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Regional and national assessment of the pressures acting on Atlantic salmon in Scotland, 2021

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Regional and National Assessment of the Pressures Acting on Atlantic salmon in Scotland, 2021

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1. Introduction

Wild Atlantic salmon populations are in decline throughout most of their native range including Scotland. In the face of declining salmon numbers and poor marine survival, it is increasingly important to protect and where possible improve freshwater salmon habitats to maintain and improve juvenile production and smolt output. This objective is at the heart of the Scottish Wild Salmon Strategy. Targeted management action requires both an understanding of the status of salmon populations at sub-catchment scales and information on the spatial extent and severity of pressures impacting those populations. Despite a substantial body of scientific information on Atlantic salmon, accurate quantitative assessments of the magnitude of impacts for individual pressures are scarce and can be site specific. In common with other countries, this situation reflects the difficulty of making appropriate controlled investigations of the species rather than a lack of ambition to obtain the information. Management therefore proceeds pragmatically on the basis of best available information, with monitoring of actions where feasible. In the absence of detailed quantitative scientific evaluations, expert opinion has a role to play (Forseth *et al.,* 2017), with the caveat that uncertainty in the veracity of assessments must be considered. This study combined expert opinion from local fisheries managers with a scientific assessment of local salmon stock status.

In 2018, the National Electrofishing Programme for Scotland (NEPS) was established as a collaboration between Marine Scotland and local fisheries managers to improve understanding of juvenile salmon stocks and develop new assessment methods[1]. In 2019, local fisheries managers were asked to map the spatial extent and severity of pressures acting on Atlantic salmon in Scotland, supported by a grant from the European Maritime and Fisheries Fund and technical

[1] National Electrofishing Programme for Scotland - gov.scot (www.gov.scot)

inputs from the Scottish Fisheries Coordination Centre and Marine Scotland Science. The pressure mapping work was updated, refined and refreshed in spring 2021 with financial support from the Scottish Government. This report presents summary findings of this work, which for the first time attempts to assess and map the impacts of different pressures acting on salmon in Scotland, with a view to informing management and policy at local and national scales.

2. Methods

To ensure that information was collected to common standards in a comparable format throughout Scotland, salmon pressures were classified into 27 individual categories within 12 broadly themed groups (See Appendix 1 for details). Information was captured in an online Geographical Information System (GIS) at two spatial scales which varied by pressure depending on the spatial extent of expected impacts on salmon. Reach scale pressures, which were appropriate to geographically discrete impacts (e.g. point source pollution), were mapped at the river segment scale. Pressures expected to affect salmon across whole river systems (e.g. predation of smolts or adults in mainstem rivers or estuaries) were mapped at catchment scales. The latter pressures were mapped only for catchments that come under The Conservation of Salmon (Scotland) Regulations 2016 ("the Conservation Regulations"), which excludes catchments not supporting salmon fisheries. The data collection process was accompanied by detailed guidance material prepared by Fisheries Management Scotland in consultation with Marine Scotland.

2.1 Severity, status and confidence

For each pressure and river reach (or catchment as appropriate), local fisheries managers, represented by Fisheries Trusts and Board biologists communicating with the Scottish Fisheries Coordination Centre, were asked to provide their assessment of the severities of each pressure (approximate level of impact on salmon), its status and the level of confidence. The juvenile survey data provided evidence of the degree to which each fish population was impacted overall by the combination of pressures. These assessments were recorded in broad categories and defined as follows:

Severity (Low to High):

- Severity A: < 5% of natural salmon production lost due to a pressure

- Severity B1: Between 5% and 26% of production lost
- Severity B2: Between 27 and 49% of production lost
- Severity C: Between 50 and 80% of production lost
- Severity D: >80 % of salmon production lost
- UNKNOWN: Pressure thought to be present, but severity of impact could not be estimated even in broad terms

Status:

- Chronic: A contemporary pressure that is present for more than 50% of the year and not trending
- Episodic: A contemporary pressure that is present for less than 50% of the year and not trending
- Historic: A pressure that is declining over time, or has been removed but has persisting effects
- Emerging: A pressure that is increasing over time
- NA: Recorded only where a pressure is not thought to be having any impact

To reduce the number and complexity of status classes it was only possible to define pressures as chronic or episodic for contemporary pressures.

Confidence:

- High : estimate of severity is supported by robust evidence
- Low: estimate of severity not supported by robust local evidence

Decision making was supported by data on the status of juvenile salmon from NEPS, together with locally collected information and spatial data on environmental status mapped and collated by the Scottish Environment Protection Agency (SEPA) to support waterbody classifications under the Water Framework Directive[2]. A high level review of the data and approach were undertaken by a Technical Working Group including representatives from SEPA, NatureScot, academics and practitioners working on salmon in Scotland (Appendix 2).

[2] Water Classification Hub (sepa.org.uk)

2.2 Summarising the impacts of pressures on salmon at regional and national scales

The impacts of pressures were assessed and summarised at catchment, fisheries district, regional and national scales for rivers that are included in the Salmon Conservation Regulations process[3]. Rivers above natural impassable barriers for salmon were excluded from the analysis. The overall impact of a pressure reflects both its severity and its spatial extent, which can be indicated by river length or wetted area. Summary metrics of overall impact were therefore calculated by multiplying the river length or wetted area by a value representative of the mid-point of the severity class definitions (Section 2.1 above), summing the resulting values to the scale of interest and referencing them to the total wetted area or river length. The output is two summary metrics depending on the measure of spatial extent; Production Impact River length and Production Impact Wetted Area. These summary metrics can be thought of as the percentage of salmon production that is believed to be lost due to each pressure. However, given the uncertainties involved in the process they are better considered as broad metrics, indicative of the scale of assessed impacts, where higher values indicate a greater expected impact.

