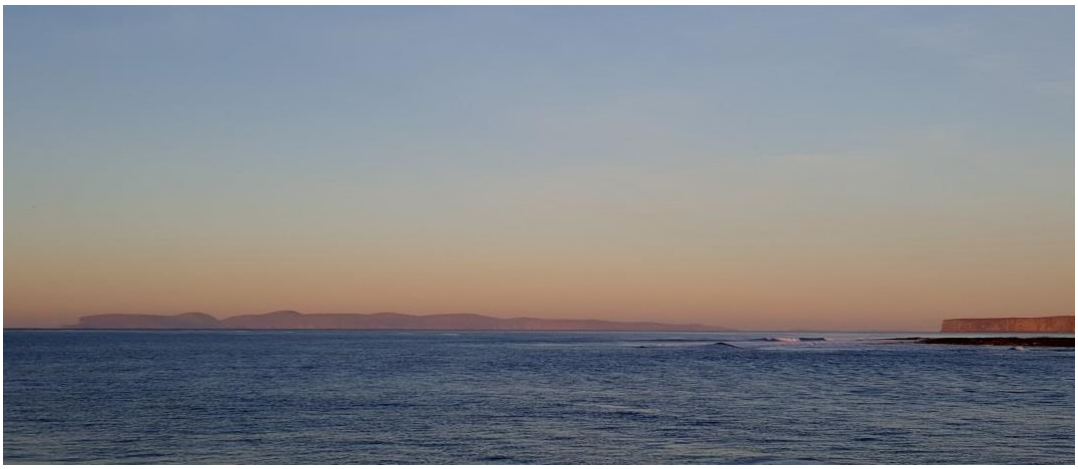
Fishermen's Knowledge: Salmon in the Pentland Firth

Alan Youngson

March, 2017.



The western entrance to the Pentland Firth looking east.

Dunnet Head is on the right. The island of Hoy is in the background.

Flow Country Rivers Trust

With financial support from The Fishmongers' Company

Contents

Summary

The Pentland Firth is the narrow strait that separates the southern Orkney Islands from northern Caithness. The Firth is a current focus for marine renewables development and, in particular, for the extraction of tidal energy. The Firth is probably also a major throughway for Atlantic salmon returning to the rivers of north and east Scotland from ocean feeding grounds to the northwest of the British Isles. The extent of any possible interaction between migrating fish and renewables installations will be affected by the numbers and origins of fish passing through and by their behaviour, including their spatial distribution in relation to the locations of renewables installations.

There is no direct information on any of these variables because salmon have not been studied in the Firth itself. The objectives of the present study are therefore to re-visit tagging studies carried out many years ago in the wider vicinity of the Firth, and particularly on the coasts of Caithness and northern Sutherland, and to match these data with less conventional sources of information derived from the accounts of local salmon netsmen and from the legacy of specialised buildings associated with the netting industry. The aim is to acquire a better conceptual understanding how salmon targeting rivers in northern and eastern Scotland may use the Firth for transit.

It is concluded (1) that passage of salmon through the Firth is predominantly from west to east, (2) that some fish from all of the East Coast rivers pass through the Firth, (3) that fish from the eastern rivers are probably present in greater numbers than the headline figures from tagging studies indicate, (4) that few fish targeting the rivers of the North Coast pass through the Firth and (5) that salmon on passage through the Firth probably bias their routes towards the southern shore.

Introduction

As is well-known, salmon spend the first part of lives in fresh water, move to the sea to make most of their growth and then return to their original rivers to spawn. Grilse (one-sea-winter fish or 1SW fish for short) return after spending one year at sea. Multi-sea-winter (MSW) salmon return after two or more years, but mostly as 2SW fish.

Grilse and MSW fish make long migrations through the northwest Atlantic. Indeed, smolts tagged in Scottish rivers have later turned up in substantial numbers in the salmon fishery in the Davis Strait on the West Greenland coast. Even as the crow flies, this is a return journey of around 5000 miles. Only MSW fish make this particular journey. The migrations of grilse are probably less extensive given their shorter absence at sea. Even now, the ultimate locations of 1SW and 2SW fish are still not fully documented and the routes taken by fish moving to and from the northern ocean are only poorly understood.

However, no Scottish fish stray into the Norwegian fisheries sector, supporting the idea of a distinct westwards bias in their distribution in the ocean. So, when the time comes to return, we probably have to imagine that the fish sweep south and eastwards as they head back towards the Scottish rivers. In this case, as the map in Figure 1 shows, the Pentland Firth and the Orkney Sounds are obvious passageways from the northwest Atlantic to the rivers of eastern Scotland and beyond.

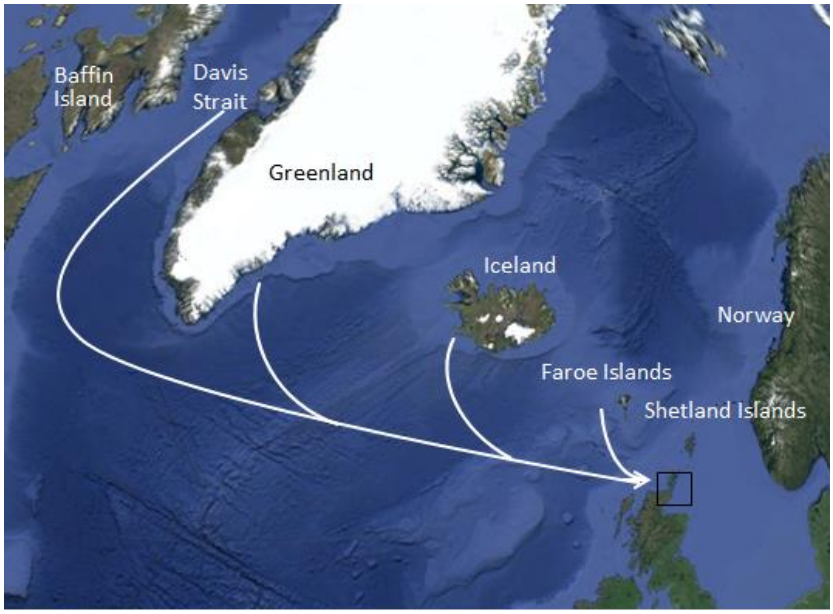


Figure 1. The geography of the North Atlantic area. The position of the Pentland Firth is indicated by the box. Indicative routes for the return migration of adult salmon to Scottish rivers are shown by the arrows.

The Pentland Firth is the narrow stretch of water that separates the northern coast of Caithness from the islands of South Ronaldsay and Hoy in Orkney. It links the Atlantic Ocean with the North Sea. The Firth is about 15 miles in length and only 7 or 8 miles wide. Huge volumes of water pass through it four times each day, moving eastwards on the two flood tides and westwards on the ebbs. Tidal conditions are among the most extreme anywhere in the world and current speeds range up to 7.5 metres per second (about 15 mph). The map in Figure 2 shows the layout of the Firth and its main geographical features.

Figure 2. The main geographical features of the Pentland Firth.

The picture of the Firth shown in Figure 3 adds some hydrographical detail to the map. It was constructed by the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrtusing) using radar images obtained by satellite. The colour coding shows the velocity of the surface

currents - red is slow and blue is rapid. The tide is on the ebb (moving westwards) and streaming around the Pentland Skerries and around the islands of Stroma and Swona. Strong flows are passing through the Inner Sound and through the channel north of Swona. However, the main flow is in mid-Firth between the two islands where, when the image was obtained, the current velocity was around 3 metres per second (about 6 mph).

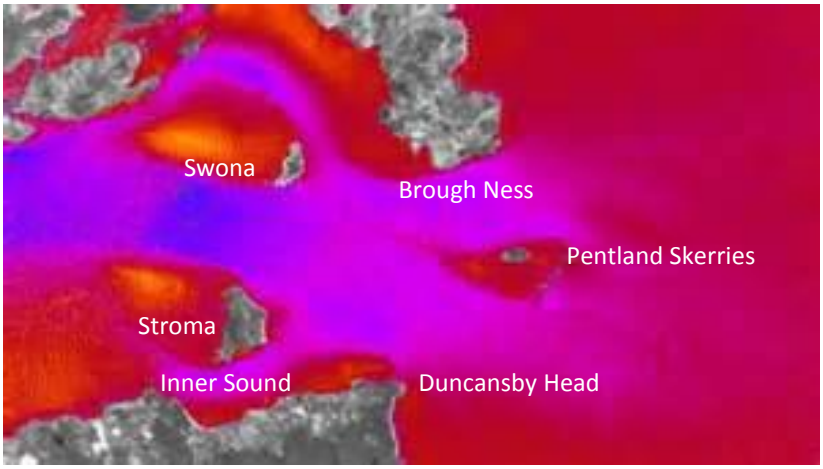


Figure 3. Patterns of tidal flow in the Pentland Firth.

The video at https://www.youtube.com/watch?v=VKRKA2aNE3A gives some idea of what this actually looks like. It shows the Swelkie, a notorious stretch of broken water that forms with the tide in mid-Firth off the northern edge of the island of Stroma.

Plans are afoot to tap into the huge amount of energy locked up in the Firth's tidal flows using arrays of turbines placed on the seabed. Development is in its early stages but the Meygen project in the Inner Sound of Stroma[1] is already underway and other, similar projects are being considered on both the Orkney and Caithness sides of the Firth.

Tidal energy is not the Firth's only attraction for developers since various other projects are being considered that will tap into wave or wind energy. Interest in these particular energy sources extends beyond the Firth itself to include its eastern approaches in the Moray Firth and the coasts of Sutherland and Hoy to the west. The BOWL windfarm project[2] in the Moray Firth, for example, is at an advanced stage of planning. Eighty-four turbines are planned extending over an area of 130km^2 about 8 miles south-east of Wick. Further similar projects are envisaged for adjacent locations and, if they go ahead, these projects will greatly expand the total area of marine development in the North.

So, although the marine renewables industry is in its infancy, it is already clear that the next few years will see extensive development in and around the Pentland Firth. Overall, construction work is likely to continue over many years as a succession of new projects – some of them phased – is brought into play. Thereafter, a variety of very different technologies will operate continuously with breaks only for maintenance when further major works may be required.

