COLLAPSE OF LOCH MAREE SEA TROUT
HOW CULPABLE IS SALMON FARMING?

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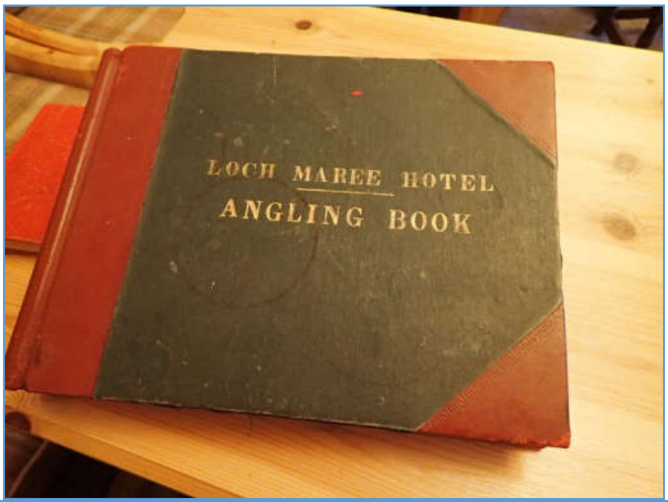
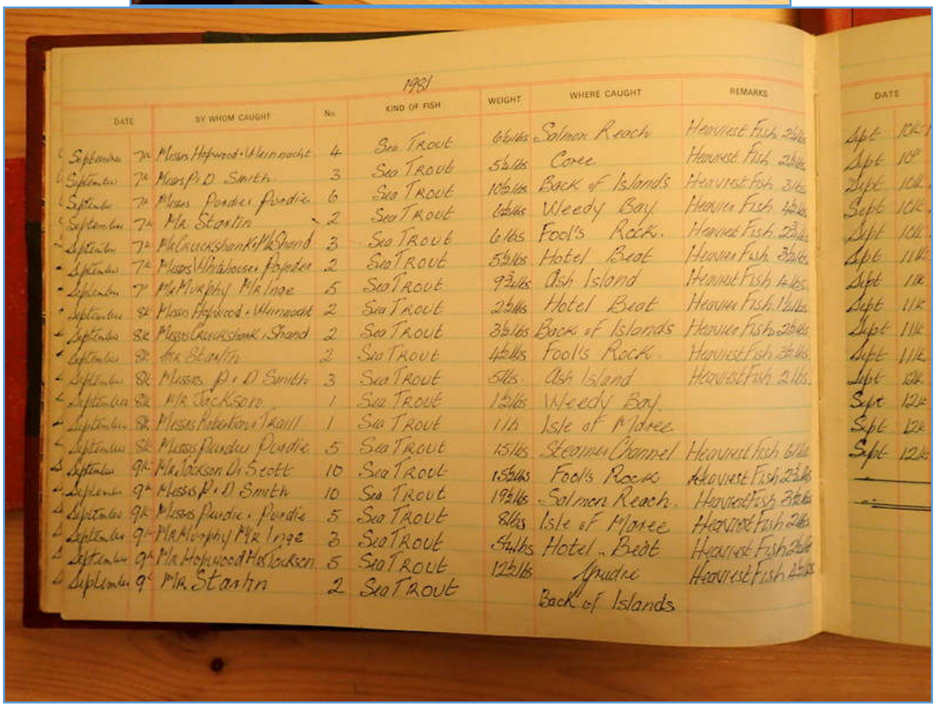
Frontispiece: A gathering of sea trout anglers at Loch Maree Hotel, facing the islands of Loch Maree, being briefed by Peter Cunningham, Senior Biologist of Wester Ross Fisheries Trust, at the beginning of an experimental fishing day on the loch, 19 September 2016. Only about fifteen brown trout and no sea trout were landed.





1981

DATE		BY WHOM CAUGHT	No.	KIND OF FISH	WEIGHT	WHERE CAUGHT	REMARKS
September	7th	Messrs Hopwood & Weinnacht	4	Sea Trout	6½lbs	Salmon Reach	Heaviest Fish 2½lbs
September	7th	Messrs P & D Smith	3	Sea Trout	5½lbs	Core	Heaviest Fish 2½lbs
September	7th	Messrs Purdie & Purdie	6	Sea Trout	10½lbs	Back of Islands	Heaviest Fish 3lbs
September	7th	Mr Stanton	2	Sea Trout	6½lbs	Weedy Bay	Heaviest Fish 4½lbs
September	7th	Mr Cruickshank & Mr Shand	3	Sea Trout	6lbs	Fool's Rock.	Heaviest Fish 2¾lbs
September	7th	Messrs Whitehouse & Poynder	2	Sea Trout	5½lbs	Hotel Beat	Heaviest Fish 3½lbs
September	7th	Mr Murphy Mr Inge	5	Sea Trout	9¾lbs	Ash Island	Heaviest Fish 4lbs.
September	8th	Messrs Hopwood & Weinnacht	2	Sea Trout	2½lbs	Hotel Beat	Heaviest Fish 1½lbs
September	8th	Messrs Cruickshank & Shand	2	Sea Trout	3½lbs	Back of Islands	Heaviest Fish 2½lbs
September	8th	Mr Stanton	2	Sea Trout	4½lbs	Fool's Rock.	Heaviest Fish 3½lbs
September	8th	Messrs P & D Smith	3	Sea Trout	5lbs	Ash Island	Heaviest Fish 2lbs.
September	8th	Mr Jackson	1	Sea Trout	1½lbs	Weedy Bay.	
September	8th	Messrs Robertson & Traill	1	Sea Trout	1lb	Isle of Maree	
September	8th	Messrs Purdie & Purdie	5	Sea Trout	15lbs	Steamer Channel	Heaviest Fish 6lbs
September	9th	Mr Jackson Dr Scott	10	Sea Trout	15½lbs	Fool's Rock	Heaviest Fish 2¾lbs
September	9th	Messrs P & D Smith	10	Sea Trout	19½lbs	Salmon Reach.	Heaviest Fish 3½lbs
September	9th	Messrs Purdie & Purdie	5	Sea Trout	8lbs	Isle of Maree	Heaviest Fish 2lbs
September	9th	Mr Murphy Mr Inge	3	Sea Trout	5¼lbs	Hotel Beat	Heaviest Fish 2½lbs
September	9th	Mr Hopwood Mr Jackson	5	Sea Trout	12½lbs	Grudie	Heaviest Fish 4½lbs
September	9th	Mr Stanton	2	Sea Trout		Back of Islands	

Plates II and III by courtesy of Loch Maree Hotel

‘*In the British Islands, it is certain, the sea-trout is indigenous to all our coasts, and particularly it exists in enormous shoals on the western coasts of Ireland and round all the coasts of Scotland, both of the mainland and of the islands, wherever access can be gained from sea or estuary to suitable inland spawning grounds.*’

(From ‘*The Sea Trout: A Study in Natural History*’ by Henry Lamond, 1916. London: Sherratt & Hughes)

EXECUTIVE SUMMARY

In the late 1980s, concurrent collapses of sea trout angling fisheries occurred in north-western Scotland and western Ireland soon after the introduction of Atlantic salmon (*Salmo salar*) farming in complexes of floating mesh cages moored in parts of bays and sea lochs (loughs), sheltered from exposure to the open Atlantic. Many of the cage units were placed close to important rivers for sea trout and salmon angling. In both countries, scientific studies identified close similarities in the patterns of sharp declines in sea trout abundance, size, longevity and fecundity. Previously unknown epizootic levels of parasitic salmon lice (*Leophtheirus salmonis* Krøyer) were detected on sea trout in salmon farming areas, but not elsewhere.

The world-famous sea trout angling fishery at Loch Maree collapsed from 1988 and has not recovered. Intensive salmon farming began in saltwater Loch Ewe in Wester Ross, NW Scotland, in 1987 and has continued there. Previously, in 1980, extensive catch sampling and electro-fishing of mature fish in the spawning burns (>1100 fish) was undertaken to provide representative biological details of the overall sea trout stock, repeating old studies carried out in the 1920s (catch sampling and netting). The results were almost identical, confirming a slow-growing, long-lived overall population, with many large, old, multi-annual, spawners and a stable stock structure. Further annual samples obtained later in the 1980s and until 2001 had to be pooled because of limited fish abundance. There was a substantial fall in mean length at sea ages, maximum sea age (from 11 sea winters in 1980 to 5 SW by 1997-2001) and in estimated total fecundity, prompting a sea trout stock collapse.

Later research in nearby sea loch Loch Torridon identified a two-year positive relationship between louse incidence on sea trout post-smolts near the River Shieldaig and on a local salmon farm, corresponding to the main production years in their two-year rearing cycle. These findings were supported by long-term scientific studies carried out in western Ireland and in Norway, highlighting extra marine survival problems for sea trout in areas of intensive salmon farming, particularly involving sea lice. Further research raised scientific awareness of acute physiological and behavioural impacts of heavy infestations of sea lice on post-smolts and the lethality of infection levels sustained above previously ambient densities. International tagging studies consistently showed that smolts treated for protection against lice in their first weeks at sea survived and grew better than untreated control batches. However, since there are many other interacting causes of marine mortality of sea trout, it has remained scientifically elusive to quantify their impacts at a population level.

Nevertheless, it can be concluded that the introduction of salmon farming in Loch Ewe close to the River Ewe's estuary played a prominent part in the changes in sea trout stock dynamics in the River Ewe system, leading to the collapse of the angling fishery in Loch Maree. The rapid change in sea trout stock structure there in the late 1980s was consistent with many other badly-affected sea trout fisheries throughout the West Highlands and Islands following the development of local intensive coastal salmon farming. There is no evidence of a collapse of sea trout catches or loss of large specimens in North Coast rivers, where the coastal environment is more exposed to the open Atlantic Ocean and rapid tidal flushing. In most other parts of Scotland, reported angling catches in recent years indicate a decline in numbers, but an increase in annual mean weight of sea trout. Both trends are at least partly explained by a gradual introduction of greater angling restrictions for stock conservation. A long-term study of an indicator population in a tributary of the River Earn in East Scotland found that the annual length and age distributions of the sea trout spawning there remained stable between the early 1980s and 2001, contrasting with north-western river systems.

Unfortunately, knowledge of Scottish sea trout stock dynamics remains weak and monitoring is patchy. Overall, while angling catches are assumed to be indicative of trends in abundance, they have many flaws. In consequence, potential crises are not sufficiently identified and accepted in time to take proper remedial action. Salmon farming has become a massively important industry, with current production already dwarfing wild sea trout and salmon populations and likely to grow substantially. Its technology continues to improve, but the present heavy dependence on floating cages with free water exchange with the open environment is in urgent need of change. In the meantime, a decision should be made to relocate existing salmon farms well away from river mouths, using scientifically predicted transport distances for sea lice infective stages under prevailing local hydrological conditions.

CONTENTS

1.0 CONTRACT

Salmon and Trout Conservation Scotland commissioned a report on the most likely main causes of the collapse of local sea trout stocks since the 1980s and therefore of the former prolific sea trout angling fishery in the River Ewe system, Wester Ross, Scotland; also, on whether the removal of salmon farming in adjacent saltwater Loch Ewe would allow recovery of the fishery. Details of the socio-economic impacts of the loss of the sea trout fishery are not provided here and require other expertise.

From 1963 until retirement in 2005, I was a member of staff at the Government's Freshwater Laboratory, Pitlochry, linked with the Marine Laboratory in Aberdeen. During my career, most of our fisheries monitoring work was on salmon in the main east coast rivers, but we also undertook fishery research projects and carried out advisory work on inland fishery matters in other regions, in an era when there were few other freshwater fishery biologists to do this. By the end of the 1970s, it was apparent that not enough was known about sea trout. We were often asked why they were more common in some rivers than others, how sustainable were their populations under various pressures and what were the best ways to protect and enhance them? This preceded the network of charitable fishery trusts which now undertakes a great deal of local fishery and related work, liaises with fishery boards and government and provides outreach to communities at a local and regional level.

2.0 BACKGROUND TO THE COLLAPSE OF THE FISHERY

The tumbling, peat-stained spate rivers and oligotrophic lochs of the River Ewe system (catchment area 441 km^2) drain westward to saltwater Loch Ewe at the small community of Poolewe, in Wester Ross, north-west Scotland. The short, mainly steep, River Ewe itself (3km) flows from majestic Loch Maree (20km long), augmented by various small, spate rivers and burns draining from the mountainous and mainly heather-clad and rocky catchment. Other smaller lochs in the system are accessible to migratory fish, especially Kernsary, Clair and Coulin. The fish species present are salmon, sea trout and freshwater-resident brown trout, Arctic charr (*Salvelinus alpinus*), European eel (*Anguilla anguilla*), European minnow (*Phoxinus phoxinus*) and three-spined stickleback (*Gasterosteus aculeatus)*. Loch Ewe (16 km long, mean depth 15m) lies in an approximately north-west direction and is sheltered from the open Atlantic by a narrow entrance (c. 2km). A large, sheep-grazed island, Isle of Ewe, lying roughly centrally, provides further anchorage protection. The Scottish Environmental Protection Agency (SEPA) website states that Loch Ewe has a maximum water depth of 73m and two sills which divide the loch into two water areas or basins and the loch takes 4 days to flush, with some deep waters exchanging more slowly than this.

Historically, and until the late 1980s, the River Ewe system, including Loch Maree and its various headwater lochs, notably Lochs Clair and Coulin, offered wonderful angling for sea trout. By the end of that decade, the fishery was a shadow of its former high status. Visiting anglers used to come with realistic expectations of large, feisty, specimen fish caught in a wonderfully scenic and tantalisingly remote, atmospheric and mountainous environment, epitomising the West Highlands of Scotland. Instead, the catches of sea trout plummeted after 1987 and the specimen fish which characterised these famous waters were gone. At the same time, there was a sharp fall in sea trout catches throughout most of the Western Highlands (Picken, 1990; Walker *et al.*, 1992; Walker, 1994a) and in the west of Ireland (Whelan, 1993; Poole and Whelan, 1996). Details of the collapse of the sea trout and angling fishery in the River Ewe system from 1981-2001 are provided by Butler and Walker (2006). Since then, the local Wester Ross Fisheries Trust (http://www.wrft.org.uk/) has continued to monitor catches and found no evidence of sustained stock recovery.

In north-western Scottish rivers, and throughout most of the country, detailed information on sea trout stock abundance is unavailable because of an absence of traps and fish counters. Therefore, catch data from fisheries are used as an indirect means of stock assessment and this approach is prone to problems of interpretation, particularly concerning weather conditions and changes in fishing effort (discussed later). With many potential causes of stock decline, a precise and quantifiable understanding of the impact of each possible factor, and how it relates to the others, has remained elusive (Walker, 1994a).

3.0 SEA TROUT CATCHES IN THE RIVER EWE SYSTEM

As is usually the case in Scotland, the rights to fish by rod and line for sea trout and salmon in the different parts of the River Ewe system or catchment are held by several fishery owners, represented by a statutory District Salmon Fishery Board. Since the early 1970s, exploitation has been limited to six recreational rod fisheries (Butler and Walker, 2006). In reviewing historical catches of sea trout, Butler and Walker (2006) confined their examination to the Loch Maree Hotel catch records from 1969 to 2001, because this was the longest time series of reliable catch data. Over this period, the fishery was consistently based on boat angling in daylight, to a maximum of nine boats per day, but this decreased during the 1990s following the collapse in catches.

The Loch Maree Hotel catches (as in any wild fishery) were always subject to peaks and troughs. Figure 1 shows that 1970 was a high point (almost 1600 sea-trout caught), followed by more modest catches between 1971 and 1977 (in the range of 600 to 1000 annually), more prolific catches between 1978 and 1981 (rising again to almost 1600), a return to comparatively modest catches between 1982 and 1984 (600 to 800 annually), a better year in 1985 (some 1100 caught) and more moderate catches in 1986 and 1987 (close to 600 annually). Until then, the annual catches show no obvious trend and those made in the 1980s were consistent with the earlier fluctuations since the beginning of the series. After 1987, the catches dropped to unprecedented levels and did not recover. The histogram extends the catch series presented by Butler and Walker (2006) by the inclusion of 2002 to 2006. By this time, reduction in fishing effort must be recognized as an additional factor depressing catches.