To facilitate presentation of information on status and confidence, these variables were assigned numerical values (Low Confidence 0, High Confidence 1, Historical 1, Chronic/Episodic 2, Emerging 3) and aggregated across regions with a weighting for habitat area (length or wetted area).

Pressures with an “UNKNOWN” severity could not be included in the main analysis and were dealt with separately. In these circumstances the spatial extent of the pressure was calculated and referenced to the total available habitat in a region, with high values again indicating a pressure with greater potential impacts.

2.3 Data presentation

The pressure data are available in several different formats reflecting varying levels of spatial resolution. Detailed data on individual pressures and river reaches can be viewed on the Fisheries Management Scotland web site[4]. In addition Marine Scotland have developed an R Shiny Application to present summary data for river

[3] Conservation of wild salmon - Salmon and recreational fisheries - gov.scot (www.gov.scot)
[4] Salmon Pressures - Fisheries Management Scotland (fms.scot)

catchments, District Salmon Fishery Board (DSFB) boundaries, broad geographic regions and the whole country[5]. This application can map spatial variability in the impacts of individual pressures, and produce tables that rank the importance of each pressure assessed within a defined geographic area. These resources provide additional detail and granularity that is not provided here.

This report aims to provide a readily interpretible high level summary of the detailed spatial data populated by local fisheries managers. Conceptually, the format of the data summaries presented here are broadly consistent with those presented by Forseth *et al.* (2017) with Status plotted on the x axis (Development in Forseth *et al*., 2017) and Severity plotted on the y axis (Effects in Forseth *et al*., 2017). This has the effect of plotting pressures of declining importance to the left, increasing importance to the right, high impact to the top and low impact to the bottom of each plot. Additionally, the size of symbols has been scaled in this report according to levels of confidence to identify those pressures for which local fishery managers consider there to be greater or lesser levels of evidence.

Data have been aggregated at two spatial scales; National, and regional (East, North, West and South West indicated in Figure 1). Note that there is substantial variation among regions in the areas of rivers and salmon stocks. There is also variation in the geographic distribution of potential pressure sources. For example, Scottish planning policy presumes against marine finfish farm developments on the North and East coasts to safeguard migratory fish species.

[5] R Shiny Application to present Pressures on Wild Atlantic Salmon

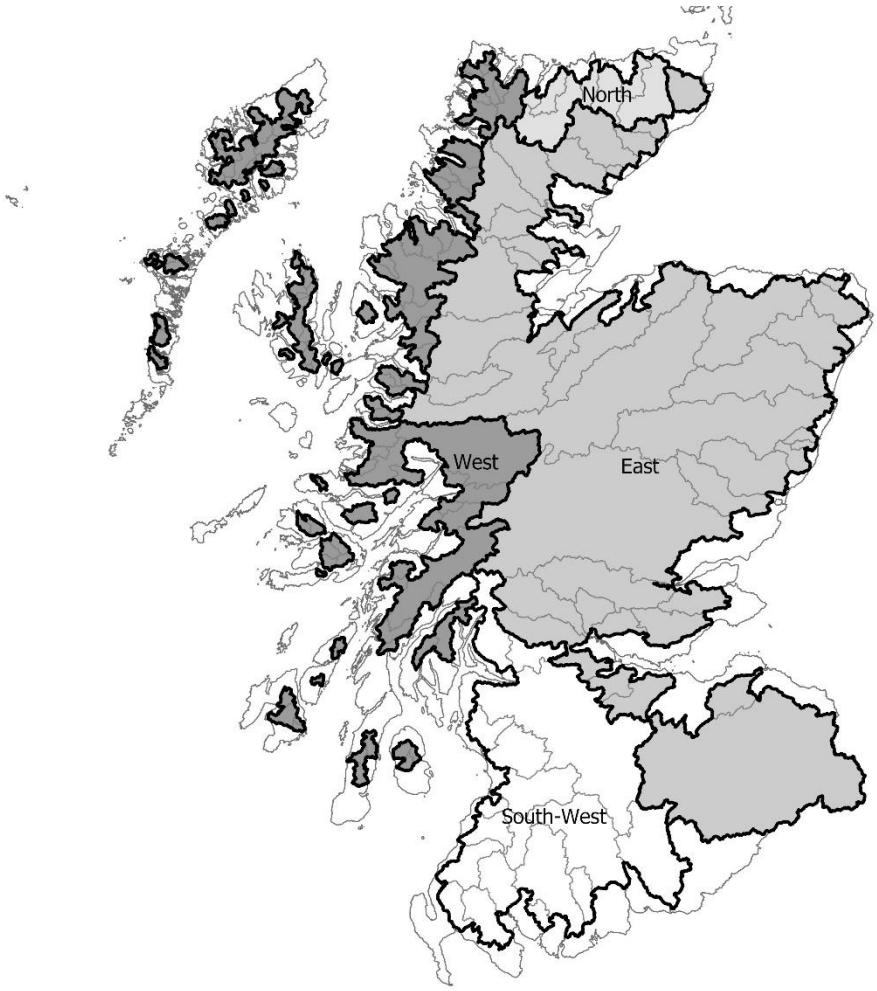

Figure 1. Map showing the spatial distribution of major river catchments and data analysis regions. Only rivers within the bold black polygons, which contain salmon fisheries and are incorporated in the Conservation Regulations process, were included in the summary analysis.