[1] http://www.meygen.com/
[2] http://www.power-technology.com/projects/beatrice-offshore-wind-farm/

Considering tidal power specifically, recent calculations[3] suggest that, in practice, an average of 1.9 GW (a gigawatt is 1 thousand million watts) of tidal power could be extracted from the Pentland Firth. Although this is less than some previous estimates, 1.9 GW is reportedly equivalent to about 40% of present electricity demand in Scotland. The final target of the Meygen development alone is 0.4 GW by the early 2020s.

Tidal power has the particular merit of being predictably reliable unlike some other renewable sources. Development of the Pentland Firth, and particularly development of tidal sources of power, is therefore well in line with the Scottish Government's aim to produce 100% of the national power requirement from renewable sources within the next few years. Development is also welcomed by most of the people living and working in the vicinity because of the positive effects on employment and commerce. On the other hand, changes to the marine environment are likely to stem from development on the large scale being envisaged and this may affect fishery and other interests.

Part of the regulatory and development process is to consider how the environment and the various creatures that use it are likely to be affected by renewables development. Some species may benefit. On a world-scale, for example, CO_2 produced from the use of non-renewable energy sources - oil and gas - is adversely affecting the environment of all the oceans; the use of renewable energy sources will reduce this effect. On a much more local scale, juvenile fish or shellfish species, for example, may benefit from the exclusion of fishing boats from off-shore wind-farm arrays such as those proposed for the BOWL project. But on the other hand, whales and dolphins or foraging seabirds, for example, may be adversely affected for any of a number reasons arising from the construction or operational phases of any of the various types of installation being proposed.

Because of all this, environmental impact assessment aims to identify potential problems early on in project design in order to eliminate or reduce impacts that can be foreseen. However, to be effective this process requires information and very often the necessary information does not exist. This is certainly the case for salmon because, for one reason or another, very little is known about the way migrating salmon use coastal waters in places like the Pentland Firth. Trying to obtain information will be technically demanding and costly. Trying to obtain it for the Pentland Firth will be especially difficult because of the extreme environmental conditions that often prevail there. At present, there are no project proposals that will directly address the need for new data and no obvious options for making rapid progress.

Because of this, the Flow Country Rivers Trust undertook to look at other, less conventional sources of information in an attempt to discover how salmon use the Firth or, if not, at least to target or focus on new ways of finding out. We have delved into the documented history of salmon netting in the North in order to understand why the fishery evolved as it did. We have examined the traces left by the fishermen because these can tell us where they found it profitable to work. We have re-examined the results of previous collaborations between fishermen and scientists that tried to find out about the patterns of movement of salmon by tagging the fish at netting stations in the North. We have asked the few remaining fishermen what they have come to understand about salmon as they go about catching them.

[3] http://rspa.royalsocietypublishing.org/content/469/2157/20130072

History of salmon netting

One of the main purposes here is to try to understand what the behaviour of the fishermen can tell us about the behaviour of the fish. This necessitates exploring the history and evolution of the netting industry in order to understand how the netsmen's activity has been restricted at various times by the practical difficulties of capturing, preserving, transporting and marketing the catch. Where all these issues can be resolved, and if fish are present in sufficient numbers, a netting station will prove viable but under any other conditions attempts at commercial fishing will fail.

In the past, netting had very long roots in Scottish national and international commerce and intimate connections in the day-to-day economies of communities almost everywhere around the Scottish coasts. Even so, until recently it has been surprising difficult to establish the history of what was such an important rural industry. Fortunately, much of the background information has now been gathered by Iain Robertson in his book *The Salmon Fishers* published in 2013[4]. This is a comprehensive account centred on the large fisheries around the big rivers of the east coast.

Despite Robertson's work, detailed information on the history of the North Coast fisheries, specifically, is still sparse. However, the large companies in the south dominated the Scottish industry as a whole through all its phases. In time their business interests came to range far beyond their home turf and they also tended to be the main innovators. One way or another, therefore, the big players in the south set the pace for the development and evolution of fisheries in more remote locations, including the north coasts of Sutherland and Caithness. So, to a large extent, the historical development of the northern fisheries mirrors developments elsewhere and much of Robertson's account applies.

Salmon have certainly been fished from the very earliest times. In particular, they can be easily captured with the most rudimentary equipment when they move into small streams to spawn in November. A slightly greater level of expertise is required to increase the harvest and spread it over the year using "cruives" (traps) or sweep nets in the rivers themselves. Thereafter, it is another relatively simple step to extend the use of sweep nets to river estuaries or to sandy beaches nearby.

In any case, sweep nets were being operated at the mouth of the River Naver, for example, by 1746 and probably before[4]. Along the coast at Thurso East, it was salmon fishermen who pulled the crew of the ship-wrecked vessel "Fisher" from the sea on Christmas Day, 1807[5]. Even as early as 1689, a quantity of salted salmon was transported from Thurso as part of a cargo consigned to Leith. In this case, the document listing the cargo was dated towards the end of April[3] indicating that these were spring fish caught soon after they returned from the sea presumably in a cruive or a sweep-net fishery of some early type.

However, it is the coastal fisheries that are the main concern of the present report because it is the coastal migrations of salmon that are of particular interest. Robertson gives a starting date for these fisheries in the 1820s when technical and legal developments made it possible to extend fishing to

[4] I.A.Robertson (2013). The Salmon Fishers: A History of the Scottish Coastal Salmon Fisheries. The Medlar Press Ltd, Shropshire. ISBN 978-1-907110-45-0.
[5] I. Sutherland (2005). The Fishing Industry of Caithness. Iain Sutherland, Wick, Caithness. ISBN 0-9513399-2-3.

sandy beaches using so-called stake-nets. However, much of the potential fishing water on the North Coast is deep and rock-bound and the key factor here was the development of the bag-net in the 1830s.

Both stake-nets and bag-nets work along the same lines. The leader net is 3 or 4m deep. It is attached to the shore and runs seawards for 100m or so to link up with a net trap. Floats support the leader's upper edge to ensure that it lies vertically in the water. Fish follow the leader out to the head of the net and enter the so-called fish-court through a series of V-shaped inscales that then prevent or impede their escape. Stake-nets are particularly suited to fishing the inter-tidal zone of shelving sandy beaches. The head of the net is permanently supported by a stake set into the sand. The whole structure is tensioned and held in place by a system of wooden pins or anchors. The fish-court can be cleared of fish at low water without the need for a boat. The bag-net is similarly designed but the entire structure is set to float and tensioned on every side by anchors or permanent fixtures on the shore. Bag-nets are fished towards slack water using a fishing coble.

The design of the bag-net has remained essentially the same since the beginning and innovation has come about through changes in the materials available for ropes and netting. The original material was hemp but this was supplanted in the mid-1800s by cotton which was tougher and lighter. In the 1960s, cotton was supplanted by synthetic materials. Synthetics have the particular advantages of being tougher still, much lighter when wet and much easier to work. Synthetics are also less visible to fish because of their lower, slicker profile and for the same reason they are less prone to fouling, easier to keep clean and, therefore, more robust when sea conditions are poor.

In some places bag-nets are linked in a series that stretches out to sea. On the North Coast, however, such an arrangement is precluded by the strong tides and because the coast faces the open ocean making it prone to heavy seas. For these reasons, all the coastal fisheries on the North Coast only cover the very fringes of the sea with nets that stretch only around 100m from the shore.

The bag-net fishery on the North Coast

By 1889, 50 stances (mostly bag-nets) were being fished between Cape Wrath in the west and Duncansby Head at the south-eastern corner of the Pentland Firth[6]. The bag-nets and stake-nets were, of course, additional to the traditional sweep-net fisheries which continued to operate in many of the river estuaries just as they had done for many years before.

From 1952 onwards, formal records were kept of the salmon fisheries and these figures are curated by Marine Scotland Science[7]. The available information includes the number of nets fished by each fishing station in each month of the season. From this it is possible to work out roughly how many stances were fished each year. So for example, in 1952, the first year of the current record, about 48 stances were operated at some point in the season – much the same as in 1889. By 1982, however, when the coastal net catch on the north coast peaked, only 36 stances were being fished. By 2000, the number of stances was down to around 10.

[6] I.A.Robertson (2013). The Salmon Fishers: A History of the Scottish Coastal Salmon Fisheries. The Medlar Press Ltd, Shropshire. ISBN 978-1-907110-45-0.

[7] http://www.gov.scot/Topics/marine/Publications/stats/SalmonSeaTroutCatches/2015/Fixedengine

Using the same official records, it is possible to work out a more accurate value for netting effort by counting the number of nets fished each month and adding up the figures to get the total "net-months" fished over the course of the season. Figure 4 shows the netting effort for the combined North Coast fisheries. As for the number of active stances, the "net-month" values show an overall decline. In both cases, the decline is partly due to the closure of fisheries but it is also partly due to a gradual move away from the spring fishing towards a shorter, summer season.

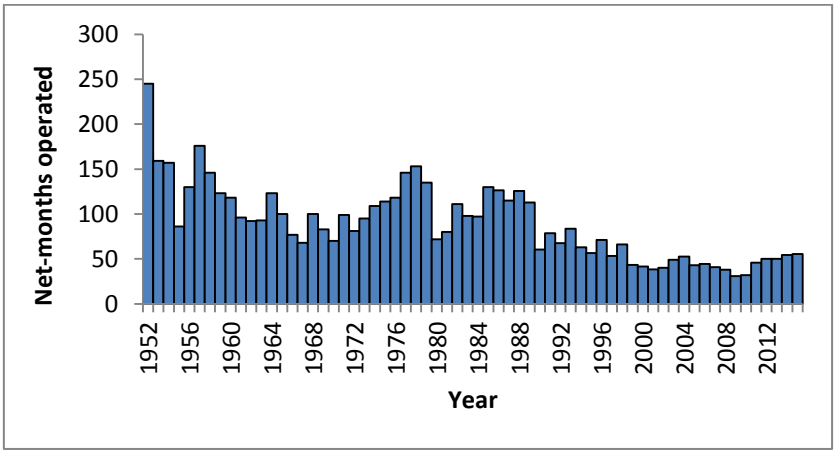


Figure 4. Annual fishing effort by bag-nets on the North Coast.

Figure 5 shows the catches made by the coastal nets on the North Coast. As can be seen, quite large numbers of fish must be present every year and sometimes the numbers must be very large. While it can be seen that the number of fish caught in recent years has been lower than before, the total amount of effort going into the fishery has also decreased, as mentioned above.

