

IMPACTS OF OPEN PEN FRESHWATER AQUACULTURE PRODUCTION ON WILD FISHERIES



Loch Tollaigh

(Photo: Dr E Verspoor)

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Homarus Ltd.
Fisheries and Aquaculture Specialists
Estate Yard House, High Street
Beaulieu, Hants, SO42 7YB, UK.

Tel: +44 (0) 1590 611250
Email: admin@homarusaquafish.co.uk
Web: www.homarusaquafish.co.uk

Client: Marine Scotland, Performance, Aquaculture and Recreational Fisheries

**Report – STUDY INTO THE IMPACTS OF OPEN PEN FRESHWATER
AQUACULTURE PRODUCTION ON WILD FISHERIES**

Authors:	Patrick Franklin, Eric Verspoor and Richard Slaski on behalf of, Homarus Ltd. Fisheries and Aquaculture Specialists
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Executive Summary

Introduction

The study described in this report was commissioned by Marine Scotland, against a backdrop of concerns about the possible impacts of freshwater aquaculture on the health of wild salmonid populations in Scotland. The study was undertaken by Homarus Ltd, a niche advisory firm in fisheries, aquaculture and the marine environment, and was managed by a Steering Group appointed by Marine Scotland.

Atlantic salmon (*Salmo salar* L) farming has expanded rapidly since the 1970's, with some 154,000 tonnes of fish being produced on the northern and western fringes of Scotland, worth £540 m annually on an ex-farm basis, and some £1 billion annually at retail. The industry is a major employer and investor in the economies of many remote rural/coastal communities. The Scottish industry exports all over the world, and sees opportunities to expand its production over the coming years, in keeping with rising global demand/need for aquaculture products in general, and Scottish salmon in particular. A mid-range target of some 220,000 tonnes per annum is assumed for the year 2022, for the purposes of this report.

Wild salmonids, and particularly salmon and sea trout (*Salmo trutta* L), are also widely perceived to be iconic features of Scotland's natural heritage, and are a "resource to be held in trust for future generations by all the fishing nations of the North Atlantic"¹. They are also integral to a range of rural businesses in Scotland, with an estimated value of £100m per annum through angling and related activities, (though this measure of economic benefit is not on an equivalent basis to farmed salmon values given above).

The status of Atlantic salmon stocks across the whole North Atlantic continues to give concern², and whilst the rod-caught (released and retained) catch in Scotland has held up well, the overall abundance of fish has probably continued to decline, given that the catch (and effort) of coastal netting stations has significantly diminished. Many factors can affect the health of salmon populations and stocks, and marine mortality is seen as a key issue at an international scale. At a local and national level, factors such as pollution, predation, over-exploitation, commercial netting, impassable barriers, degradation of spawning/feeding environments and the presence of aquaculture are all important in terms of fisheries management, policy planning and grounds for conservation-based intervention. The current study is intended to address a sub-set of one of

¹ David Crawley, Chair of the Scottish Mixed Stock Salmon Fisheries Working Group.

² <http://www.ices.dk/committe/acom/comwork/report/2011/Special%20Requests/AdviceNASCOIntroduction.pdf>

these factors: possible impacts on wild salmonids from the presence of pen-based salmonid farming in freshwater bodies.

The study has addressed two fundamental questions:

What is the strength of evidence for negative effects on wild salmonid populations caused by freshwater pen culture?

What are the costs and benefits associated with partial or total phasing out of freshwater pen culture?

Evidence for Interactions between Freshwater Pen Farms and Wild Salmonids

The study has reviewed all of the available scientific literature in this field, as well as entering into dialogue with a range of national and international experts. The biological review has focused on three main subject areas:

1. Evidence of the potential pathways and mechanisms for freshwater pen aquaculture to impact on wild fisheries, whether through direct or indirect physical or environmental pathways, or through interactions of one sort or another with the genetic character of individual wild salmonid populations
2. Evidence of whether the identified pathways *could* occur in Scotland, given the physical co-occurrence of pens with wild stocks and farming practices
3. Evidence of whether such impacts *have* occurred in Scotland.

The physical co-occurrence of pen farms with wild salmonid stocks has been considered, and the following points are highlighted in the report:

- There are 42 pens sites for salmon smolts and 6 sites for rainbow trout (*Oncorhynchus mykiss*).
- These sites currently produce 20.3 million smolts per annum, and 1600 tonnes of marketable table trout.
- This pen output is on average 49% of the total smolts produced in Scotland in recent years, the remainder being produced in land-based farms of various levels of sophistication. The trout production is 32% of the total trout harvested each year, with the remainder being split between land-based sites and marine pen sites.
- In terms of co-occurrence between salmon smolt pen farms and other features/areas:

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- 6 out of the 42 salmon sites (14%) are located within 3 catchments that contain part of their river systems designated as Special Areas of Conservation (SACs) primarily designated/featured for Atlantic salmon (and also often freshwater pearl mussel (*Margaritifera margaritifera*)) – of which there are 17 such SACs in total in Scotland.
 - Wild salmon are known to be present in the catchments where 34 of the sites are located (81%), while sea trout are probably present in all of them.
 - Pen farms are present in 17 of the 109 Fishery Districts in Scotland, and these 17 districts contribute 11% of the overall annual Scottish wild salmon catch.
- In terms of co-occurrence between trout pen farms and other features/areas:
 - 2 out of the 6 trout sites are located within 2 catchments that also contain part of their river systems designated as Special Areas of Conservation (SACs) primarily designated/featured for Atlantic salmon and freshwater pearl mussel.
 - Wild salmon are known to be present in the catchments where 4 of the sites are located (80%), while sea trout are probably present in all of them.
 - Pen farms are present in 4 of the 109 Fishery Districts in Scotland, and these 4 districts contribute 12% of the overall annual Scottish wild salmon catch.

The review of the literature for the potential interaction between wild and farmed salmonids suggests that existing biological understanding, combined with what is known specifically about freshwater loch (lake) ecosystems, shows there to be a general biological potential for reproductive and ecological interactions between wild salmonid fish populations and Atlantic salmon and rainbow trout reared in freshwater pens in lochs where the two are coincident.

Few scientific studies have been carried out into specific effects of freshwater pen rearing on wild salmonid populations and understanding of the actual potential for interaction is limited. What studies have been undertaken support the view that there is a *possibility* of impacts on wild populations of salmonids in Scottish freshwater lochs from freshwater pen operations with farmed Atlantic salmon or rainbow trout. However, more research is needed to understand the nature of actual interactions that could occur and the extent of any impacts that might arise.

The report describes the current practices of the freshwater aquaculture sector, and focuses on recent improvements in equipment and operating standards. It also describes possible future advantages to increased use of freshwater pens, in terms of lowering production costs and improving the prospects for sea lice management in the marine environment.

The history of reported escapes is reviewed, as is evidence that some escape incidents appear to have gone unreported.

Consideration of what is generally known about the state of wild salmonid populations suggest that wide ranging population-level impacts have not taken place. MSS catch statistics show no dramatic differences in numbers over the last two decades between rivers with or without freshwater pens. There are no instances where rivers with freshwater pens have lost their salmon runs or have even become severely depressed when compared to rivers without freshwater pens. In contrast there are cases where dramatic declines have been associated with hydroelectric developments.

Lack of firm evidence does not necessarily indicate that impacts are not or have not been occurring, only that they have not so far been clearly identified. That there is the theoretical potential for them to exist is clear. The report goes on to discuss the types of future monitoring and specific research that are required in order to answer the question with any degree of certainty.

Costs and Benefits Associated with any Policy Change

The second part of the study has been progressed as per the brief, even though it remains unknown whether the use of freshwater pens has, or might in future, impact upon wild salmonids. It considers what the hypothetical implications of such policy shifts might be, if they were to be contemplated in the future, perhaps on the basis of new evidence.

The main focus has thus been on establishing the likely costs and benefits associated with alternate arrangements for freshwater stages of production, with particular focus on the restriction or phasing out of freshwater pen use.

Working with industry and its suppliers, and cross-referencing with literature reports, models of the capital and operating costs of salmon smolts and rainbow trout are presented, differentiated between different types of pen and land-based production. These core assumptions about cost are then factored into a consideration of a range of scenarios that might arise if policy changes on freshwater pen production are implemented.

The growth potential of the industry is a key element of such an analysis, as are more detailed considerations such as ongrown product yield per smolt put to sea. Taking a range of projections into account, it is possible that within the next 10 years, the Scottish salmon industry might

require (at a mid-range estimate) some 55 million smolts per annum, i.e 19 million more than the current production. High and low estimates of smolt demand are also examined.