3. Results

3.1 Scotland

- The pressure data coming from East coast rivers dominates the national picture (Figure 2) due to their greater river length and wetted area once standing waters are excluded.
- Exploitation of salmon by coastal and in-river nets is considered to be historic and of minor and declining importance, at least partly reflecting the legislative ban on the retention of salmon in coastal waters implemented in 2016.

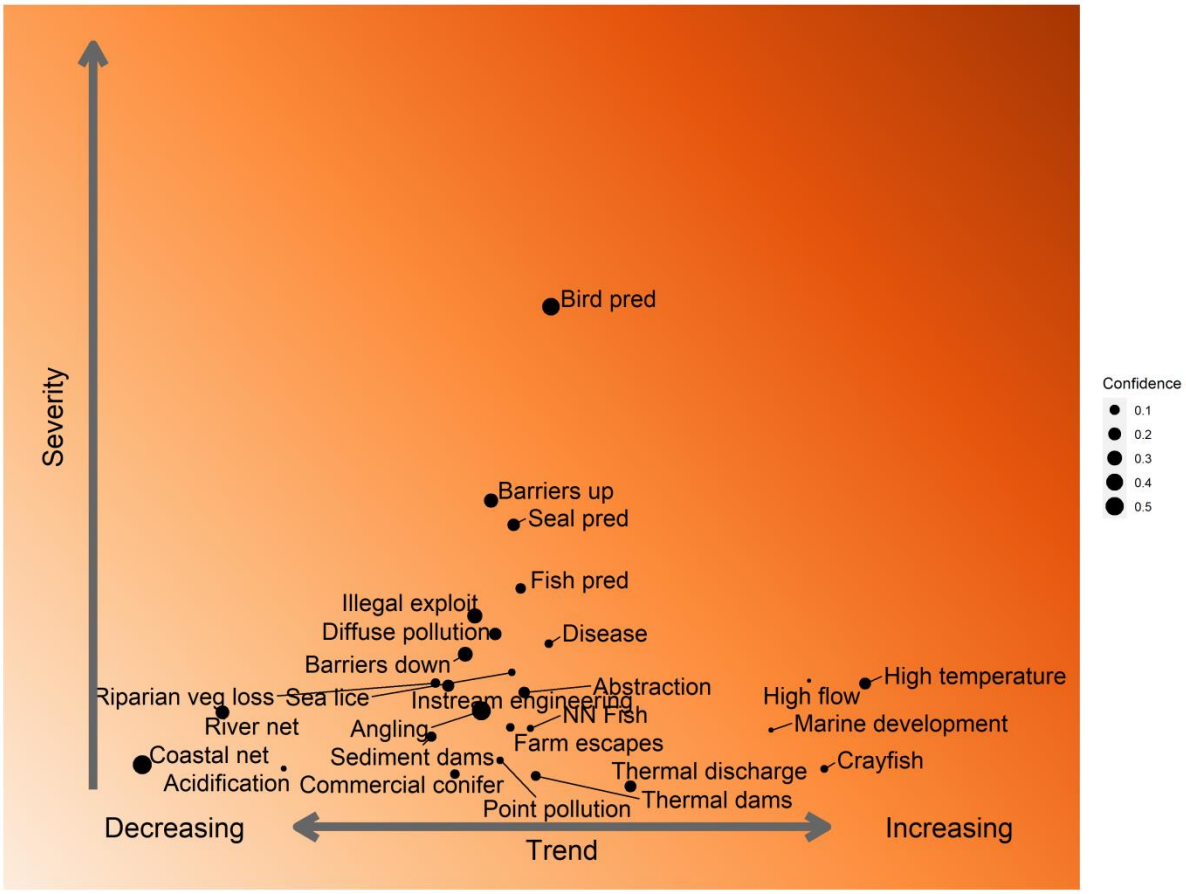

Figure 2. Summary of the importance of pressures across Scotland. The horizontal x-axis indicates whether a pressure is declining / historical (left), generally stable / contemporary (centre) or increasing / emerging (right) over time. The vertical y-axis indicates the current severity of pressures as assessed and recorded by local fisheries managers. The size of points indicates the confidence that fisheries managers have in their assessment of the severity of an impact, with larger circles indicating greater confidence and underlying evidence of impacts. Lines connect points to associated labels of pressure categories.

- Predation by birds and seals, and upstream barriers are considered to be the most severe contemporary pressures acting on wild salmon.
- Of the emerging pressures, high river temperatures are thought to have the greatest current impact and this is expected to increase in coming years. Increasing high river flows under climate change, marine developments and the North American signal crayfish are also thought to be increasing pressures, although confidence in these assesments is lower, particularly in the case of high flows.

3.2 East

- The relative importance of different pressures on the East of Scotland (Figure 3) is generally similar to that across the country as a whole, although sea lice are not considered to have any substantial impact in this region.
- Coastal nets, acidification and to a lesser extent in-river nets are considered to be declining pressures.
- Bird predation and barriers to upstream migration are considered to be the greatest pressures on salmon at the current time.
- Pressures related to climate change are considered to be the greatest emerging threats, including increasing river temperatures and high flow extremes.
- Thermal discharges are considered to be of increasing concern, but are currently of very low severity. Marine developments and crayfish are also thought to be developing pressures, but their current severity is thought to be low and there is considerable uncertainty over impacts.

