divert water flow, dams, and increasing shallowness of the river. Within parts of the River Dee, there has also been rubbish dumped into some of the burns. The rubbish has included bicycles, barrels, fridges, tyres and plastic materials. There may also be pollution from sewage works and human activities within rivers and on the river banks, and this can deliver chemicals that are toxic to fish, and can also reduce the levels of oxygen in the water, making areas difficult for salmon to survive.

The Generation of Sediment within Rivers

Heavy sediment deposits can affect salmon spawning adversely. The female salmon create their spawning grounds by digging into the gravel substrate, and this is more difficult with deeper layers of sediment. From surveys on the the tributaries of the River Dee it was concluded that many of the sedimentary problems had resulted from changes in farming practices on the adjacent land. The changes included ploughing of the land, and the presence of cattle. Ploughing on the farm land can result in sediment (silt) entering the river, especially when there is heavy rain causing flooding on the land. Farmers may allow their cattle to access the burn to have water drinking opportunities. Nevertheless, trampling by cattle of the bank-side can result in the release of sediment and faecal material into the burn. Fencing may be required at some locations to control the access of cattle to the burns. The installation of water troughs for the cattle, fed by springs or by the mains water supply, may resolve this problem. However, it is important to install silt traps on farm ditches to limit sediment inputs. Clearing ditches, and excavating the burn itself can cause damage to salmon spawning areas.

Recently, damage has been done to parts of a tributary of the Dee, the Beltie Burn. The River Dee Board and Trust carried out work that focused on the protection of salmon and sea trout stocks, aiming to ensure that the tributary is a healthy thriving natural environment with good quality salmon spawning and rearing habitat. The burn was diverted to meander through some fields, and new buffer strips were placed along the bank to improve the water quality, and prevent water run off from the fields. However, it is now evident that the major changes that have been made are likely to result in even more water, soil and rocks falling into the Beltie Burn. The new buffer strips contain rocks and soil (Figure 5), and are quite steep, and it is evident that much sediment has actually already entered the burn, and there is likely to be damage to salmon and sea trout stocks.

The Significance of Trees around Rivers

River water tends to be warmer in a deforested area. Warmer water is less healthy for salmon, and their health tends to be adversely affected when their river banks become deforested. Higher river temperatures lower the availability of dissolved oxygen, and can increase the respiration and oxygen demands of the salmon. They can also change the availability of prey and especially aquatic insects. Increased temperature is often derived by the combination of ultraviolet radiation received from the sun, infrared radiation released from earth surfaces, and terrestrial energy conducted from the earth's interior. Broad-leaf trees close to the bank can reduce the light that enters the water from the sky. Planting trees along the river bank can therefore control the water temperature. Some bank stability can also be obtained by the planting of bank-side plants, including trees, provided that they are not too close to the water. However, trees can cause some erosion of the water. Falling trees and branches can create blockages and affect the river substrate adversely, and need regular attention and clearing.

Possible Invasion by Non-Native Salmon Species

Anglers in Scotland (in the rivers Ness, Dee, Helmsdale and others) have recently reported the capture of fresh run non-native Pink Salmon (*Oncorhynchus gorbuscha*). Such fish have also been reported in some salmon net fisheries in Scotland and both rod and net fisheries in England and Ireland. Pacific or Pink salmon are also known as hump backed salmon as the males develop a pronounced humped back during their spawning migrations. These salmon, which inhabit rivers and waters on the west coasts of the USA and Canada, were introduced into some Russian rivers in the 1960s. They have since been found in rivers in Norway, Finland and Iceland, and have recently been found in the lower stretch of the River Dee. There is now real concern that pink salmon populations have now established themselves in several Norwegian rivers. Many of those fish examined in Norway have been mature and ready to breed, as have some of the fish that have recently been caught in Scotland. The presence of these salmon is of concern because of the possible impact it could have on local stocks of Atlantic salmon. The presence of these fish should be closely monitored in view of the threat it poses to Scotland's native salmon. It is possible that they may force the native Atlantic salmon to compete with them for habitats and food.