The **costs** of meeting such a requirement for smolts is considered according to different scenarios of restriction on pens in freshwater bodies, compared to a “do nothing” situation under which it is assumed that smolt production would gradually expand, retaining the current ratio of pen to land-based capacity. The same type of scenario modelling is also undertaken for rainbow trout production. The costs are ascribed in numeric economic terms to the industry, and qualitatively to other sectors that might be involved, e.g. public sector and other stakeholders. In summary, the net present costs of the different scenarios of change at varying projections for industry expansion are shown in Table A:

Table A: Summary of estimated costs associated with scenarios for change in freshwater pen production (central projection for smolt demand white, high demand projection pink, low demand projection brown)

Scenario	Description	Aquaculture Industry Net Present Cost (£m)			Other (relative score)			
		Central	High	Low	Public	Angling	Env	Total
1	Improved containment	3.6	4.3	2.9	2	0	2	4
2	No FW pens, no new land-based capacity, replace with imports	10.5	13.2	8.2	5	4	4	13
3a	Hold pens at 2011 levels, expand using new land-based capacity	11.9	23.7	2.0	2	0	4	6
3b	Reduce pens to half 2011 levels, replace and expand using new land-based capacity	27.0	38.6	16.9	3	0	6	9
3c	Reduce pens to zero, replace and expand using new land-based capacity	41.8	53.5	31.7	4	0	6	10

In the latter three scenarios, additional smolt capacity is assumed to be provided by a combination of modern flow-through land based farms and RAS units.

The **benefits** of the changes of policy scenarios are also described, although the difficulty in ascribing a numeric economic value to these is considered and discussed. Some numerical economic consideration is given to the possible defensive benefits to the commercial angling sector, on the assumption that catchments associated with pen aquaculture production might be affected if there were demonstrable future (and negative) impacts from the continuation of the aquaculture operations.

The costs described above are economic, but the report also considers the financial and strategic implications of any policy changes with respect to use of freshwater pens, should policies be introduced on the basis of new information or as a precaution. These are discussed in conjunction with issues such as industry profitability, historic and projected market price changes, existing regulatory costs and the ability of the sectors to raise capital, if required. The main findings are:

- The capital costs of the most restrictive options (phasing out of pens) are significant and could be challenging for the Scottish salmon farming subsidiaries of international companies in terms of attractiveness of Scotland for future investment. They would be unaffordable for the trout sector, automatically leading to a further decline in overall production in Scotland.
- The increased production costs arising from the different options might seem affordable based on salmon profitability trends in recent years, but could become very problematic in the future if global salmon prices decline. The margins in trout farming are already very low, and the increased production costs that might arise as a result of some of the policy options would seriously endanger the viability of that sector.

One of the scenarios modelled assumes that any restrictions on future use of pen farms in freshwater might prompt the salmon sector to seek its additional smolt requirements by way of imports from areas of equivalent health status. The implications of this possibility are discussed, and generally considered to be undesirable. The other important consideration is uncertainty about whether sufficient suitable locations exist for constructing new large land-based units. Economy of scale would be an important feature of any future development, irrespective of policy scenarios.

Discussion and Conclusions

Several key points have emerged from this study:

- The theoretical potential for negative impacts on wild salmonids as a result of the presence of freshwater aquaculture is clear where they are physically coincident
- At a national level the large majority of the wild salmon and trout populations in Scotland are not physically coincident with freshwater pen sites
- The actual impacts on wild salmonid populations in Scotland from freshwater pen rearing of salmon and rainbow trout remain more or less unknown. Only a few studies, many quite old, have been carried out to date which address the question of actual interactions and impacts. These studies are restricted in the scope of their investigation of the question of impacts and confined to investigations of single lochs

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- There is no evidence of broad-scale impacts in terms of catch statistics and other obvious measures of wild salmonid stock/population health
 - Freshwater pen aquaculture is only one of the several factors that might affect the health of wild salmonid stocks/populations
 - Pen-farmed salmonids still escape, and therefore still offer a potential threat to wild salmonids – no matter how remote or how equivocal in terms of current scientific evidence
 - There is evidence that some pen escapes have not been reported through the Marine Scotland mandatory self-declaration system
 - The benefits of a change of policy now are by no means clear, taking into account current scientific knowledge
 - The impact of financial costs on salmon production arising from restrictions in freshwater pen use to rear smolts range from minor to moderate in years of strong market prices and good profitability, to major or possibly prohibitive in years with poor prices and profitability. The impact on trout production is considered major or prohibitive throughout.

On the basis of the above key points and the other wide range of evidence gathered for this study, the authors conclude that:

- There does not appear to be a robust evidential case for suggesting radical and potentially expensive policy change regarding freshwater pen use.
- The least radical option in terms of costs would be mandatory improved containment. This would reduce but not eliminate most of the potential risks to wild stocks in those catchments in which pens are located. Tightening of the regulatory regime in this regard would not be unreasonable given the current state of knowledge regarding impacts. It would be logical for improvements in freshwater containment to go hand-in-hand with that for marine pens.
- Associated with improvements in containment, it is recommended that
 - A formalised regime of sampling for escaped fish in catchments containing pens should be established, independent of the industry self-reporting system that currently exists. Details of such a scheme require further consideration: scope of sampling, how much it would cost, and how it would be funded
 - Scientific Assessment of Impacts of Escapes. There should be a robust scientific assessment, probably on a specific catchment/project basis, of the *actual* impacts of farmed escapes, if and when they occur.

1 Introduction

1.1 Study overview

This report covers work undertaken on a Contract Research Fund study commissioned by Marine Scotland: "IMPACTS OF OPEN PEN FRESHWATER AQUACULTURE PRODUCTION ON WILD FISHERIES".

The study was undertaken by Homarus Ltd, a niche advisory firm in fisheries, aquaculture and the marine environment. It is being managed by the Performance and Aquaculture Division within Marine Scotland who have established a Steering Group to assist with oversight of the study.

The study was commissioned in late August 2011, with a start-up Steering Group meeting in early September 2011. Interim reporting and a Steering Group took place in late January and early February 2012, followed by a draft final report and Steering Group meeting in April 2012. This report is the final version and incorporates comments made by the Steering Group. Other outputs include a technical workshop for stakeholders which is planned for July 2012.

The study objectives and methods requested by Marine Scotland in the study brief are set out *verbatim* in Appendix 1.

1.2 Study background and rationale

The development of marine salmon farming in the northern and western fringes of Scotland has been rapid, with production rising to some 154,000 tonnes in 2010³ from small beginnings in the 1970's. The ex-farm value is £540m and global retail sales value of some £1 billion, (latest Scottish Government estimates). The industry is a major employer and investor in the economies in the remote rural fringes⁴.

To achieve this output, the ongrowing industry uses around 40 million smolts that are currently produced in tanks using river water or pens located in freshwater bodies, mostly in western and northern Scotland. The number of smolts stocked in marine sites has been relatively static or trending slightly downwards in recent years. However, there are medium to long term plans to

³ Scottish Fish Farm Production Survey Report, 2010. Marine Scotland Science

⁴ See, for example, Scottish Salmon Producer Organisation Industry Research Report at: <http://www.scottishsalmon.co.uk/mediacentre/releases/2010/documents/FINALSCOTTISHSALMONFARMINGINDUSTRYRESEARCHREPORT.Dec2010.pdf>

expand the industry, provided that profitability can be maintained, with a prevailing view that EU and global demand will stay strong. With yields per smolt possibly near a realistic maximum, expansion of salmon production in Scotland is going to increase demand for smolts. Indeed, estimated smolt production in the latest Marine Scotland survey suggests a sharp upswing for 2011 and 2012. Recent smolt usage, trends and predictions in demand are discussed in more detail later in the study.

Just under half of Scotland's smolt production is from pens in freshwater bodies, while the remainder is derived from tank-based systems.

Concern in a number of stakeholder sectors has been expressed that freshwater pen production may lead to significant negative impacts on the character, productivity and viability of wild fish populations, and in particular those of Atlantic salmon, sea and brown trout. Concern is currently largely focused on the direct effect of escaped farm fish, through either ecological or reproductive interactions, the former encompassing both farmed salmon and rainbow trout and the latter focused on farmed salmon.

The concerns are also set out in the study brief and cover possible interbreeding, competition for habitat and alterations to behaviour. Both large episodic escapes and ongoing, low level, unrecorded escapes are perceived as being potentially problematic and contributing significantly to observed, documented declines in Scottish salmon and sea trout stocks observed over the past three decades. The status of Atlantic salmon stocks across the whole North Atlantic continues to give concern⁵, and whilst the rod-caught (released and retained) catch in Scotland has held up well, the overall abundance of fish has probably continued to decline, given that the catch (and effort) of coastal netting stations has significantly diminished. In some parts of Scotland, declines in sea trout appear even more marked than for salmon and significant differences appear to occur across regions.