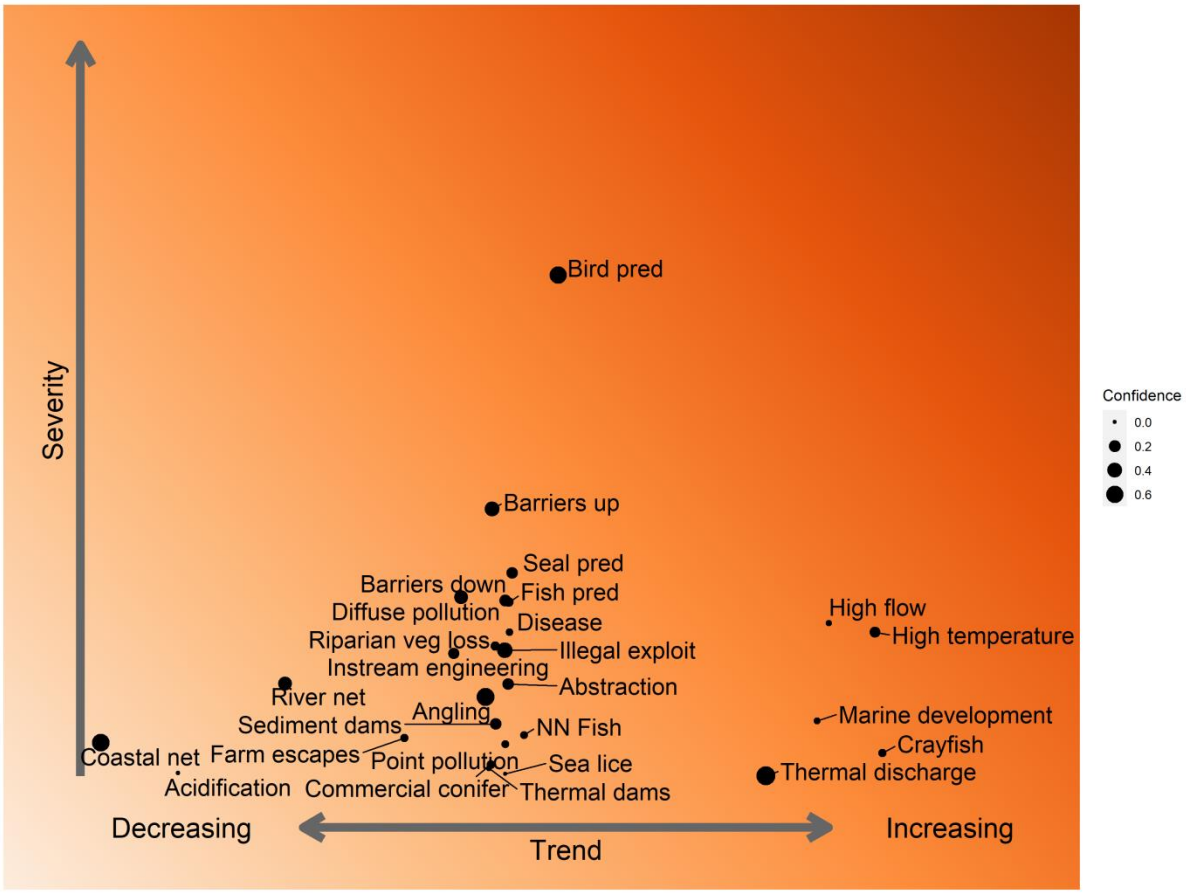

Figure 3. Summary of the importance of pressures on the East of Scotland. The horizontal x-axis indicates whether a pressure is declining / historical (left), generally stable / contemporary (centre) or increasing / emerging (right) over time. The vertical y-axis indicates the current severity of pressures as assessed and recorded by local fisheries managers. The size of points indicates the confidence that fisheries managers have in their assessment of the severity of an impact, with larger circles indicating greater confidence and underlying evidence of impacts. Lines connect points to associated labels of pressure categories.

3.3 North

- In general it is considered that there are few pressures affecting salmon in Northern rivers (Figure 4).
- The greatest contemporary pressures are thought to be associated with predation of salmon by seals and birds, although there is substantial uncertainty over the impact of birds.
- Angling, fish disease, marine development and high river temperatures are considered to be increasing pressures.