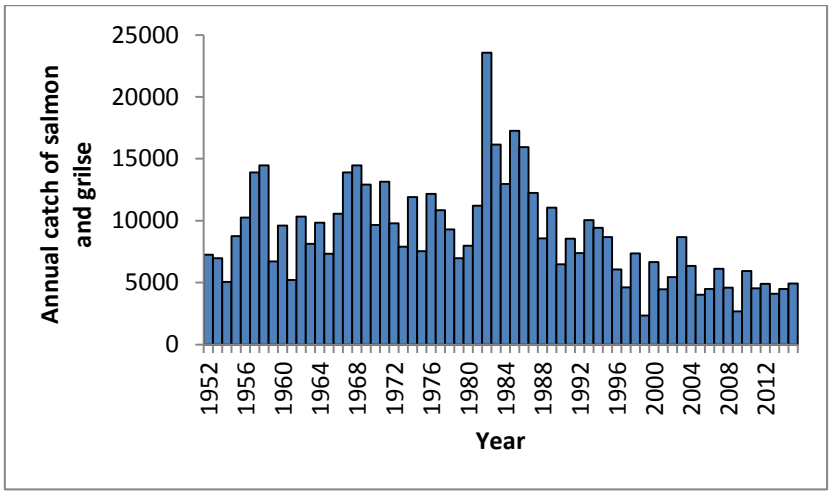


Figure 5. Annual catch of the North Coast bag-nets.

Tagging studies

Figure 5 refers to fish caught on the coast rather than in the rivers or estuaries that might have shown that they were near to their final destination. The obvious question therefore arises as to where the fish might have ended their journeys if they had not been caught. The main source of information on this point is contained in a series of tagging studies that started more than one hundred years ago. Many of the original sources are obscure and difficult to access but most were re-examined and synthesised by Malcolm et al (2010)[8] in the present-day context of migratory fish and marine renewables development. Shearer presents a similar series of more recent tagging studies in his book, *The Atlantic Salmon*[9]. Unfortunately, no tagging studies have ever been carried out within the Pentland Firth itself.

Malcolm's report shows that many of the fish caught in bag-nets on the West Coast, tagged with small numbered tags, and then released - at Loch Inchard, near Kinlochbervie, further south at Raffin near Stoer Point, at Soay off Skye and at Fascadale in Ardnamurchan – spilled around the North Coast to reach rivers as far south as the Tweed, presumably by way of the Pentland Firth. A similar study at Enard Bay and Badentarbet, south of Lochinver, showed much the same pattern (see Figure 9.3 in Shearer).

By contrast, few fish captured and tagged on the Angus coast, or even in the Moray Firth, are reported later from the north coast fisheries. A single exception is evident in the studies listed in Malcolm's report. Thus, one of about 350 recaptures from the tagging study carried out in 1912 at Kintradwell, north of Brora in eastern Sutherland, was recaptured at Clachtoll in western Sutherland. Further to this same point, between 1984 and 1988, fish were tagged at Berriedale - slightly further north than Kintradwell - and on the eastern Caithness coast. A total of 1750 fish were tagged and 390 were recaptured (see Figure 9.5 in Shearer). Many were re-caught in the sea, or in rivers, near to the tagging site but 159 tagged fish were recovered to the south and/ or eastwards around the Moray Firth. Only 16 fish were recaptured beyond the Pentland Firth, in rivers or nets between Thurso Bay and Strathy Point; a further two fish were caught much farther west beyond Cape Wrath.

In the particular context of the Pentland Firth, the study carried out by W.J.M. Menzies (the Inspector of Salmon Fisheries for Scotland) at Loch Inchard [10] between May and August in 1936 proves to be most informative. The Inchard tagging site lies 20km south of Cape Wrath in northwest Sutherland on the western fringe of the North Coast fisheries. A total of 1255 fish were tagged and a large number (145) were later recaptured. Enough of the original detail of the study remains to make it worthwhile looking at the data again.

[8] www.gov.scot/Resource/Doc/295194/0111162.pdf

[9] W.M. Shearer (1992). The Atlantic Salmon. Fishing News Books. ISBN 0-85238-188-3.

[10] Menzies, W.J.M. (1937) The movements of salmon marked in the sea I. The northwest coast of Scotland in 1936. Fisheries, Scotland, Salmon Fish, 1937, No1.

The geographical distribution of the recaptures is shown in Figure 10 of Malcolm's report. Some of the fish (11) were captured again very near to the tagging site. Among the others, 29 moved southwards reaching as far as Mull about 250km distant and 105 moved eastwards. It is these latter fish that are of most interest here.

Overall, 23 (16%) of the 105 were shown to be destined for rivers lying at various points beyond the Pentland Firth which lies 130 km to the east of Loch Inchard. In fact, 16% is likely to be an underestimate since some of the fish recaptured in nets between Loch Inchard and Thurso may well have been bent on heading much further east and south. The most distant travellers turned out to be a single fish recovered from Sognfjord in western Norway (650km distant) and a single fish recaptured off the Yorkshire coast near Whitby (800km distant). Otherwise, all the recaptures beyond the Pentland Firth were from rivers or coastal waters in Scotland, ranging southwards from the Moray Firth to the Tweed.

An estimate of travel speed for each fish can be obtained by calculating the shortest possible sea route between the Loch Inchard tagging site and the site of recapture and then dividing this distance by the days elapsed. Fish recaptured in rod fisheries are excluded from consideration because they may well have been resident in the river for some time before being caught and only the values for fish recaptured in the sea are shown in Figure 6.

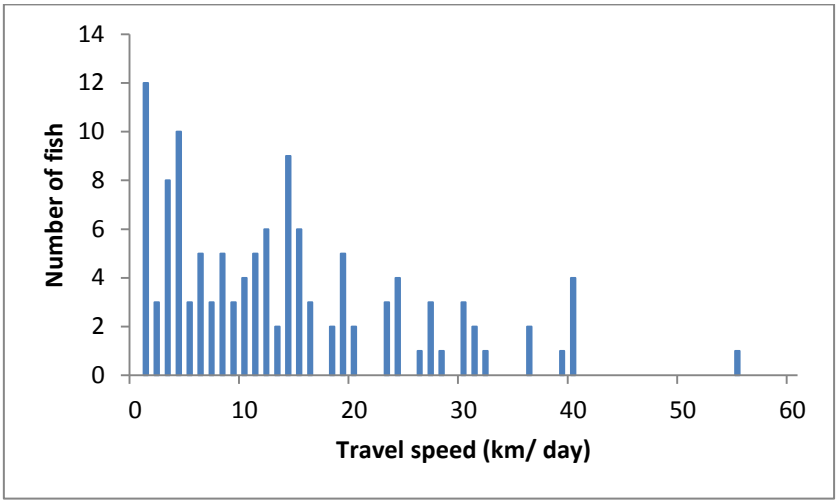


Figure 6. Travel speeds of salmon recaptured after being tagged at Loch Inchard; recaptures in rivers have been excluded.

Many of the fish travelled quite slowly but the most rapid progress was made by a fish recaptured in the Firth of Forth. This fish, which was reportedly a grilse, had moved at an average speed of around 55 km/ day. The most rapid rate of swimming which fish can indefinitely sustain is around 1 body length/ second. For a grilse of around 60cm, 1 body length/ second equates to around 50 km/day. So, this long-distance traveller must have been swimming near its maximum sustainable rate over all the 9 days and 490 km between Loch Inchard and the Forth.

More generally, all the fishes' travel speeds are shown in Figure 7 plotted against the distance travelled between tagging and recapture. There appear to be at least two broad groups of fish showing different behaviours. Long-distance migrants showed the fastest travel speeds (as was noted by Menzies at the time). Fish recaptured within, say, 150km of the tagging site travelled more

slowly on average. In fact, this latter group contains an obvious mixture of slow and fast travellers but it is again necessary to recall that some of those fish recaptured near to the release site may have been intent on heading much further afield. The simplest interpretation of Figure 7 is that the Loch Inchard fishery captured a mixture of fish, many of which had slowed because they were closing in on their intended destination and others that were still swimming rapidly towards more distant targets.

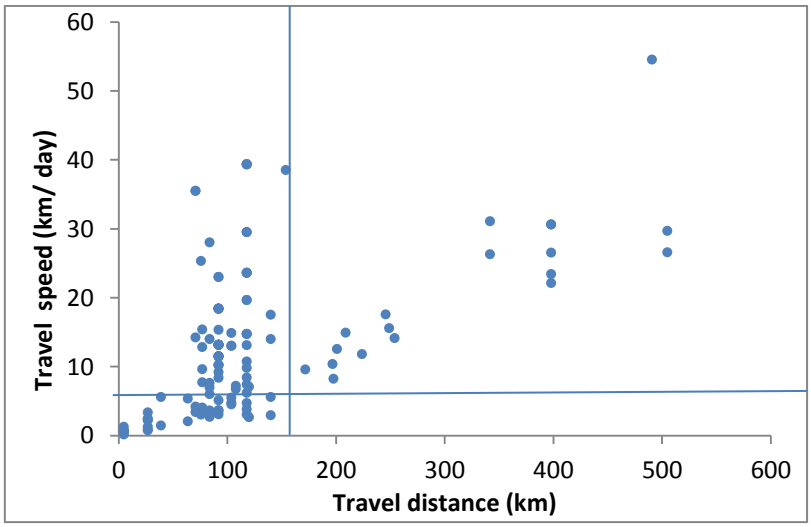


Figure 7. Relationship between the distance to the recapture point and travel speed for salmon tagged at Loch Inchard; recaptures in rivers have been excluded.

Turning now to consider the 17 fish excluded from Figure 7 because they were recaptured in rivers rather than in the sea - four were returned from the Rhiconich River near the tagging location. A further seven were reported from rivers on the North Coast between 60 and 70 km distant from Loch Inchard - five fish from the River Dionard and one each from the Hope and the Naver. Four fish were returned from rivers on the West Coast, between 70 and 90km from the tagging site. The remaining two fish were reported from East Coast rivers. So, the pattern of destinations of these fish is generally similar to the pattern for the others.

At first sight, therefore, the Loch Inchard fishery might be thought to be mainly targeted on fish belonging to the rivers of the nearest coasts - say, those within 100km. On the other hand, the relationship shown in Figure 7 suggests that after they were tagged and released the intended journey of many of the fish was, again, cut short by nets further along the coast.