During the summer of 2017, the Dee Trust identified more than 200 pink salmon redds along the Dee between Banchory and Garthdee, although investigation of these "redds" yielded no eggs. A high number of

Figure 7. Much of the new part of the Beltie Burn, of the River Dee, below a new bridge, is shallow, and contains a great deal of silt and stones, washed in from the new banks.

the pink salmon were later recorded in 2019. The Trust has been reported as being keen to work with Fisheries Management Scotland, SNH and SEPA to develop a clear strategy for dealing with the entry of pink salmon into the Dee and other rivers. However, thus far the Scottish Government has said that no support will be provided, because of uncertainty over the most appropriate management options, and the true threat the pink salmon poses.

It will be important for anglers to report the presence of pink salmon within European rivers. Any such fish that are caught should be retained, and tests carried out to try and ascertain where they have come from. The pink salmon may be one of the most damaging invasive species in Scotland, and they are likely to be especially damaging, as the Atlantic salmon are already under considerable adverse pressure.

Water Quality Within the River Dee

Studies of water quality within the Dee were recently carried out by the University of the Highlands and Islands. Water samples were examined along the full length of the river in 2018 and 2019, and 8 target pharmaceuticals and 10 water quality parameters were monitored at different locations. There were significant differences in pharmaceutical concentrations between sampling sites, with the highest levels close to toilet water processing stations. Water quality was highest in the upper part of the river, but was especially bad below the Banchory WWTP Sewage Works, where a number of pharmaceutical chemicals were entering the river, including Paracetamol, Carbamazepine, and Ibuprofen. The highest concentrations were found during a drought period in 2018. Such chemicals may have adverse effects upon fishes, and also upon humans drinking water taken from the river.

The Effects of Other Species upon Salmon

A number of species within the sea, estuaries and rivers can affect salmon stocks. Although some species may offer assistance to salmon, others may damage the salmon stocks. The damaging species may include seals, whales and dolphins, large fishes in the sea, and beavers and otters within rivers. Herons and other predatory birds may also consume salmon, especially the juveniles.

Beavers

Beavers are large, semiaquatic rodents. They build dams in rivers and streams, using tree branches, vegetation, rocks and mud, to give themselves access to deep pools of water, so that they can move about and feed in safety. They are herbivorous and they consume tree bark, aquatic plants, brush, and grasses. They can transform their surroundings by cutting down small trees for food and for building supplies. Beavers create wetland habitats that can benefit many other species including water voles, amphibians, dragonflies and birds. The water velocities preferred by both beavers and spawning salmon are similar. A Norwegian study actually found that beavers preferred the salmon spawning areas on small tributaries to colonize. [46] actually found that beavers on smaller streams preferentially chose salmon and sea-trout spawning areas to set up their colonies, i.e. there were more often colonies in such areas than would be expected by random, and when beavers build dams it is in the areas that they colonize [15]. Location of beaver dams and autumn streamflow interact to govern adult Atlantic salmon spawner distribution, which then dictates juvenile production and effects on fish community [39]. Losses of nursery areas due to beaver dams and other causes would not have been so critical in the past, when marine survival would have been so much better than at present. However, every square meter of nursery area for salmon is needed nowadays which is why Salmon Fishery Boards and Trusts should continue to spend much time and money on removing or easing obstacles to fish migration. However, currently, beavers have gained protection as a native species in the UK under government plans to enable many to be released into the wild to multiply and spread in rivers across the country. It can be illegal to kill, injure or capture beavers.

The presence of beavers may not help to increase salmon and trout populations, as these fishes may use beaver habitats for spawning, overwintering, feeding and as refuges from increased water flow. The beaver area can produce at least some juvenile salmon and trout if spawning adults can get to it, but it is important that the adult salmon should be able to reach it. The beaver dams can prevent or restrict salmon from getting further upstream. It is uncertain whether the positive effects of beaver dams on fish are greater than potential negative effects, such as the inhibition of migration.