In addition to their inherent conservation value, both salmon and sea trout are targeted by game anglers and any significant decline in their stocks risks declines in angler activities and spending in rural areas, as well as reduced capital values of game fishing waters and depressed amenity values of catchments. Expenditure on angling for salmon and sea trout in Scotland was estimated at £73m in the early 2000's⁶. This information is now somewhat old and inflationary factors mean this figure might currently be around £100m. Angling thus represents a significant economic activity and is a direct and indirect employer.

⁵ <http://www.ices.dk/committe/acom/comwork/report/2011/Special%20Requests/AdviceNASCOIntroduction.pdf>

⁶ Economic Impact of Game and Coarse Angling in Scotland, Scottish Executive, 2004

Concern also exists, though this is less widely or strongly expressed, with regard to the impacts of freshwater cage farms on the nutrient loading and the biological communities of lochs in which they are placed, as well as to local wild fish stocks feeding on farm pellets falling through and below cages. Increased nutrient levels have the potential to change the abundance of planktonic and benthic species with possible knock-on effects for the viability of some resident fish species. There is also concern that the presence of an additional, alternative food source may reduce the tendency of local trout stocks to undergo a marine migration thereby reducing local sea trout numbers. These concerns have become more focused since the introduction of new water body classifications, recommended by the UK Technical Advisory Group under the auspices of the Water Framework Directive and accepted by Scottish Ministers. This issue, of considerable interest to SEPA and other parts of the Scottish Government, is complex and largely outside the scope of this project, but reference has been made to aspects of it within the report, where they are relevant to any considerations or conclusions.

Any aquaculture operation involving pens involves risk of escapes, no matter how good the equipment. As such there is a call from some quarters that the risk should be removed completely by the transfer all of the freshwater phase of smolt to tanks and the replacement of freshwater pens for trout with conventional systems (ponds and raceways) or sea water pens. The economic costs of such changes are likely to be substantial, primarily in respect of capital expenditure but also in operational terms.

The study thus aims to address two fundamental questions:

What is the strength of evidence for negative effects on wild salmonid populations caused by freshwater pen culture?

What are the costs and benefits associated with partial or total phasing out of freshwater pen culture?

The study is therefore split into two main workstreams:

1. Evidence of effects on wild populations

This essentially addresses the state of knowledge concerning the interaction of farmed salmonids in freshwater pens and wild salmonids. It is achieved through a literature review of the situation both in Scotland and further afield. It also includes a synthesis of

information on river systems where pen farms are located. This section finally includes a review of research activities and knowledge gaps in this field.

2. Mitigation options and economic and financial implications of a change to closed tank systems

This part of the study makes a brief review of “high level” mitigation options for reducing potential impacts to wild salmonids. It then goes on to make a more detailed analysis of the consequences of possible policy change regarding permitted production methods involving freshwater pens. Various scenarios are used to assess the economic costs associated with restriction on further expansion in the use of pens, as well as reduction from their current use and their total phasing out. The majority of this workstream concerns salmon smolt production, as the number of open pen sites currently used and their economic importance is considerably higher than those for trout. Implications of enforced changes in production technique are also assessed in financial terms as well as site and employment requirements.

1.3 Study implementation

Study team

The study was carried out by a team of three led by Patrick Franklin of Homarus Ltd. Members of the study team and their broad areas of responsibility are outlined below.

- Dr Eric Verspoor: One of the UK’s leading salmon biologists and authorities on wild salmon genetics, with over 35 years experience in genetics and fisheries science, has authored over 150 peer reviewed papers, book chapters, and reports, and for the last 20 years worked in Scotland with the salmon aquaculture and wild fisheries sectors; led 2002-2005 EU SALGEN review of Atlantic salmon genetics related to their conservation management; member of steering committee for 2007-2009 EU GENIMPACT review of genetic impacts of cultivated native European species on wild stocks; recent work encompasses studies of loch fish biodiversity in Scotland and direct genetic impacts of smolt escapes from freshwater cages.

Eric was responsible for the review of the state of national and international knowledge related to potential for impacts, examination of the evidentiary basis for impacts in Scotland and identification of research needs and priorities.

- Richard Slaski: Senior and established advisor in fisheries and aquaculture at strategic, policy and management levels in Scotland. Excellent existing working relationship with

many of the stakeholder individuals and groups who need to be consulted and proven track record in stakeholder engagement in Scotland. Over 30 years experience of designing, building, operating and consulting on land-based aquaculture in the UK, Europe, Canada, Chile, Turkey, New Zealand and China.

Richard led on assessment of current freshwater farming practices and developing capital and operational cost models for different methods of production.

- Patrick Franklin: Significant knowledge of the UK and Scottish aquaculture industry, technologies and economics. Long experience of leading impact studies in the fisheries and aquaculture sector on behalf of EU, government and private sector, leading researcher and author of several aquaculture-related studies on behalf of Scottish Government in recent years.

Patrick led on scenario building and testing and in assessing the implications of a change in production method for the overall industry.

Structure of this report

The structure of this Final Report follows that set out in the Interim and Draft Final reports and was accepted as broadly meeting the needs of the study by the Steering Group. It is set out in a logical sequence with two main sections, one describing methods used in the study (Section 2), followed by all the study findings in one substantive section (Section 3). Each of these main sections is divided according to the two main workstreams of the study, i.e.

- biological aspects of interactions between open pen aquaculture in freshwater and wild salmonids
- costs and implications for restricting open pen aquaculture in freshwater in Scotland.

Section 2 thus describes information sources, approaches to the workstreams and methods used to analyse data. Section 3 covers all findings of the study, opening with a review of the evidence of impacts freshwater pen farming on wild populations, followed by an assessment of costs which might arise from a change in smolt production methods. Section 3 closes with an assessment of financial implications for the aquaculture industry of such changes.

2 Study methods

2.1 Impacts on wild populations

Review of published biological studies

Published scientific literature relevant to understanding the impacts of freshwater cage rearing of salmonids in the northern hemisphere was assembled and reviewed. In the first instance, the review encompasses the literature related to defining the general potential for impacts on local native fish populations, based on current scientific understanding of population interactions in freshwater ecosystems. Secondly, the review examines the published scientific evidence that impacts have actually occurred in respect of populations of Scottish salmonids. These two sets of evidence are considered separately.

The review first addresses whether there is a general case that impacts could occur from freshwater pen rearing and secondly the specific evidence of interactions between pen-reared salmonid fishes and wild salmon populations generally. A conceptual framework for interactions is set out using insights from the broader biological literature relating to interactions between cultured and wild fish in aquatic environments. It encompasses all likely sources of impact and pathways of interaction, including both direct genetic and indirect ecological impacts, and considers the available scientific evidence for the nature and importance of each framework element. This framework is used to structure the way in which the actual evidence for impacts is considered. The general observational or experimental evidence that potential interactions may in fact occur, focusing on studies of salmonid species is reviewed. However, where salmonid studies were limited or lacking, the review was extended to evidence from studies of other species. The objective of this part of the review was to identify those potential pathways for which there was actual evidence regarding the effects of pen rearing or of impacts.

A potential for impacts to occur does not mean that impacts have actually occurred in a specific context, only that they could. For impacts to occur, interacting elements must be spatially coincident. Thus the spatial co-incidence of freshwater cages and salmonid populations in Scotland is reviewed. The overlap in the distribution of freshwater pen sites with those of the six Scottish salmonid species is examined. In addition to spatial coincidence, the extent of any interaction will be conditioned by the absolute numbers of the interacting elements as well as their relative abundance. Thus the spatial coincidence of wild and farmed fish, as well as their absolute and relative numbers, needs to be considered in determining the actual potential for impact in a given context.

Towards addressing this issue, the latest information on the distribution of freshwater pen and wild salmonid species in Scotland is compiled. Additionally, numbers of reported escaped farmed salmon and rainbow trout were collated from MSS information and discussions were held with MSS in respect of the ability to accurately quantify number of wild salmonids in lochs ecosystems generally and the availability of useful information for lochs with freshwater pens considered.

Finally, the review considers published scientific papers as well as unpublished reports providing insight into the actual nature and extent of interactions and impacts in locations in Scotland where freshwater pen rearing and wild salmonid populations are coincident. The scope for comparing the status of salmonid populations in catchments with freshwater pens compared to those without is explored in respect of Atlantic salmon, the only species for which there is widespread data on numbers of juvenile or adult fish. The quality of the science and the evidentiary base, its comprehensiveness and the specific research gaps that might limit the ability to draw conclusions, were evaluated.