The Inchard study was designed to determine the destinations of fish whose river source was unknown. In other studies, smolts have been tagged and then recaptured as adults a year or two later at locations that are assumed to lie on their return route to their home river. Data sets like these have been obtained by Marine Scotland Science for smolts tagged on Scottish east coast rivers - at the Girnock Burn on the River Dee, at Kinnaber on the North Esk and on the Tay

The Girnock Burn population is of little interest in the present context. The Girnock fish are early-running 1SW and early-running MSW, or “spring”, fish. By early summer when the north coast fisheries tend to start, most of the MSW fish and many of the grilse are already close to their final destinations. The Tay and the N. Esk support more complex fish populations. The pattern of

recaptures for the North Esk fish (tagged 1991-2007) is shown in Figure 16 of Malcolm's report. Recaptures in coastal nets were dominated by the home fisheries around Montrose although single fish were returned from nets in Dumfries and Galloway, Wester Ross, western Sutherland and Strathy. The earlier dataset for the River Tay (smolts tagged leaving the Almond, 1969-72 and the Tummel, 1971-1986) proves more informative.

For the Tay fish, 34 (23%) of 148 coastal recaptures were from west of the Pentland Firth ranging out to Dingle and Waterford in southern Ireland, almost 1000km distant. Some of the recapture locations in Ireland were not precisely specified but the distribution of known recapture locations west of the Pentland Firth is shown in Figure 8.

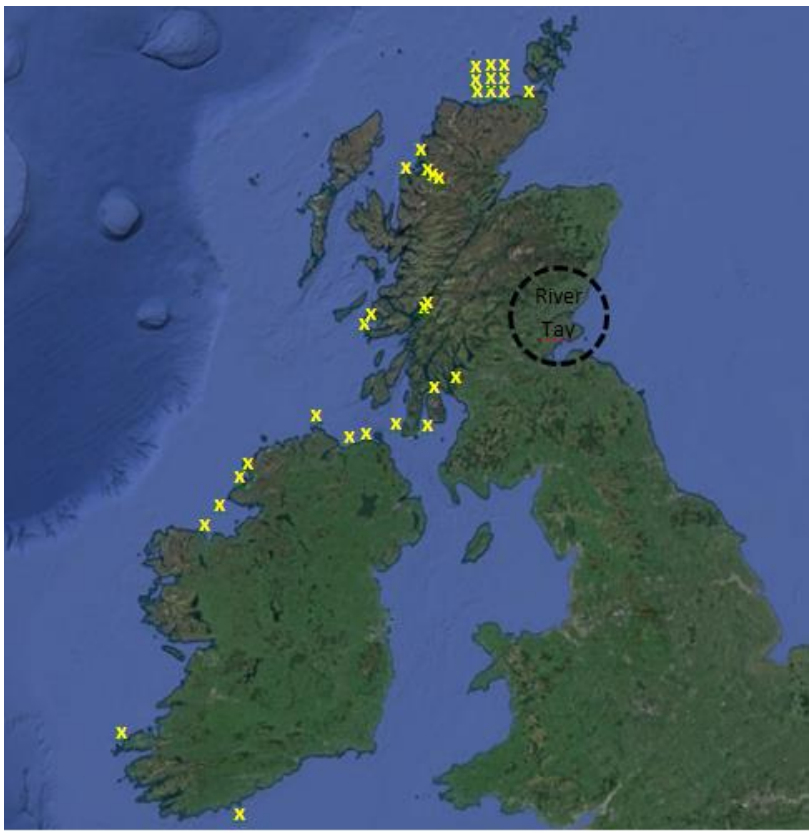


Figure 8. Recapture locations of Tay fish in coastal fisheries to the west of the Pentland Firth. The fish had been tagged one year previously (for the case of grilse) or two years previously (for the case of 2SW salmon) as smolts leaving the Almond or Tummel.

The pattern of recoveries indicates a distinct western bias for the initial phase of the coastal migration. This in turn suggests that, ultimately, a substantial proportion of all the fish shown in Figure 8 might well have taken a route home to the east coast through the Pentland Firth, the Orkney Sounds or even further north because their way eastwards is otherwise blocked by land. The cluster of 10 coastal recaptures on the north coast, around Strathy and at Dunnet Head indicates that the short route eastwards through the Pentland Firth may well be favoured by at least some Tay fish.

However, the outcome of tagging studies and the extent of their coverage are totally dependent on recaptures. The pattern of recaptures reflects the distribution of fisheries as well as the distribution

of fish and fish moving through areas without fisheries therefore do so undetected. Since no coastal fisheries appear to have operated to the north of the Pentland Firth at any time a complete picture of the coastal migration may not be disclosed by the tagging data.

The northern limit of the fisheries

The seeming lack of salmon fisheries on the coasts of the Orkney or Shetland Islands is of interest. The absence of contemporary or historical records on such a wide scale is anomalous for Scotland generally and it may indicate that fish are absent or scarce along the coasts of the Northern Isles.

A query to the Orkney Heritage Society and further discussions with local experts results only in recollections of undocumented, minor fisheries in the recent past; some of these refer to salmon caught offshore some distance to the west of Orkney.

The North Atlantic Salmon Conservation Organisation (NASCO) maintains a data base of salmon rivers[11]. The database for Scotland lists three "natural salmon stocks" in Orkney and 41 in Shetland[12]. The criteria for inclusion in the data base are not stated and the entries are not qualified but all the stocks listed are associated with very small streams. In fact, the NASCO database risks over-stating the importance of all these salmon stocks. So, for example, the Shetland Anglers Association is much more circumspect stating only on its web-page that "salmon are sometimes caught in the voes, burns and lochs of Shetland"[13]. Malcolm Thomson of Stromness confirms that salmon are a very minor feature of the renowned sports fisheries for trout and seatrout on the lochs and coasts of the Orkney Islands.

It should also be considered that salmon aquaculture has been widespread in the Northern Isles in recent decades. Since escapes occur and large numbers of fish are sometimes involved, it would be a surprise if farmed fish were not sometimes present in the local bays and burns. It is sometimes difficult to distinguish escaped farmed fish from wild fish because the differences are often quite subtle and evident only to the practised eye.

The final word can therefore rest with the writer of *General Observations on the County of Shetland* in the Second Statistical Account of Scotland[14]. "*Most of the fishes found on the British coasts are to be met with here. Those in the small lakes and rivulets are the eel, common trout, and sea-trout. I doubt if it can be affirmed that salmon have been caught in Shetland; but when eminent and experienced icthyologists find it to be a matter of such difficulty to furnish an accurate specific distinction for this fish, it would be presumptuous to assert that it does not occur here*".

So, it would seem that although salmon are a feature of coastal and fresh waters in the Northern Isles they are few in number, probably sporadic and, in recent years, possibly of farmed origin. Although it is difficult to be precise about something so ephemeral, there are certainly no local stocks of sufficient size to drive a fishery. But then, as discussed above, the fisheries on the North

[11] http://www.nasco.int/RiversDatabase.aspx
[12] http://www.nasco.int/pdf/riversdb/JurisdictionReportUK%20-%20Scotland.pdf
[13] http://www.shetlandtrout.co.uk/
[14] Second Statistical Account of Scotland (1834-45)

Coast are not solely reliant on local stocks. In fact, a large proportion of their catch appears to be of fish coursing through on passage to distant rivers.

There is one remaining possibility for exploring undocumented fisheries. Characteristic and unusual structures were built at various stages in the development of the salmon fisheries. Some of the more durable structures are still evident today – harbours, piers, nousts[15], bothies, stores. However, it is often now impossible to associate them specifically with salmon fisheries because they are identical or similar to structures intended for other types of fisheries or because their use has evolved over time. Today, most old buildings along the shore-line contain a miscellaneous assortment of abandoned fishing equipment – creels, fish boxes, oil drums – that does not reflect their original purpose.

The icehouses are different. They were built to service the salmon netting industry and were a central part of operations for much of the 19th - and 20th Centuries. The buildings were substantial stone structures and many have consequently survived. They are of characteristic design and readily identifiable. So, what does the distribution of icehouses tell of the distribution of salmon fisheries - particularly around the Pentland Firth?

The distribution of the icehouses

There has always been a brisk exchange across the Pentland Firth from the earliest days. So, in the mid-19th Century when coastal salmon fisheries were expanding along the North Coast those watching from the other side of the Firth must have been acutely aware that a similarly lucrative fishery might be possible there - for example, on the coasts of South Walls or South Ronaldsay. Equally, the large east-coast netting companies that spurred on the Scottish fisheries must have been alive to the opportunities for expansion beyond northern Caithness to the southern shores of Orkney. It would be inexplicable if test fisheries did not take place given the potential rewards. Setting nets in these waters would undoubtedly be challenging but no more so than on the North Coast and, for example, there are obviously suitable locations in relatively sheltered places like Aith Hope and Kirk Hope in South Walls and Herston in South Ronaldsay - all within sight of the fisheries on the Caithness coast.

Even on the mainland the locations of all the salmon fisheries that have been worked at one time or another are unknown. In the early days, the bag-net stations were probably small and especially numerous given that several unwieldy cotton bag-nets had to be serviced daily by fishing cobles powered only by oars. All the fishing stations cannot be identified now but their general distribution can be checked by examining the legacy of specialised buildings and, particularly, the icehouses.

In the early days, the catch was salted. A ready home market for salted salmon did not exist and it was sent to markets in Europe. Later, fish were par-boiled and pickled in vinegar. This product found a ready outlet in London and the South and the pickled fish were dispatched there in barrels (“kits”). Collection and transport was by smacks plying a coastal trade. In general, boiling and kitting were

[15] A noust is an area on a rocky shoreline cut or cleared to create a haul-out for a small boat.

carried out near the fisheries and the abandoned boiling-house at the mouth of the Naver[16] is a legacy of the fishery there. There was also a boiling house at the fishing station at Rispond near the mouth of Loch Eriboll from about 1840 and it now forms part of a dwelling house[17]. For a time, a boiling-house at Wick (and an early icehouse) was used to process the Thurso catch[18]. To avoid the difficulties sometimes posed by the unruly waters of the Pentland Firth, the fish were brought overland from Thurso, presumably in panniers borne by horses. This unwieldy arrangement ceased when a new boiling-house was constructed at Thurso East around 1790.