Beavers were wild animals that were originally common in Scottish rivers, up until the 16th century. They were hunted throughout Europe and became extinct or were reduced to remnant populations in many countries. There are several populations of beavers that have been brought back to some Scottish rivers, and they are being re-introduced into several other parts of Great Britain. They can improve water quality and create new habitats that can provide some support for other species. Beavers have gained protection in English rivers as a native species. Although they were once hunted in the UK, they have now been reintroduced at some locations. In 2019, they were declared a protected species in Scottish rivers and landowners must apply for licences from the Scottish Government to kill beavers. NatureScot, formerly known as Scottish Natural Heritage (SNH), is the public body responsible for Scotland's natural heritage and working to improve natural environments in Scotland, and it currently allows beavers to be killed.

Otters

Otters are largely solitary, semi-aquatic mammals that get most of their food from lochs, rivers or the sea. The otter (*Lutra lutra*) declined in most of England and Wales between the 1950s and the 1970s because of pesticide pollution of rivers. But it survived in Scotland's cleanest bodies of water. Today, the species is flourishing across Scotland, including the River Dee. In rivers, the otters feed mainly on fish such as trout, salmon and eels, and also on on spawning frogs and toads in spring. Occasionally they attack other mammals and birds. The otters that live in freshwater are mainly active at night and they can occupy very large home ranges (around 32km for males and 20km for females). They occupy homes that are used for shelter and breeding and they may consist of a burrow, a natural hole, a cave or any other suitable structures. They may also rest or seek temporary shelter in above-ground structures known as 'couches'. Britain's otters may breed during any month of the year. Predation by otters upon the salmon may damage the salmon stocks.

The Response to Declining Salmon Numbers

It is evident, based on salmon catches, and other methods for estimating salmon abundance, that salmon are in state of decline in Scotland, and especially on the River Dee. As a result of this decline, the Scottish Government commissioned a Wild Fisheries Review in 2014. Essentially, however, the review was a political exercise, aimed at developing a new centralised fisheries management system, rather than attempting to deal with the problems experienced by the salmon themselves, and deciding how these might be resolved. Little attention was devoted to the current poor state of some Scottish salmon fisheries, and the potential impact upon salmon stocks of other activities, including agricultural practices and land use, the building of new housing and industrial developments along the rivers, and increasing developments in coastal waters.

A number of administrative changes were suggested by the review, including a new National Wild Fisheries Unit to centralise salmon management within government, and the formation of a number of locally led Fisheries Management Organisations (FMOs) that would form the delivery end of the system. The potentially contentious issue of a national rod licence was also considered. The report concluded that the benefit of introducing such a licence was likely to be significant, as it would provide a possible funding source for a new national angling development programme. Other recommendations on management regulations included:

- The system of closed days should be abolished, except with regard to the use of certain types of interceptor coastal and estuarine nets for salmon and sea trout where there was genuine scientific evidence to support the need for periodic closure.
- The system of closed seasons should be reviewed and brought under national control.
- New regulations would be introduced for each fishing season, as necessary.

During 2015, a consultation article was produced which summarised the responses to the Wild Fisheries Review. Overall, there has been little support from stakeholders for these proposals for reform. It was said by many that the government should be considering wider pressures on salmon and sea trout stocks, resulting from other activities that make use of water bodies (including but not limited to aquaculture and the management of predators).

Following on from the Review, Marine Scotland embarked upon a programme of Wild Fisheries Reform, including a package of new Conservation Regulations. The Salmon Conservation Measures (formerly known as the Kill Licence) were developed separately from the wider reform programme. Key aspects of the regulations for the 2017 fishing season were:

- the prohibition on the retention of salmon caught in coastal waters remains in place due to the mixed stock nature of the fishery and limited data on the composition of the catch.
- killing of salmon within inland waters is permitted where stocks are above a defined conservation limit.
- mandatory catch and release is introduced in areas with rivers which fall below their defined conservation limit.
- the completion of a Conservation Plan for all areas that have been assessed.