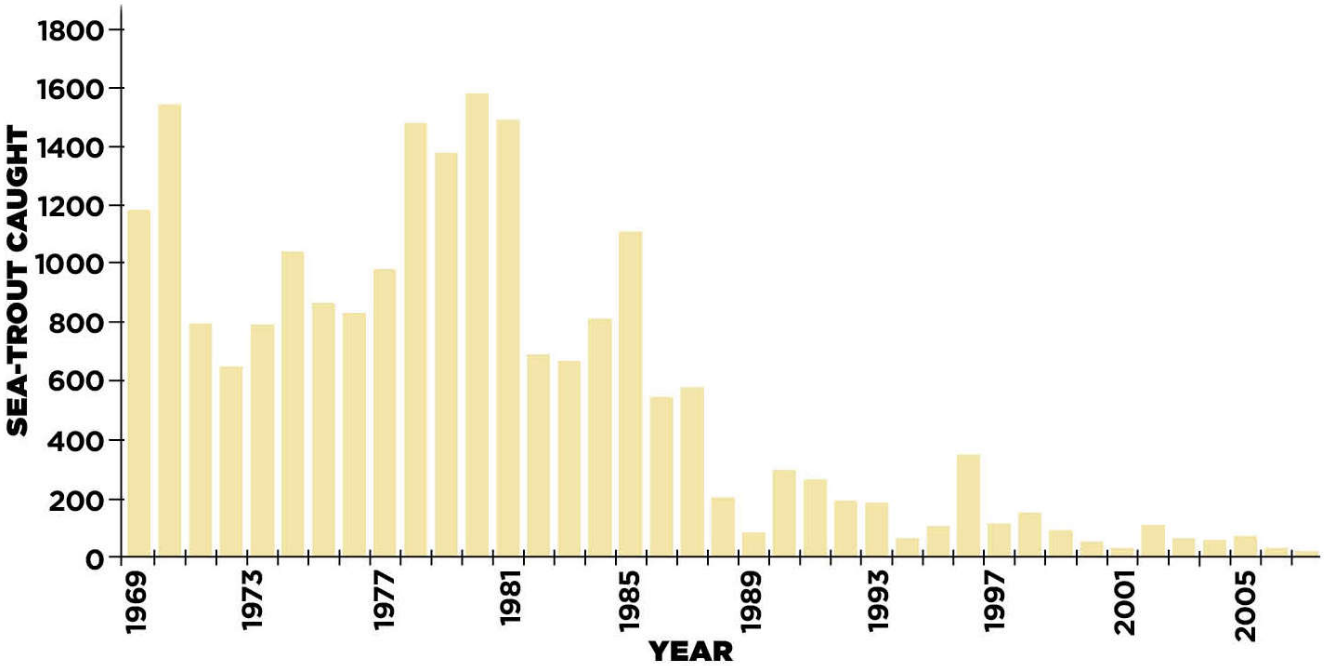


Fig. 1. Annual catches of sea trout from the Loch Maree Hotel (1969-2006)

The Wester Ross Fisheries Trust Review published in May 2016 (www. wrft.org.uk) reports the '*River Ewe - Loch Maree system sea trout catch in 2015 was just 99 fish: comparable to previous recent years*.' Note that this was the combined total of sea trout for the entire catchment, not just from the Loch Maree Hotel boats. Fig. 2 (below), also copied from the same source, shows Ewe system sea trout and 'finnock' catches during 2004-2015, emphasising the continuing poor rod catches and lack of recovery. Finnock, in biological nomenclature, are 0+ sea year sea trout. They are mostly immature fish, also known regionally as herling, or whitling, (*although the latter term, confusingly, can mean one-sea year sea trout in the River Till, Northumberland, part of the Tweed catchment*). Throughout most of Scotland, anglers tend to class sea trout weighing less than c. 450 g. (a pound) as 'finnock'. In some West Coast river systems, including the Ewe system and Loch Maree, where local sea growth is relatively slow, this size group includes some sea trout in their second sea year after smolt migration (Nall, 1930; Walker, 2004).

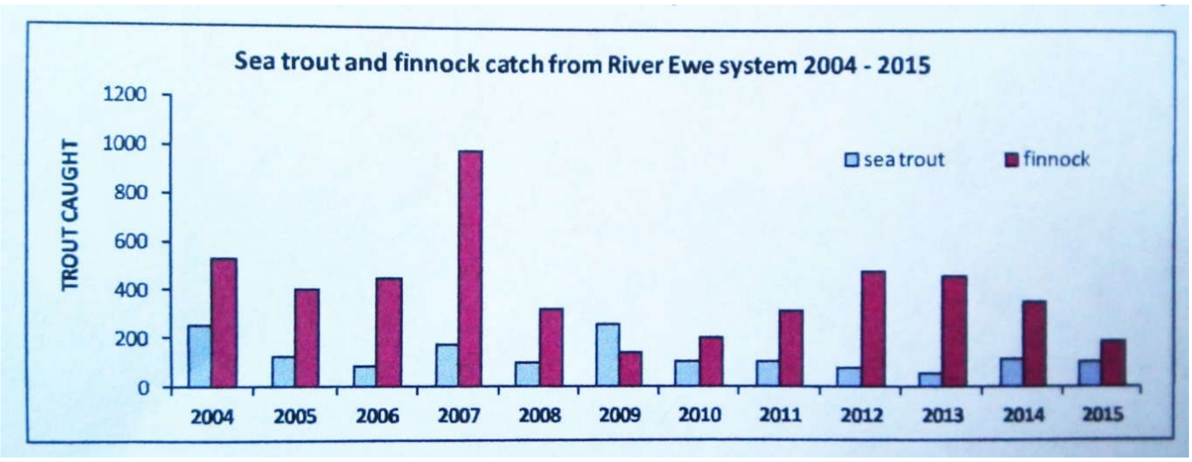


Fig.2 Sea trout and finnock catches from the River Ewe system (2004 - 2015)

Many people believe that salmon farming has been the new factor depressing sea trout stocks in the marine aquaculture areas of the West Coast. It is pertinent therefore to add, without further comment at this stage, that two salmon farming units of cages were established in Loch Ewe in 1987, sited 4 and 7 km from the river mouth, operating to consented biomass limits of 919 and 950 tonnes. Other than these sites (only one of which is currently active), the nearest active marine salmon farms to the river mouth were and are 40 km by sea to the north in Little Loch Broom and 55 km to the south in Loch Torridon (Butler and Walker, 2006).

4.0 SAMPLING OF SEA TROUT IN THE RIVER EWE SYSTEM

Apart from useful netting studies in north Argyll sea lochs in the 1960s and 70s (Pemberton, 1976 a&b), little had been published on sea trout in western Scotland since the widespread and seminal netting, scale reading and tagging work of the Fishery Board for Scotland in the 1920s (Nall, 1930). As part of efforts to update this information, a population study was carried out on River Ewe system sea trout by the Freshwater Laboratory (then part of DAFS) in 1980, with help from the Ewe District Salmon Fishery Board, local fishery owners and anglers. Scale samples, together with length and weight data, were taken from a large sample of the sea trout rod catch, supplemented by electro-fishing for adults during spawning surveys, for comparison with the historical data (Nall, 1925; 1928 and 1930). In 1980, scales and related information were obtained from 1163 fish with an average weight of c. 1.1 kg. Nall's larger collection from 2442 fish, based on sampling in several years between 1920 and 1927, included a much greater proportion of 'finnock' (46% compared with our 5%). Nall records that the register of the Loch Maree Hotel showed '*the average number of sea trout taken by Hotel anglers in the period 1918 to 1925 was about 2,100 per annum, of an average weight,* ***finnock included****, of about 15 oz*' (c.430 g). The inclusion of 'finnock' suggests no size limit was in operation at the Hotel fishery at that time. In later years leading to World War II, the catches ranged from about 650 to 3,000 fish, still averaging only 340-680 g. A size limit of c. 900 g. (two pounds) was applied for some years in the post-War era, but the limit was reduced again to 450 g in 1965 (Miss K. Moodie, pers. comm.). These changes in size limit make it hard to compare the early Hotel catches with the later ones.

4.1 Catch sampling results from 1980

The scale sampling survey carried out in 1980 found that the structure of the catch closely resembled Nall's results from half a century earlier (Walker, 1982). In the 1980 collection, the largest fish measured 76 cm and the heaviest weighed 4.76 kg (10.5 lbs). The most common age was 5 years and the oldest was 14 years. The mean smolt age was 3.2 years. A total of 588 fish (50.6%) had spawned at least once, the maximum being 11 times. Most had matured for the first time at sea age 1+ and 2+ (42% and 53%). As Nall had found, the Ewe system sea trout were still slow-developing and long-lived by Scottish standards.

Further annual scale collections were made and the sampling data were consolidated into groups of years by Butler and Walker (2006). With the fishery collapsing at the end of the 1980s, the maximum spawning frequency fell from 7 times in 1989-90 to 4 in 1992-93 and to 2 times in 1997-2001. Figure 3 shows the decline in marine growth and sea age. Mean length at all sea ages declined significantly, as did maximum sea ages (11 years in 1926 and 1980, 8 years between 1980 and 1989-90, 6 years between 1989-90 and 1992-93 and 5 years between 1992-93 and 1997-2001). The lack of sea trout aged five sea winters or older is striking, and the mean length at two and three sea winters, which were estimated at 416 mm and 467 mm in 1926-28, were only 359mm and 397 mm in 1992 (Walker, 1994b).

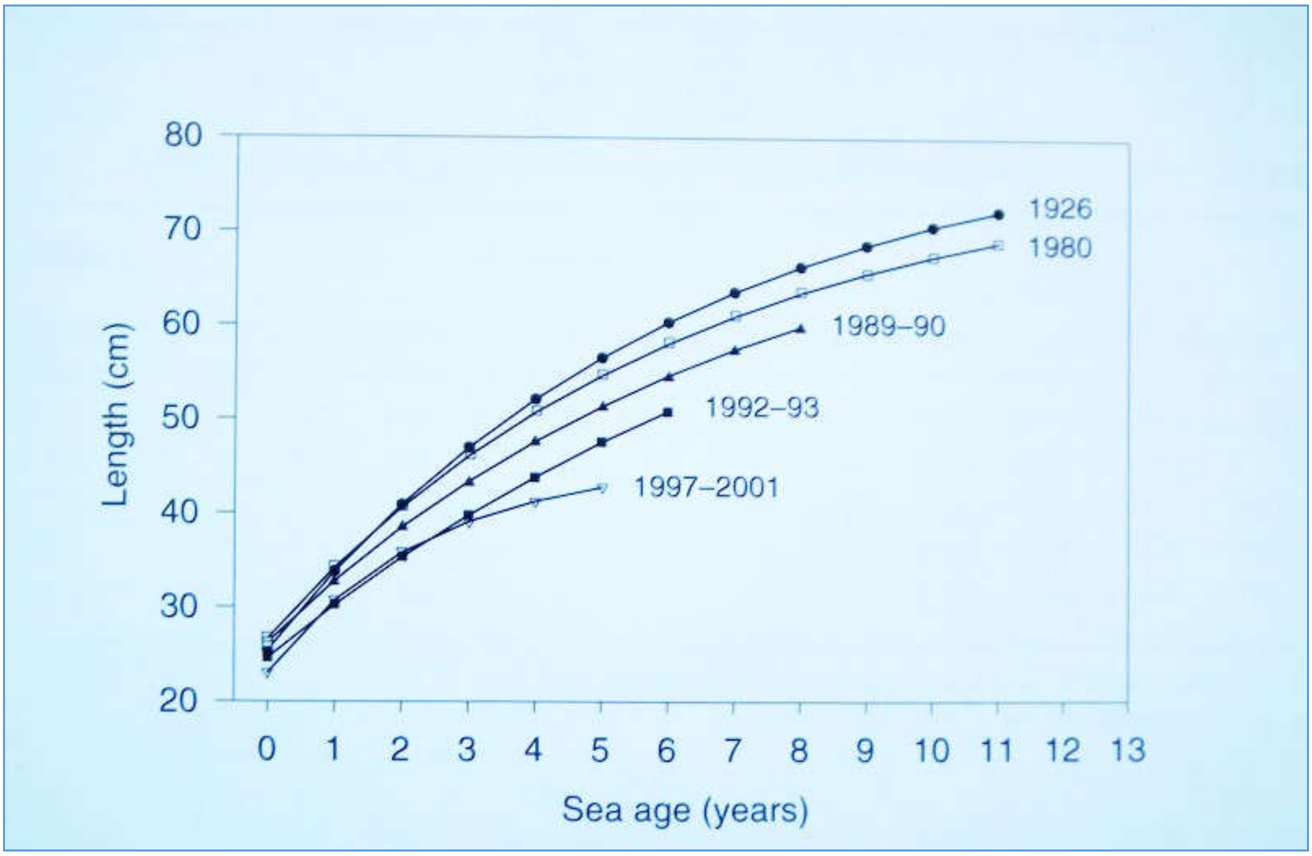


Fig. 3. Mean lengths at sea age from von Bertalanffy growth curves for Ewe System sea trout (From Butler and Walker, 2006)

Potential egg yield from individual female Ewe system sea trout at different body lengths was estimated from regression parameters based on 53 mature hen fish sampled in spawning burns at Lochs Maree (31) and Coulin (22) between 1980 and 1993 (Walker, 1994b). Assuming the fecundity/body length relationship had not changed over time, fecundity estimates were weighted by the proportion of the overall scale-sampled fish found at individual sea ages in the individual surveys. This showed that less than half as many eggs were available for deposition by a typical 1000 females by 1992 compared with a typical 1000 females in 1980. However, the overall egg deposition levels depended on the numbers of fish as well. At the end of the 1980s catches collapsed, implying acute scarcity of adult sea trout and a lack of sustainability in the overall stock (Walker, 1994 a&b; Butler and Walker, 2006).

4.2 Relationship between Ewe sea trout and brown trout

Sea trout and brown trout are variants of the same species (*Salmo trutta*) in anadromous and freshwater-resident forms. Experimental stocking trials in the headwaters of the River Earn in Eastern Scotland have confirmed that sea trout pairings can produce stream-resident, river-migrant and sea-running progeny (Walker, 2006b). Conversely, brown trout introductions to the Antipodes have resulted in the establishment of sea trout populations (MacCrimmon and Marshall, 1968; MacCrimmon *et al*.,1970). Sea trout progeny may adopt variable life history tactics based on environmental conditions, effectively 'deciding' whether and when to become smolts and migrate (Walker, 1994a, 2006; Jonsson, 1985; Butler and Walker, 2006; Jonsson and Jonsson, 1993). Increased freshwater growth rates may inhibit the anadromous tendency (Morgan & Paveley, 1993).

Formerly, the Loch Maree Hotel fishery caught and released many small trout of pre-smolt size and only recorded larger ones weighing ≥0.5 kg. Regular ghillies and anglers at Loch Maree used to report that very few brown trout of that size were caught there by fly-fishing, although there is also a larger, piscivorous (ferox) form which is more likely to take trolled lures. After 1988, brown trout weighing ≥0.5 kg began to appear more often and by 1997-2001 outnumbered the small numbers of sea trout landed. During the 1990s, similar improvements in brown trout size were observed in other collapsed sea trout fisheries, including the Rivers Balgay and Gruinard and Lochs Eilt and Shiel. Declining adult sea trout abundance and less juvenile recruitment may have led to better growth of brown trout (Walker, 1994b; Butler and Walker, 2006). Many juvenile potentially migratory trout spend part of their early life in West Highland lochs, but their densities there are much less readily obtained than by electro-fishing in streams, other than by destructive gill-netting, and acoustic methods of stock assessment are limited by problems of species identification and data interpretation.

5.0 SEA TROUT ROD CATCHES ELSEWHERE IN SCOTLAND

At the end of the 1980s, when sea trout catches throughout most of the West Highlands and Islands went into steep decline, East Coast stocks seemed at first to be more stable. However, that has changed. During almost the last two decades, formerly prolific eastern sea trout rivers, including Spey, Deveron, Ythan, South Esk, Earn, also Solway and Ayrshire rivers, especially Annan and Nith, Stinchar and Doon, also reported seriously declining rod catches, although catches have held up better in North Region and locally in parts of the Outer Hebrides. Unlike commercial netting of sea trout, which was carried out at a small number of locations, rod catches are much more widely spread around the country. The Rivers Annan and Nith produced good angling catches, but the Tweed reported surprisingly modest levels for its very large and productive catchment. Now Tweed rod catches of sea trout are much-improved, a change commonly attributed to the gradual closing of the netting stations at Berwick and the phased reduction of the North-East English driftnet and trap-net fisheries operating off Northumberland and Yorkshire. Other likely stock enhancing factors may include the easing or removal of redundant mill weirs and road culverts that formerly impeded upstream migration of migratory fish, carried out by the Tweed Commissioners and Tweed Foundation.

In contrast to the Tweed, the most recent published statutory catch returns show a long-term overall national decline of Scottish sea trout angling catches (http://www.gov.scot/Publications/2016/04/1137/2). This decline was due in part to a change in recording practice for 'finnock' introduced in 2004. Prior to that year there was a lot of inconsistency among angling fisheries in the reporting of 'finnock.' Some did not report them while others did, probably making a big difference to both numbers and mean weight. In the earlier part of the catch series the numbers of sea trout might have been even higher had all 'finnock' been reported. Since 2004 their catches have been required, but are recorded separately from 'Sea Trout,' which adds to the difficulty in making comparisons with the older catch data. Figure 4 shows the All-Scotland Rod and Line catches of 'Sea Trout' from 1952 to 2015. 'Finnock' are shown in red. The addition of 'Finnock' from 2004 until 2015 would moderate the overall pattern of decline, but the reported catches made in recent years would still be among the lowest in the series.