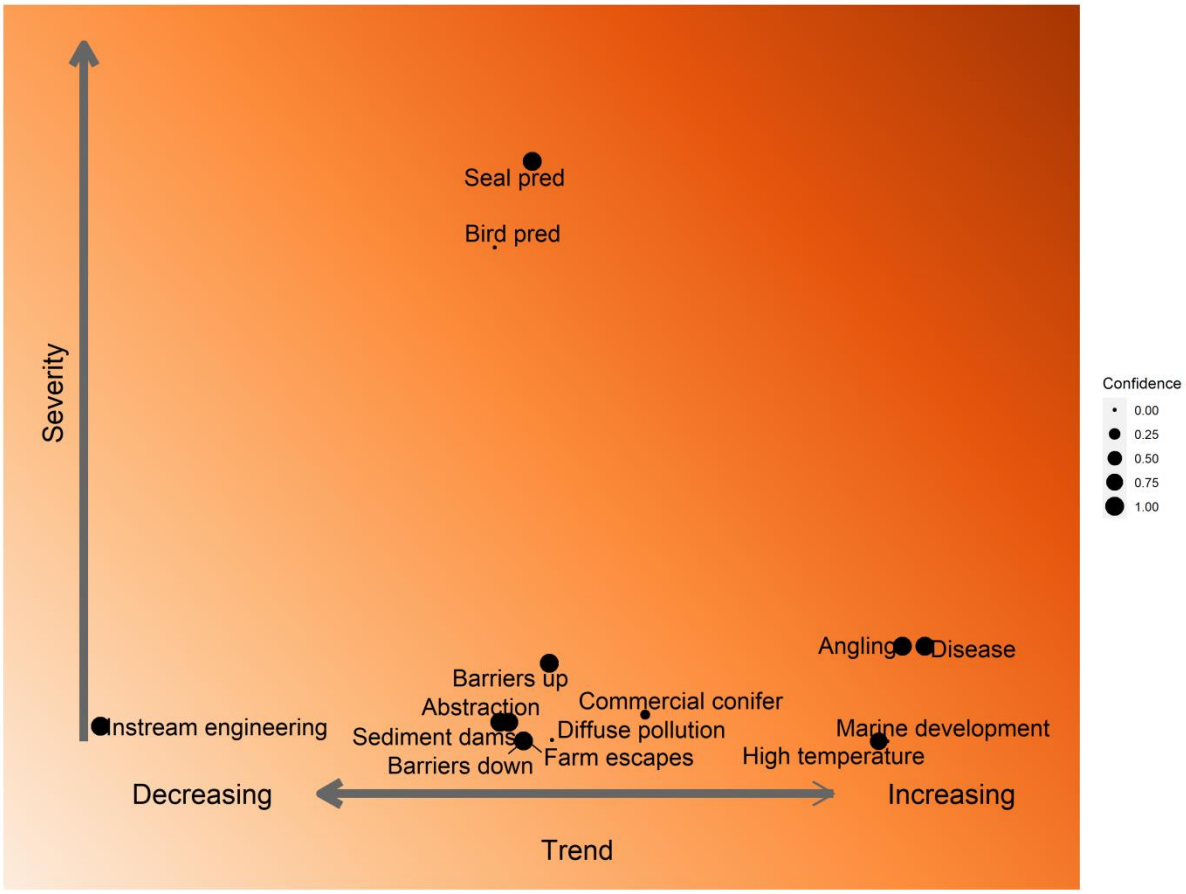

Figure 4. Summary of the importance of pressures in the North of Scotland. The horizontal x-axis indicates whether a pressure is declining / historical (left), generally stable / contemporary (centre) or increasing / emerging (right) over time. The vertical y-axis indicates the current severity of pressures as assessed and recorded by local fisheries managers. The size of points indicates the confidence that fisheries managers have in their assessment of the severity of an impact, with larger circles indicating greater confidence and underlying evidence of impacts. Lines connect points to associated labels of pressure categories.

3.4 West

- On the West of Scotland (Figure 5), coastal and in-river nets are considered to be historical pressures that are no longer having a major effect on salmon production.
- Sea lice from aquaculture is considered to be the greatest contemporary pressure, followed by predation from birds and seals.

- Climate change-related impacts of increasing temperature and high flows are highlighted as emerging pressures, but with very low current impacts. Thermal discharges are also highlighted as emerging pressures.