The search for relevant primary literature was carried out in the first instance using Google Scholar. Libraries such as that of Marine Scotland Science Freshwater Laboratory were visited to search for historical literature and general biological information relevant to the review. Additionally, Trust biologists working in the field were consulted as were individuals working in the farming sector. Finally, scientists working in the field of interactions between farmed and wild salmonids in Canada, Iceland, Norway, Ireland and the UK, the countries, where freshwater cage rearing has been carried out historically or is presently practised, were contacted.

Scale and location of industry

In order to assess the implications of freshwater aquaculture in relation to any possible interaction with wild freshwater species, it is essential to know in detail:

- Where each aquaculture unit is located, and what species it produces
- What type of unit: tank-based; pen-based
- What scale of production (either as annual production biomass or maximum permitted biomass on site)
- How aquaculture units are located with respect to salmonid fishery districts

Information sources have been as follows:

*Marine Scotland Science Annual Production Survey*⁷.

The most recent version of the survey to have been published is 2010 and provides good national level information on freshwater production, number of type of sites, volumes involved etc. Unfortunately spatial information is rather limited.

Public Database of Production Sites

Additional information was obtained about freshwater aquaculture units from the Scottish Government website⁸. The Excel file is useful because it provides:

- The name of the fish farming company and the name of the site
- The registration number for the site
- OS Grid reference
- An indication of the type of aquaculture unit: fresh or sea water; pen or tank/raceway/recirculation system
- Species of fish produced
- Various aspects of fish health status

The Excel spreadsheet requires significant manipulation in order to analyse it for particular types of species or production system, and it contains no information about the size or volumes of the fish holding units. It also does not contain any details about scale of annual production (in terms of number or biomass of fish) or about maximum holding capacity in terms of biomass.

Specific Information from MSS

The individual site key information was requested from MSS for the current and historic freshwater sites in Scotland.

The study team received information in the form of various spreadsheets and several shape files. These various files, together with the public database, have allowed the team to sort the various sites and generate a list of freshwater pen sites in terms of:

- Site number
- Site name
- Location

⁷ <http://www.scotland.gov.uk/Publications/2011/11/17152846/4>

⁸ <http://www.scotland.gov.uk/Topics/marine/science/Publications/publicationslatest/farmedfish/apbs>

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- Species
 - Production method
 - Holding volume
 - Date of registration / becoming inactive / becoming deregistered

No information was provided about quantity of production from each site. Production levels for salmon smolt can be inferred by comparing water holding capacities given for each with the national average output per unit volume available from the MSS Annual Survey reports.

By comparison of the OS grid reference in these datasets with various on-line map resources, the team have been able to identify the freshwater body and river or catchment system within which each site is located, and therefore those where interactions with wild salmonids can potentially take place.

Fish Farming Companies

The production companies themselves are potentially important sources of information with respect to geographic presence and scale/type of operation in different regions of Scotland. They are also sources of key information for other parts of this study (see below). Four large companies, covering both salmon smolt and rainbow trout production, together with one smaller specialised smolt producer shared detailed information with the study team. Initial cost models derived from that information were then consulted upon with all fish farming companies in Scotland for whom there were contact details, and additional information was received and used to refine the models further.

2.2 Costs, benefits and financial implications of changes in production practices

2.2.1 Conceptual approach

Any change in policy regarding the reduction in use of freshwater pens potentially gives rise to a range of costs and benefits that will be felt variously by the private sector, public sector, angling sector and wider society from changes to the natural environment.

It is common practice to subject public sector investment or policy options to cost-benefit analysis, which aims to capture all of the costs and benefits of a project or policy over its lifetime to assess whether the investment is worthwhile to society overall. In the current debate there are four main sectors or groupings in society which may be affected by a change in policy regarding use of aquaculture pens in freshwater lochs: the aquaculture industry itself, the public sector, angling sector (anglers, river owners, River Boards and Trusts), and wider society who may benefit from amenity and conservation values of fresh water bodies and their wild fish populations. Set out below is the conceptual framework of current costs and benefits that may arise for each sector with and without freshwater lochs being used for production of fish.

Table 1: Conceptual framework of costs and benefits from use of freshwater bodies with and without rearing fish in pens

Use	With pens		Without pens	
Sector	Costs	Benefits	Costs	Benefits
Aquaculture industry	Capital costs pens Operational costs pens	Production of smolt, trout	Capital costs of alternatives (tanks) Operational costs alternatives (tanks) / other smolt sourcing	Availability of smolt, trout
Public sector	Regulatory costs pens	None	Regulatory costs for alternatives	None
Angling	Angling costs	Angling (potentially reduced)	Angling costs	Angling (potentially improved)
Environment	Discharges to air, water, land. Potential conservation value loss Visual/amenity impacts from pens	Avoided cost of land-based alternatives / other smolt sourcing	Discharges to air, water, land. Visual/amenity impacts from land based / other sourcing	Avoided cost of loch-based alternatives. Potential conservation / amenity value enhancement

Potential for quantification

In many examples of policy change, the costs are fairly easy to determine in monetary terms but the benefits much less so. This particularly applies where the policy relates to potential improvements to the natural environment, as in this case. A change in production method has the potential to alter each of the costs and benefits within the framework above. The potential to measure these changes is as follows:

Aquaculture sector, costs: A change from current pen use, either to improve containment standards of pens or to remove them entirely and replace them with tanks on land, will create a new set of capital and operational costs. These can be estimated through the literature, interactions with industry and cost models based on first principles. Detailed methods are set out in Section 2.2.4

Aquaculture sector, benefits: Aquaculture sector benefits are considered to be neutral from a change in production method. The unit value of salmon smolt and trout is only marginally influenced, if at all, by the method of production. Benefit to industry will thus be the same provided the same volume of fish can be produced using new methods.

Public sector: The public sector incurs costs through regulating the industry. These may change somewhat in a newly structured freshwater industry, and there will be a cost burden with implementing any change. These will be relatively minor compared to industry costs and difficult to quantify and so will be considered as a simple semi-quantitative score between options for change.

Angling sector: Changes in costs and benefits relating to the angling sector could potentially arise if it was established that removing pen production would enhance wild stocks. Angler spend is the only means of quantifying economic activity in this sector and methods are available for estimating this in those catchments which overlap with pen production. Other non-use values of wild fish stocks are considered under environmental costs and benefits.

Environment: Changes in production method will cause a different set of environmental impacts. Movement of pen capacity to land-based tanks will have impacts on land use, resource use etc and these will be described for scenarios of change. Changes to scenic and amenity values are also considered under the heading "environment". Regarding wider ecosystem services, DEFRA has produced guidance on valuing changes to the natural environment likely to arise from policy options in terms of changes to ecosystem services that may arise⁹. This takes

⁹ An introductory Guide to Valuing Ecosystem Services, DEFRA, 2007.

the basic position that ecosystem services should be considered in terms of benefit to humans, i.e. ecosystem services:

- Generate income and wellbeing
- Prevent damage that might otherwise inflict cost on society

The suggested approach valuing changes in ecosystem services is to:

1. Establish the environmental baseline
2. Identify the potential impacts of policy options
3. Quantify those impacts on specific ecosystem services
4. Assess the effects on human welfare
5. Value the changes in ecosystem services

The DEFRA guidance acknowledges the many difficulties in quantifying changes to ecosystem services and states that the approach is “purposefully introductory”. Nevertheless the approach can help in identifying impacts from policy change, so is a prompt to ensure that all potential changes are listed and discussed qualitatively, if not quantified.

In 2011 DEFRA published a very wide ranging UK National Ecosystem Assessment. This assessed the state and value of the natural environment and ecosystem services for the whole of the UK¹⁰. Unfortunately there is little within the National Ecosystem Assessment that helps us with valuing the services provided by freshwater lochs in Scotland. The chapter on economic valuation discusses the various possible approaches to valuations and the “Stated Preference” method is given as probably the most applicable to valuation of such services as “water quality” or “species conservation”, which are those of closest relevance to the current study.

Undertaking a “Stated Preference” study of the public’s views regarding wellbeing of wild salmonids in certain river systems would require a significant primary survey exercise and is outside the scope of this study.

The only valuation data within National Ecosystem Assessment provided in relation to fish populations rivers is in the Working Paper “Freshwater, Wetland and Floodplain Ecosystem Services” which provides some headline figures on angler spend in England and Wales in 2009, based on research by the Environment Agency. The nearest equivalent for Scotland thus appears to be the Radford report on economic impact of freshwater angling in Scotland, (already cited).

Given these constraints it appears to be impossible to monetarise any benefits to river ecosystem services that may arise from policy options regarding changes to freshwater pen production.

¹⁰ <http://www.defra.gov.uk/environment/natural/uknea/>

Within the conceptual framework, therefore, the only change that is possible or appropriate to monetarise is that for aquaculture industry costs.