At about this time it was recognised that salmon could be kept in good condition for 10 days or so by packing them in ice. This opened up a lucrative market for whole fresh fish. Gradually the trade in iced fish displaced the trade in kitted fish but for a time both products continued to be collected and dispatched to the south by sea. Eventually, transport by rail supplanted coastal transport when the railway was extended northwards to Thurso and Wick in 1874 and the use of ice for packing then became universal.

In order to access the fresh fish trade a copious and continuous supply of ice was required throughout the spring and summer when the fisheries were being pursued. The obvious supply problem was addressed by constructing icehouses. These buildings vary in style but all comprise a vaulted stone building, often set into a hill-slope, and roofed with turf. At the lower level, an entrance-way lets on to a packing house and beyond this is a large ice-store that was charged during the winter months via a separate hatchway in the roof. The ice was cut and transported by horse and cart from lochs or ponds nearby. In this way the insulating qualities of the building's design and the large mass of stored ice ensured that sufficient material was made available for packing fish throughout the summer. Some of these unusual and interesting buildings have been lost over the years but many others still remain (Figure 9).

Figure 9. The abandoned ice-house and salmon coble at Keiss fishing station in Caithness. The packing station is at the front of the ice-house. The ice-store is to the rear and was charged from the upper level via a hatchway let into the turf roof.

[16] S.B. Calder (1974). The Industrial Archaeology of Sutherland: a Scottish Highland Economy, 1700-1900. M. Litt. University of Strathclyde.
[17] J.R. Hume (1977). The Industrial Archaeology of Scotland. 2. The Highlands and Islands. Batsford, London.
[18] First Statistical Account of Scotland (1791-1799).

The locations of the icehouses can be checked using national and local government lists of buildings of historical importance. Icehouses are recorded because of their intrinsic interest and some are even Listed Buildings protected by law. In Scotland generally, there are two classes of icehouse associated either with salmon fishing stations or with large houses where they were used to store perishables for the kitchen. In fact, it is very likely that the same buildings were sometimes used for both commercial and domestic purposes where salmon packing stations and large houses were in close proximity – for example, at Bighouse at the mouth of the Halladale. In other cases, usage switched over time. Butler (1988) examined the Thurso East icehouse and deduced from the various phases of its structure that it started life as an adjunct to domestic arrangements at nearby Thurso Castle and was only later converted to service the fishery at the mouth of the Thurso River[19]. For present purposes it is necessary to screen the list of icehouses in order to identify facilities closely associated with salmon stations and exclude those likely to be used solely for domestic purposes.

The CANMORE database maintained by Historic Environment Scotland covers all of Scotland - including the Orkney and Shetland Islands. A search of the database under the search term "icehouse" shows 16 sites in the area of the North depicted in Figure 11. One of the listings is for Isauld, on the opposite side of the bay from the Sandside icehouse near Reay. However, the OS grid reference given for the Isauld icehouse is an obvious error and its true location is probably at Isauld House exactly 1km eastwards. Isauld has therefore been excluded from consideration. A search of the Historic Environment Register maintained by The Highland Council yields a further three records for the area. In addition, local sources have pointed out icehouses that are not listed on either of the registers. Eddie McCarthy reports the Crosskirk icehouse at the mouth of the Forss, Barbara Hiddleston notes the building at John o' Groats and Fergus Mathers the one at Inverhope. Figure 11 therefore shows the documented locations of 21 icehouses but only 15 of them are listed in the national CANMORE database.

[19] http://www.caithness.org/caithnessfieldclub/bulletins/1988/october/thursoeasticehouse.htm

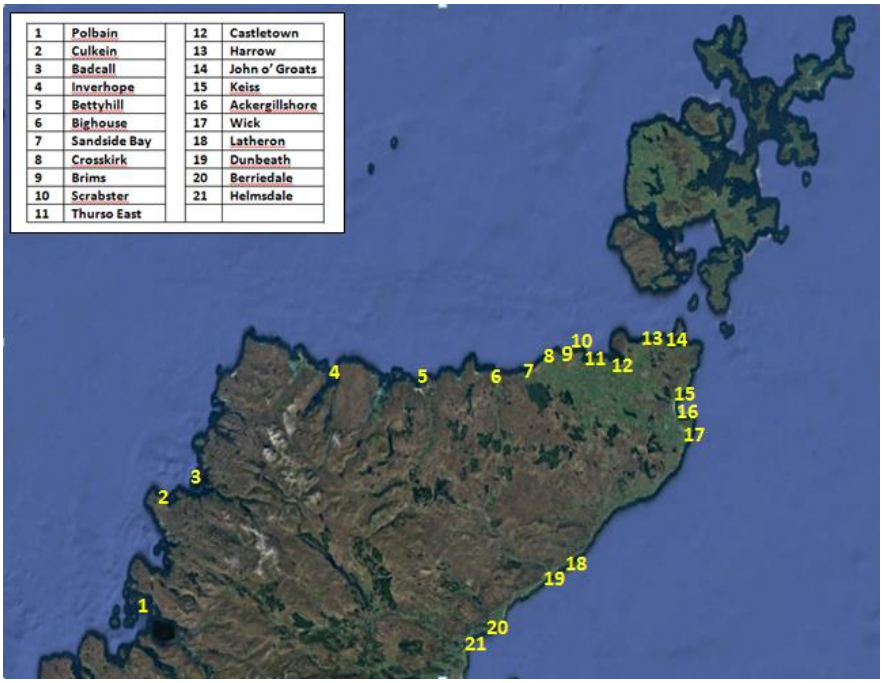


Figure 10. The distribution of icehouses in the North.

Some fisheries were not directly associated with an icehouse and they probably relied on facilities elsewhere. The notable antiquarian John Nicholson (1838–1934) was a farmer and laird's man at Auckengill near Keiss and his life spanned the period when the salmon fisheries evolved most rapidly. One of his seasonal employments was to transport salmon by horse and cart to Wick from outlying fisheries[20]. So, it is likely that transport of ice between stations, exchange of fresh fish for icing, and of iced fish for onwards transport were features of the trade. At various stages some of the main icehouses are likely to have served as hubs for other local fisheries that lacked equivalent facilities. Because of all the likely links, the icehouses track the general distribution of the salmon fisheries rather than showing the locations of them all.

This point can be examined more closely for the particular case of the parish of Canisbay on the southern fringe of the Pentland Firth. *Lest We Forget: The Parish of Canisbay*[20] contains photographs of salmon fishing in the area and reminiscences by local people on a wide range of topics including salmon. These accounts can be pieced together to give a fuller account of the local fisheries. Harrow is confirmed as a salmon fishing station from at least 1861 when the icehouse was built[21] until around 1939 when fishing ceased. Additional, lost salmon stations are identified at Brough, Gills and John o' Groats. There were salmon bothies at Harrow, Gills and John o' Groats and an icehouse that still stands at John o' Groats. This was dual-purpose in serving both the fishery and the local hotel. In addition, John Mackay notes the salmon bothy still present at Brough. There were therefore four salmon stations on the coast opposing Orkney although only Harrow shows up in the official records. The stations were spaced around 5km apart and all four were apparently substantial sites with permanent (and costly) buildings.

[20] A.L. Houston (ed.) (1996). Lest We Forget: The Parish of Canisbay. Canisbay Parish Church. ISBN 0952916703.
[21] Pers. comm. Barbara Hiddleston

The pattern of distribution of the icehouses shown in Figure 10 has two noteworthy features. Firstly, the concentration of buildings in and around the Pentland Firth suggests, once again, that it is an important bottleneck on the route for salmon heading through. The second notable feature is the absence of icehouse records from the Orkney (and Shetland) Islands. This supports the view that salmon fisheries were not developed to the north of Caithness at least during the period when the London trade in iced fish was being pursued. Why might this have been?

Why are no salmon fisheries recorded from Orkney?

Undoubtedly, sea and tide conditions limit the range of potential locations for fisheries on the southern coasts of Orkney. Yet conditions there are no more unfavourable than on the northern shores of Caithness and Sutherland and it seems inconceivable that a single, viable site for a fishery could not be found. Transport and marketing would also pose problems. Yet the same problems were faced by other trades and these were serviced for centuries via ferry connections to the mainland transport network or by direct sea-links elsewhere. It is true that there are no substantial rivers in the Northern Isles and therefore no significant local populations of salmon to be exploited. However, in Loch Inchard the catch was not dominated by fish from the rivers nearby. Almost 90% of the recaptures of tagged fish were from locations more than 30km distant. Indeed, many were recaptured at a distance of more than 100km, putting Orkney well within their potential range. Certainly, southern Orkney is within easy range of the fish that were caught at fishing stations like Harrow only 15km across the Firth. The River Thurso, a potential contributor to the Harrow catch, is roughly equidistant from the opposing Orkney and Caithness coasts. So, if the Harrow and John o' Groats fisheries proved sufficiently viable to justify the construction of substantial icehouses, why was no matching facility established on the northern side of the Firth? Why are there no records of salmon fisheries for Orkney?

The most likely possibility is that salmon are not abundant there. In a report to The Crown Estate, Guerin et al. (2014)[22] argued on purely biological grounds that a southern bias to the distribution of salmon across the Firth's breadth might arise from changes in their migratory behaviour as they enter coastal waters. In essence, the bias would arise from the overall north-to-south direction of travel between the fishes' ocean feeding grounds and their home rivers, reinforced by the fishes' reaction to the barrier to southwards travel posed by the east-to-west line of the North Coast. In other words, fish making landfall from the northwest - from around Greenland, for example - would hug the north Sutherland and Caithness coasts in order to find a rapid onwards route. Moreover, for fish heading in from further east, say from around the Faroe Islands, the waters of the northern Pentland Firth would lie in the "shadow" cast by the Orkney landmass. Figure 11 summarises this speculation in a diagram.