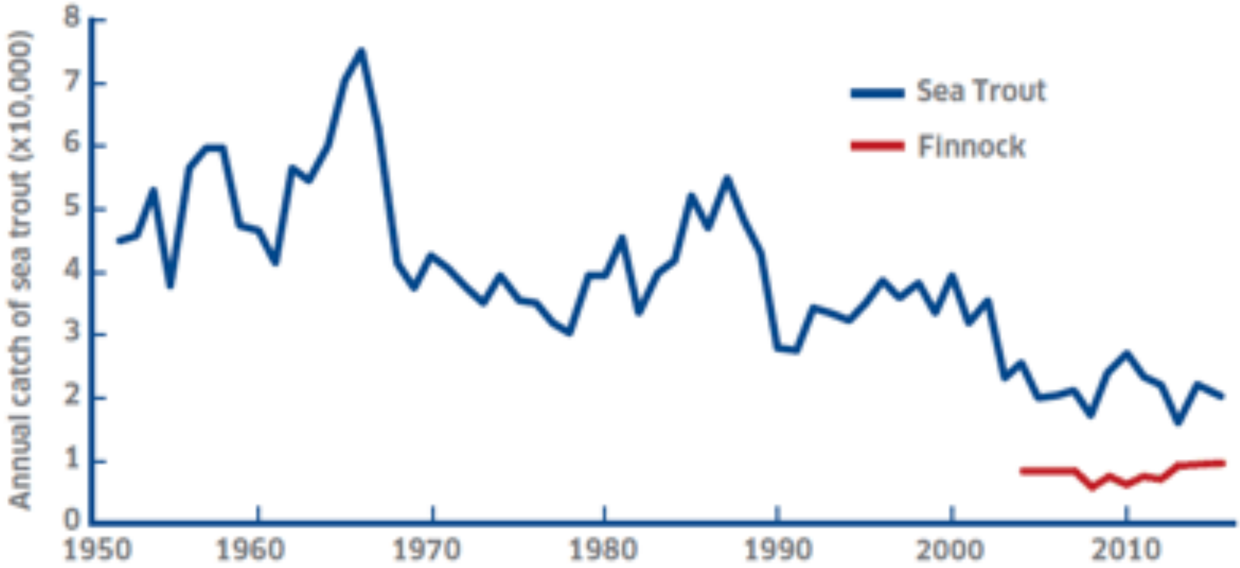
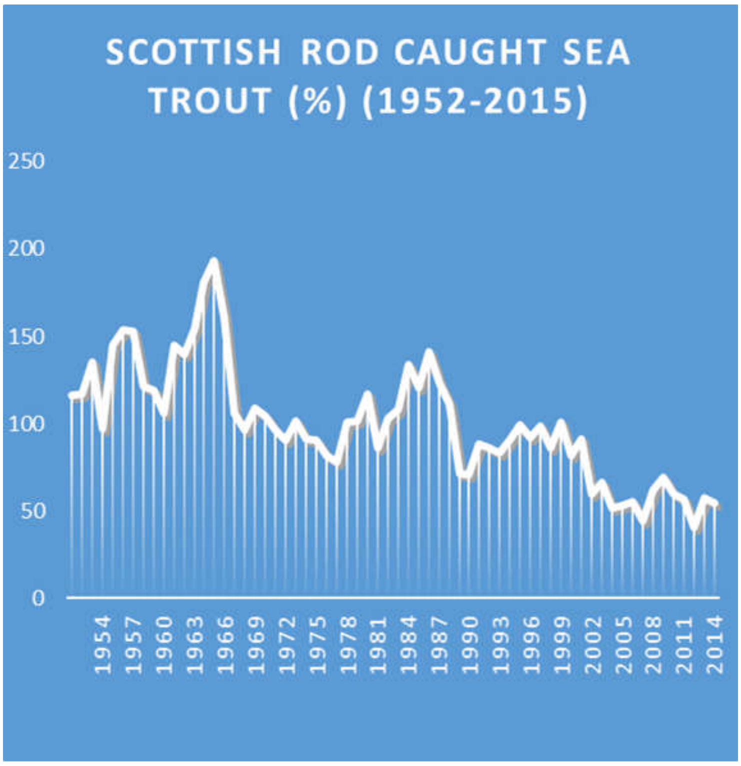


Fig. 4. All-Scotland Sea Trout Rod and Line Fishery (1952-2015)

5.1 Regional Comparisons of Numbers of Sea Trout Caught

The following graphs (Fig. 5a-j) allow comparison of the rod and line catches of sea trout from Scottish Fishery Regions, using percentage deviation to adjust for differences in scale. [Orkney, with no records and Shetland, with data gaps, are omitted].

The western Regions, North West, West, Clyde Coast, Solway Firth and Outer Hebrides, show a long-term catch decline. Of these Regions, only Outer Hebrides avoids record lows towards the end of the series. Moray Firth resembles the Solway graph, with best catches in the 1950s and 1960s, and again through the 1980s, then a clear decline in the last decade. In contrast, North and especially East Regions show an overall increase. North East Region has no obvious pattern, except that rod catches are consistently poor in the last decade. Rod catches in East Region (especially Tweed and Tay) may have benefited more than some other Regions through the decline of salmon and sea trout netting. Other special features of the Tweed have been discussed already. However, North Region requires further examination. Sea trout catches there show no downward trend.



SCOTTISH ROD CAUGHT SEA TROUT (%) (1952-2015)
250
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150
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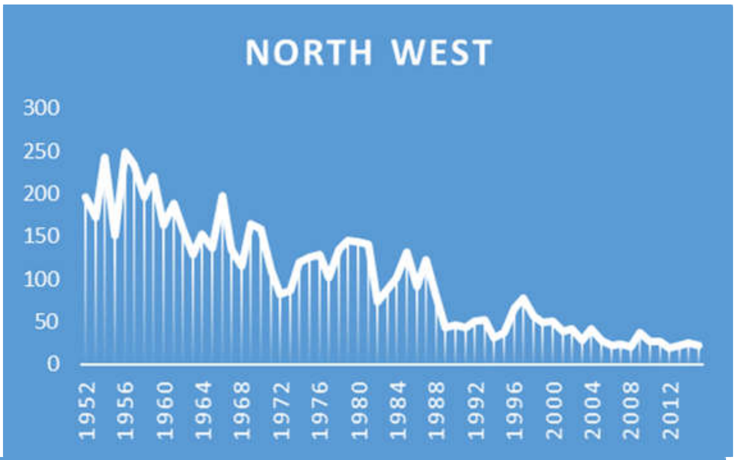
NORTH WEST
300
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200
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2000
2004
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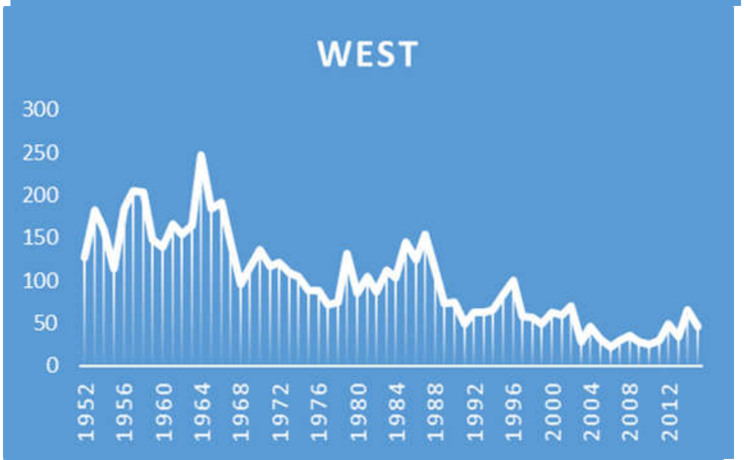
2012


WEST
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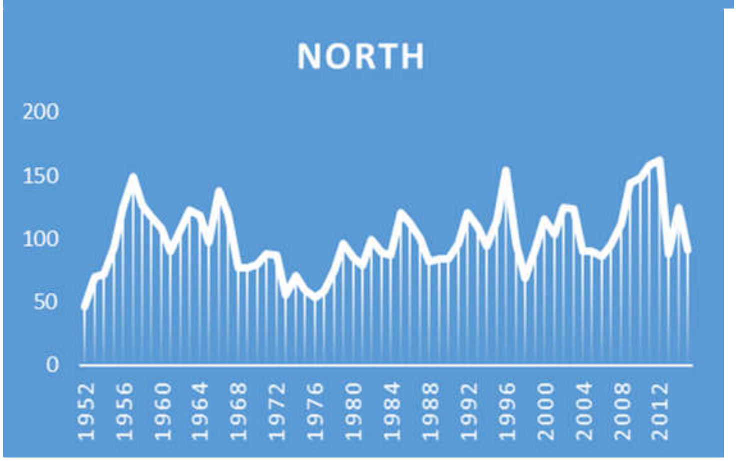
NORTH
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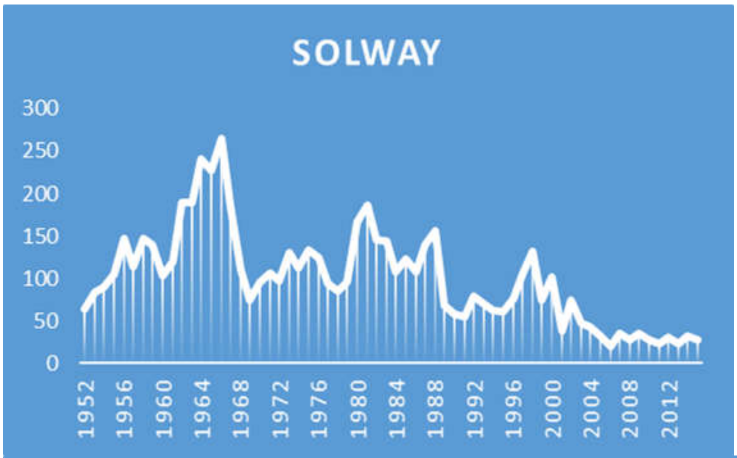
SOLWAY
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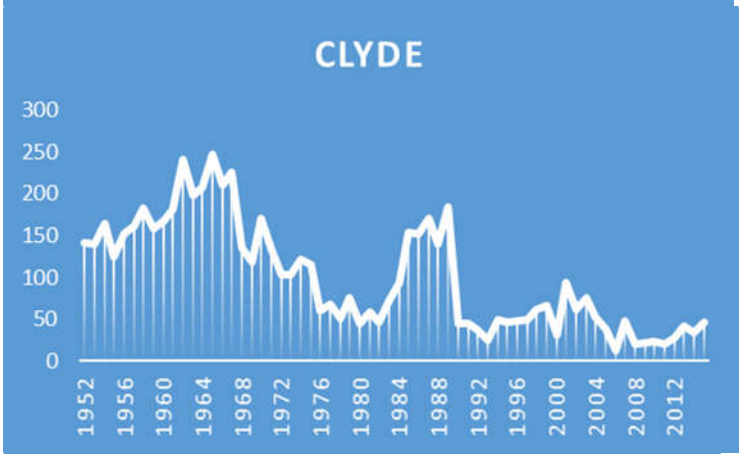
CLYDE
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200
150
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50
0
1952
1956
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1964
1968
1972
1976
1980
1984
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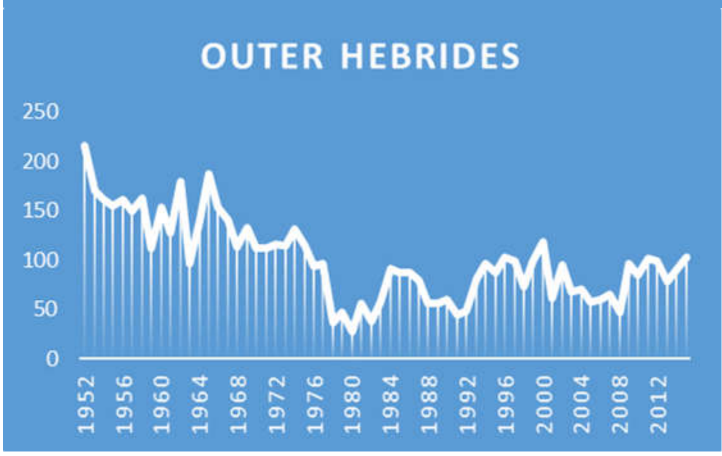
2004
2008
2012


OUTER HEBRIDES
250
200
150
100
50
0
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012

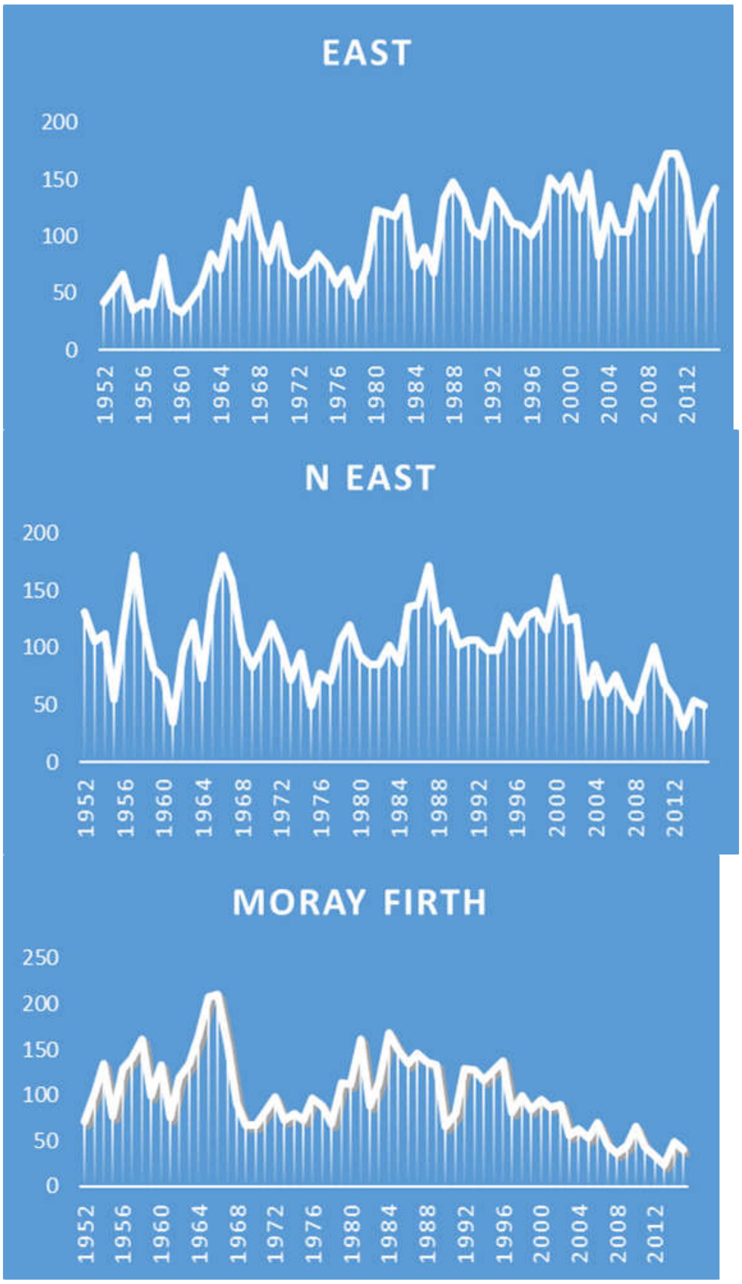


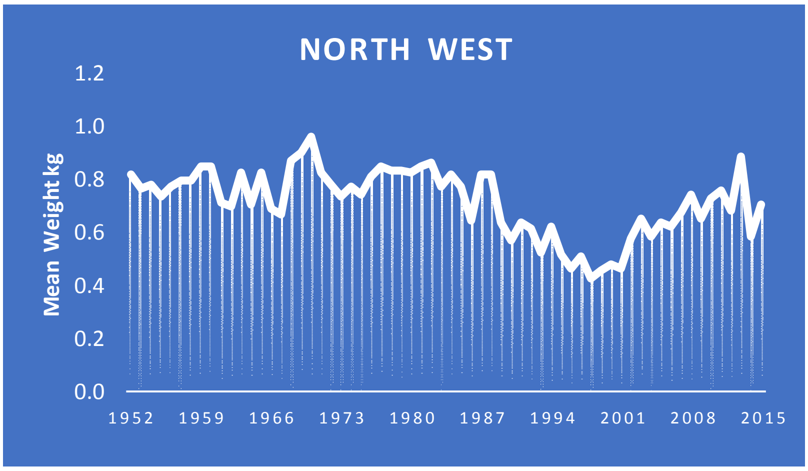
Fig. 5 a-i. Annual numbers of rod-caught sea trout (*presented as percent. deviations from the period mean catch levels*) from nine Scottish Fishery Regions and the overall Scottish R&L catches (1952-2015).

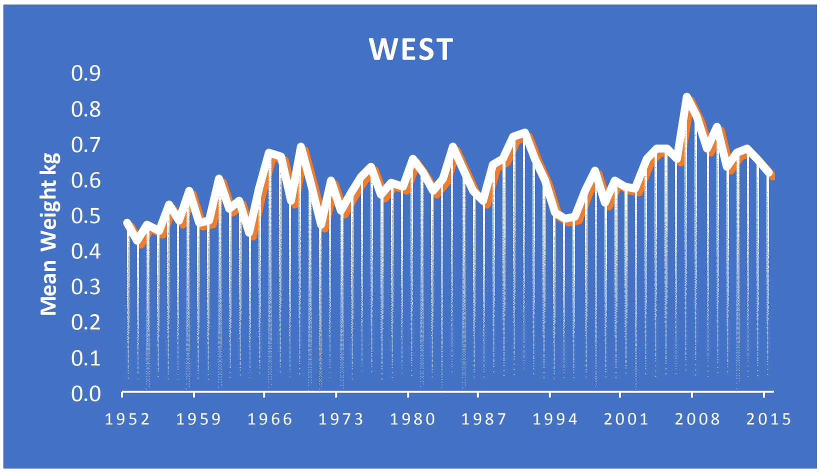
5.2 Trends in annual mean weight

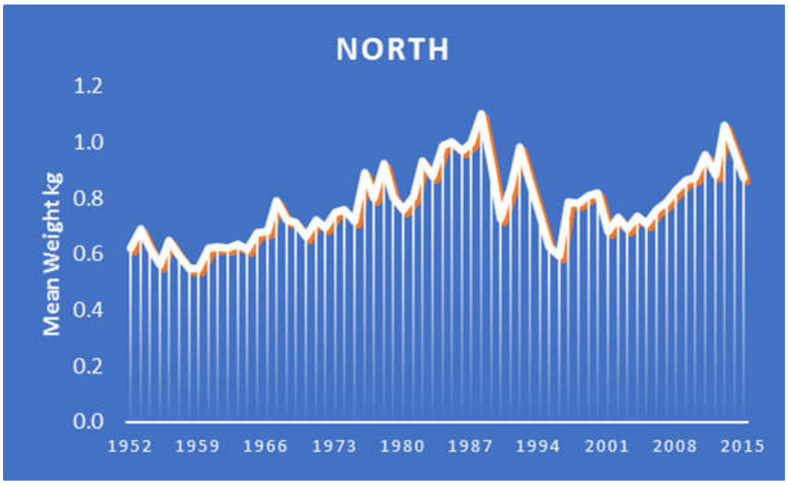
Analyses of Scottish catches of sea trout tend to concentrate on numbers and very seldom are mean weights, or weight frequency distribution, considered, even though fishery owners are required to submit monthly weight data as well as numbers. The weight data are not published graphically, but weights of catches at District Fishery level are available on request from MSS. Once again, the caveat is that the basic data submitted by fishery owners are taken as reported and their accuracy cannot be guaranteed. As with catch numbers, the annual mean weight data may have been affected by changes in angling practices.