It is not clear what is now happening to the Wild Fisheries Reform Process. Many stakeholders have opposed the introduction of Fishery Management Organisations (FMOs), considering that they were not needed. Moreover, there is a risk that a more centralised system of governance would prevent local proprietors and anglers from objecting to government policies for the salmon fisheries. If any changes are required they could be implemented through the existing system of District Salmon Fishery Boards and Trusts. Stakeholders have emphasised the importance of management at a local level by those with local experience and expertise. Ministerial intervention should only take place when necessary. Overall, there appears to be little support for the proposals for reform being put forward by the Scottish Government. However, it is evident that there are serious problems with Scottish salmon stocks that must be resolved. The local Boards can play a lead role in investigating these problems and proposing solutions.

The Atlantic Salmon Trust (AST) recently announced that it is embarking upon a study to reveal the causes of dwindling salmon numbers. Their major area of concern is the mortality of juvenile salmon during their long migration at sea before returning to UK rivers as adults. A new “Suspects Framework Study” was announced at a symposium and gala dinner to mark the 50th anniversary of the Trust, attended by AST Patron HRH The Prince of Wales and His Majesty King Harald V of Norway. The Prince of Wales has said: “Our greatest concern is that today a very small proportion of salmon smolts leaving their rivers return as adult salmon. Thirty years ago, one in four would make it back. Today, it is only one in twenty, yet we do not know why this has happened and until we do we will not be able to put solutions in place”. Professor Ken Whelan, Research Director of the AST, said: “Scientists are increasingly concerned about the future of the wild Atlantic Salmon, …just 20 years ago, if you recorded 100 juvenile salmon leaving a UK river, more than 20 would return as an adult fish to spawn. In most UK rivers, fewer than five now return. We are determined to rescue this most valuable species and hope that the study we are announcing today will lead to an international framework that will give us the information we need to achieve this". This is an important initiative by the Trust that deserves support.

What Now Needs to be Done?

Improving Conditions for Salmon at Sea

The apparent decline in salmon stocks on the Dee and other rivers has generally been attributed to increasing mortality at sea, with the major factors implicated being changing ocean temperatures, competition with species like the herring and mackerel, unaccounted by-catch in pelagic fisheries, higher levels of predation, and a reduction in the food available for salmon in the sea. This decline is especially correlated with widespread sea surface temperature warming of the NE Atlantic Ocean, which may have affected the size of the foraging areas exploited by salmon of European origin.

There should now be closer examination of the by-catches of salmon taken in the herring, mackerel and blue whiting fisheries on the high seas, mainly utilising pelagic (mid-water) trawl nets. If it turns out that the salmon by-catches are large, then there will be a need to make changes to those fisheries to reduce the by-catch.

Dealing with natural losses of salmon as a result of increased predation in the sea and rivers is a more difficult problem. The main predators of salmon, including birds, otters, seals, whales, and dolphins, have strong legal protection and many species are expanding in numbers. If these predators continue to increase, then the levels of natural mortality of salmon in the sea and in rivers must be expected to remain high.

There are particular problems that may be arising for salmon and other fishes as a result of human business developments in coastal waters. Developments are taking place along the coast which may be harmful to migrating salmon that are leaving or returning to rivers. These include the construction of wind farms and new harbour developments. Wind farms may operate for many years, and therefore they have the potential for affecting salmon and sea trout stocks over an extended period. The construction and operation of wind farms involves the generation of high levels of low frequency noise, to which salmon are especially sensitive. There may also be a release of silt and other contaminants, and electromagnetic fields may be generated by the extensive electrical cabling that runs to the shore through the area traversed by salmon. These changes to the marine environment may affect the ability of salmon to migrate along the coast and to locate their home rivers.