2.2.2 Economic analysis

Policy options on the possible future constraint of freshwater pen use are roughly framed in the study brief as either no further expansion, or a programme of phasing out freshwater pen use.

To test the impact of changes, “Base” Scenarios, i.e. estimates of what would happen without any policy intervention, are constructed for estimates of industry demand for smolts and trout in future, using estimates from industry, government and the study team’s own assessment. As well as a main future demand figure for smolt and trout as the base case, low and high projections of demand encompass plausible range of demand, to inform possible range of additional costs.

Three “High level” Scenarios regarding changes to the method of sourcing of smolt are examined, along with sub-scenarios considering various degrees of change within some of the “High Level” Scenarios. Costs which could arise in the various Scenarios of change are compared to the “Base” Scenario, i.e. they are those which will be additional to those which would occur anyway. As discussed above, benefits will not change from the Base Scenario for fish production and are otherwise uncertain for the other sectors. Thus, for comparison of Scenarios, additional costs only will be presented, rather than a conventional cost-benefit analysis. These will be expressed as Net Present Costs, which shows costs that may occur over an extended period in present terms, in line with normal public sector practice comparing policy options.

For context, the study also examines the likely losses which would occur if activities were to cease completely in extreme scenarios of change, i.e.

- a) if freshwater pens were totally removed and their capacity not replaced with land based facilities
- b) if freshwater pen use continued but was so damaging that all angling in the affected catchments were to cease.

For scenario a) the ongrowing units have no alternative uses and so the loss of supply of smolt which are currently supplied from pens would result in the loss of profit for around half of the output of the salmon production industry. About one third of trout production would be lost.

For scenario b) angler spend in all those catchments where cages exist would be lost, although some degree of substitution of activity could occur.

These extremes are very unlikely to occur and so are not subject to comparative analysis with the more plausible scenarios.

2.2.3 Financial analysis

A mandatory change in the methods of freshwater production will have various implications for industry which need to be considered beyond purely economic costs. Aquaculture businesses would need to raise capital to invest in new land based facilities and this is discussed. Also assessed is how new regulation may affect industry viability, as well as implications for the number of new large land-based sites which might be needed, as well as possible implications for employment.

2.2.4 Methods for quantification of costs of change to industry

The study used four main approaches to assessing costs:

- Direct requests to industry participants to share (on a strictly non-attributable basis) some key cost information.
- Peer-reviewed literature and 'grey' literature (where we consider the information sources to be reliable).
- Equipment and system suppliers, who are commonly able to discuss operating cost implications of the types of capital equipment they are providing to the sector, as well as capital costs themselves.
- Internal knowledge, based upon the team's own experience of building and operating tank-based aquaculture systems, and upon its knowledge of the biological needs of the species involved, and of the sources of up to date information about the cost of supplies required to meet those needs.

Direct Requests to Industry

The study team contacted many key industry figures, and requested non-attributable information about different aspects of costs involved in smolt and trout production. Feedback from industry was generally very helpful, and is reported in detail in Section 3. Details of all contacts are included in Appendix 2.

Literature

It should be noted that almost all available literature concerning aquaculture production costs, whether capital or operating costs, is of relevance to this study. Pen production is different from

land-based production in many ways, but within each of those broad categories the principles of producing fish are generally very similar. The key issues are:

- **Production of Biomass.** The inputs and outputs for a particular type of fish production unit all relate to the active biomass on the farm. Smaller fish are generally metabolising food and growing faster than larger fish, but that difference is taken into account by the different stocking densities that prevail for each size range. Published capital and operating costs of land-based ongrowing farms can thus be used as guidance for possible costs for producing juvenile fish such as smolts, as long as production volumes are known and key operating features, such as stocking density, water flow rate and oxygenation are taken into account.
- **Value of Biomass.** Taking into account the point made above, it is relatively easy to see why land-based units, and particularly complex ones such as recirculation systems (RAS), are likely to be more economically viable for juvenile fish such as salmon smolts – they are worth considerably more on a ‘per kg’ basis when sold into the market. One kilogram of salmon smolts is notionally worth £10, whereas one kilogram of adult salmon might be worth some £3.00 – £3.50, but the systems used to produce them have potentially very similar inputs in terms of costs. Recent experience with RAS ongrowing farms in the UK has demonstrated how difficult it is to keep production costs down to a level where the enterprise is viable, whether the species is tilapia¹¹, sea bass¹² or barramundi.¹³
- **Species Irrelevance.** Information about the economics of production of one type of finfish aquaculture species, in a particular type of production system, is of direct relevance to considerations about another type of species in a similar system. As long as basic biological differences such as growth rate, food type, food conversion and stocking density are taken into account, it is possible to gain useful insights from almost any published study. A good example would be to consider modern Danish ‘model trout farms’¹⁴ as just another way of holding, growing and harvesting cold water salmonids – which could be trout, or which could be salmon smolts.
- **Seawater and Freshwater.** Whilst there are some very clear differences between operating characteristics of seawater and freshwater RAS units (e.g. buffering capacity, waste particle buoyancy, effectiveness of foam fractionation), for more traditional flow-through land-based farms, and for pen-based farms, the differences between seawater and freshwater economics are not necessarily so marked. This is particularly true if modern freshwater pen units in Scotland are being engineered to the high technical standards ordinarily seen in marine pens. Marine land-based units always require

¹¹ <http://marinemanagement.org.uk/fisheries/funding/documents/fcf-recirculation.pdf>

¹² <http://www.yorkshirewired.co.uk/news.php/208627-Selonda-UK-fish-farm-on-Anglesey-in-talks-over-problems>

¹³ <http://www.fishupdate.com/news/fullstory.php/aid/8725>

¹⁴ See for example: http://www.aquamedia.org/FileLibrary/10/Aquaetreat_Modelfishfarms_Design.pdf

pumped water supplies, whereas many freshwater land-based units do not. However, as long as the differences between specific systems are understood, published information about costs in marine systems can be informative when considering freshwater production economics.

For the reasons outlined above, this study has obtained published information about the economics of many types of finfish aquaculture. Assessment of the value of the literature and its specific applicability to the present study is presented in Section 3.2.

Equipment Suppliers

The study team was able to interview several suppliers of land-based aquaculture equipment at the Aquanor exhibition in Trondheim in August 2011 – specifically in relation to the present study. Several suppliers indicated they might be willing to supply additional written information to this study. These groups were contacted in November 2011, and information was requested. One of the main European suppliers of recirculation systems for smolt production shared a significant amount of information about capital and operating costs, and provided the study with several Excel models that allowed easy ‘what-if’ scenario testing.

Internal Knowledge

One of the study team members has been involved commercially in land-based aquaculture for many years, and has also studied and reported on the technical aspects and economics of such systems on many occasions¹⁵. The importance of this experience comes into play when interpreting and collating the various sources of information as described above in the detailed analyses in Section 3. It is important to stress that, with the exception of some industry-standard technical and biological knowledge, the analysis in Section 3 is completely based on new information obtained for this study.

Cost implications

The financial implications of additional costs from any change in sourcing or production on an industry wide basis have been examined through comparing these to the average profit both on a unit cost (per kg) and on a whole industry basis, so as to place additional costs in context. Industry profit margins have been determined from annual or quarterly accounts of the leading production companies for Scotland, which represent a large sample of the whole Scottish industry, from 2006 to 2011, also a smaller sample back to 2000. These have been applied to the total tonnage produced in Scotland from MSS surveys. Other qualitative implications which

¹⁵ See for example:

<http://books.google.co.uk/books?id=rqdZXjTj4WwC&pg=PA5&lpg=PA5&dq=forster+and+slaski+fish&source=bl&ots=tBu2cRlZTj&sig=zX8lKdSmkvDORlGhJGKJvN6GNrY&hl=en&sa=X&ei=XqH4Tu77D8GT8gOs2s2qBQ&sqj=2&ved=0CB0Q6AEwAA#v=onepage&q=forster%20and%20slaski%20fish&f=false>

could arise from change in practices are assessed from discussions with industry and the team's own knowledge.

3 Findings

3.1 Effects of freshwater pens on wild salmonid populations

3.1.1 Introductory comments

General

There are a number of natural and anthropogenic events or activities that could have an influence on the status of wild salmonid populations and/or river stocks in Scotland. When considering the possible impact of commercial netting on salmon and sea trout stocks in 2009 and 2010, the Scottish Mixed Stock Salmon Fisheries Working Group¹⁶ recognised the importance of considering all such impacts before conservation measures aimed at any one of them could be contemplated. Its final report proposed a formalised three-step template approach to deciding whether conservation interventions would be required on a catchment-by-catchment basis:

1. Assessing whether or not there are grounds for conservation concerns over one or more stock components in any specific catchment.
2. Considering whether **all** the appropriate conservation measures have been applied to the catchment.
3. If action in relation to mixed stock fisheries appears to be one of the appropriate management/conservation options, considering what that action might be, and its implications.