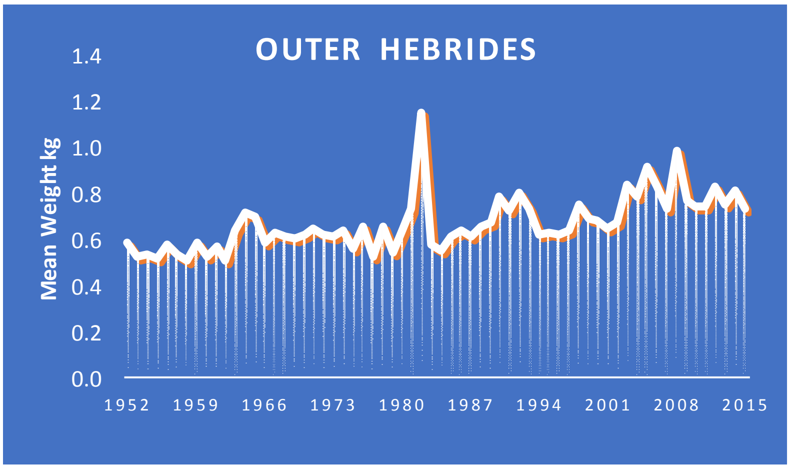
Plots of the annual reported mean weights (kg) of rod-caught sea trout (combining Retained and Released) from nine Scottish Fishery Regions from 1952 to 2015, prepared for this report, are presented below (Fig. 6 a-i). Most of the plots show quite a lot of annual variation, although some large spikes in single years may seem less likely to be correct and are unexplained.

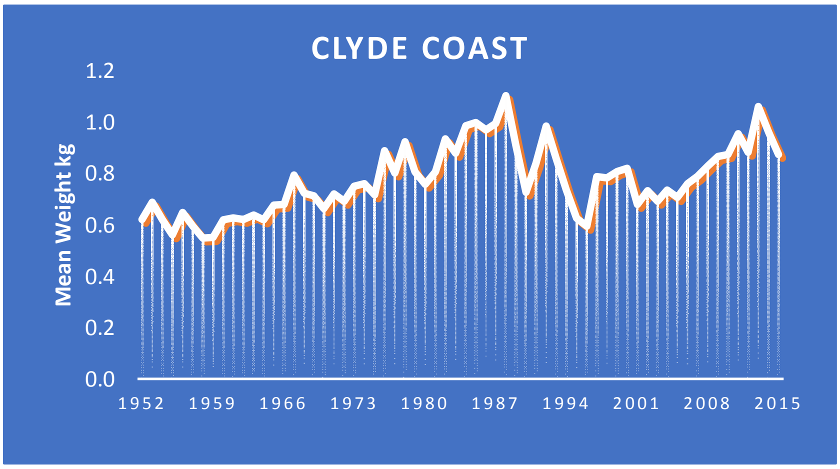
Most of the Scottish Regions show a long-term rise in annual mean weight, opposite to the long-term decline in numbers. North West Region (including R. Ewe system) shows a roughly stable pattern (c. 0.7 - 0.8 kg) from 1952 - 1988. Mean weight then falls during the next decade to less than 0.5 kg, then rises again in recent years to 0.6 - 0.8 kg. West Region, also containing areas of intensive coastal cage farming, shows a rising trend, as do Clyde, North and Outer Hebrides (apart from an unexplained one-year spike). East, North East and Moray Firth show a clearly rising trend. Solway presents a fairly consistent annual mean weight pattern. The rising trend in annual mean weight of Scottish sea trout runs counter to widespread angling experience, or biological sampling. Very few anglers believe that sea trout in most parts of the country are bigger now than they used to be. How can that be? The following section discusses some of the likely factors influencing reported catch numbers and mean weights.

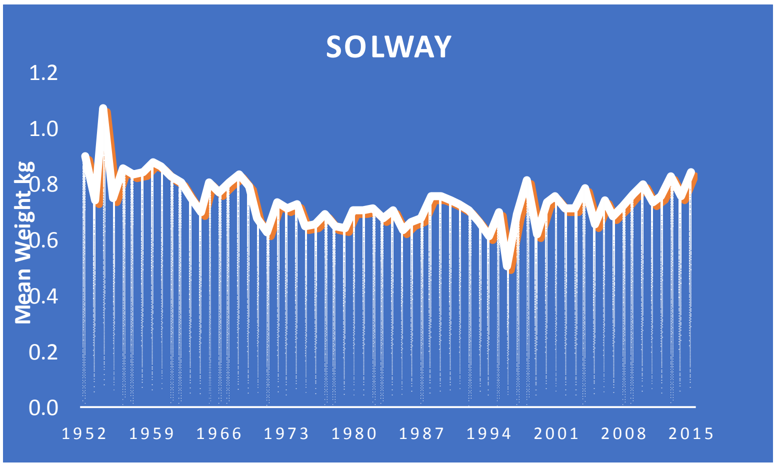

NORTH WEST
Mean Weight kg
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1952
1959
1966
1973
1980
1987
1994
2001
2008
2015

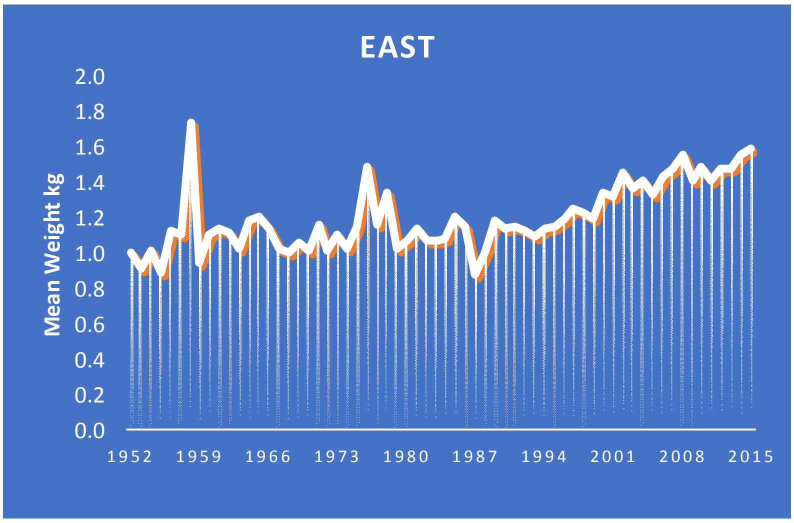

WEST
Mean Weight kg
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1952
1959
1966
1973
1980
1987
1994
2001
2008
2015

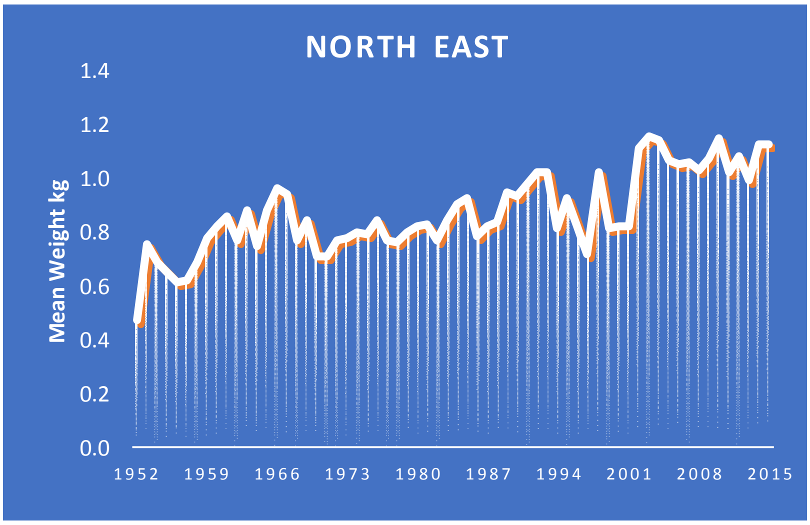

NORTH
Mean Weight kg
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1952
1959
1966
1973
1980
1987
1994
2001
2008
2015


OUTER HEBRIDES
Mean Weight kg
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1952
1959
1966
1973
1980
1987
1994
2001
2008
2015


CLYDE COAST
Mean Weight kg
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1952
1959
1966
1973
1980
1987
1994
2001
2008
2015


SOLWAY
Mean Weight kg
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1952
1959
1966
1973
1980
1987
1994
2001
2008
2015





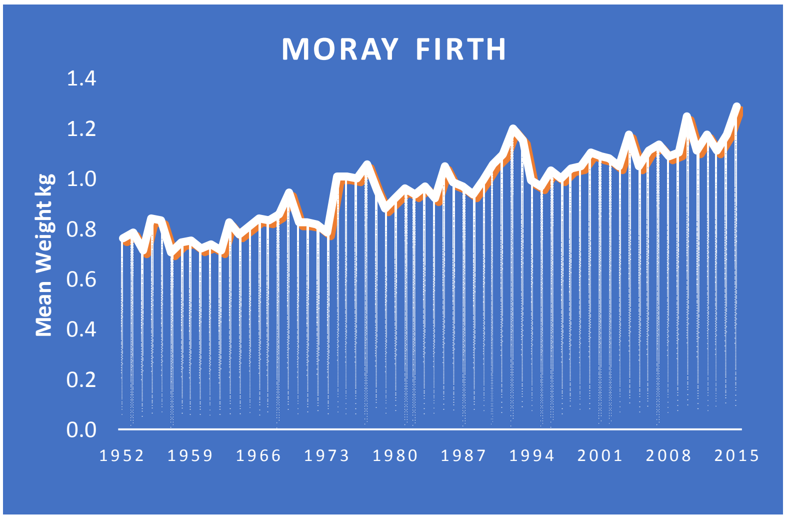


Fig 5 (a-i) Annual mean weight of Regional Scottish sea trout

5.3 Conclusions from catch analysis

Angling catches aggregated on sufficient scale are often assumed to be indicative of stock abundance, but this is not always true. With sea trout, apart from the effect of weather conditions on fishing effort and success, there is the 'finnock' problem where, in the past, some fisheries included them and others didn't. Overall reported numbers were inflated by 'finnock' even though not all of the catch data were provided. From 2004, 'Finnock' were required to be reported, but became a separate category from 'Sea Trout', therefore reducing overall numbers and inflating mean weights. Also, having the same effect, there was a gradual rise in size limits on individual angling fisheries, introduced for reasons of conservation. Then came an increasing reliance on C&R. Some, perhaps many, anglers over-estimate the size of the fish they release, whether through excitement, inexperience, or for 'bragging rights.' Some anglers are believed to have given up fishing for sea trout because of widespread adoption of C&R. A further possible factor in the rise in mean weight is the effect of the long-term decline in commercial netting, albeit mainly targeted on salmon. Less commercial netting ought to mean greater numbers of mature sea trout available for anglers to catch in areas where netting used to be a common feature. The same would be true if as seems likely there has been a decline in poaching. However, reduced netting and poaching would imply higher numbers for anglers, yet the overall national pattern shows a decline. It appears likely therefore that raising of size limits, removal of 'Finnock' from 'Sea Trout' and various effects of C&R, including a possible reduction in angling effort, have all contributed to the observed overall decline in numbers of sea trout reported landed (including those released) and the overall increase in mean weights.

5.4 Additional comments on sea trout in North Region

By 1990, it was already suspected that the sea trout problems seen in the West Highland and Islands etc, and often linked with the development of coastal salmon farming, were not happening along the northern coast of Sutherland bordering the open Atlantic and the vigorous currents of the Pentland Firth. North Region covers from Kyle of Sutherland to Hope and Grudie in the extreme west of the north coast. In or close to the latter locality lie several medium-sized rivers, famous for sea trout (and salmon), notably Dionard, Polla, Hope and Naver, which drain from the nearby mountains, moors and large lochs, mostly through estuaries and into sea lochs, a combination of habitats resembling many West Coast rivers.

To gain more information on the status of sea trout in this outer North Coast area of Sutherland (before the present Fisheries Trusts were established), sea trout catches were investigated in the Hope System during 1990-1992 (Walker, 1993). The Hope System flows into the outer end of Loch Eriboll, a sea loch containing two salmon farm sites, at Sian Bay and Kempie Bay. The Aquaculture Framework Plan of The Highland Council (Anon, 2000) states the Sian Bay site gained a 20-year lease in 1989, while the Kempie Bay site held a Pre-consultation era lease of the same length. In describing Loch Eriboll, the Aquaculture Plan notes that '*the northern aspect of which and its alignment in a NNE/SSW direction distinguish it from most other sea lochs in the Highland area. The rugged outer loch area is exposed to north and north-westerly winds and swell and is fairly open to south-west winds as well. The inner loch is less exposed, but shelter is still somewhat limited compared with many of its more southerly counterparts. This is because the high ground on the west side lies well back from the shoreline and there are few pronounced bays or headlands. Loch Eriboll is 15.5 kms long with a surface area at high water of 32.4 sq.km and an intertidal area equivalent to 4% of this. Its mean depth at low water is 26m and its maximum is 68m with the main basin lying in the narrows between Rubha Ruadh and Ard Neackie. The loch is fairly well flushed in its outer and middle reaches with no very pronounced sills. Towards the head of the loch, more limited water depth and circulation limits the practical scope for aquaculture to shellfish farming. The main input of freshwater to the loch is from the Hope catchment although there is also a significant input from the River Polla………The latest national planning guidance (October 1999) includes a precautionary presumption against further development of marine finfish farms on the north coast.*'

Once again due to excellent cooperation from fishery owners, ghillies and guests, scale samples and body measurements were obtained from 1,225 fish caught by angling in the Hope system. As in the River Ewe system, the Hope sea trout showed a slow-growing, late-maturing and long-lived life history pattern. Most had migrated first to sea as smolts after three or four winters, reached a large size by multiple marine visits and, based on 'spawning marks' in their scales, returned to spawn on multiple occasions (up to six times). The most common total age (freshwater and marine) at first spawning was 5+. Nall (1925) reported on 236 sets of scales from the Hope System, finding fewer sea age groups and not as many large fish (2-4 kg) as our later study, but this may have been due to the smaller size of his collection. However, the Hope sea trout were larger for the same sea ages (Fig. 7). The nearly parallel growth curves for the two stocks indicate that most of the difference in size probably occurred early in sea life, as there were no indications from electro-fishing studies that the Hope smolts were significantly larger than their Ewe system counterparts. Ewe sea trout reached a mean length of 245mm (fork length) at one sea-winter, whereas Hope sea trout were 308mm at the same age. Ewe sea trout took another year to reach that length. Overall, there was no indication that the marine growth level of the Hope sea trout had declined, unlike the Ewe sea trout. There were no reports at Hope of unusual fish emaciation or severe infestations of sea lice, unlike the situation in Wester Ross. It seems reasonable to speculate that the more open and agitated sea conditions along the northern coast and the rapid flushing rate of Loch Eriboll, compared with the more enclosed and sheltered location of Loch Ewe would help to moderate any environmental impacts from intensive salmon farming at local cage sites, including epizootics of sea lice.

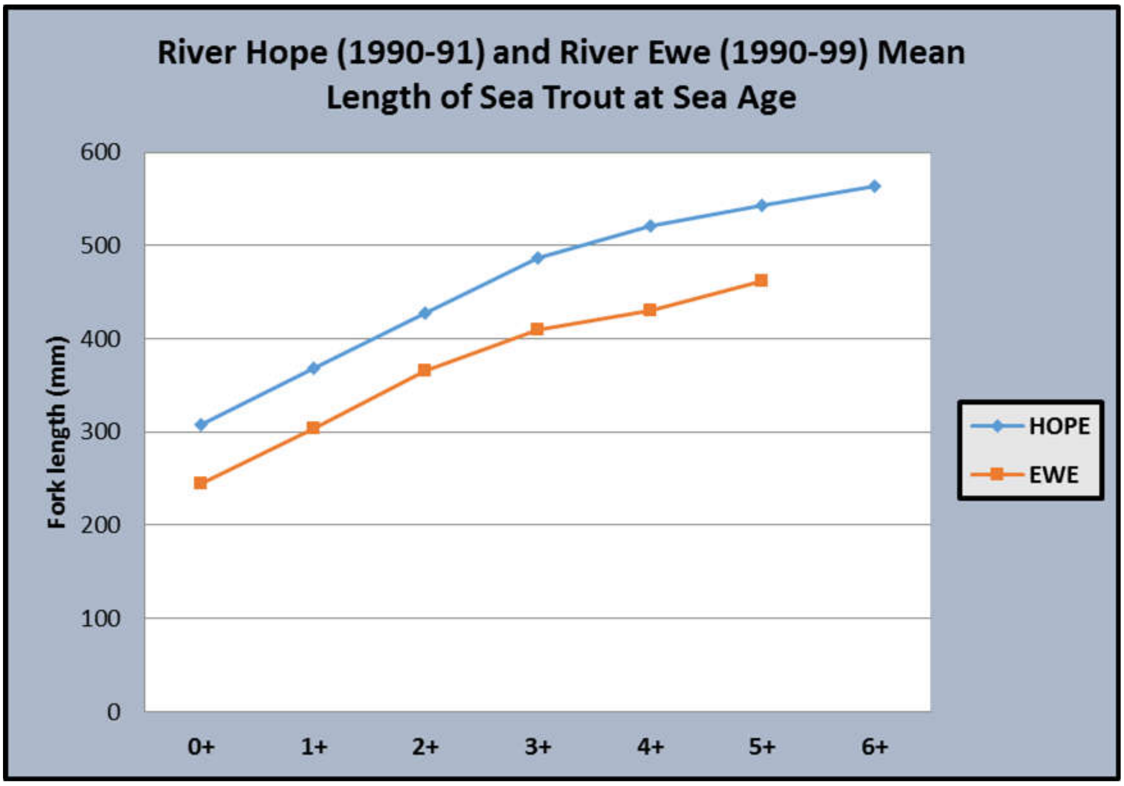


Fig.7. Mean length at sea age - Rivers Ewe (n=1163) and Hope systems (n=1225)

6.0 CATCHES OF SEA TROUT BY COMMERCIAL NETTING

The reported catches by Net and Coble and Fixed Engines have declined too, but there was also a steady fall in netting effort over the series of years. (Fig. 8 a&b). By 2015, Net and Coble and Fixed Engine fisheries contributed only 11%

and 6% of the national catch, while Rod and Line made up the remainder (83%). As with rod-caught sea trout, catches by both netting methods peaked in the 1960s, fell in the 1970s, recovered briefly around 1980, then continued to decline. The substantial fall in netting effort should benefit the national rod catches through greater escapement into the rivers. However, even with that buffering effect, angling catches of sea trout have become very poor.