There has been increasing presence in some river estuaries, and coastal waters, of large commercial vessels. Cruise ships are known to release quantities of pollutants into the sea. They are free to dump raw sewage 12 miles offshore. They can also flush out "grey water" containing contaminants from sinks and showers. The noise, pollution, and other disturbances created by the increased number of large ships may especially affect migrating salmon adversely.

It is important that the possible impacts from these and other developments upon salmon are investigated. It is especially important that salmon are not killed, injured, or exposed to additional predation risk as a result of their passage through development areas. Exposure to predation can result from delays and deflections resulting in salmon becoming concentrated at locations favoured by predators under conditions that offer them little protection. Salmon also need to have access to the various environmental cues that they use to position and orientate themselves during their migrations. During passage through the sea, salmon may use a variety of cues to orientate and navigate, including natural soundscapes, the Earth's magnetic field, and water currents. The sense of smell is also important for salmon in locating their home rivers. Alterations to these migratory cues as a result of wind farm and other coastal and estuarine developments may have adverse effects upon migratory fish populations and must be avoided or minimised. Any changes in water quality, or to salinity and temperature gradients or water currents may interfere with detection of odour cues. The presence of excessive sediment may also affect the ability of salmon to detect the subtle smell of their home river. There is potential for salmon to be affected adversely by any increase in freshwater and marine pollution and disturbance arising from boats and other activities during both the construction and the future operation and maintenance of coastal developments.

There is a strong case for closer studies of the movements of migrating salmon, both post-smolts and returning adults, and to determine the environmental cues that are important for the migrating fish. It is unfortunate, however, that little work is currently being done to follow the movements of salmon to examine how they migrate along the coast and whether they respond adversely to offshore developments, including wind farms. It is especially important to examine the effects of noise, electromagnetic fields, and contamination of coastal waters upon the movements of salmon, and the extent to which these factors may influence their ability to locate their home rivers. There is currently great enthusiasm for offshore renewable energy sources, and the adverse effects of such developments need to be examined.

Monitoring the Numbers of Returning Adult Salmon

Reported catch data provide an indication of the state of salmon stocks, but one of the problems is that fishing effort may change from year to year, and the skill of anglers may also change. Ideally, some form of independent assessment of the number of salmon entering rivers is also required. We have seen that the optical fish counter on the Beltie Burn has provided accurate data on the number of salmon and sea trout entering that particular tributary, and it was evident that the number of fish entering in a particular year was very dependent on the river conditions in that year. To monitor the state of salmon stocks more comprehensively it will be sensible to insert salmon counters within rivers and their tributaries, and to compare the numbers entering each part during the year. Optical fish counters, provided they are installed with care and regularly cleaned, appear to be more effective at monitoring the passage of salmon than fish traps. It is especially important to monitor the number of salmon entering the main stem of rivers, and passing upstream. There are some difficulties in achieving such counts using existing technology, and there is a need to seek expert technical advice on the design of fish counting systems for installation on the main stem and on the larger tributaries.

Juvenile Surveys

Juvenile surveys on rivers and their tributaries should continue to take place, and perhaps be enhanced. A full range of habitats should be included. Systems are also needed to record fry and parr survival. Where survival is poor the underlying problems will need to be identified and addressed. Low numbers of spawning adults may explain some of the low fry densities. However, poor habitat quality may contribute to the under-production in some areas. It will be important to continue to carry out fry and parr surveys in the future, and especially to determine which tributaries and parts of the rivers show especially low fry and parr densities, through low numbers of spawning adults, poor environmental conditions, or the presence of predators. Underperforming parts of rivers and tributaries must be identified and then it will be possible to decide what actions need to be taken to restore juvenile densities in particular areas.