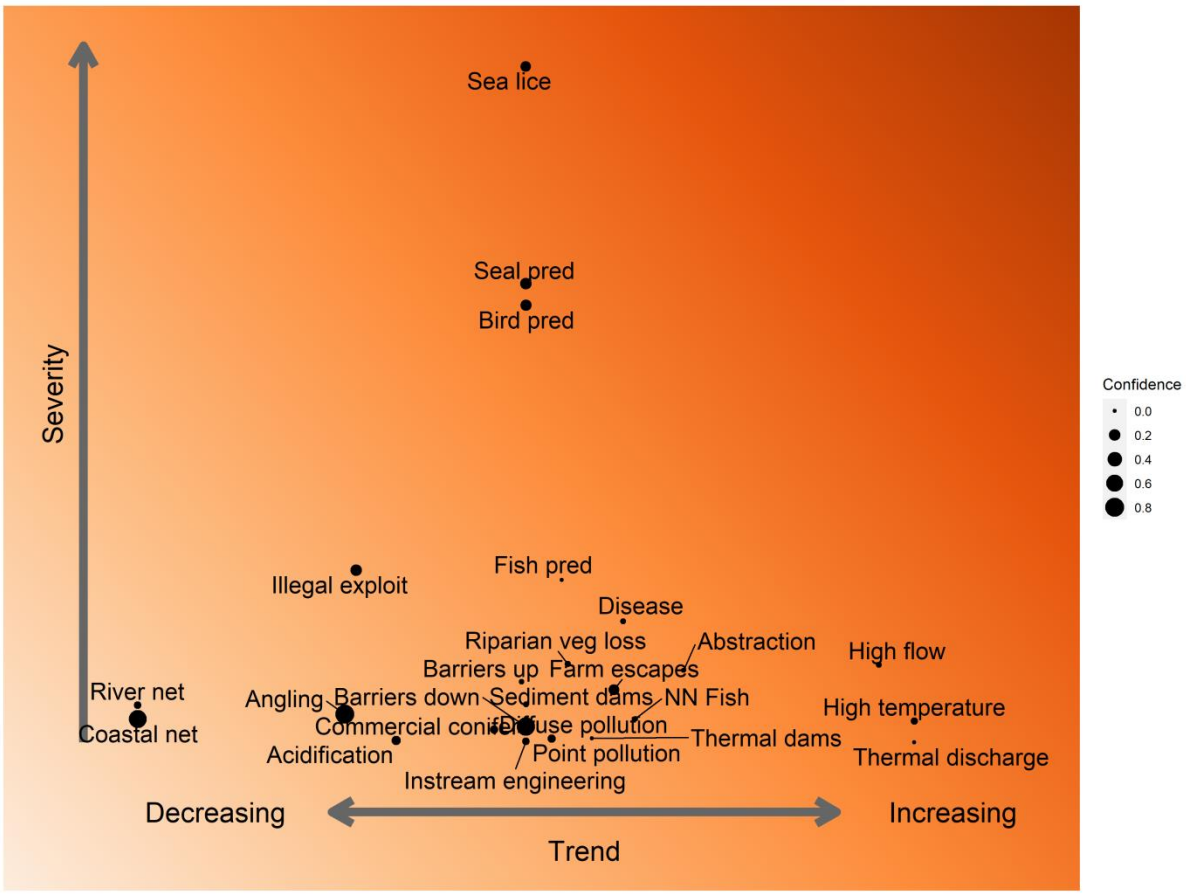

Figure 5. Summary of the importance of pressures on the West of Scotland. The horizontal x-axis indicates whether a pressure is declining / historical (left), generally stable / contemporary (centre) or increasing / emerging (right) over time. The vertical y-axis indicates the current severity of pressures as assessed and recorded by local fisheries managers. The size of points indicates the confidence that fisheries managers have in their assessment of the severity of an impact, with larger circles indicating greater confidence and underlying evidence of impacts. Lines connect points to associated labels of pressure categories.

3.5 South West

- In the South West of Scotland (Figure 6) in-river netting is highlighted as a declining pressure, but with a greater remaining severity than in other regions. The loss of natural riparian vegetation was also considered to be a declining problem, potentially in response to improved forestry practices.

- Barriers to upstream migration were considered the greatest contemporary problem followed by bird and fish predation and illegal exploitation, although confidence in the latter pressure was low.
- High river temperature and escaped salmon from fish farms were highlighted as the dominant emerging pressures. The latter pressure was considered to be of greater impact at the present time, but with very low confidence.

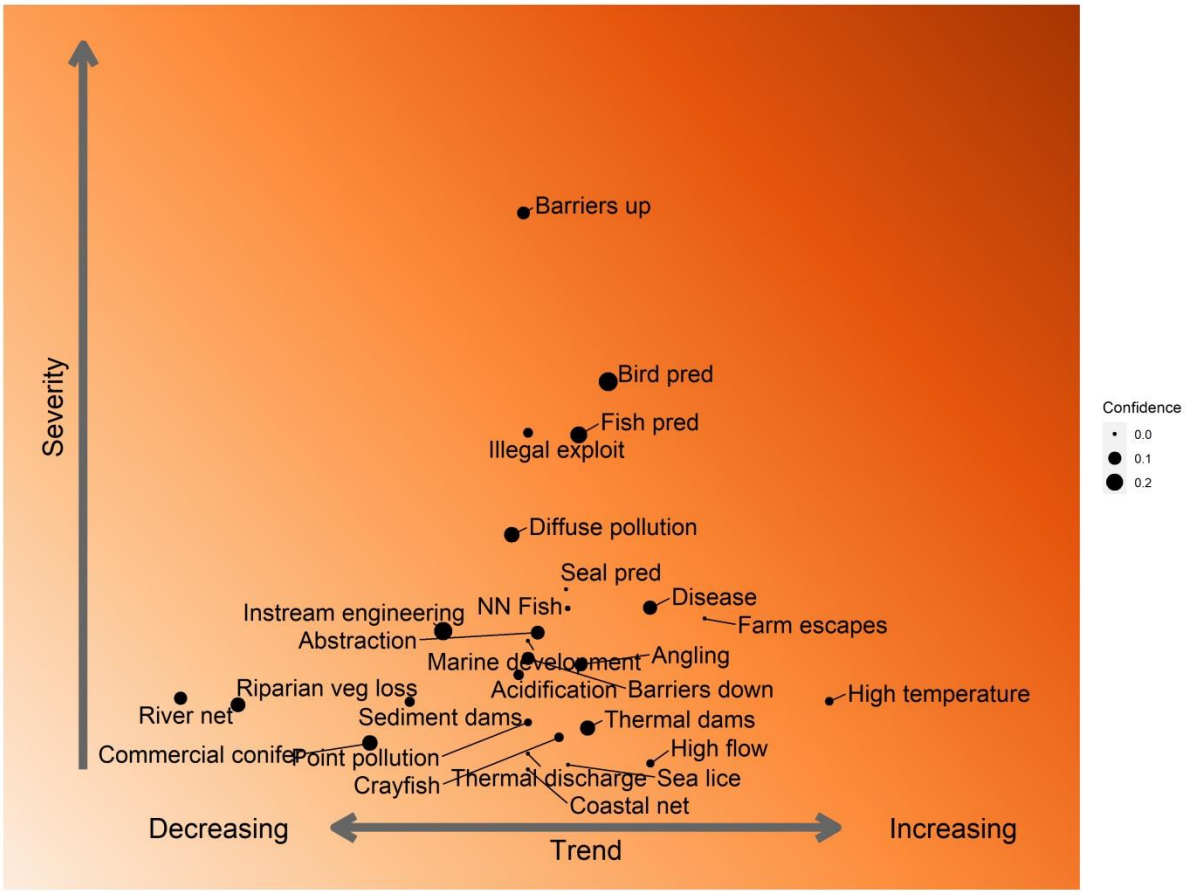

Figure 6. Summary of the importance of pressures in the South West of Scotland. The horizontal x-axis indicates whether a pressure is declining / historical (left), generally stable / contemporary (centre) or increasing / emerging (right) over time. The vertical y-axis indicates the current severity of pressures as assessed and recorded by local fisheries managers. The size of points indicates the confidence that fisheries managers have in their assessment of the severity of an impact, with larger circles indicating greater confidence and underlying evidence of impacts. Lines connect points to associated labels of pressure categories.