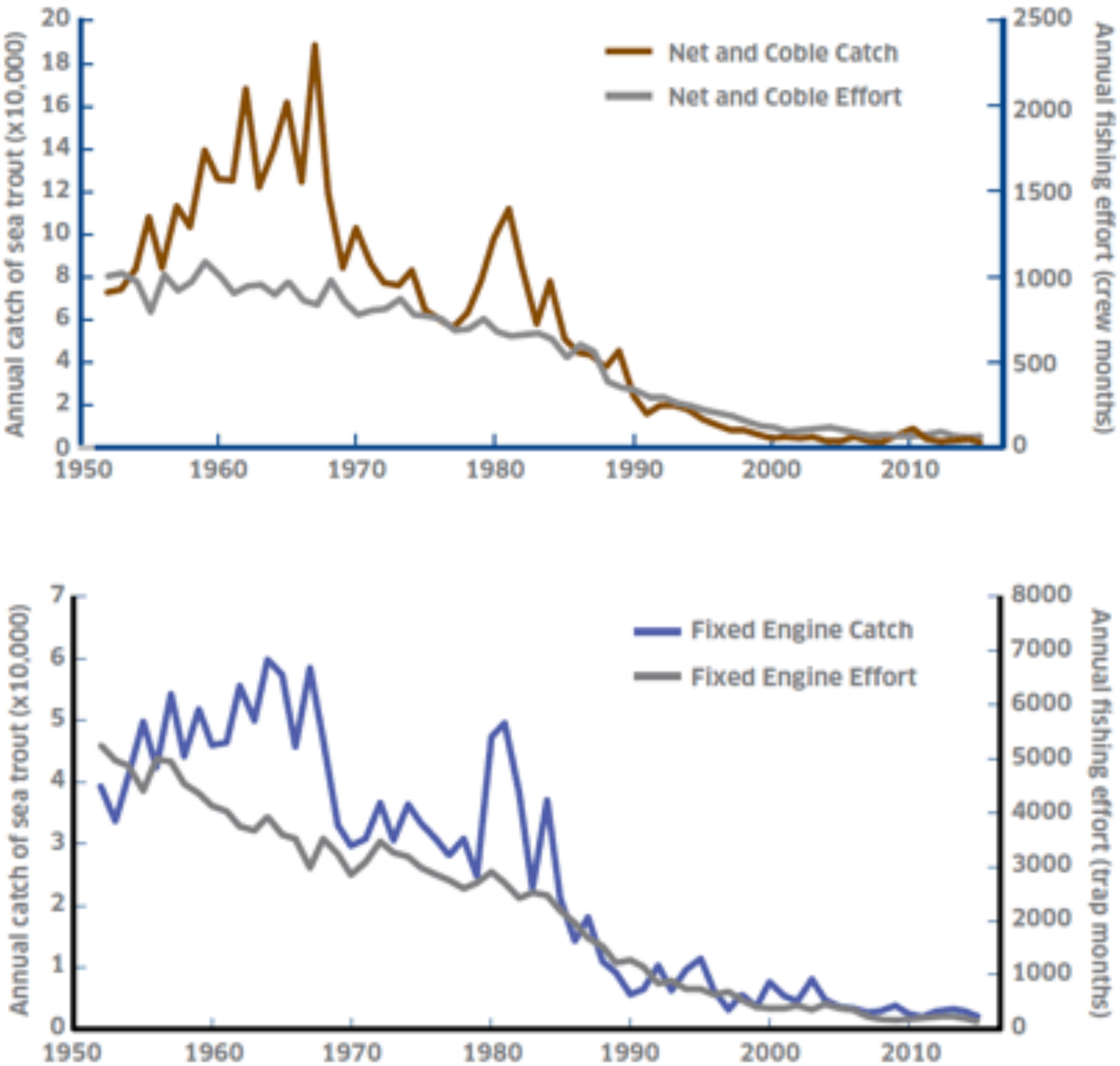


Fig. 8 (a&b). All Scotland sea trout catches and netting effort (1952-2015)

7.0 SYNCHRONOUS COLLAPSE IN WESTERN IRELAND

Scotland lacks detailed knowledge of sea trout population dynamics and stock status, much more research attention having been paid to salmon, especially in the more productive rivers of the East Coast and Solway, also through sampling opportunities provided over many years by the salmon netting industry. Facing the decline in the North-West, the Report and Action Plan of the broadly-based West Highland Sea Trout and Salmon Group (Anon 1995) described a need for two-way research traps and counters in West Highland rivers, in combination with marking and tagging studies. This was to provide a direct measure of migratory fish stock levels, while recognising that there were many practical and logistical difficulties, especially where research traps are operated in spate rivers.

Traps, however, were already in use in the West of Ireland, on the Burrishoole System by Newport and the River Erriff in County Mayo (Mills *et al*, 1990; Gargan *et al*, 2000) and the research there in both rivers showed a similar serious problem of acute decline of sea trout stocks, synchronous with the Scottish picture. Trapping results at Burrishoole showed an earlier period of slow decline, attributed largely to poaching with fine monofilament nets and a range of environmental problems, including drastic drainage schemes, commercial conifer afforestation and severe hillside erosion due to overgrazing by sheep. Beginning in 1986, there came a more serious decline in both sea trout runs and angling catches, followed by a widespread stock collapse in 1989, which critically affected most mid-western Irish rod fisheries (Whelan and Poole, 1996; Poole *et al*., 1996; Gargan *et al*, 2016).

A main feature of the Irish accounts at that time was an unusually early return of large numbers of sea lice-infested post-smolt sea trout soon after sea entry. Accusations began to circulate in the Irish press about impacts of lice from salmon farming. Sea lice, especially the salmon louse, *Lepophtheirus salmonis*, or 'Leps,' were already known to be a scourge of intensive coastal salmon farming. The first outbreaks of salmon lice infestation occurred on Norwegian Atlantic salmon farms during the 1960s, soon after cage culture began (Pike & Wadsworth 1999). Similar outbreaks occurred in Scottish salmon farms from the mid-1970s (Pike & Wadsworth 1999). Prior to then, there were no records of similar lice problems in all three countries. Angling books often mentioned migratory fish 'covered with lice,' but on enquiry these were larger fish returning with moderate numbers of mobile lice stages, not post-smolts stricken by epizootic levels of very small infective copepodid stages. The lice were regarded simply as a sign of 'freshness' of return to fresh water.

Soon scientific reports, papers and controversy began to mount on the possible causes of lice epizootics off the west coast of Ireland (e.g. Tully and Whelan, 1993 a&b; Tully et al,1993 a&b). In 1991 the Irish Department of the Marine established a Sea Trout Working Group (Anon, 1991, 1992, 1993, 1994), which defined their 'sea trout problem' as the following:

- Early return of smolts
- Severe infestations of juvenile stages of lice (*L. salmonis*)
- Presence of larger badly emaciated fish
- Severe reduction in spawning stock, across all age classes
- The 'sea trout problem' was only observed in areas adjacent to intensive salmon farming

(Source: http://www.atlanticsalmontrust.org/policies-and-research/a-historical-view-of-the-collapse-of-sea-trout-stocks.html)

8.0 HEALTH STATUS OF SEA TROUT

In Scotland, fish disease and parasite specialists from the Marine Laboratory and the University of Aberdeen, working in collaboration with the Freshwater Laboratory, were sampling at the same time to consider whether disease and/or parasites had contributed to the Scottish decline in wild stocks. At a one-day conference, held in November 1993 at Drumossie and published in the Atlantic Salmon Trust Blue Book series ('Problems with Sea Trout and Salmon in the Western Highlands'), McVicar *et al*. (1993) reported:

- There was insufficient evidence that infectious disease was the cause of the decline and no evidence of a change in pathogenicity of an already existing disease.
- No internal parasites had been implicated.
- The possibility of a chronic disease such as IPN, furunculosis and lice infestation, causing debilitation of individual fish at sea and increased predation or death, should not be ignored.

- Higher levels of infestation with sea lice (*Lepeophtheirus salmonis*) had been shown to occur in west Scottish stocks of sea trout compared to east/north stocks.
- As in western Ireland, this pattern of infestation coincided with the main distribution of salmon farms.

These were interesting findings, but there were caveats that 'The lower levels of lice levels recorded, the scarcity of early returning sea trout smolts and lesser severity of lesions in Scotland compared with Ireland does not correlate with the relative sizes of the salmon farming industries (several times larger in Scotland) or with the severity of lice problems in each area; a significant proportion of the Irish farmed salmon production is from offshore cages with less lice problems.' McVicar *et al.* (1993) requested more research on the biology of sea trout in the period immediately after sea-entry, on the pattern of accumulation of sea lice infection and on the effect of different levels of lice infestation on the survival and behaviour of individual fish. Survival of sea trout at a population level was not mentioned, nor were sea lice levels on salmon farms, or that farmed fish could be an important new source of lice infection for wild migratory salmonid fish populations.

As one of the authors of that paper, my experience in north-west Scotland at that time was of many stressed post-smolts with skin lesions, darkened skin patches and fin erosion, 'flashing' with unusual darting and jumping behaviour. Others were listless, weak and apparently moribund. When post-smolts were sampled in saltwater, or had recently returned to fresh water from the sea, these indications of stress usually were associated with large infestations of juvenile sea lice. In this condition, many post-smolts probably succumbed unseen to predation by larger fish, birds and seals. These observations were consistent with the reports and papers coming from the Irish research trapping (Tully and Whelan, 1993 a&b; Tully *et al*, 1993 a&b; Whelan, 1993) and Norwegian studies (Finstad *et al*, 1994). Although we had no access to salmon farming lice data, we knew the industry had serious problems in managing sea lice, yet the numbers of wild fish potential hosts by then were limited.

Two years later, the Annual Review of the Freshwater Fisheries Laboratory for 1994-1995 (Anon, 1996) reported that '*several factors are likely to have contributed to the decline [of sea trout in the western Highlands], but heavy infestations of the salmon louse, Lepeophtheirus salmonis,…..in conjunction with unusual climatic conditions, may be of particular significance.'* Also, that *'the sea louse problem may be linked to intensive salmon culture.*'

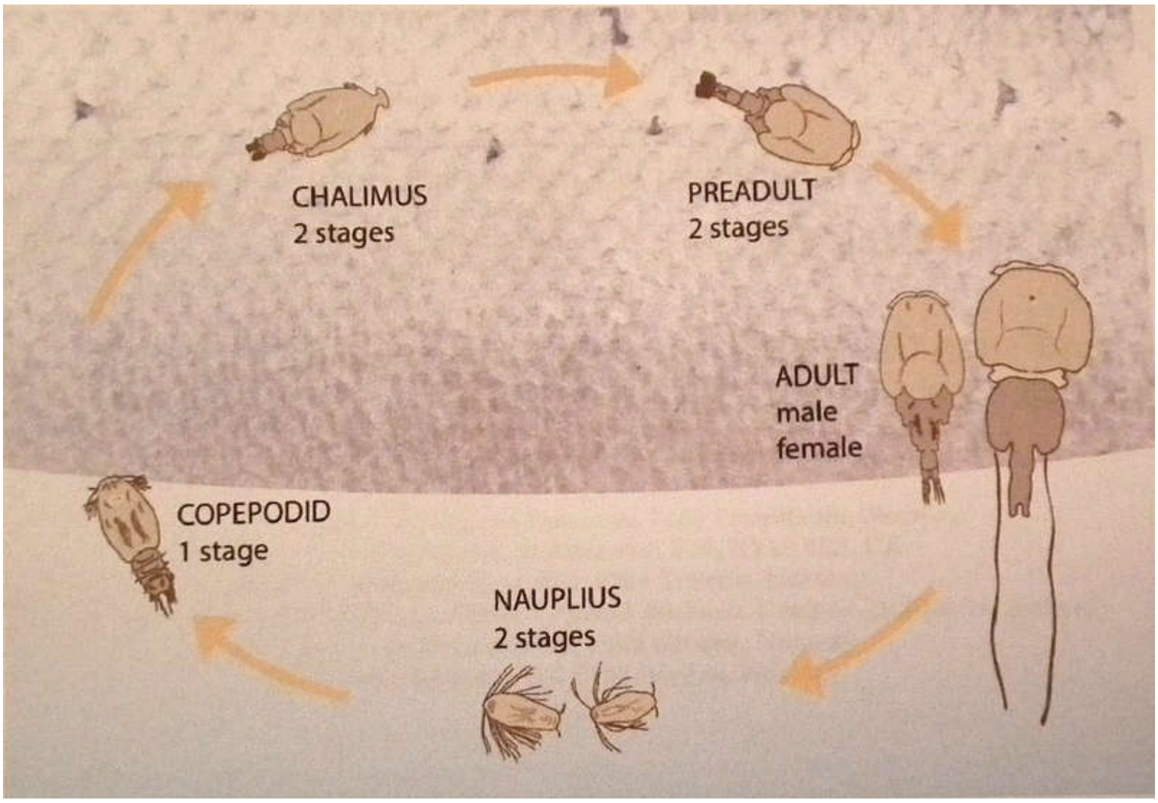


Plate I. Five phases of salmon louse lifecycle (not shown to size)
Adults 5-6mm males, 8-12mm females (after Thorstad *et al.*, 2015)

9.0 FURTHER RESEARCH

We continued to seek opportunities to develop further sea trout research in the West Highland region. A concept paper (Walker, 1994) promoted the idea of Area Fisheries Trusts with biological support in the West Highlands and the need for one of more traps to be installed there to monitor any attempts to restore sea trout populations. After publication of the Report and Action Plan of the WHST&SG, an initial five Trusts were formed. An Association of West Coast Fisheries Trusts was then established and gave unqualified support to our setting up of a widely-funded research trap in 1999 on the River Shieldaig in Wester Ross. This would be used as a model for monitoring sea trout population dynamics and restoration research in north-west Scotland. Previous work had shown that the Shieldaig was one of our smaller rivers whose sea trout stock had collapsed (Walker *et al.*, 1998). Seasonal sampling of post-smolt sea trout there and elsewhere continued apace (Northcott and Walker, 1996) then, linked with this, acoustic transmitting tag trials in the sea, first at Loch Ewe (Johnstone *et al.,* 1995*)* and later at Shieldaig (unpublished), using hand-held hydrophones and inflatable rubber boats. At both sites, the recent entrant to seawater fish remained mostly inshore, spending a lot of time in the seaweed (*Fucus*) zone, until flushed out by receding tides. Interactions with predatory species were observed, most obviously common seals (*Phoca vitulina*) which hunted close to the river mouth and in the estuary, as well as along the seaweed beds, where the post-smolts tended to be when the tides raised the water level. Collaborative research, including tracking studies, on seals was also begun with the Sea Mammals Research Unit at the University of St Andrews.

At Shieldaig, some conventionally tagged post-smolts were sampled back in fresh water bearing heavy louse infestations (mainly chalimus stage) after only a few days at sea. This finding prompted us to begin sampling for sea lice infective stages in the inter-tidal zone around the mouth of the River Shieldaig, using towed plankton nets. When this was found successful, we set up a regular plankton monitoring programme, and this began to unravel some of the complexities of the early lice infestations on post-smolt sea trout (and salmon) and their relationship with salmon farming. An internal report describing this innovative and fundamentally important research, '*The primary location of infection of sea trout, Salmo trutta L., post-smolts by sea lice, Lepeophtheirus salmonis (Krøyer), in a Scottish sea loch*' (Northcott *et al.* 2001*)*, was rejected for publication by our Directorate. As well as demonstrating the early plankton work, the paper confirmed the high level of sea lice infection pressure (mainly chalimus I and II) on 'prematurely' returning juvenile sea trout in the lower River Shieldaig during May 1999 (Table 1. reproduced below). The paper's Abstract stated '*Sea trout post-smolts were found to return to fresh water, shortly after they had descended to sea, with very high levels of infection with juvenile sea lice (up to 1059). In view of the low level of return of wild sea trout to the monitored river, and the absence of wild salmon, it seems likely that the source of the larval sea lice was the large number of farmed salmon in the sea loch at that time.*' 'Absence of wild salmon' requires clarification; two neighbouring small rivers, the Balgay and Torridon, held wild salmon, but they would be expected to be very scarce or absent in the Loch Torridon area in late spring, at the time of sea trout smolt migration. We searched for and found no evidence of lice overwintering as eggs, so the high levels of infective stages acquired by post-smolt sea trout so rapidly after first sea entry had to come from another nearby source. Local salmon farming was an obvious prime candidate for investigation.

Table 1. Details of prematurely returning juvenile sea trout captured in the lower River Shieldaig showing the level of infection with sea lice (mainly chalimus I and II). (NK = not known; NR = not readable).

Fish no.	Date captured	Max. no. days at sea	Length (mm)	Sex	Age (scale reading)	Total sea lice present
1	11/5/99	NK	142	M	2+	214
2	11/5/99	NK	146	M	2+	680
3	11/5/99	NK	218	M	4+	560
4	11/5/99	NK	275	M	3+	258
5	11/5/99	NK	286	F	3.0+	0
6	11/5/99	NK	295	F	3.1+	1059
7	14/5/99	NK	153	F	2.0+	176
8	14/5/99	NK	154	F	2.0+	180
9	14/5/99	NK	132	F	2.0+	13
10	14/5/99	NK	153	F	2.0+	236
11	14/5/99	NK	167	F	3+	129
12	26/5/99	NK	183	F	4.0+	368
13	27/5/99	14	158	F	2.0+	0
14	27/5/99	5	178	F	3+	20
15	27/5/99	14	151	M	2+	0
16	27/5/99	13	140	F	2.0+	544
17	27/5/99	NK	192	F	NR	425
18	27/5/99	5	205	F	3+	436
19	27/5/99	14	154	F	2+	0
20	27/5/99	15	201	F	3+	977
21	27/5/99	15	199	M	NR	30

Eventually, however, with further fish trapping and zooplankton sampling and farm lice data at last becoming available through a system of Area Management Agreements, colleagues were able to confirm an off/on pattern of infection via copepodid lice in the plankton and relate this to the year of production on the local salmon farms in Loch Torridon, i.e. higher infection pressure in the second year compared with low levels during the first year of production when the cages were stocked with salmon smolts and consequently ovigerous lice were absent in spring and early summer (McKibbon and Hay, 2004). The same two-year oscillation of lice infection was shown on early-returning post-smolt sea trout and strongly indicating that ovigerous lice levels on the local salmon farms were indeed a threat to the wild sea trout stock (Hatton-Ellis *et al.*, 2006; Middlemas *et al.*, 2010). Biologists from the Shieldaig Station continue to work closely with local wild fishery proprietors and fish farming companies through the Torridon Area Management Agreement Group to help ensure that the health and survival of wild fish are maximized (Shieldaig 2009 - a booklet created by volunteers from the local community). Further tracking of sea trout post-smolts was carried out by means of a series of acoustic receivers positioned strategically throughout Loch Shieldaig and Upper Loch Torridon. This work confirmed that during their first 50 days at sea, the post-smolts spent much of their time around the shoreline near the mouths of their parent rivers (Middlemas *et al.*, 2009), then Middlemas *et al.*, 2013 published further important studies on the relationship between sea lice levels on sea trout and fish farm activity in western Scotland.