The second-step template sets out the range of possible impactors on the health of a salmonid river, one of which is possible effects of escapes from aquaculture units. Others include: mixed stock fisheries; predation; over-exploitation; impassable barriers; degraded spawning habitats; pollution; and sea lice. Re-stocking of wild fish between catchments and the deliberate release of farmed salmon smolts at the request of proprietors were not included, largely because it was felt that these were historic activities.

The current study has been specifically asked to consider the possible impact of escapes and other interactions between freshwater pen culture of salmonids on the wellbeing of wild Scottish salmonid stocks, and this aspect is the main focus hereafter. However, it is important to keep in mind that there are several other possible sources of impact on populations and stocks, including any genetic legacy of the now largely discontinued practices of re-stocking and

¹⁶ <http://www.scotland.gov.uk/Publications/2010/03/31154416/0>. See Section 6.4.

deliberate farmed release, which may frustrate attempts to isolate linkages between use of pens and health of wild stocks.

The importance of addressing the potential confounding impacts of stocking on the issue of impact of farm escapes becomes relevant where an association between farms and impacts on wild salmonid populations is detected. It then becomes relevant to establish whether one or both factors have contributed to the observed change in salmonid stock character, abundance or viability. Thus consideration of the issue of the nature and extent of stocking carried out as part of salmonid management programmes in Scotland has been deferred until after the review of the evidence for effects of use of pens. If there is no evidence of an association of negative changes to populations with pen-rearing, there is no need to consider possible alternative causes.

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Sequencing of information

The study attempts to present the information which might answer the question of whether freshwater pens cause impact to wild stocks in a logical sequence.

The first section below examines the theory of impact pathways, exploring mechanisms by which impacts to wild stocks *could* occur. This is then followed by an assessment of the literature to see what evidence there is that these mechanisms *have* occurred - in the broadest sense – from aquaculture installations around the world.

The study then considers which of these mechanisms *could* occur in the Scottish setting, given the physical co-incidence of pens with wild stocks and farming practices, followed by a review of the state of knowledge as to whether they *have* occurred in Scotland.

This section ends with a review of current research and further research needed to shed better light on possible interactions.

Technical jargon

The use of technical jargon has been minimized to the extent possible in the discussion of potential impact. However, to provide clarity of meaning the use of some technical terms is unavoidable and even essential. Some of these will be unfamiliar while others will have different and varied meanings depending on their context. Even within the biological sciences a term may be employed in different ways in different areas of study and scientists are often guilty of assuming that others, including their colleagues, know exactly what they mean. Furthermore, technical terms may often be used in the same scientific report in different ways, e.g. sometimes in a general sense and other times in a very specific sense. These differences can be extremely

important to understanding what is meant, and even to a biologist meanings are not always clear and, if not precisely set out, can lead to confusion.

An illustration of this problem is the use of the term “population”. In biology, it is used to refer to groups defined using statistical, demographic, evolutionary, or genetic reproductive criteria. These groups may overlap in composition but they seldom represent the same group of individuals. For example, the “demographic population” of salmon in a river may contain one or more genetic/ reproductive populations. These differences are not trivial and it is important that they are clear if the biological points being made are to be successfully communicated.

Glossary of Terms

Hybridisation – the interbreeding of individuals from two genetically distinct populations of individuals. This may represent interspecific hybridisation where the two populations are classified as being from different species, or intraspecific hybridisation where they belong to the same species.

Impact – a change to a population induced by a perturbation, here, the presence and operation of a freshwater pen rearing facility.

Interaction – where perturbations associated with one component of a system affect the character or functioning of another component of a system; in the current context, the physical presence or operation of a freshwater pen rearing facility affects the character of the freshwater loch ecosystem in which it is placed.

Loch ecosystem – the loch itself and all inflow and outflow rivers and burns accessible to mobile elements of the loch’s biological community, also mobile components of the associated adjacent terrestrial areas of the catchment and downstream components of the overall river system using the loch.

Salmonid – a fish placed in the taxonomic family, the Salmonidae; in Scotland, this encompasses powan, vendace, grayling, Arctic charr, brown trout and Atlantic salmon.

Stock – an arbitrary group of individuals defined for purposes of management e.g. a river stock, or the early running stock in a river.

Population – an intergenerational group of individuals within which breeders mate more or less at random, while interbreeding with other such groups is more or less absent.

3.1.2 Potential biological interactions with wild fish populations

The biological nature of, and potential for, interactions between freshwater pen rearing and wild salmonid populations that could lead to impacts is considered here. This consideration does not address whether interactions between the two will, or do, occur and lead to impacts in a given

situation. It only addresses whether the possibility of interactions is a concern or not based on current general knowledge about such biological situations.

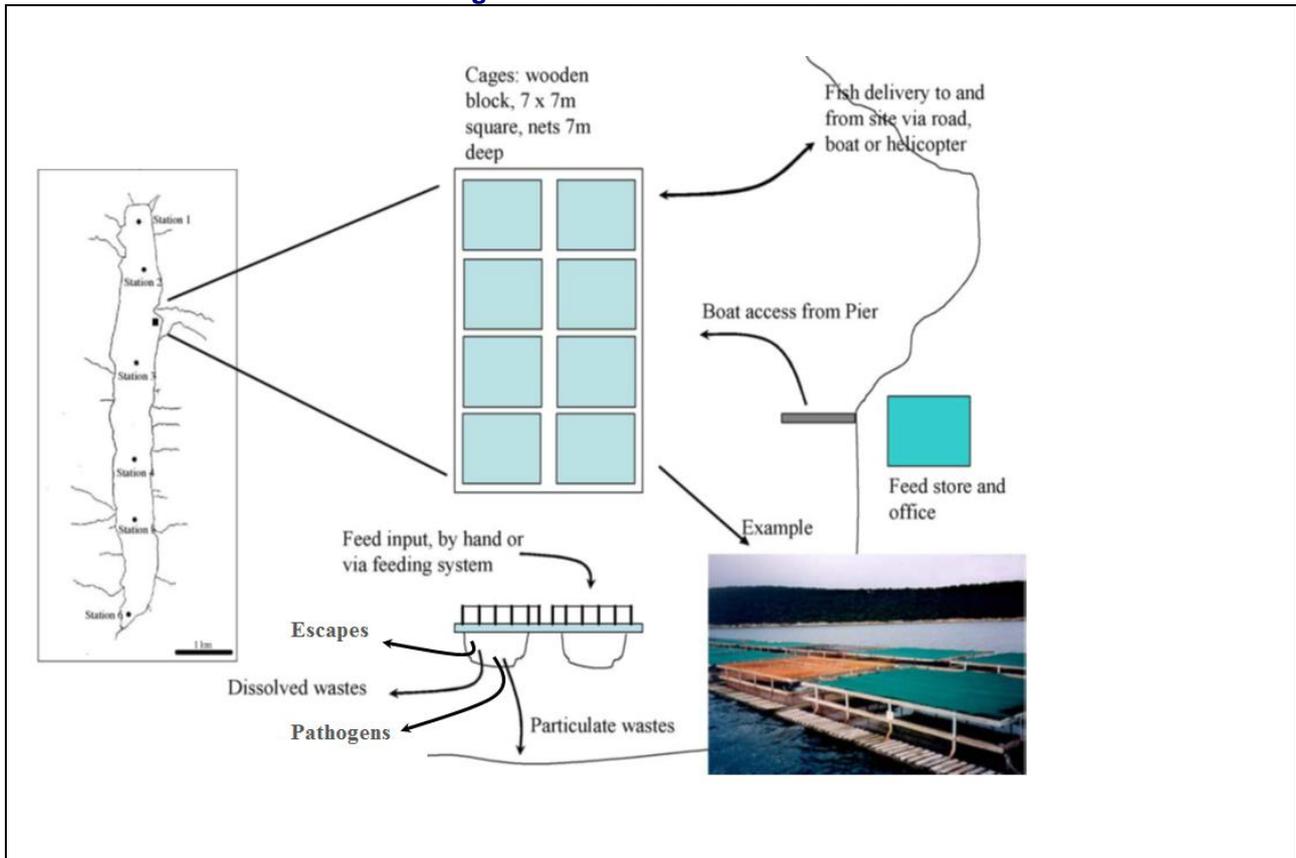
The basic situational context of pen rearing of both Atlantic salmon and rainbow trout, in Scottish freshwater lochs is set out in Figure 1, although the use of wooden pens is probably less common today., Figure 2 shows the general ecological context of a typical freshwater loch. This schematic sets out at a basic level the elements of a freshwater loch in a simple northern hemisphere context. To some degree, each freshwater pen rearing facility, either by its physical presence and its operation, will lead to perturbation of the local freshwater loch ecosystem in which it occurs, including its fish populations.