[22] https://www.thecrownestate.co.uk/media/5534/published-eri-salmon-migration-report.pdf

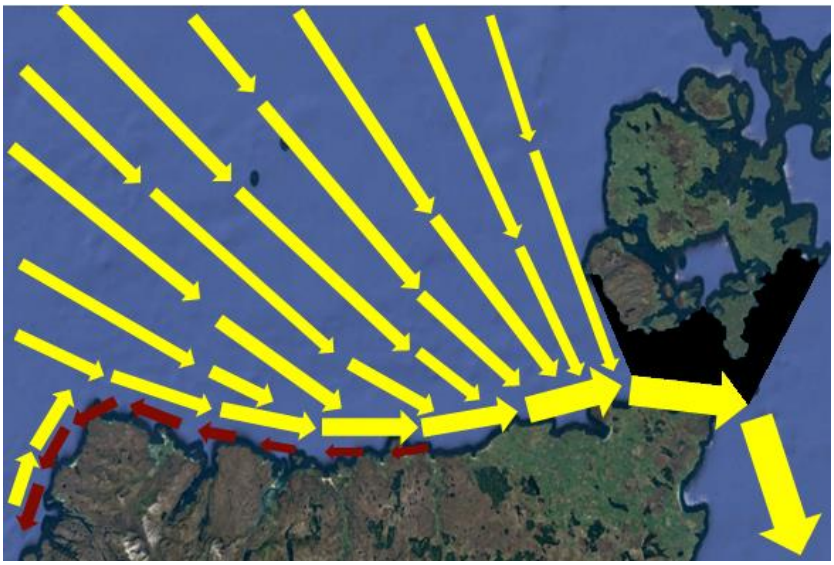


Figure 11. The possible pattern of migration of salmon on the North Coast.

The yellow arrows in the upper left show the inwards headings to the North Coast for fish leaving the ocean. The starting points range eastwards from the southern tip of Greenland (2100km distant) to the Faroe Islands (370 km). Once they encounter the coast fish follow it eastwards. Fish are also shown rounding Cape Wrath from the south as the tagging data suggests. All the fish are shown taking the short route towards the rivers of eastern Scotland via the Pentland Firth. A smaller westwards counter-migration is shown in red. The Pentland Firth is shown as a bottleneck that brings large numbers of fish within range of the north coast on the western side of the Firth. The distribution of fish within the Firth is determined by the presence of the southern coast. Fish are absent from the northern part of the Firth (in black) because of the directness of their inward travel and their tendency to hug the coast once they encounter it.

Figure 11 shows a smaller, westwards counter-migration that tagging studies show to take place. Some of these fish may just be making local adjustments on the approach to their home river. However, others are shown to be headed much further west and south. Some of them are probably returning westwards in response to errors in their original route. However, it must also be considered that some of the fish are on direct routes to the northern and western rivers reached via the Pentland Firth from sea areas to the east of Orkney.

In both cases, the tagging studies discussed above suggest that any westwards transit through the Firth must be rather low-key relative to eastwards movement. Thus, for example, it can be seen from Malcolm's report that the patterns of movement revealed by tagging studies carried out in eastern Scotland (shown in Figures 5 to 8 of the report) differ from those carried out in western Scotland (and shown in Figures 9 to 12). In particular, the two groups of patterns are asymmetrical. The western tagging studies show substantial numbers of fish passing over long distances north and eastwards to rivers and fisheries beyond the Pentland Firth. By contrast, although many fish tagged on the east coast subsequently move northwards, very few of them then move westwards through the Firth. Traffic there appears to be predominantly one-way.

If these arguments are correct, it is clear why fisheries might not be successful on the northern side of the Pentland Firth. The many fish on passage eastwards are running close to the southern shore, there are few fish on passage from the northern North Sea that might follow the Orkney shore westwards, there are few counter-migrants probing for a suitable return route back to the west and there are no local fish milling around near their home rivers.

An eastwards route north of the Pentland Firth?

Of course, the diagram in Fig 11 is over-simplified. It shows fish heading in from the northern ocean in a neat series of near-parallel tracks. In fact, as shown in Figure 8, the incoming Tay fish appear to make landfall over a wide range of divergent headings. And, once again, the northern edge of this distribution may be missing due to the lack of fisheries beyond Sutherland and Caithness. The true pattern of return routes is probably therefore less orderly than Figure 11 suggests. If the spread of incoming routes does indeed extend further north, then fish coming in on the most eastwardly headings may strike the western shores of the Northern Isles and have to find their way around them.

All the older tagging studies rely on fisheries both to capture fish for tagging and to recapture them later on in their journey to show their new position. This gives just two point locations in places where both fish and fisheries are present. However, a more recent study on the North Coast by Godfrey et al.[23] has used satellite tracking technology to open up a new range of possibilities by reducing the previous reliance on fisheries. Satellite tagging still relies on fisheries to capture salmon for tagging but recapture is not required. Instead, the tag breaks free from the fish at a pre-determined time and, when it surfaces (the tags cannot transmit while they are submerged), its location, along with additional research data, is transmitted to a passing satellite. The new tags still provide only two locations on each fish's route.

Godfrey's study was carried out at the Armadale fishery in northern Sutherland. The main aim of the work was to gain information on swimming depth and sea temperature but in many cases the location of tag release was also known. The pattern of movement revealed by satellite tags can be compared with the patterns discerned from previous tagging experiments. However, it must be noted the satellite tags are much larger than conventional tags and that they were applied only to large, MSW salmon rather than the smaller 1SW fish that seem to have made up the bulk of fish followed in previous studies. In addition, Godfrey tracked tags rather than the fish themselves. This may seem a trifling distinction but two of the tags were deduced (from the tags' temperature recordings) to have been transported for part of their way by large predators that had consumed the tagged fish.

Figure 1 of Godfrey's satellite tracking study shows that many of the fish apparently followed the usual coastal routes, passing on towards the Minches in the west or eastwards to the Moray Firth. Indeed, one of the tags surfaced in the Pentland Firth itself. However, in the present context it is the most northerly tag locations, where fisheries have always been absent, that are of most interest. Strangely, one tag (of 34) was logged about 100km to the northwest of the release site suggesting

[23] http://icesjms.oxfordjournals.org/content/early/2014/07/16/icesjms.fsu118.full

that the fish carrying it had back-tracked towards the northern ocean. Four tags were logged to the west of the Orkney Islands and more than 40 km distant from the North Coast hinting that some fish heading eastwards may pass to the north of Orkney.

Is this likely or is it even possible? Figure 6, above, showed the travel speeds achieved by the fish that were tagged at Loch Inchard. The calculated values assume that the fish made the shortest possible journey between the tagging location and their recapture points. Their real travel speeds will have been faster if the journeys were more convoluted. In particular, if any of the fish that were recaptured to the east of the Pentland Firth had, for some reason, made the longer journey via a route around the north of Orkney rather than through the Firth itself, then they must have travelled more rapidly than Figure 6 shows. Journeys via Unst in Shetland are longer still and the required travel speeds are therefore greater again.

Figure 12 shows the travel speeds required to cover the distance between Loch Inchard and recapture points on the East Coast assuming alternative way-points in the Pentland Firth (red), near North Ronaldsay in Orkney (blue), or near Unst in Shetland (grey). The maximum swimming speed of salmon is linked to their size but, as a rule of thumb, the maximum travel speed observed on the North Coast is around 50 km/day. This value is indicated on Figure 12 by the dashed line.

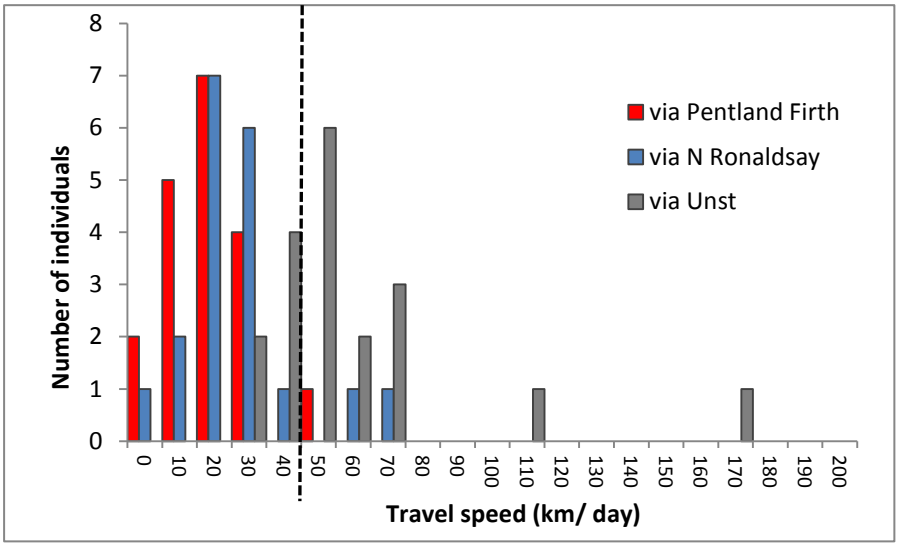


Figure 12. Average travel speeds required of fish tagged at Loch Inchard and recaptured on the East Coast for a route via the Pentland Firth (red), north of Orkney (blue) or north of Shetland (grey).

In general, travel speeds become increasing implausible as they increase towards 50 km/ day because this value is near to the maximum. Values much above this are probably not achievable and some of the high values shown in Figure 12 are impossible. Based on the required swimming speeds, at least seven of the 19 fish shown in Figure 12 could not have used the route via northern Shetland. Judged by the same criterion, 16 of the 19 fish were easily capable of having made their journey by the route north of Orkney. Two individuals must have used the Pentland Firth. In short, some fish took the direct route from Loch Inchard to the North Sea by moving directly along the North Coast and passing through the Pentland Firth but it cannot be shown that they must all have done so.

The fishermen's knowledge

At present, fishing for salmon with coastal bag-nets has been suspended by the Scottish Government under arrangements that will remain in place until 2018. However, even before this the bag-net industry had been in decline for several decades. As a result, the number of people with practical experience of the fisheries on the North Coast is now quite small. However, nearly all of those who have worked nets on the North Coast have contributed their understanding of how the fish behave in a series of interviews conducted as part of the present project.

The contribution of the fishermen is informal and it comes from a unique point of view. Fishing bag-nets on the North Coast is not to be undertaken lightly and a first-rate understanding of the behaviour of salmon is essential for success. What the fishermen know has been hard-won and passed on over successive generations in the course of trying to make a living from the fishery. So, the fishermen's take is likely to be illuminating and what follows is an attempt to weave it into what has already been discussed.