10.0 SEA LICE PATHOGENICITY

Research on the physiological impacts of sea lice on early post-smolt and larger sea trout, especially their seawater tolerance at differing lice levels and stages have provided further insights into the differences in fish pathology and mortality between normal background and enhanced levels of lice infection (Pike and Wadsworth, 1999; Bjørn and Finstad, 1997; Dawson *et al.*, 1998; Wells *et al.,* 2007). Anadromous fishes such as sea trout experience a physiologically challenging environmental shift when migrating from freshwater to seawater. In seawater, water is lost from the fish by osmosis, whereas salts tend to be gained. The fish gradually become dehydrated if they do not compensate, which most fishes, including sea trout, achieve by drinking seawater and actively excreting the excess salts through the gills and kidneys. The mechanical damage of the skin, mucus surfaces and dermal tissue caused by salmon lice impairs the barrier between the fish body and seawater, and results in increased leakage of water from the fish and thereby an osmotic and ionic imbalance (Bjørn & Finstad 1997). In laboratory studies, copepodids tend to show an attachment preference for gills and fins, and especially the dorsal fin. Whilst the attached copepodid typically do not cause visible tissue damage at initial attachment, the damage to host tissues caused by the (sessile) chalimus stages is obvious but usually relatively minor, except in dorsal fin areas where damage can be severe for heavily infested fish. The most severe tissue damage arises from the feeding of the mobile preadult and adult stages. It has been shown in laboratory studies that 0.04–0.15 lice per gram fish weight can increase stress levels. Laboratory studies have also demonstrated that infections of 0.75 lice per gram fish weight, or approximately eleven sea lice per fish, can kill a recently emigrated wild salmon smolt of about 15 g if all the sea lice develop into pre-adult and adult stages. These studies indicating a critical level of lice infection confirmed our concerns based on field observations of sick post-smolt sea trout at Shieldaig, the River Ewe and various other parts of the West Coast visited for sampling purposes.

Yet, laboratory studies only reveal part of the story. Predator/prey interactions show that sick and moribund small fish and other animals do not survive for long in the wild. Describing habitat use and dispersal of post-smolt sea trout *Salmo trutta* in the Torridon sea loch system, Middlemas (2009) states *'any management of predators or other mortality agents should be targeted towards mouths of rivers during and immediately following smolt emigration.'* Also, from NASCO, '*While laboratory estimates of lethal loads [of sea lice] and physiological responses are attractive to predict impacts on wild populations, this is likely an over-simplified view because natural ecological processes such as predation and competition will probably remove infected fish before lice kill the fish directly. Early marine growth is important for smolts to enable them to reduce the risk of predation and to allow access to more diverse prey fields……reduced growth rates will affect fish under resource-limited or parasitized conditions'* (ICES Report to NASCO 2016).

11.0 MULTI-DISCIPLINARY APPROACH TO SEA LICE RESEARCH

In 2010, Marine Scotland stated **(TOPIC SHEET** no. 52 v1) that '*In terms of sea lice, Loch Torridon is one of the most intensively and extensively researched areas in the world.'*......and……'*The increasingly serious effects of sea lice infections on the welfare of farmed salmon and the possible association between sea lice and the decline in sea trout populations in western Scotland has motivated the development of a multi-disciplinary sea lice research programme …. using all the areas of expertise within the directorate.'* Informing also that '*Research is expanding to include Loch Linnhe where development of a sea lice dispersal model has been initiated alongside tagging and acoustic tracking of sea trout and migrating salmon smolts'.* It provided the following bullet points:

• Modelling sea lice dispersal has the potential to reduce sea lice infections/re-infections on farms, and associated risks to wild fish, through improving delimitations of management areas and siting of farms within these areas.

• The more complex situation in Loch Linnhe with respect to environment and aquaculture, compared to that of Loch Torridon, will allow better testing of the model's ability to accommodate environmental conditions and to identify farm/farm interactions, firebreaks, and infection gradients with respect to sea lice dispersal.

• Overlapping of sea lice dispersal predicted by the model, and the movements of tagged wild salmonids will allow risk of interaction to be better assessed.'
(http://www.gov.scot/Topics/marine/Salmon-Trout-Coarse/Freshwater/Research/Aqint/troutandlice)

Also, see Middlemas, S. J. (2010). Temporal and spatial patterns of sea lice levels on sea trout in western Scotland in relation to fish farm production cycles. [*Biol Lett 6:548-51. 2010].* '*The relationship between aquaculture and infestations of sea lice on sea trout, Salmo trutta L., is controversial. Here, the association between sea lice infestations on wild sea trout and characteristics of local Atlantic salmon, Salmo salar L., farms were investigated using data collected on the Scottish west coast. The proportion of sea trout with louse burdens above a critical level was positively related to the fork length of the sea trout and the mean weight of salmon on the nearest fish farm, and negatively related to the distance to that farm. The distance to the nearest fish farm did not influence the probability of infestations above the critical level beyond 31 km although there was considerable uncertainty around this cut-off distance (95% limits: 13–149 km). The results support a link between Atlantic salmon farms and sea lice burdens on sea trout in the west of Scotland and provide the type of information required for marine spatial planning.*'

More recently, there have been several reviews and further examinations of internationally published studies of sea lice interactions with wild and farmed salmonid fish (e.g. Whelan, 2010; Costello, 2009; Revie *et al.*, 2002; Salama and Raba, 2013; Thorstad *et al.*, 2015; Shephard *et al.*, 2016). Thorstad *et al.* (2015) concluded that '*in farm-intensive areas, lice levels on wild sea trout are typically higher, and more variable than in farm-free areas. Lice on wild sea trout are found at elevated levels particularly within 30 km of the nearest farms but can also extend to further ranges. Salmon lice in intensively farmed areas have negatively impacted wild sea trout populations by reducing growth and* *increasing marine mortality. Reduced growth and increased mortality will reduce the benefits of marine migration for sea trout, and may also result in selection against anadromy in areas with high lice levels. Salmon lice-induced effects on sea trout populations may also extend to altered genetic composition and reduced diversity, and possibly to the local loss of sea trout, and establishment of exclusively freshwater resident populations.'* Based on studies of >20,000 sea trout sampled from 94 separate river and lake systems in Ireland and Scotland at varying distances from marine salmon farms, Shephard *et al* (2016) modelled the potential effects of distance to a salmon farm, rainfall and ambient temperature on sea trout lice infestation and body condition (weight at length). Their results indicate that sea trout captured closer to salmon farms had significantly higher levels of lice infestation, and that this effect was exacerbated in warmer years. Sea trout sampled closer to salmon farms also had significantly reduced weight at length (impaired condition), with the strongest impact in dry years. All these results indicate a need to be very careful in choosing sites for salmon farming in relation to damaging effects on wild sea trout populations. By implication, especially since the climate is warming, salmon farms shown to be too close to these populations and failing to control sea lice on the farmed fish to consistently extremely low levels should be moved to less damaging locations.

12.0 SCOTTISH PRODUCTION OF FARMED ATLANTIC SALMON

Salmon farming has grown exponentially and, especially in remote areas, governments support the continued growth of this relatively new industry for the economic and social benefits that result. With Scotland currently providing 94% of farmed salmon production in the EU, and large amounts exported, farmed salmon is now our main food export. In 2014, in the North Atlantic, salmon farming production exceeded the nominal catch of wild salmon by more than 1900 times (NASCO 2016). Scotland produced over 180,000 tonnes of farmed salmon in 2014 (Fig. 9) and the industry, which is largely Norwegian-owned, targets 210,000 tonnes by 2020 (Scottish Salmon Producers Organisation, 2016). At present, almost all this production takes place in sheltered sea lochs along the North-West coast, the Hebrides and Northern Isles. With continuing intensification of production in these semi-enclosed areas have come mounting accusations of environmental damage. It is now accepted internationally that farming salmon in mesh cages floating in coastal bays and sea lochs, or fjords, carries a threat to wild sea trout and salmon from elevated sea louse burdens and novel infectious diseases and it leaves a further environmental 'footprint' on the sea bed through the 'rain' and build-up of excess feed and faeces, although the extent of ecological damage must vary with local marine exposure and currents, salinities and water temperature regimes.

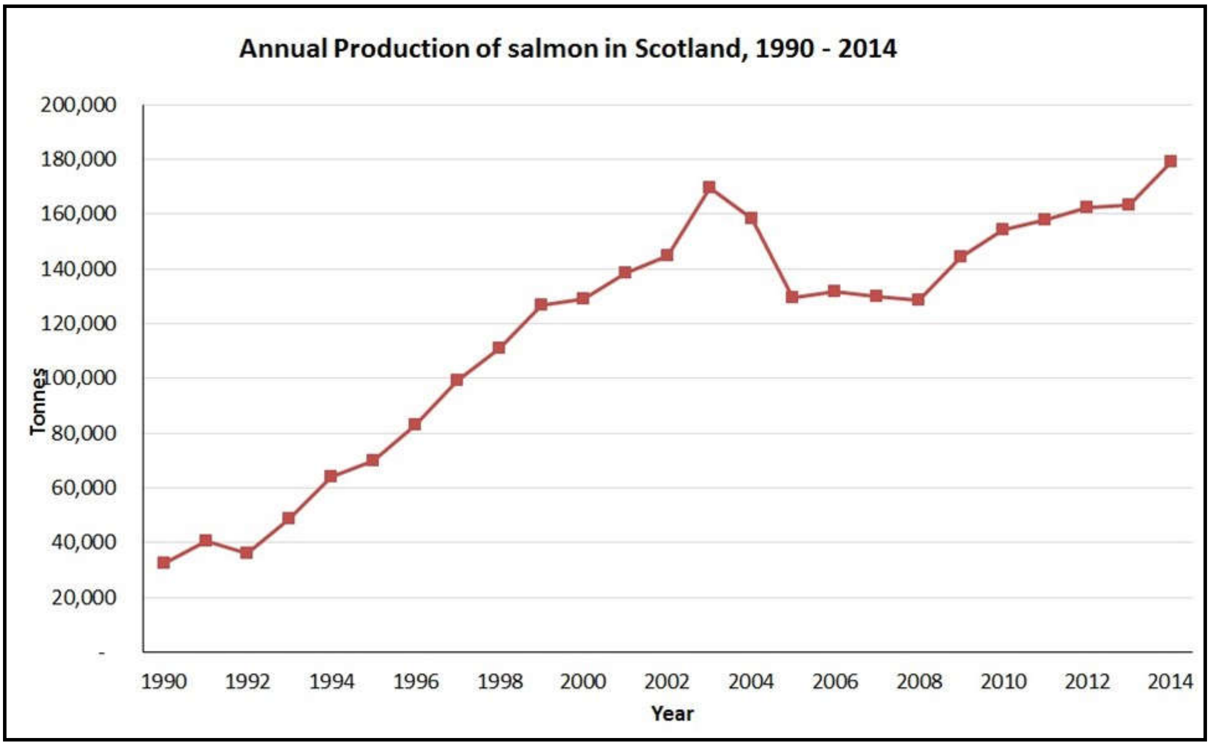


Fig. 9. Annual production of farmed salmon in Scotland (1990-2014)

13.0 ANNUAL MEETING OF NASCO (2016)

In contrast to the burgeoning growth of farmed salmon production, the Annual Meeting of The North Atlantic Salmon Conservation Organisation (NASCO), held in Bad Neuenahr, Germany in June 2016, took place against a background of continuing low, and in some areas, critically low abundance of wild salmon throughout the North Atlantic and the need for urgent action to understand the causal factors *(*NASCO, 2016*).* As well as a full account of the status of salmon in the member countries, a day was devoted to a discussion of impacts of marine aquaculture (mainly salmon farming) on wild salmonid populations.

Since the late 1980s, there has been developing controversy over the potential impacts of salmon farming on wild salmonid fish species (e.g. Ford and Myers, 2008). Wild salmon catch and abundance have declined dramatically in the North Atlantic and in much of the north-eastern Pacific south of Alaska. In these areas, there has been a concomitant increase in the production of farmed salmon. Previous studies have shown negative impacts on wild salmonids, but these results have been difficult to translate into predictions of change in wild population survival and abundance. Ford and Myers (2008) compared marine survival of salmonids in areas with salmon farming to adjacent areas without farms in Scotland, Ireland, Atlantic Canada, and Pacific Canada to estimate changes in marine survival concurrent with the growth of salmon aquaculture. Through a meta-analysis of existing data, they showed a reduction in survival or abundance of Atlantic salmon; sea trout; and pink, chum, and coho salmon in association with increased production of farmed salmon. In many cases, these reductions in survival or abundance were greater than 50%. Meta-analytic estimates of the mean effect were significant and negative, suggesting that salmon farming has reduced survival of wild salmon and sea trout in many populations and countries.

Prior to the annual meetings, NASCO receives the best available scientific advice from the International Council for the Exploration of the Sea (ICES). In relation to marine aquaculture, ICES advised in spring 2016 (http://www.nasco.int/pdf/2016%20papers/CNL_16_9_ICES_Advice.pdf) that monitoring programmes had been implemented in several countries to assess lice levels to inform management decisions. Given the difficulties of sampling out-migrating wild salmon smolts, sea trout could be used as a proxy for potential levels on salmon. In Norway, lice infection on wild salmonid populations is being estimated through a national monitoring programme (Serra-Llinares et al., 2014; Taranger et al., 2015). The aim of the lice monitoring programme is to evaluate the effectiveness and consequences of zone regulations in national salmon fjords (areas where salmon farming is prohibited), as well as the Norwegian '*strategy for an environmentally sustainable growth of aquaculture*'. Monitoring is carried out during the salmon smolt migration and in summer to estimate lice levels on sea trout and Arctic charr. ICES commented that '*The risk for sea trout (and Arctic charr in the Northern regions) is higher compared with Atlantic salmon post-smolts and the results show moderate-to-high risk of lice-related mortality on sea trout in most counties with high salmon farming activity*.'

The scientific advice from ICES also reviewed estimates of population-level impacts of lice infestation in Atlantic salmon post-smolts from a series of long-term studies in Ireland and Norway. These studies involved paired releases of post-smolt salmon treated or not treated (controls) against sea lice effects in their first few weeks at sea (Jackson *et al*., 2013; Gargan *et al*., 2012; Skilbrei *et al*., 2013; Krkošek *et al*., 2013; Vollset *et al*., 2014). In each country, despite the short period of protection afforded by treatment, the trials revealed higher survival of the treated groups. However, significant spatial and temporal variability was shown by the recapture levels and the resulting estimates of marine survival were open to different interpretations. Thorstad *et al*. (2015) argued that mortality attributable to salmon lice can lead to an average of 12-29% fewer salmon spawners. A meta-analysis of Norwegian data (Vollset et al., 2015) based on 118 release groups (3,989 recaptures out of 657,624 released), reported an intermediate odds ratio of 1.18:1 (95% CI: 1.07–1.30), that is a mean increase of 18% also in favour of the treated fish. Survival of Atlantic salmon during their marine phase has fallen in recent decades, evident over a broad geographical area, and associated with large-scale oceanographic changes. For monitored stocks around the North Atlantic, current estimates of marine survival are at historically low levels, with typically fewer than 5% of smolts returning to their home rivers for most wild stocks (ICES, 2015). Vollset *et al*. (2015) concluded that much of the variation among the paired treatment trials could be explained by release location, experimental time period and baseline marine survival. When marine survival was low (few recaptures from the control group), the effect of treatment was relatively high (odds ratio of 1.7:1). However, when marine survival was high, the effect of treatment was undetectable (odds ratio of ~1:1). Vollset *et al*. (2015) concluded that, although their study supported the hypothesis that lice contributed to the mortality of salmon, the effect was inconsistent and strongly modulated by other risk factors and that population-level effects of lice on wild salmon stocks could not be estimated independently of the other factors that affect marine survival. Earlier in this report, I mention that causes of increasing post-smolt mortality at sea may be additive and circular in effect; e.g. louse infection and/or disease increase the likelihood of predation, while rising water temperatures reduce lice generation times and increase overall lice infection pressure, thus risk of disease.

Both ICES and the NASCO conference concentrated on Atlantic salmon, but each acknowledged that sea trout populations are likely to be more susceptible than salmon to mortality from heavy lice infestation. In a Scottish context, salmon smolts leaving north-western rivers head out quickly to the open sea and, unless they move down fjordic sea lochs containing cage farms, will have less chance of exposure to high lice infestations than north-western Scottish sea trout, which can remain in sea lochs for several months, or more. If these sea lochs contain active salmon farms with a continuing lice problem, especially during second years of farmed production, sea trout remaining in sea lochs for extended periods have a potentially much longer period of maximum risk of exposure to elevated lice infestation pressure than juvenile salmon will experience in the open ocean.