Types of potential impacts on populations

The impacts on a wild population of fish, or any other species, that are of relevance to its well-being can be categorised as pertaining to changes in one or all of the following non-exclusive biological facets:

- Morphological, physiological and behavioural character
- Genetic character
- Demographic abundance
- Viability

Figure 1: A schematic of the basic physical nature of a typical freshwater pen facility used for rearing salmonids in freshwater lochs¹⁷.

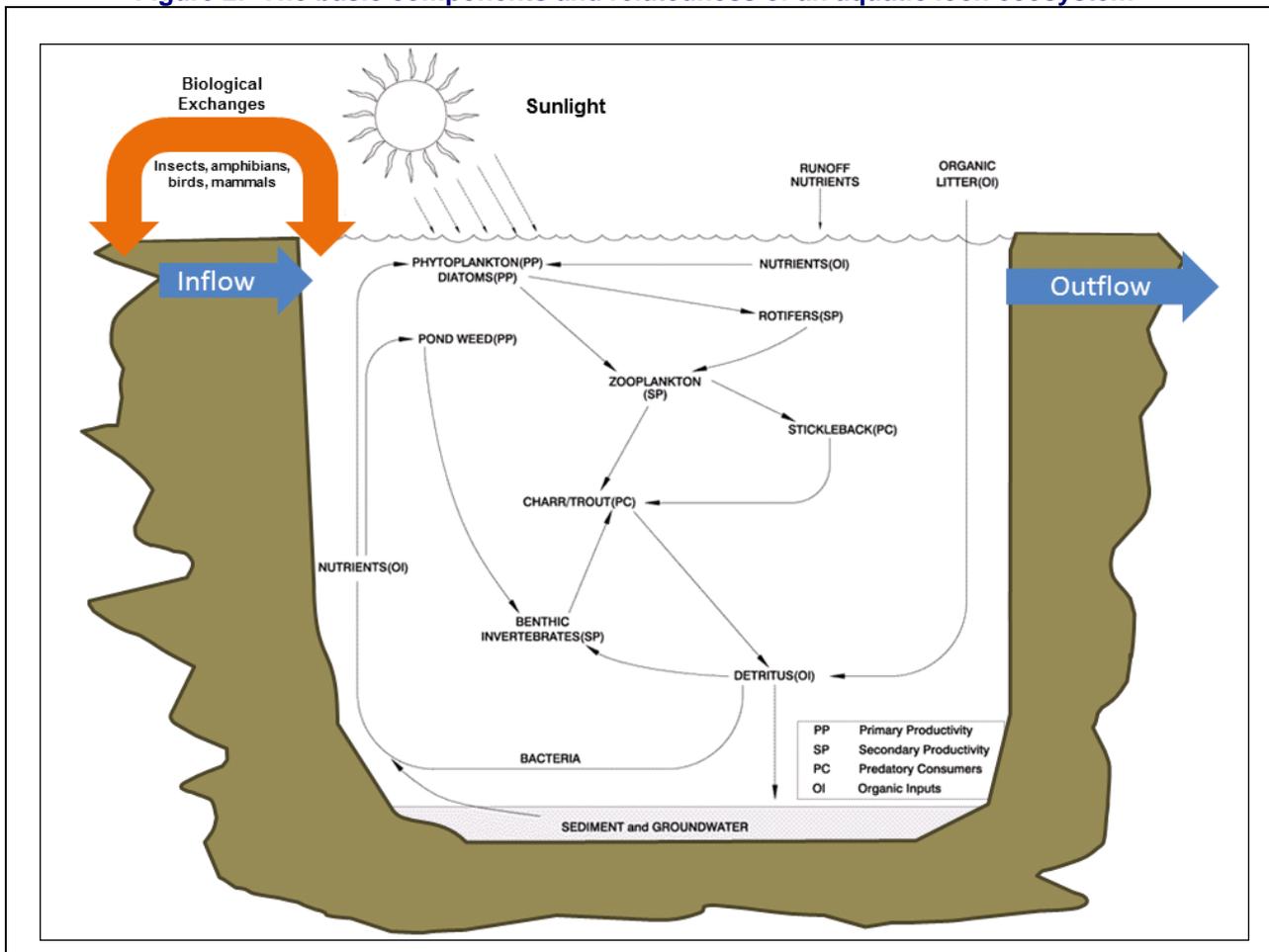


An example of a change in morphological character would be reduced body size, growth or condition. This might for example occur in response to increased food availability. An example of a change in a genetic character would be a shift in frequencies of genetic variants as a result of interbreeding with farm escapes. Finally, an example of a change in demographic abundance would be reduced numbers of returning adults, increased numbers of breeders, or reduced densities of juveniles.

Viability is a more difficult measure to address but relates to the capacity of a population to continue to exist in the future. The concept of viability encompasses the cumulative effect of factors such as current abundance, reproductive success and adaptive capacity, and relates to the likelihood of continuing to exist in the future under expected environmental conditions. Viability is normally expressed as the probability of a population going extinct and is usually based on mathematical projections of the implications of particular changes in demographic abundance.

¹⁷ modified from Figure 6 by Richard Corner in Bergheim et al., 2009

Figure 2: The basic components and relatedness of an aquatic loch ecosystem¹⁸



Population impacts will be the cumulative effects of direct and indirect impacts on individuals within a population. Some individuals by virtue of their inherited or acquired character, their life-history stage, or chance, will be more affected than others. Impacts may be significant in the short-term i.e. within a single generation (up to 20 years for some salmonid populations in Scotland), if they result in a reduction in the numbers or quality of individuals available for exploitation or that are required to maintain sufficient numbers for generating new recruits.

Impacts will be significant in the longer term if they lead to increased mortality or reduced reproductive success or to changes in the genetic character of a population that alter population success in the future. The latter can occur if genetic change reduces the reproductive success of individuals, overall or selectively, or alters the overall capacity of a population to adapt to future environmental change and fluctuation, thus reducing future population abundance and viability.

¹⁸ modified from <http://www.vbnc.com/eis/chap11/chap11.htm>

Impacts on the heritable (i.e. genetic) character of a population can arise directly from interbreeding, or indirectly by induced changes to patterns of selective mortality or differential reproductive success. They can also occur indirectly by reducing numbers of breeders or increasing variation in breeding success among individuals, altering the rate of genetic drift. They can also arise from environmental changes associated, for example, with changes in the amount and quality of food. Where altered environmental conditions lead to heritable modifications of the DNA, this is referred to as epigenetic change (e.g. Christie et al. 2012)¹⁹. Alone or together these various genetic changes can in turn affect future population abundance, character and viability.

Impact Pathways

Figure 3 sets out the potential pathways by which the different perturbations associated with freshwater pen-rearing could interact with a freshwater loch ecosystem and result in impacts on local native salmonid populations. The immediate effects of perturbations will be on individuals, through altered behaviour, nutritional status, or physiological or biochemical condition (including disease resistance). These may in turn lead to changes in individual growth, probability of survival, and reproductive success, and to overall changes to the collective character of the population to which individuals belong.

Types of interactions

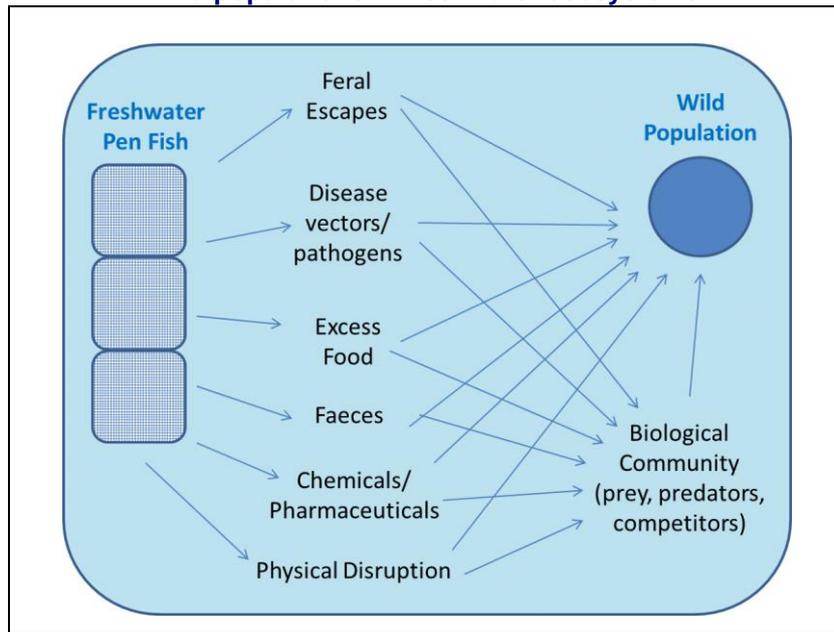
The basic interaction pathways between perturbations and wild populations set out in Figure 3 can be classified as direct or indirect. Each perturbation could in principal impact a population directly through either ecological or reproductive interactions, or indirectly through reproductive or ecological interactions with other components of the biological community that then, in turn, affect the wild population. In principal at least, both direct and indirect interactions could happen simultaneously and both lead to impacts. These may or may not lead to short or long-term changes in the character, abundance or viability of effected populations. Both reproductive and ecological interactions can potentially lead to genetic change with potential implications for population viability as set out in Figure 4.