Dealing with Environmental Problems within Rivers and Burns

Measures for monitoring and preventing sediments entering rivers and burns must be taken, so that the habitat quality for salmon is not allowed to deteriorate. Salmon and other freshwater animals require water that is clean and relatively free from pollutants. Rivers are especially subject to threat from the abstraction of water, and the release of processed water. Sewage disposal systems may be especially harmful. The production of sewage is often greatest during summer months when river levels are at their lowest. The dilution of contaminants entering the river at this time is reduced, leading to higher concentrations in the water. The contaminants released may include biologically active substances including dissolved medicines, contraceptive substances, and micro plastics. Plastic debris in the environment is more than just an unsightly problem. Images of litter and floating plastic bottles in rivers may first come to mind, but much concern about plastic pollution must be focused on micro plastic particles that are too small to be easily detected by our eyes. Levels of micro plastics measured within the Dee ranged from around 5-40 pieces per 100g sediment sample, with an average of around 20. It is evident that even the Dee, which is thought to be a relatively unpolluted river, contains quite a lot of micro plastics.

The presence of biologically active contaminants can be a particular problem in rivers. Oestrogen, at levels common in municipal wastewater, can cause fish populations to decline. The hormone feminises the male fish, which renders them infertile. In some rivers, oestrogen is present in wastewater due to the widespread use of contraceptive pills and other medicines. Both natural and synthetic forms of the hormone can cause feminisation of fish, reducing the sperm quality of male fish and affecting their breeding behavior. The volume of contraceptive pills and other oestrogen-like chemicals being flushed from toilets means that some male fish in some rivers may be adversely affected. Many chemicals from sewage plants may have oestrogen-like effects. Some may be creating 'trans-gender' fish, and also affecting fish physiology in detrimental ways ways. Drugs such as anti-depressants may also be altering fish's natural behaviour. There is a need for more research on these problems.

Under very low flow summer conditions, salmon have suffered previously at the lower end of the River Dee, presumably as a result of low oxygen and high contaminant levels. The rapid and continuing growth of human populations within river areas, together with the inadequacy of sewage processing, is likely to adversely affect the salmon and other fishes.

Areas within rivers and their tributaries affected adversely by poor farming and forestry practices must also be identified, and steps taken to return them to a satisfactory condition. Road works and farm tracks through fields may also especially cause problems. There is a need to monitor river sites to examine potential pollution and other forma of damage to the salmon. Such adverse environmental impacts need to be monitored and then minimised, in order to ensure that further damage is not done to the salmon stocks.

Dealing with Water Abstraction

Rivers, like the Dee, often provide the main sources of water supply for local towns and houses in the surrounding areas. In some areas, there are water reservoirs established but often water is taken directly from the river. It is often assumed that there will always be sufficient flow in the river, and that there is no need to provide water storage. However, low flows in the river may influence the upstream movements of adult salmon adversely. They may also result in higher concentrations of pollutants. The wet areas available for juvenile salmon may also be reduced. Fry and parr can be overpopulated and trapped in dried out areas, which may result in their dying or showing increased competition for food and space. Increases in housing close to rivers will require more water to be taken from the river and may result in higher levels of contaminants entering the river from housing, sewage works and other developments. Anticipated climate change is likely to result in lower summer flows that will have serious implications for the extent of the natural habitat available to support salmon, especially when water is abstracted from the river. Low flow conditions may be insufficient to encourage upstream migration of adult salmon through the lower reaches of the river.

Under the UK standards, the maximum abstraction permitted to achieve a 'high' standard at low flows (≤Q95) is 5% of flow, while to achieve a 'good' standard the abstraction is limited to 7.5% of the flow, which is lower than the current levels of abstraction permitted on the Dee.