At the NASCO meeting, the Scottish Government, via MSS, endorsed NASCO's goals of minimising any potential impacts of aquaculture on wild salmon (also sea trout), adding '*It is the aim of the Scottish Government and the Scottish aquaculture industry to reduce interactions of aquaculture with wild fish by lessening incidences of escapes and managing sea lice to the lowest achievable level.*' They outlined a continuing commitment to research to address the issue of sea lice management in Scotland, including lice dispersal monitoring. Together with industry, they will review the boundaries of Farm Management Areas 'to ensure they are optimal for sea lice management… *'In the shorter-term it is expected that expansion of the aquaculture industry will occur in higher energy, more exposed sites….and will aim to achieve its 2020 sustainable production targets under improved management in a shared space…In the longer term, Scottish Government will engage with the aquaculture sector to enable expansion of the aquaculture industry further offshore into the open sea using innovative engineering and design………*' And '*Expansion into offshore waters should reduce interactions with migratory fish, and help to mitigate against some of the current fish health issues, including sea lice management.*'

This enabling of further expansion into more exposed offshore sites, in the longer term, did not mention the closure of inshore sites already near to sensitive wild salmon and sea trout breeding populations, where expanded farm tonnages are already causing environmental stress. MSS went on to state that all Scottish salmon farms are now required to produce a site-specific escalation plan, to be triggered at levels above 3.0 average female lice. This '*will allow monitoring during any escalation in sea lice numbers and intervention where it is demonstrated that satisfactory measures to control sea lice are not in place. Exceeding a level of 8.0 average female lice will result in* *enforcement action, including the potential to require reduction in biomass…Scottish Government have worked cooperatively with the aquaculture industry to agree this new policy and industry in turn are also revising their own integrated sea lice management strategy. This will lead to future updates to the industry Code of Good Practice.*'

The decision-making process behind the trigger levels of sea lice infestation introduced on Scottish salmon farms appeared arbitrary and did not seem to relate to the protection of wild salmonids. Key to this concern are the massive numbers of caged fish carrying sea lice held on individual sites. Pertinent to Loch Ewe, the Wester Ross Area Salmon Fishery Board wrote as a statutory consultee to SEPA expressing deep concern about an application for a CAR licence to increase the maximum biomass of salmon at a site in Loch Shieldaig to 1750 tonnes. As planning authority for this area, Highland Council gave consent on restricted ten year terms (pers. comm. P. Jarosz). Meanwhile, the current maximum allowed biomass for the Isle of Ewe site in Loch Ewe is 1027 tonnes. Loch Ewe has three sites, although only Isle of Ewe is in operation at present. The pressure for growth within the salmon farming industry continues unabated and a major increase in rearing tonnage is planned.

In marked contrast with the Scottish approach, other countries represented at NASCO took a much stronger position on lice control. Norway, with by far the largest share of farmed salmon production in the Atlantic, presented a clear acceptance that the environmental footprint of aquaculture should decide production areas and sets much lower lice targets to protect wild migrating smolts: '*Norwegian fish farmers are required to take coordinated de-licing measures every spring at low treatment thresholds (0.1 motile/adult female lice), to protect the Atlantic salmon smolt migrating to sea.'* The Norwegian report further states '*We now shift the main monitoring over to a model based system using data on sea lice (copepodites) emission from all sea based facilities in a production area, and relate this to the risk for unacceptable impact on wild salmonids.'* Furthermore, the Norwegian report to NASCO (2016) describes a movement towards the use of much larger smolts (c. 400 g) to reduce marine rearing time to harvest and states a keen interest in closed containment and onshore developments. The Norwegian Parliament is *'not limiting the number of licences to onshore salmon farming. Furthermore, such licences will be granted without paying the normal licence-fee.*'

It was made very clear at the full day session of NASCO in Bad Neuenahr, Germany, in 2016 that salmon farming can and does impact wild salmonid stocks and there remains an urgent need for better controlling regulation. In this regard, Scotland appeared to be out-of-step with international expert opinion on the levels of sea lice management required and reluctant to take strong precautionary actions on farm siting and practices to protect already depleted wild salmonid stocks.

14.0 SCOTGOV ADVICE ON SEA LICE

A recent summary of information to the public from the Scottish Government (Anon 2016) discusses the impacts of salmon lice from fish farms on wild Scottish sea trout and salmon and focuses on key issues relevant to locating fish farms in the coastal zone (www.gov.scot/Topics/marine/Salmon-Trout-Coarse/Freshwater/Research/Aqint/troutandlice). It is repeated here (without refs):

'*Are salmon farms a significant source of salmon lice?*
Yes, salmon farms have been shown to be a more important contributor than wild fish to the total numbers of salmon lice in the environment.

Is there an association between levels of lice on salmon farms and in the surrounding environment?
Yes, environmental larval lice concentrations relate to local farm lice loads. The distribution of lice depends on hydrodynamic conditions and so the relationship may be highly variable at any specific location.

Is there an association between levels of lice on salmon farms and on wild sea trout?
Yes, analysis of data from Norway highlights a significant relationship between infection potential from farms and settlement on wild sea trout. Data collected throughout the west coast of Scotland shows that the proportion of individual sea trout with sea louse burdens above a level known to cause physiological stress increased with the mean weight of salmon on the nearest fish farm (a measure of where they are in their production cycle), and decreased with distance from that farm.

Is there an effect of salmon lice on wild sea trout at the individual level?

Individual wild sea trout sampled on the west coast of Scotland have been shown to have salmon louse infestations above a level known to cause physiological harm.

Is there evidence of an effect of salmon lice on wild sea trout at the population level?

No such direct evidence for a Scottish situation has been published. An experiment in Norway, comparing survival of anti-lice treated sea trout smolts with non-treated smolts, indicated an increased survival rate of 3.41% over 1.76%. This is about a 50% reduction in the stock returning to the river, suggesting that salmon lice can negatively affect sea trout populations.

Is there an effect of salmon lice on wild salmon at the population level?

Declines in catches of wild salmon have been steeper on the Scottish west coast than elsewhere in Scotland and Norway, although this did not prove a causative link with aquaculture. The reduction in the catches and counts of salmon on the west coast has been correlated with increased production of farmed salmon. In addition, rivers with farms had significantly lower abundances of juvenile salmon than those without farms.

Experiments comparing survival of smolts treated or untreated with anti-sea lice medicines have shown that sea lice adversely affect certain salmon populations in Norway and Ireland. There is a great deal of year-to-year and site-to-site variability in the magnitude of such impacts and the reduction in numbers of returning salmon associated with lice infestations is in the range of 0-39%. A meta-analysis of all available Norwegian studies showed anti-lice treatment increased returns of adult salmon by an average of 18%. It is not clear in these studies how much of the estimated impact of lice is due to baseline natural levels in the environment and how much is associated with an additional effect caused by salmon aquaculture.

No information exists on impacts of lice on wild populations of salmon in Scotland. However, the estimated mean effect size of lice seen in other countries is of a similar magnitude to the difference between the aquaculture zone and east coast of Scotland in the reduction in abundance of wild salmon determined using data from fish counters. It is not clear how much of this regional variation may be due to factors besides aquaculture.

Over what distance do farms influence environmental lice levels?

Salmon lice transport modelling in a Scottish system reports that >97.5% of sea lice are transported within 15 km of fish farms. However, site specific factors such as prevailing wind and currents, and local topography can have a large *impact on the direction and distance of lice dispersal. Infestation levels were highest when sea trout were sampled near to a salmon farm and reduced as the distance to the nearest farm increased.*

Can fish farmers reduce numbers of lice released into the environment?
There are control strategies that farms can use to reduce salmon lice infestation. These include chemical, physical and biological methods. Historically chemical treatments have been favoured, reduced efficacy of treatments has been documented as has increased frequency of treatment. This has encouraged alternative control methods to be investigated. One of these is the use of cleaner fish, such as wrasse, as a biological control. These fish are introduced into pens to directly eat lice off salmon. This adds an additional method to control sea lice as part of integrated pest management; other methods include functional feeds, cage design to control salmon's depth, and selective breeding.

SUMMARY of ADVICE (from Scotgov)

Salmon aquaculture can result in elevated numbers of sea lice in open water and hence is likely to increase the infestation potential on wild salmonids. This in turn could have an adverse effect on populations of wild salmonids in some circumstances. The magnitude of any such impact in relation to overall mortality levels is not known for Scotland. However, concerns that there may be a significant impact of aquaculture have been raised due to declines in catches of both salmon and sea trout on the Scottish west coast. There is scientific evidence that individual Scottish sea trout can experience physiologically detrimental burdens of salmon lice in areas with salmon aquaculture but the effects on populations in different areas are not known. Scientific evidence from Norway and Ireland indicates that early protection against salmon lice parasitism results in reduced absolute marine mortality, increasing recapture rates of experimental salmon, and reduces the time spent at sea, indicating that salmon lice can influence the population status of wild salmon. Marine Scotland Science has recently commenced a project to address this data gap for Scottish salmon. Further information on this project can be found online and details of references cited are also available'.

Unfortunately, the notification of research to fill a *'data gap'* on Scottish salmon makes no mention of quantifying the effects of aquaculture on Scottish sea trout at population level in different areas. Also, many observers will be disappointed by the weakness of the statement that there '*is scientific* *evidence that individual Scottish sea trout can experience physiologically detrimental burdens of salmon lice in areas with salmon aquaculture*' as it fails to acknowledge the widespread scale of a problem which has been apparent for almost 30 years (1989-2016).

15.0 DISEASE PROBLEMS

Over the years since the industry began in Scotland, virulent infectious diseases have struck salmon farming, from Furunculosis to Infectious Pancreatic Disease (IPN), Infectious Salmon Anaemia (ISA), Bacterial Kidney Disease (BKD) and now Amoebic Gill Disease (AGD). SEPA has revealed that the number of salmon killed by disease at Scottish fish farms exceeded 8.5 million in 2015. Furunculosis, a bacterial disease, had a devastating impact on salmonid aquaculture up until the late 1980's. Vaccines are still widely used, but antimicrobials are often used in tandem

Bacterial kidney disease has been present here since the 1930s when outbreaks of 'Dee disease' occurred in wild salmon on the Aberdeenshire River Dee. The first recorded outbreak in farmed fish in Scotland was in rainbow trout in 1976. Since then, BKD has not been reported in wild fish, although the causative agent has been detected using the qPCR screening method. Outbreaks of BKD have occurred in Scotland in freshwater and marine trout farms and marine salmon farms. The characteristics of these outbreaks have varied considerably depending on the type of farm involved. The spread of disease such as BKD requires contact processes between infected and uninfected farms. These contacts may be through the water, or over longer distances via anthropogenic processes such as transport of fish between locations, or movements of wellboats. From the case studies presented, anthropogenic links clearly account for most of the spread of *R. salmoninarum*.

ISA is an infectious viral disease of Atlantic salmon (*Salmo salar L.*). The disease was first reported in Norway in 1984, but has since been reported in Canada, the USA, the Faroe Islands, Ireland and Scotland. The outbreak of ISA in Scotland in 1998-99 was successfully eradicated. Atlantic salmon is the only susceptible species known to develop the clinical disease, but ISA virus can replicate in rainbow trout (*Oncorhynchus mykiss*) and sea trout (*Salmo trutta L.*).

Infectious haematopoietic necrosis (IHN) is a viral disease affecting most species of salmonid fish reared in fresh water or sea water, but so far undetected in British waters. IHN was first recognised in the 1950s in sockeye and chinook salmon and has had most economic significance for freshwater farms, although Pacific and Atlantic salmon in both fresh and sea water have also been severely affected. IHN virus spread across North America in the 1970s in rainbow trout, apparently originating from fry or egg shipments from a single source. The virus was also introduced to Japan in 1968 by eggs from Alaska and has since spread to continental Europe.

Serious outbreaks of Amoebic Gill Disease (AGD), caused by a protozoan parasite (*Neoparamoeba perurans*), have been reported recently in Scottish salmon farms, including Loch Ewe and the Western Isles. The disease has also been reported in Ireland, Norway, Chile and other countries. Affected fish can appear lethargic, breathe rapidly and congregate near the water surface. Their gills show patches of white to grey swollen tissue and increased mucus, eventually leading to asphyxia and death. Affected fish are more susceptible to other infections but, conversely, fish suffering from other diseases may also be more susceptible to AGD (http://www.gov.scot/Topics/marine/Fish-Shellfish/aquaculture/diseases/notifiableDisease/).

There is a constant threat of disease outbreaks when animals are reared at high densities and/or other adverse conditions and become stressed. In addition, variant genetic forms of disease agents are likely to emerge more frequently and be 'cultured' in intensive rearing conditions, both in fresh water and at sea. Sea trout post-smolt and older age classes are likely to be exposed to novel infections from marine cage sites because of their coastal feeding behaviour. However, any related mortality is difficult to detect, quantify and monitor, especially as most sick fish or dead fish will be consumed by predators and scavengers. Methods for prevention or control of potent diseases found in coastal salmon farming are hugely expensive and there is a constant need to evolve new treatments and recycle old ones to mitigate commercial losses. Unfortunately, wild fish populations sharing these waters have no such protection.

16.0 MARINE FISH STOCKS

Changes in seasonal abundance of small clupeid fish, such as young herring, sprats and sandeels, might be implicated in sea trout declines. Pemberton (2006) examined the contents of 986 sea trout stomachs from the Loch Etive area (1970–1973), and 291 stomachs from the Loch Eil area (1964–1973), finding that benthic feeding (Crustacea and annelids) was more important in winter, while midwater and surface organisms (young fish and insects) were preferred in summer. Young fish (mainly clupeids and sand eels) featured more in the diet of the larger trout ((≥21 cm). On their return to fresh water, adult sea trout tend to fast and lose weight in proportion to the time spent there. They lose more weight when they spawn, only recovering fully when they return to feed at sea. The seasonal timing of availability and abundance of small clupeids and other marine species upon which the sea trout will feed may change from year to year. A close parallel can be found in sea bird species which depend on a diet of sand eels for their breeding success. Scottish Natural Heritage (Anon, 2016) confirms that '*Of the 12 species for which we can calculate trends in their breeding numbers, 11 have shown sustained declines mostly from around 2000 onwards. The largest declines have been for Arctic skua, declining by 80% from 1986 levels, black-legged kittiwake (71%) and European shag (54). …. Declines in black-legged kittiwake populations have been particularly notable in the Northern Isles with some colonies declining by over 90%. Changes in sandeel availability are considered the most likely cause*' (http://www.snh.gov.uk/indicators/). However, SNH also states that '*Seabird abundance in the UK [mainly Scotland] increased between 1970 and 1999, and has since declined*' (see http://jncc.defra.gov.uk/page- 4235). It would appear therefore that the sea bird declines came after the sea trout collapse in the River Ewe System, although a possible link with local sand eel or other clupeid availability cannot be discounted (Wright and Reeves, 1994).

Other major changes in West Coast fisheries have occurred since the 1970s, notably a collapse in the stocks of the main commercial demersal species, cod, haddock and whiting and a transition to a (*langoustine - scampi*) *Nephrops*-dominated fishery. These changes have been linked variously with climate change, over-fishing and the removal of the three nautical mile limit and coastal fish farming (McIntyre *et al.,* 2012).

17.0 CLIMATE CHANGE

Climate change may be an overarching factor affecting sea trout stocks, also driving long-term variation in salmon abundance and run-timing. The Met Office reports '*Since the 1980s the sea surface temperature of the seas around the UK have risen at a rate of about 0.2–0.6 ºC, and seven of the warmest years in UK coastal waters since records began in 1870 have occurred in the last decade. In the open ocean, shelf edge regions and northern North Sea, temperature increases throughout the year of ~1.5 –2.5ºC are projected to occur. Larger increases of ~2.5–4 ºC are projected for the Celtic, Irish and southern North Sea*' (Lowe *et al*, 2009). Sea trout and salmon populations can hardly be unaffected by this complex and evolving picture. Marine hydrographical shifts are happening, along with changes in geographical distribution of plankton and fish species. On land and at sea, southern species are moving northwards. However, fjordic river systems along the north coast, unlike those discharging into the Minch, have not suffered from sea trout decline and collapses. This may be associated with Atlantic exposure and the strong currents that sweep through the Pentland Firth and promote rapid water exchange in the northern sea lochs, countering any salmon farm-related problems with sea lice and disease. Similarly, sea trout stock composition and abundance seems to be maintaining well in river catchments and sea lochs in parts of south-west Lewis in the Hebrides, also exposed to the Atlantic (pers. obs. and catch data).

18.0 DISCUSSION

In the late 1980s, significant changes occurred in sea trout population structure in the River Ewe system (including Loch Maree) in Wester Ross. Angling catches collapsed and have not recovered to previous levels. Without a trap or other means to measure the annual runs of adult sea trout, reliance is placed on indirect methods of stock assessment and mostly the statutory reported catches of sea trout made throughout Scotland from 1952 until 2015. The absence of a direct count, or even a robust indirect measurement of stock abundance at a range of indicator sites, hampers closer investigation. Catch records cannot substitute for long-term knowledge of actual population densities and a detailed understanding of their dynamics. Unfortunately, the statutory sea trout catch statistics are difficult to interpret, although often assumed to be indicative of stock status.

The All-Scotland graph shows a long-term declining trend in numbers of fish caught per year (Retained and Released combined) and culminates in several years with record low levels. It should be noted, however, that the decline is influenced by a gradual introduction of local size and bag limits, brought in for conservation reasons. Older catch records often included smaller and younger, therefore more numerous, fish (usually called ‘finnock’), partly because of a lack of a national minimum size, therefore their inclusion swelled the numbers. However, since 2004, all ‘finnock’ catches in Scotland were required to be recorded, but now are reported separately and not included as ‘Sea trout,’ exacerbating any actual decline in numbers and probably raising mean annual weights.