3.6 Pressures with an unknown severity

- In some circumstances local fisheries biologists considered that a pressure may have an impact, but that the severity of the impact was too uncertain to estimate. In these circumstances, the severity of the pressure was recorded as “unknown”, but the spatial extent of potential impacts was recorded. By calculating the percentage of river wetted area affected by this classification it is possible to highlight potentially important pressures for which there was a poor evidence base at the time of the pressure mapping exercise. The top ten most important pressures of unknown severity are shown in Table 1 below.
- In the case of predation and sea lice, these were also highlighted as regionally important pressures. In the case of marine development this highlights general concerns over a pressure for which there is not felt to be a strong evidence base on the likely severity of impacts.

Table 1. The percentage (area) of rivers in Scotland where a pressure was recorded as having an “UNKNOWN” severity. This indicates where local fisheries biologists consider that a pressure could be acting on salmon, but were unable to assign a probable severity of impact at the time of data collection.

Pressure	% Area
Marine development (Catchment Scale)	52.28
Farmed escapees (Catchment Scale)	40.21
Seal predation (Catchment Scale)	38.55
Changing Temperature Patterns & Loss of Shading (Reach Scale)	31.44
Sea lice (Catchment Scale)	26.88
Piscivorous fish (Catchment Scale)	25.68
Extreme high flow events (Reach Scale)	20.59
Stocking (Reach Scale)	18.45
Disease (Catchment Scale)	14.26
Non-Native or Translocated Fish (Reach Scale)	14.10

4. Summary

This report presents the first national summary assessment of the pressures acting on wild Atlantic salmon. Pressure data were populated by fisheries managers, who are tasked locally with safeguarding and improving wild salmon in Scotland. The data provide a baseline from which to assess change in perceptions and highlight areas where local managers believe there to be a particular need for improved evidence and understanding. This information will inform policy development and decision making in relation to managing pressures on wild salmon.

It should be acknowledged that understanding of the impacts of individual pressures is incomplete. As such there was a need for expert judgement, which will necessarily be based on a number of assumptions given available information and evidence. In addition, the initial assessments which underpin this report were undertaken in 2019, with a short period of refresh in early 2021. Since then new evidence has become available including improved understanding of genetic introgression[6] and the threats posed by climate change and water scarcity[7]. The current report should be considered in this context and represents a snap shot in time. Nevertheless, these caveats are by no means intended to diminish the value of the exercise since management of natural resources almost invariably requires the pragmatic application of best available information at the time.

This report has focussed on providing a high level summary of pressures; the associated Shiny Application and online GIS provide more detailed spatial information that will support the development of local fisheries management plans and management action to improve habitat for salmon.

Acknowledgements

The initial concept for mapping salmon pressures was developed by the Fisheries Management Plan template Working Group.

Sean Dugan of Fisheries Management Scotland / Scottish Fisheries Coordination Centre developed the online GIS used to hold data collected under this project.

The project was developed and managed as a collaboration between Marine Scotland and Fisheries management Scotland.

Pressure data were populated by Kyle of Sutherland Fisheries Trust, Cromarty Firth Fisheries Trust, Ness & Beauly Fisheries Trust, Findhorn, Nairn & Lossie Trust, Spey Foundation, Deveron, Bogie & Isla Rivers Charitable Trust, River Ythan Trust, River

[6] A national assessment of the influence of farmed salmon escapes on the genetic integrity of wild Scottish Atlantic salmon populations | Marine Scotland Data Publications

[7] NatureScot Research Report 1228 - Anticipating and mitigating projected climate-driven increases in extreme drought in Scotland, 2021-2040 | NatureScot

Don Trust, River Dee Trust, The Esks Rivers & Fisheries Trust, Tay Foundation, Forth Rivers Trust, Tweed Foundation, River Annan Trust, Nith Catchment Fisheries Trust, Galloway Fisheries Trust, Ayrshire Rivers Trust, Clyde River Foundation, Loch Lomond Fisheries Trust, Argyll Fisheries Trust, Lochaber Fisheries Trust, Outer Hebrides Fisheries Trust, Skye & Wester Ross Fisheries Trust, West Sutherland Fisheries Trust, Flow Country Rivers Trust, Caithness DSFB, Helmsdale DFSB, Brora DSFB, Kyle of Sutherland DSFB, Cromarty DSFB, Beauly DSFB, Ness DSFB, Nairn DSFB, Findhorn DSFB, Lossie DSFB, Spey DSFB, Deveron DSFB, Ugie DSFB, Ythan DSFB, Don DSFB, Dee (Aberdeen) DSFB, Esk DSFB, Tay DSFB, Forth DSFB, Tweed DSFB, Annan DSFB, Nith DSFB, Urr DSFB, Dee (Kirkcudbright) DSFB, Fleet DSFB, Cree DSFB, Bladnoch DSFB, Luce DSFB, Stinchar DSFB, Girvan DSFB, Doon DSFB, Ayr DSFB, Eachaig DSFB, Argyll DSFB, Laggan and Sorn DSFB, Lochaber DSFB, Skye DSFB, Wester Ross DSFB, Western Isles DSFB, The North and West DSFB, Northern DSFB

Karen Millidine and Iain Malcolm developed approaches for summarising and presenting the pressures data at different spatial scales and drafted this report.