The first point of note is that the bag-net stances are not distributed evenly along the coast. The fishermen avoid the open coast and set their nets inside shallow bays – Armadale, Melvich and Sandside – or in the lee of heads - Strathy Point, Brims Ness, Holborn Head and Dunnet Head - where they are partly protected from the most destructive tides and swells. All the nets differ in their relationship to the adjoining coast, the coast's conformation in the vicinity and the nearness of rivers. All these factors affect the way in which fish come to the nets. In addition, the vagaries of the tides and winds affect the efficiency of different stances in different ways and they also affect the behaviour of the fish themselves. It is therefore unlikely that all the nets catch a similar, random sample of all the fish that are passing along the coast. Despite this, the fishermen consistently make several telling points that are important for understanding the wider picture. The most important point relates to the "wave" of fish that appears to roll along the coast in summer.

The fishermen put gear at risk and they balance this against the likelihood of catching fish. The fishery has therefore started later in recent decades because the spring fisheries have declined and summer runs of salmon and grilse are now predominant. At present, if the nets are set out in early June, for example, they are quite likely to catch fish immediately although probably in small numbers. However, this is a prelude to the main event several weeks later when the big run of summer fish reaches the coast.

The arrival of the first wave of summer fish is quite sudden and it cannot be accurately predicted because its timing varies. Indeed, the summer run's arrival has tended to slip back in some recent years for reasons that are unexplained making prediction even more difficult. The run is also quite compact so its arrival is a key event. The fishermen therefore have a keen interest in being forewarned that the main run is about to commence. So, when the first big "shot" of fish is made on the North Coast the news quickly spreads and those waiting at other stations along the coast know when the fish are likely to reach their own nets.

The leading edge of the incoming run moves from west to east. Consequently, it is the River Naver or the Armadale fishery that first see the run and the stations further east that benefit from advance warning. The time delay between stations is quite long and even stations that are quite closely

spaced measure their wait in days. Table 1 gives the days that elapse - as cited by the various fishermen - between the arrival of the summer run at pairs of fisheries along the North Coast.

The calculated average rates of travel are all very similar and rather slow at 3 – 7 km/day. However, they are entirely consistent with the slow travel rates noted for many of the fish tagged at Loch Inchard. It will be remembered that many of these fish showed average travel speeds of 5 or fewer km/ day on journeys of up to 150 km from the tagging site - roughly equivalent to the full length of the north coast through to Duncansby Head.

Fishing stations	Days elapsed	Distance (km)	Travel Speed (km/ day)
Naver to Armadale	2-3	13	4 - 7
Armadale to Strathy	2-3	11	4 - 6
Strathy to Melvich	2	6	3
Melvich to Sandside	2	8	4
Strathy to Scrabster	7	30	4
Strathy to Thurso East	7-10	33	3 - 5

Table 1. Days elapsed and travel speed of the main summer run as observed by the fishermen for pairs of fishing stations on the North Coast.

It is also evident that the wave of fish rolling at such a slow speed along the north coast cannot continue on through to the east coast fisheries. So, for example, at 5km/ day, fish passing Strathy in mid-July could not reach Helmsdale before mid-August or Montrose before mid-September. This is entirely inconsistent with the peak dates for the fisheries in each of these locations. On balance, therefore, it is likely that the particular wave of fish tracked by fishermen on the north coast dissipates near that coast's eastern limit. Indeed, the fisheries at Keiss and Ackergill in Sinclair Bay, about 20km south of Duncansby Head, were not considered to be closely linked to the North Coast sequence. The disconnect between the north and the east coast fisheries need not indicate that the inwards routes of fish heading for rivers on the respective coasts are substantially different. The same disconnect would arise if east coast fish (the fast travellers?) spend less time on inshore diversions into the bays and bights where the nets are set.

The tagging studies at Loch Inchard and elsewhere show that many fish are capable of travelling at speeds of 10 to 50 km/day and that they tend to do this on relatively long journeys. Many of the fish exhibit much slower speeds to reach locations that are rather nearer at hand. Presumably the slower class of fish has replaced fast swimming with slow searching as they get close to their target river. Yet, the tagging studies show that "close" in this context means anything up to 150 km distant. This is much too great a distance for the fish to be aware of any home river cues and some other cue must be involved in causing them to slow. Irrespective of what this cue might be, the fishermen's observations show that the fish direct their slowed travel to probing their way eastwards along the coast.

The fishermen state that fish enter places like Armadale, Strathy, Melvich and Sandside Bays on the flood tide (when tidal currents are moving west to east on the outer edge of the coast) and leave on the ebb. This again suggests that the fishes' rate of progress is rather slow because a diversion from the outer coast and a circuit of Melvich Bay, for example, is at the very most about 5km in extent. However, most of the bays receive fresh water from streams or rivers on their inner edge. Fish are probably delayed by encountering freshwater sources that are at least candidates for being from their home river. Indeed, some fish must identify their home river at this point and separate from the group of fish that moves on.

Most of the nets are said to fish better on the ebb tide and east-facing nets are said to fish best. Bearing in mind that many of the nets are set in small bays or to the east of headlands, this suggests that as the tide falls the fish move closer along east-facing shores in the bays as they make their way back to the main migration path on the outer coast.

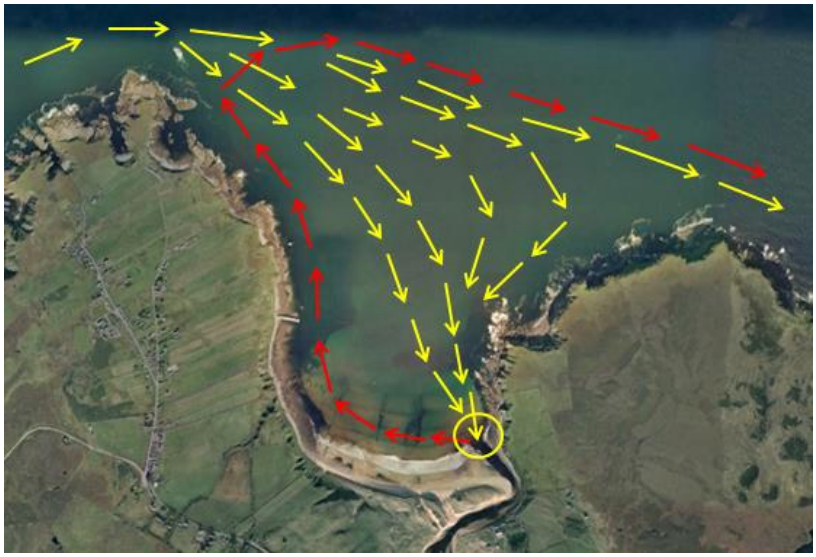


Figure 13. Possible patterns of movement for fish behaving as fishermen describe. The example is for the fishery at Melvich. Yellow arrows indicate tracks and directions of travel on the flood tide and red arrows those on the ebb. The mouth of the River Halladale is marked by the circle.

Perhaps this can be visualised as shown in Figure 13 for the example of Melvich Bay. It shows how some fish following the coast could peel off in a dispersed pattern at the mouth of the bay where the coast recedes and re-group when they make contact with the coast again inside the bay.

While the salmon that make their way into places like Melvich Bay may well be predominantly slow-moving fish targeting rivers on the north coast, some of them are not. The tagging studies (see again the previously cited reports by Malcolm and by Godfrey) show that a substantial proportion of the fish caught in all the North Coast fisheries are moving on more rapidly for more distant destinations. The proportions of slow- and fast-moving fish in the fisheries could, perhaps, be used to assess the proportion of East Coast fish that pass along the north coast but only if the fisheries were considered to catch a random sample of all the fish passing by. However, the fisheries in question tend to be in relatively sheltered inshore locations and the high travel speeds of the fastest moving fish show that they cannot expend much time exploring the innermost fringes of the coast. Since the question of randomness of the catch is therefore in doubt, the issue of whether most, or just some, of the East Coast fish use the route along the North Coast and through the Pentland Firth remains open to question, too.

All the accounts so far have described the bag-net fisheries but, in the past, sweep-nets also operated at the mouths of most of the rivers on the north coast, targeting fish as they moved from the sea into the rivers themselves. The sweep-net fishery at the mouth of the River Thurso has not operated for many years. However, a first-hand account of its operation is still available and this provides an insight into the behaviour of fish on the boundary between fresh water and the sea.

The sweep-net was fished at Thurso harbour where the river enters the sea. Fish move towards the river in discrete shoals (or “swims”) that are held together by common purpose and the sweep-net was used to encircle a swim as it moved past the netting stance. It is important to note that this was a sight-fishery and completely reliant on accurate observation of the fishes’ behaviour. Much of the crew’s time was therefore spent watching for and observing the fish rather than actually working the net.

This waiting was important because once the sweep-net was shot it took a considerable amount of down-time to recover it and put it back in order. The skipper’s responsibility was therefore to optimise the use of the net over the time available under the additional limitations set by river level, wind and tide. Consequently, there was a premium on targeting the larger swims even if this meant passing up on lesser opportunities. Gauging the approach of a swim and its size necessitated noting and interpreting the signs that the fish make as they approach the river-mouth.

Fish give their presence and their progress away by jumping intermittently and more especially, when conditions are favourable, by “nervous water”. Nervous water is the surface disturbance caused by swims approaching the river just below the surface in the slick of river-water that spreads out across the bay. Indeed, the fishes’ line of approach varies with wind direction because the wind deflects the river plume to east or west. Nervous water is particularly evident on a calm day or with a down-river breeze and can be noted at considerable range. The extent of the nervous water roughly indicates the size of the swim. Early in the season, a swim of 2SW salmon typically comprises 10 to 30 fish but later on a typical swim of grilse can be much larger.

Travel on the surface is the norm but when the river is high the nervous water may disappear at crucial times in the netting operation because the swim has moved deeper on its approach. An approaching swim may also turn before reaching the net, especially when the river is low, and the fish then retreat back into the bay. When the fish break back they return to their holding location several hundred meters offshore where the general body of waiting fish shows from time to time.