Catch data from several Scottish Fishery Regions show an increasing trend in mean weight of reported sea trout in contrast to declining numbers. An added driver of weight increase could be the long-term decline of coastal and estuarine salmon netting (with sea trout mainly a bycatch), allowing increasing escapement of adult sea trout into rivers. However, most anglers perhaps other than those who fish the River Tweed, are likely vehemently to dispute that sea trout are now more numerous, or larger, than they used to be. Also, the synchronous timing of catch patterns shown across most parts of the country, including extremes of better and poorer catches, suggests there is some underlying factor or factors affecting catches, which may be abundance-related, but could be an artefact of weather conditions and fishing effort. Broad positive correlations can be made between reported sea trout catches and amounts of summer rainfall (Walker, 1984), although the correlations break down during extremes of river flow. Reported catches, therefore, can be misleading and should not be taken at face value. What is patently clear from observations made by competent observers, both anglers and fishery scientists, is that sea trout are scarcer in west Highland river systems than they used to be and the large, multi-annual spawning sea trout which were common historically, certainly until the early 1980s, are now rare.

Detailed catch and stock sampling undertaken by the Fishery Board for Scotland in the 1920s (Nall, 1930) and further angling catch sampling in 1980 in the angling fishery and examination of adults sampled by electro-fishing in the spawning burns by the Freshwater Fisheries Laboratory, then part of D.A.F.S., gave an impression of stock stability, having almost identical results (Walker 1982). Ewe sea trout were slow-growing and long-lived and included many multiple annual repeat spawners. Old, large, repeat-spawning sea trout were typical of West Highland and Islands rivers and lochs with open access to and from the sea (Nall, 1930). After the 1980 study, annual catch sampling in the Ewe system towards the end of that decade revealed an apparently unprecedented and abrupt reduction in marine survival and growth at all sea ages, accompanied inevitably by a substantial fall in total egg deposition levels, dependent on the fall in numbers of fish and in their body size. There are insufficient CPUE data to derive a quantitative measure of the decline in numbers other than indicated by catches. However, in addition to the substantial decline in growth at sea, the maximum sea age fell from 11 to 5 years and the maximum spawning frequency fell to 2 times in 1997-2001, highlighting the lack of older, large, specimen-sized sea trout, with their disproportionate capacity to supply large numbers of big eggs, producing large fry (Walker 2006b).

Long-lived sea trout stocks should be resilient to bad years for recruitment or adult survival because of the multiple year-classes involved and the implied temporal and spatial spawning diversity. Harris (2006) describes a robust sea trout stock as having a range of smolt and sea age groups and a high incidence of repeat spawning, as was evident in the River Ewe system and elsewhere in north-western Scotland until the late 1980s. The historic robustness and resilience of many north-western sea trout stocks to natural annual variation in environmental conditions, including within the River Ewe system, may have been severely damaged. In marked contrast to these observations, a long-term investigation (Walker, 2006b) of the sea trout and brown trout population of a large headwater stream (Findhu Glen Burn) in the upper River Earn catchment, in eastern Scotland, found no significant change in the marine growth, body size, age, or sex composition of the stock over a 23-year period, during 1980 to 1986 and 1990-2003.

In the late 1980s, an apparently new phenomenon, epizootics of infective stages of salmon lice (*Lepeophtheirus salmonis*), was implicated in the abrupt lack of sea trout in the Ewe system angling catches. Heavy infestations of early post-smolt sea trout in Loch Ewe, mirrored in many other West Highland rivers from the Laxford system in north-west Sutherland at least as far down the West Coast as the Loch Shiel system in Inverness-shire. These early epizootics were soon linked with salmon farming in floating mesh cages, often anchored near rivers, in coastal sites with greater protection from adverse sea conditions. Salmon farming arrived in Loch Ewe in 1987 and has been there ever since. Other contributing factors, including changing climatic conditions, predation, or annual variation in marine food availability, may have influenced the decline of the sea trout, but if so they were not as discernible contributing factors as the lice problem. Over-exploitation of the sea trout stocks did not seem a plausible explanation for the abruptness of the changes in stock composition and collapse of catches that occurred at the end of the 1980s. Before that decade, gill-netting was reported to be commonplace in some areas after the introduction of light, mono- and poly-filament gill-nets in the 1960s, although Fishery Board bailliffs, estate staff and police were active in limiting illegal fishing. Also, the conservatively managed and protected River Ewe system, including world-famous Loch Maree, was not a hot-spot for poachers. It is evident from the excellent catch records at the Loch Maree Hotel that the rod catches, while subject to normal annual fluctuations, remained relatively stable until the end of the 1980s, coinciding with the arrival and subsequently rapid development of Atlantic salmon farming in Loch Ewe and elsewhere in the north-west of Scotland, the Hebrides and the Northern Isles. Despite facing regular problems of disease, sea lice infestations and escapes of stock, the industry has burgeoned here and in several other countries, most notably including Norway. By 2014, it was reported at NASCO (2016) that the numbers of captive farmed salmon in the North Atlantic had risen to 1900 times the numbers of wild salmon, sea trout and anadromous Arctic charr.

Concurrently with the sudden decline of sea trout catches in north-west Scotland and parallel decline in length at sea age, longevity and estimated population fecundity, a very similar situation developed in the salmon farming areas of western Ireland, where researchers had the advantage of traps and long-term monitoring programmes (Poole *et al.,* 1996, 2006; Gargan, 2016) based in the Burrishoole system and the River Erriff, also in Co. Mayo. The Erriff is the National Salmonid Catchment for Ireland. Soon after the commencement of salmon farming in 1986 in Killary Harbour, a narrow sea lough which receives the flows from the Erriff and Delphi, significant decreases were found during 1990-1994 in the number and length of sea trout kelts, the estimated number of eggs deposited, the sea trout rod catch, the proportion of older (1+ and 2+ sea age) fish and the frequency of repeat spawners. Also, a significant positive relationship was found between the number of salmon lice (*L. salmonis*) found in the local salmon farm and the number of lice on sea trout in the Erriff and Delphi rivers. The annual numbers of salmon smolts introduced to the cages had increased significantly by the end of the 1980s. Prior to 1989, the Erriff sea trout data indicated a stable stock structure typical of western Ireland, with the population dominated by finnock (≤ 32 cm), with a second peak of 1 sea winter (≤ 40 cm) and some older and larger sea age classes and previous spawners of > 40 cm (Gargan *et al*, 2016). A similar stable population structure was recorded in the Burrishoole catchment prior to 1989 (Poole *et al*., 1996) and in four neighbouring fisheries (Ballinahinch, Cashla, Gowla and Bundorragha) (Went, 1962). Poole *et al*. (1996) reported an unprecedented failure of smolts emanating from the Burrishoole system in the sea, with high mortality also of all age classes of adult sea trout. Whelan *et al*. (1993) investigated environmental factors influencing the migration and survival of sea trout stocks in the Burrishoole system during the 1989 stock collapse. They concluded that while environmental factors might play a pivotal role in regulating the numbers of migrating smolts, they did not provide an explanation for poor marine survival and that the cause of the population crash lay in the marine environment.

The similarity of the Irish situation with the timing and extent of the changes in sea trout stock composition, namely decline of marine growth, sea age and abundance in the River Ewe system and other rivers in north-west Scotland, suggested a common problem. The contemporaneous link with the development of salmon farming in open cages in large units commonly anchored near sea trout and salmon rivers, and the proposed mechanism for greater mortality of wild sea trout through rapid elevation of parasitic sea lice populations, remains highly plausible and has gained momentum through the years with ongoing research studies.

The collapse of sea trout angling catches and stocks in the Ewe system including Loch Maree may also have been influenced by a subtle biological shift of trout away from anadromous towards freshwater-resident tendency, due to changing environmental conditions, although Butler and Walker (2006) found no general evidence of such a recent change in the Ewe System. Parts of Lochs Clair and Tollaidh in the headwaters had been used for cage-rearing of smolts for marine farming and this can have an enriching effect and lead to enhanced growth of wild trout and Arctic charr populations. However, any such enrichment is unlikely to have been substantial and to have materially affected the production of sea trout smolts in the huge volume of water in Loch Maree, or in its other main tributaries (Butler and Walker, 2006). Also, sea trout stocks collapsed in many diverse north-western river catchments at the same time, some with lochs carrying smolt cages, e.g. Loch Damph, by Shieldaig in Torridon, Loch Eilt in the River Ailort System and Loch Shiel, but others without them. Some north-western catchments, including Loch Maree, contained areas of commercial conifer afforestation which may have contributed problems of acidification and exacerbated the effects of droughts and spates because of drainage issues, but others did not. The decline and apparent collapse of sea trout occurred also in the famous sea trout lochs in Skye, Loch Coruisk and Loch na Creithe, which drain pristine southern rocky slopes of the majestic Coulin Range and discharge over very short courses to the sea, with no anthropogenically-induced environmental change evident in their catchments. Furthermore, careful investigation of the sex ratios of smolts, finnock and adult sea trout and brown trout found nothing to suggest a sudden change in migratory strategy had occurred in the late 1980s (Anon, 1993; Butler and Walker, 2006). Nevertheless, the severe decline in overall egg deposition from sea trout and implied reduction in trout parr migrating from spawning streams into freshwater lochs, like Loch Maree, may have provided better feeding conditions and explain why anglers fishing there in the 1990s began to catch more and larger brown trout (≥0.5 kg) than were common in the past. Also, possible impacts of general climatic warming on the ecology of freshwater systems and dynamics of fish populations should not be overlooked, although examination of this suggestion is beyond the scope of this report.

Sea lice continue to pose a very substantial threat to the profitability and sustainability of Scottish and international salmon farming, although the industry has made huge strides in expanding its production levels and plans further substantial expansion. Yet there appears to have been no decrease in lice problems for the industry despite their efforts to control sea lice and deep concerns remain within the industry over site to site infective lice transmission, which can take place over large distances (≥30 km), potentially impacting on and interacting with other companies, operating their own commercial rearing practices. The introduction of in-feed treatments, such as Slice (Emamectin), to control sea lice on the salmon farms appeared to offer a respite for the hard-pressed wild sea trout and salmon populations, but all chemical methods of treatment seem to lead inexorably to genetic adaptation and resistance among the sea lice and lack of treatment efficacy (Costello, M.J. 2009). The much-publicised use of cleaner fish (wrasse and lumpfish) can play a useful part in a wider suite of control measures, but has its own practical difficulties. The movement of the industry offshore invites further problems of health and safety, storm damage to cages and major escape events, but could address better the concerns for wild salmonid populations over the sea lice epizootics and disease outbreaks, and the dispersal of particulate and dissolved effluents. The best solution appears to lie with closed-containment (in tanks either in the sea or on land), providing a barrier to free water interchange with the environment and progress is being made with the technological development of commercial-scale units. Currently, the main problem for the wider adoption of closed containment appears to be higher capital costs of installation, rather than technological development and running costs.

At a population level, despite prophylactic lice treatment and tagging/tracking experiments comparing the survival and growth performance of treated and untreated batches of smolts in different marine locations, science has still to determine how to measure the proportionate impact of sea lice on the mortality of post-smolt and older sea trout, compared to other sources of mortality. However, it has been established beyond reasonable doubt that epizootics of infective stages of sea lice are likely to come from caged salmon held in very large concentrations, unless adult lice levels on the farms are controlled to nearly zero levels. Also, the problem worsens in warmer conditions due to accelerated lice development and our seas are known to be warming. In combination, physical damage on farmed fish caused by sea lice increases the risk of diseases spreading from intensive cage-rearing to wild salmonids, where the effects of infection are likely to remain very difficult to monitor. Captive populations can be treated with medicines, but wild fish cannot. In addition, sea lice infections beyond low threshold levels can cause significant physiological challenges to wild sea trout and salmon post-smolts, increasing their vulnerability to predation from larger wild fish species, seals and birds. Those heavily lice-infested wild fish which survive long enough to mature grow less well, are smaller in body size and produce fewer eggs. The combination of smaller and fewer adults can cause drastic reductions in total egg deposition.

Whether a severe drop in egg deposition from returning adult sea trout will result in stock collapse of the entire trout complex will depend on where individual populations lie on their stock recruitment curves, which may be complicated by egg production from freshwater-resident brown trout females. Smolt numbers can be buffered for an unknown length of time by eggs from co-occurring brown trout, as in some Irish catchments where adult sea trout stocks collapsed (Gargan et al., 2016). However, in most north-western Scottish sea trout rivers, sampled in parts of the catchments where sea trout had access to spawn, also in the Earn and Tweed systems in eastern Scotland, almost all the mature brown trout were male fish (Walker, 1994 a&b). Either way, the numbers of adult sea trout in the River Ewe system are likely to remain low unless there is a substantial improvement in marine growth and survival to levels which can restore the former dynamic balance of trout stocks between anadromy and freshwater-residence. As potential hosts for sea lice, farmed salmon already hugely exceed the numbers of wild salmon and sea trout and the tonnage of farmed salmon continues to rise as new sites are established and older ones are further developed. Yet, the international salmon farming industry patently is already failing adequately to control sea lice and related disease infection to levels which are safe for wild salmonid fish populations (NASCO, 2016). In Scotland, as in Norway, sea lice have developed resistance to successively introduced, chemical control treatments, including potent pesticides, the continuing use of which may enter the food web and affect other marine life, such as shellfish, living close to the farmed sites.

Salmon farming in Loch Ewe, and possibly at salmon farm sites relatively nearby to the south and north, is likely to have contributed to or caused sudden changes in sea trout stock composition and abundance leading to severely reduced total egg deposition levels in the River Ewe system and the collapse of the iconic and world-famous angling fishery in Loch Maree. A synchronous collapse of sea trout abundance, marine growth, survival and total fecundity and angling fisheries in western Ireland occurred soon after the introduction of salmon farming in Killary Harbour, the sea loch receiving the flow from the River Erriff, the National Index Catchment for Ireland (Gargan *et al*., 2016). Long-term trapping and marking studies there and in the nearby Burrishoole system found sharply reduced marine survival levels between 1988 and 1990 and a failure of stock recovery (Poole and Whelan, 1996; Poole *et al.*, 2006). Norway, with similar concerns over declining wild stocks in proximity to aquaculture, set up some fjords as no-farming salmon refuges (NASCO, 2016). Scotland has a stated presumption against salmon farming on the East Coast and further expansion on the North Coast, but nowhere in the West. Under European legislation, Scotland has several Special Areas of Conservation (SACs), taking account of Atlantic salmon as a listed conservation species, but none for sea trout/brown trout. *Salmo trutta* is not one of the listed species. SACs are designated under the European Habitats Directive, transposed into Scottish law through the Habitats Regulations, and are part of the European network of Natura sites. The nearest SAC to the Ewe system is for the Little Gruinard River and it is primarily for pearl mussels (*Margaritifera margaritifera*), a species believed to be critically endangered. Pearl mussels are dependent on salmon parr and sea trout/brown trout which act as temporary hosts for the juvenile stage (glochidia), and are therefore crucial for the population status of the mussels. Unfortunately, sea trout have not been given the same conservation status as salmon although, under Scots law, they enjoy the same legal protection. In 2007, both brown trout and sea trout were included in the UK Biodiversity Plan Priority Species List, but it is not apparent how much, if any, impact this inclusion could have in relation to the development of aquaculture sites.

Following their recent freshwater fisheries review, Scottish Ministers have proposed significant changes for the management of fisheries for migratory and freshwater-resident fish species, although much of this initiative has been curtailed by Brexit negotiations and implications. One of the positive proposals already well underway is the requirement for a Conservation Plan for each river catchment, irrespective of conservation status, informing further management measures and actions for consideration at local, regional and national level. For salmon, the conservation plans must include factors with potential material impact, such as marine renewable energy, predation, aquaculture and barriers. Rivers are categorised by their probability of attaining conservation limits within the next five years, effectively estimates of annual ova deposition in relation to available river habitat. If rivers are failing to meet these spawning targets, further management action may be necessary to reduce exploitation. Confidence limits for sea trout are much more complex because of their relationship with brown trout, so have yet to be discussed in detail.

Despite the present inadequate knowledge of how to estimate conservation limits for sea trout, given the critical status of sea trout stocks in the River Ewe and other north-western systems and lack of evidence of any sustained recovery on the horizon, many people believe it is incumbent on Government to require more radical conservation measures to be implemented, including stronger controls on the management of sea lice and infectious diseases and re-siting of the salmon farms which are presently in close proximity to important sea trout and salmon rivers. In a relatively short time, Scottish salmon farming has become a major national asset, both in terms of domestic product availability and public acceptance and through its very substantial exports. While accepting this reality, a better balance needs to be struck with conservation. Encouragement of closed containment on a commercial scale to replace existing open cage technology seems the best way forward to address most of the ongoing and deeply-felt environmental concerns.

CONTRACT RESPONSE

1. **It is highly likely that the introduction of salmon farming in Loch Ewe 1987 was a major cause in the collapse of the sea trout angling fishery in Loch Maree**, at the end of the 1980s and that salmon farming is hindering stock recovery, although other factors may be involved which are less, or not, addressable.

2. **Removal of the rearing cages in Loch Ewe is justifiable, even on a precautionary basis.** But, this would not necessarily result in rapid recovery of the old levels of sea trout stock composition and abundance in the River Ewe system. The following bullet points summarise some of the related problems:

   - There is no guarantee that Loch Ewe will remain unaffected by sea lice and disease management practices on other salmon farms in neighbouring areas. Also, some Ewe sea trout may interchange with those from neighbouring sea lochs and estuaries, particularly those in Loch Torridon, Little Loch Broom and Loch Broom and possibly Skye, and still be susceptible to any lice and disease problems existing there.

   - Marine growth of Ewe system sea trout may improve through reduction in lice infestation pressure, but the marine growth of Ewe sea trout historically was relatively low. Therefore, it could take several years for the numbers and proportion of older specimen-sized fish to recover.

   - The smolt output of trout from the Ewe system may have declined substantially since the sea trout stock collapse, unless supplemented by eggs from freshwater-resident brown trout, as has been found in Irish studies.

   - Improved survival of 0+ and 1+ sea-year sea trout is the main consideration for stock recovery. In the Ewe system, most of these fish spawn for the first time at the end of their second marine growing season. Therefore, maturing sea trout weighing 0.5 – <1.0 kg could become more noticeable from two years after fish farm removal. There may be a quicker pace of stock recovery if kelt survival and growth also have been heavily compromised by lice. However, it is likely that a full replacement of all previous age groups, if this is feasible, could take five to ten years.

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