Stocking

There is little that can be done in the short-term to reduce the effects of increasing mortality of salmon at sea, and reductions in the numbers of returning adults. In view of this, a major advantage for management of the salmon stocks may be to manage juvenile populations within the river. It may be possible to enhance the natural production of juvenile populations to maximise smolt numbers. Maximising juvenile salmon production and the numbers of smolts leaving the river may result in more fish returning to the river as adults. Identifying any environmental deterioration within the river and improving freshwater habitats may go some way towards improving smolt numbers. The first step must always be to improve the habitat available to salmon. However, there is also a strong case for re-stocking those tributaries that have been subject to environmental damage, once the causes of damage have been removed. In addition, there is a strong case for enhancing juvenile production in those tributaries where the number of adult entrants may be limited as a result of barriers or obstacles to upstream migration. Ideally, any barriers to movement should be removed, or effective fish passes introduced. Self-sustaining populations of salmon cannot be found in blocked tributary streams. However, even before removing barriers it may be appropriate to enhance such tributaries and other locations by means of stocking them with juvenile salmon reared in captivity, as they are at salmon farms. A hatchery can be established on the river bank. Brood stock may be taken from other locations and their progeny retained in the hatchery over winter. Unfed fry can then be planted out in chosen areas in the spring. However, stocking can negatively impact every life stage of naturally produced salmon stocks, either through direct competition for resources during freshwater life, reduced marine survival, and through genetic mechanisms leading to reductions in fitness and an inability to cope with environmental change at an evolutionary level. Survival rates of stocked fish may be lower than that of wild fish. Stocking should only be targeted at the most vulnerable components of the river stocks. Maintenance of good habitat conditions is essential if stocking is to be a success. Tributaries that will definitely benefit from stocking should be identified as a priority. These may include sites that have been subjected to environmental damage, and then restored, and sites where access by adults is poor. However, there is a need for stronger emphasis on the improvement and restoration of suitable habitat in rivers, including those which have been subjected to habitat damage from a variety of causes.

Changes to the Fishing Season

Another fisheries management action that might be taken to conserve salmon stocks is to reconsider the length of the fishing season. Extending the fishing season into the autumn and winter runs the risk of damaging fish that are about to spawn, as the numbers of fish caught can be quite high. It is likely that such fish, which are about to spawn, may be especially vulnerable to damage, even through catch and release. It may be better to revert to closing the fishing season well before the spawning season in order to prevent damage to the spawning salmon.

Reporting the Presence of Foreign Salmon

The presence of pink and other foreign salmon should be investigated, and any such fish that are caught should be retained, so that tests can be carried out to try and ascertain where they are coming from. They may also need to be removed, as they may pose a risk to local stocks.

Definite Steps that should be taken to Improve Salmon Stocks

Steps should include:

By-catches of salmon taken in the herring and mackerel fisheries on the high seas should be examined closely. If they are large, there will be a need to make changes to those fisheries to reduce the salmon by-catches.

Salmon fisheries should only be allowed to take place on rivers where stocks have been shown to be at full reproductive capacity, and where their habitats, especially including the spawning areas, and the areas occupied by the juvenile salmon, are well protected.

Additional fish counting systems should be placed within rivers and some of their tributaries to monitor the numbers of returning adult salmon.

Juvenile surveys on the river and its tributaries should continue and perhaps be enhanced.

There is a need to ensure that adverse environmental impacts upon salmon are minimised, both within the rivers and in coastal waters. Proposals for new developments must be scrutinised closely, and objected to if necessary, in order to ensure that further damage is not done to salmon stocks.

Research is needed on the coastal movements of both post-smolts and returning adult salmon to determine the environmental cues that are important for the migrating fish, and to examine the impact of coastal developments upon their migrations and their ability to locate their home rivers.

Consideration should be given to resetting the closed season on the river by preventing any fishing close to the time of the year when salmon are starting to spawn.

Those parts of the river and its tributaries where the upstream migrations of salmon, the spawning of adult salmon, and the production and survival of juvenile salmon, is being compromised by farming, forestry, and other practices, must be identified, and steps taken to return them to a satisfactory condition.

Parts of the river and its tributaries that would benefit from salmon stocking should be identified and facilities developed for enhancing juvenile salmon populations by planting out eggs and juveniles derived from the stocked salmon.

The presence of any foreign salmon in the river should be determined and reported. Any such fish that are caught should be retained and tests carried out upon them to try and ascertain where they are coming from, as they may pose a risk to local stocks.

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