At first sight it might be thought that by the time fish reach Thurso harbour, near the western extremity of the north coast and on the very edge of the Pentland Firth, their intentions are finally settled. However, the tagging study carried out in Thurso Bay in 1920[24] by W.L. Calderwood, Inspector of Salmon Fisheries for Scotland at the time, showed that even at this stage some fish relocate and in some cases they cover substantial distances. Calderwood captured fish for tagging in bag-nets “placed fairly near the mouth of the Thurso River". Between May and September, 478 fish were tagged and 62 fish were recaptured. Fifteen were re-caught in the nets where they were tagged and 20 were recaptured in the Thurso River itself. Five more fish were returned from nets at Scrabster and Castlehill, still within Thurso Bay. All this is probably as expected for a tagging position so near to the river mouth. Yet, a further 15 fish were re-captured at Crosskirk on the River Forss, 12 km to the west. Two more were recaptured in nets further west again at Sandside Bay (22 km). One each was captured by rods on the River Halladale (29km) and the River Hope (81km) and one in nets set at Laide in Wester Ross (210km). Just two fish were recaptured on the east coast - near Wick about 50km from Thurso Bay.

Conclusions

The central theme of this report is the use of the Pentland Firth by adult salmon returning to Scottish rivers and particularly to the rivers of the Flow Country Rivers Trust area. The Trust area includes the Pentland Firth and all the rivers that are closest to it. The particular context of the report is the current and proposed development of the Firth for renewable energy and its potential impact on salmon returning from the ocean to their rivers.

For the Scottish rivers, in general, the main origins of incoming fish are probably in the areas of the North Atlantic lying to the north and northwest of Britain and Ireland. The starting point for this report is that the Pentland Firth is therefore an obvious way-point and a narrow bottleneck on the direct route to the rivers of the eastern coasts and also, plausibly, a westwards route for any fish that move in from the northern North Sea to the rivers of the North Coast.

Malcolm et al. (2010) previously covered some of the same ground in the same context. However, the present report focuses more closely on the Pentland Firth. It does this by taking a closer look at some of the tagging studies, considering information supplied by the netsmen and mapping the distribution of past fisheries through the legacy of icehouses. On this basis, the following points can be made.

[24] Calderwood, W.L. (1920) Salmon research in 1920 - Sea netting results. *Fisheries, Scotland, Salmon, Fish., 1920 No. I.*

1. Direction of movement of salmon in the Pentland Firth

All the tagging studies reported by Malcolm (2010) and Shearer (1992) show that, after tagging, some fish move along the coast in each of the opposing directions. However, tagging studies provide only two locations on the fish's route and only then in places where there are fisheries. The actual route is likely to be more convoluted than the tagging data indicate. The real route might include undetected offshore travel, hidden reversals of direction by searching fish - or even the random wanderings of fish that are hopelessly lost. Moreover, recapture is the end of the road and it usually occurs at an arbitrary point in the journey where the final destination is still not clear. None of this complexity can be resolved using conventional tags.

Bearing all this in mind, the main thrust of the tagging studies is still clear and it is also consistent with the fishermen's independent observations. Both point to a major migration route eastwards along the North Coast and through the Pentland Firth.

However, the tagging studies also show that many fish are moving westwards along the North Coast and that some of these fish make major journeys towards distant locations. Some of the fish may just be reversing their course to correct over-shoots or other errors. Some fish may continue smoothly westwards towards their target after an incoming journey southwards along the western coasts of the Northern Isles. However, the main focus of this report is on the Pentland Firth and the most important point to be resolved here is whether any fish move westwards through the Firth itself from a starting point in the North Sea.

Over the years many hundreds of salmon have been tagged in the North Sea over a wide range of locations - ranging from the drift net fishery off the Northumberland coast to the bag-nets of the Moray Firth. Only the northernmost of these studies, at Berriedale in southern Caithness, showed that a small proportion of these particular fish made their way through to the North Coast, presumably via the Pentland Firth. Elsewhere, only a single fish, tagged at Kintradwell in eastern Sutherland, was recaptured beyond the Firth. Due to the lack of fishery information, the possibility that some fish move westwards from the seas to the east of the Orkney Islands must remain. But if this is the case, there is certainly no counterpart to the extreme, broad-scale movement of Tay fish from west to east as inferred from Figure 8. Any westwards movement of fish via incoming routes to the east of Orkney is probably therefore minor.

In summary, it can be concluded that passage in the Pentland Firth is predominantly from west to east, that a relatively small number of fish move through in the opposing direction and then only from starting locations restricted to the very northernmost part of the Moray Firth.

2. Destinations of salmon passing through the Pentland Firth

Tagging studies carried out in the western and north coast fisheries demonstrate that fish move along the north coast to target rivers along the full length of the east coast. The Pentland Firth is a passageway for at least some of the fish passing eastwards. Other, less plausible west-to-east routes are possible further north but the high density of past salmon fisheries in the Firth and on its fringes suggests that most fish take the direct route.

In the Inchard study, some tagged fish moved long distances before being caught again. Some of the fish moved only over short distances but it is likely that some of these were still far from their home target when they were recaptured. Positional data alone cannot resolve this point. However, travel

speed appears to be correlated with the distance covered between tagging and recapture suggesting that faster travellers are intent on longer journeys. In the Inchard study (see again Figure 7), the proportion of fast travellers was much greater than the proportion of fish that actually proved to migrate long distances. This suggests that the Inchard catch was dominated by long-distance migrants but that, after being tagged, many of the fish were again thwarted by the nets after completing only a short section of their intended onwards journey.

In the Inchard study, 16% of recaptures were reported from beyond the Pentland Firth. Based on travel speeds and the grid-lines imposed on Figure 7, it can be estimated that the actual proportion of the catch that was targeting locations to the east of the Pentland Firth was around 65%. In other words, the potential importance of the Firth as a through route for east coast fish is probably much greater than the headline figures for the Inchard and other tagging studies suggest. This is a matter of potential importance because the question of a separate inwards route to the eastern rivers via the northern North Sea - and independent of the Pentland Firth route – is still unanswered[25]. In this context, allowing for the large difference in the total production of the rivers of the north and east coasts, the 65% figure suggests that East Coast fish were only slightly less exposed to the Inchard fishery than fish heading for the North Coast rivers. So, the route to the eastern rivers through the Firth may indeed be the dominant one.

Fish from all the east coast rivers are likely to use the Firth, including fish targeting the rivers of eastern Caithness. By contrast, the tagging studies carried out on the east coast show that fish returning to the rivers of the north coast are less likely to be present in the Firth - presumably because most of the fish approach their home rivers from the west. The east coast tagging studies also indicate that few fish backtrack through the Firth after over-shooting rivers on the north coast.

3. Spatial distribution of salmon passing through the Pentland Firth.

Salmon have not been studied in the Firth itself probably because of its notorious tides and seas. Despite this, salmon netsmen did work the southern side of the Firth in the past. The density of abandoned fishing stations there is high and all the stations were sufficiently productive to justify permanent buildings. These fisheries were part of a continuum stretching west to the Naver and southwards along the eastern Caithness coast and beyond. However, Figure 10 shows the dense aggregation of icehouses centred on the Firth and its approaches between Crosskirk, on the north coast of Caithness, and Wick on the east. There are no salmon rivers east of Thurso or north of Wick so the fisheries within the Firth were directed solely towards fish on passage.

It is significant that no evidence can be found for matching fisheries on the northern shore of the Firth suggesting that fish were not present there or, at least, not present in the numbers that sustained the Caithness fisheries. This in turn suggests that fish passing through the Firth bias their routes towards the southern shore. The spatial extent of any bias to the south need not be large to preclude viable fisheries in the north because the nets can only be fished close inshore. Bag-nets are only 100m in length and fish passing only a little further offshore cannot be captured. Therefore, the spatial extent of any bias cannot be judged from available evidence.

[25] www.gov.scot/Resource/0042/00426601.pdf

It is possible to consider the inwards routes of fish and the mechanisms that might lead to interaction with the shoreline. This procedure results in the patterns outlined in Figure 11. These show how any bias in the distribution of the fish across the width of the Firth might be very marked if fish follow the shoreline consistently and closely once they encounter it on their inwards journey. However, Figure 11 is speculative and cannot be used as evidence without being tested using direct observational data from the Firth itself.

In summary, therefore, it is likely that salmon moving eastwards through the Pentland Firth bias their migrations away from the Orkney Islands and towards the southern shore. However, the spatial extent of the bias is unknown and it may be minor. It cannot be estimated from data generated from the fisheries because, for operational reasons, they sample only the periphery of the Firth's expanse.

There is one more point to consider. Over periods of more than a few minutes, salmon can only swim continuously at about one body length per second - say, between 0.5 and 1.0 meters per second. Returning to Figure 3, it can be seen that the surface current velocities across much of the Firth are far in excess of this value when the tide is running. On the flood tide, therefore, fish moving eastwards in mid-Firth will be carried along much faster than they can actually swim. However, on the ebb tide, the same fish will be pushed back westwards over long distances. This raises two possibilities. First, fish moving eastwards may attempt to stem the ebb flow, fail to do so and get displaced backwards to the west, making up the lost ground on the next flood tide. Or, fish may seek passage through the fringe of slacker water that is always present nearer the shore. If the latter is the case, then the absence of salmon fisheries on the Orkney side of the Firth suggests that it must be the Caithness shore that the fish favour. Again, this is speculative and it is not possible resolve the issue without direct observational study.

4. Can these issues be further resolved?

The purpose of this project was to use all of the very few sources of available information to construct a better understanding of salmon in the Pentland Firth than was available before. In order to do this, the sparse data available from previous fishery studies has been strengthened with new information drawn from unconventional sources. However, since direct biological information on salmon passing through the Firth is still lacking the conclusions that are drawn are based on inference and speculation. Therefore, the picture is still not sufficiently informative and, in particular, it lacks the clarity that would allow salmon to be confidently considered in the context of renewables development. This situation will not change until new studies of salmon are carried out in the Pentland Firth itself.

In the past, the Pentland Firth was a very difficult environment in which to study salmon, partly because of the extreme sea conditions that often prevail. With the advent of modern tracking technologies, particularly those using acoustic tags and automatic listening stations[26], some of the logistical difficulties can probably now be overcome. Direct observation of the behaviour of salmon in the Firth is probably feasible, especially by way of a strategy based on the conclusions of the present study.

[26] http://vemco.com/

Acknowledgements.

I wish to thank the netsmen - James Mackay, Willie Grant, Dougie Reid, Eddie McCarthy and Ian Paterson - for giving me their time so freely. I also wish to thank all those who helped in my search for information and especially Julie Gibson and Malcolm Thomson in Orkney. I thank John Mackay and James Fleming of the Flow Country Rivers Trust for their interest and encouragement. Finally, financial support from The Fishmongers' Company made this project possible.