The overall approach and resulting data summaries were reviewed by a Technical Working Group whose members are outlined in Appendix 2.

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Torbjørn Forseth, Bjørn T. Barlaup, Bengt Finstad, Peder Fiske, Harald Gjøsæter, Morten Falkegård, Atle Hindar, Tor Atle Mo, Audun H. Rikardsen, Eva B. Thorstad, Leif Asbjørn Vøllestad, Vidar Wennevik, The major threats to Atlantic salmon in Norway, ICES Journal of Marine Science, Volume 74, Issue 6, July-August 2017, Pages 1496–1513, https://doi.org/10.1093/icesjms/fsx020

Appendices

Appendix 1. Summary of Pressure Themes, Individual Pressures, Short Names, Spatial Scales of Data Capture and Definitions used in this Report

Theme	Pressure Name	Short Name	Scale of Data Capture	Brief Description
Exploitation	Illegal exploitation	Illegal exploit	Catchment	Poaching or illegal killing of salmon from rivers classified as category 3 under the Scottish Government Conservation Regulations
	Coastal netting	Coastal net	Catchment	Impacts of coastal netting (now only historical)
	In river & estuarine netting	River net	Catchment	Legal net fisheries operating in rivers and estuaries. May include impacts of historical fisheries which have now been closed
	Rod & line	Angling	Catchment	Killing of salmon by rod and line fisheries
Predation	Piscivorous birds	Bird pred	Catchment	Impact of predation by piscivorous birds on salmon smolts
	Piscivorous fish	Fish pred	Catchment	Impact of predation by piscivorous fish on salmon smolts
	Seal predation	Seal pred	Catchment	Impact of seal predation on adult returns
Disease	Disease	Disease	Catchment	Effects of disease on adult spawner numbers and condition
Farmed escapees	Farmed escapees	Farm escapes	Catchment	Impact of genetic introgression or direct competition resulting from escaped farmed salmon
Marine development	Marine development	Marine development	Catchment	Impact of marine developments including harbour developments and marine renewables but not aquaculture which is addressed separately
Sea lice	Sea lice	Sea lice	Catchment	Impact of sea lice from aquaculture
Invasive Non-Native Species (INNS)	Crayfish	Crayfish	Reach	Impact of invasive crayfish
	Non-Native or Translocated Fish	NN Fish	Reach	Impact of fish that have been introduced outside their native range

Habitat - Water Quality	Acidification	Acidification	Reach	Impact of acidification
	Point-source pollution	Point pollution	Reach	Impact of point-source pollution (e.g. septic tanks or licenced discharges)
	Diffuse pollution & Eutrophication	Diffuse pollution	Reach	Impact of diffuse pollution and eutrophication (incl. sedimentation, high nutrient concentrations, pesticides etc.)
Habitat - Water Quantity	Abstraction & Flow Regulation	Abstraction	Reach	Impacts resulting from a reduction in water quantity through abstraction and flow regulation (e.g. hydropower)
	Extreme high flow events	High flow	Reach	Impact of extreme high flow events
Habitat - Thermal	Changing Temperature Patterns & Loss of Shading	High Temperature	Reach	Impacts caused by an increase in water temperature due to loss of shading and / or climate change
	Thermal discharge	Thermal discharge	Reach	Impacts of discharging warm water by industry (e.g. whisky distilleries)
	Thermal Modification due to Impoundment	Thermal dams	Reach	Impacts of altered thermal regime caused by large impoundments
Habitat - Instream & Riparian	Loss of sediment transfer	Sediment dams	Reach	Impacts due to a loss in sediment transfer (e.g. sediment starvation below dams)
	Instream Works Including Canalisation / Dredging / Boulder removal	Instream engineering	Reach	Effects of instream engineering works
	Loss of natural riparian vegetation	Riparian veg loss	Reach	Effects of losing natural riparian vegetation; changes in habitat and resource provision
	Conifer afforestation	Commercial conifer	Reach	Effects of commercial conifer afforestation (e.g. impacts on in-stream productivity and food availability)
Obstacles to Fish Passage	Downstream passage	Barriers down	Reach	Effects of reduced downstream connectivity
	Upstream passage	Barriers up	Reach	Effects of reduced upstream connectivity

Appendix 2. Members of the Technical Working Group who Provided High Level Review of the Assessment of the Pressures

Alan Wells	Fisheries Management Scotland (chair)
James Hunt	River Tweed Foundation
David Summers	Tay District Salmon Fisheries Board
Keith Williamson	Kyle of Sutherland Fisheries
Alan Kettle-White	Argyll Fisheries Trust
Jamie Ribbens	Galloway Fisheries Trust
Chris Todd	University of St Andrews
Sean Dugan	Scottish Fisheries Coordination Centre
Colin Bean	NatureScot
Peter Pollard	SEPA
John Armstrong	Marine Scotland Science
Iain Malcolm	Marine Scotland Science
Karen Millidine	Marine Scotland Science
Antje Branding	Marine Scotland

Appendix 3. List of Abbreviations

DSFB District Salmon Fishery Board

GIS Geographical Information Systems

NEPS National Electrofishing Programme for Scotland

SEPA Scottish Environment Protection Agency

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