Reproductive interactions

These involve attempted or actual interbreeding between escaped fish from pens and wild fish. They will generally be confined to interaction with wild individuals of the same species as pen-reared fish but may also, in some cases, involve populations of closely related species.

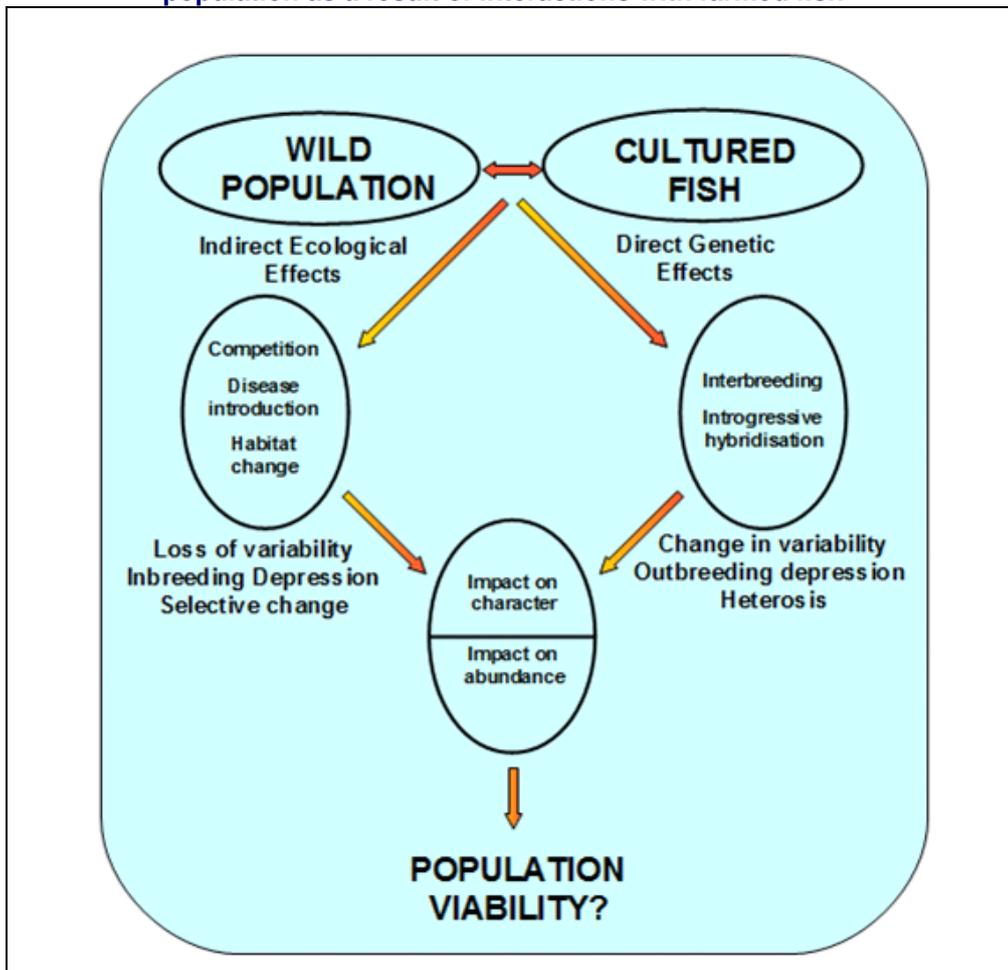
¹⁹ Christie, M.R., Marine, M.L., French, R.A. and Brilouin, M.S. (2012) Genetic adaptation to captivity can occur in a single generation. Proceedings of National Academy of Sciences – early release online

Figure 3: A schematic showing the basic pathways between the potential sources of impacts on wild populations in freshwater ecosystems



Where interbreeding occurs among closely related species, even if offspring are not viable, the impact on a wild population will be the loss of wild gametes as a reduced number of individuals may be realised in the next generation, or the genetic character of the next generation may as a result be different. For example, if a wild female sea trout were to spawn with a farmed Atlantic salmon male, her eggs would not contribute to subsequent generations, even though hybrids do survive well and might contribute to local salmonid abundance. As hybrids are not easy to identify in the hand, such an impact would not be obvious from a survey of juvenile abundance even though abundance of sea trout offspring capable of contributing to the next generation would have been reduced. In the case of interspecific interbreeding, the reproductive output lost would be the proportion of its eggs or sperm that were involved in the hybridisation event.

Figure 4: The direct and indirect pathways by which genetic changes can occur to a wild population as a result of interactions with farmed fish²⁰



The impact of lost output may be nominal where the individuals involved represent a small proportion of the wild population and can generally be expected to be compensated for in respect of any impact on population abundance by reduced density-dependent mortality in the remainder of the population. In contrast, where numbers of wild spawners are limited and wild populations are below carrying capacity, impacts would be more severe and could negatively impact the numbers of adult fish and numbers of spawners in subsequent generations. The actual extent of interactions will be conditioned by the degree of overlap in spawning timing and location of feral and wild individuals.

Where reproductive interaction involves intraspecific interbreeding, the production of hybrid offspring is more likely and these can be expected to be generally viable. However, due to genetic differences among populations, offspring resulting from intraspecific hybridisation may

²⁰ Source: Gilbey et al. GENIMPACT

well have lower fitness, something known as outbreeding depression. This results from one of two factors. The first is a reduction in offspring of the genetic variants that adapt individuals to their local environmental conditions; these will be lower in non-native and farmed individuals, which are adapted to a different environment and have other genetic variants at higher frequency as these will adapt them to their particular environments of origin. As a result, following hybridisation, fewer individuals will have the locally advantageous genes. The second is the result of incompatibilities between the genetic variants in one population and those in the other; when they are mixed up in hybrid offspring, they just do not work well together. This is an effect which represents a breakdown of the co-adapted gene complex of the native population. The co-adapted gene complex embodies the concept that the genetic variants within a population have been selected for by nature as a set of variants that work well together to increase survival and reproductive success. In general, the more evolutionarily separated two populations within a species are, the greater outbreeding impacts caused by the breakdown of co-adapted gene complexes can be expected to be when they hybridize.

Ecological Interactions

Ecological interactions encompass functional relationships between species other than interbreeding. They include relationships such as mutualism, commensalism, predation, herbivory, parasitism and competition (Moon et al. 2010)²¹. Depending on their precise nature, they can lead to changes in the demographic, morphological, physiological or behavioural character of species populations as well as genetic change. In turn, these may affect population viability. Impacts on a population may occur through direct interactions between two populations of individuals of the same or different species, or indirectly, through effects on other species.

Direct ecological interactions include, but are not restricted to, competition for food and territory, predation and transfers of parasites and pathogens. These can affect behaviour, survival and growth, with the latter potentially influencing reproductive success. For example, the presence of penned fish may cause wild fish to be attracted to pens rather than moving more widely, so changing their distribution. Ecological interactions could affect reproductive success directly if behavioural interactions occur such as if escaped fish interfere with the breeding of wild fish e.g. they disturb mating, eat the eggs of wild spawners, or disturb habitat in which eggs have been deposited.

Interactions are indirect when the effect of one ecosystem component for example fish in or from freshwater pens, on another, for example a wild salmonid population, is mediated through one or more other components. For example, this would be the case if the presence of freshwater pens

²¹ <http://www.nature.com/scitable/knowledge/library/direct-and-indirect-interactions-15650000>

attracted larger numbers of predators, increasing predation rates on wild populations. While many such interactions can be envisioned, the actual nature and extent of potential indirect interactions in freshwater ecosystems is poorly understood, in part because of the limited scope of existing studies on freshwater ecosystems structure and the way in which the different components interact (Figure 2). In terrestrial ecosystems, where indirect interactions have been more extensively studied, they are commonly found, but even the simplest of loch ecosystems are physically, chemically and biologically complex. They encompass various poorly understood sub-communities of phytoplankton, zooplankton, aquatic plants, insects, fish, birds, mammals and parasites. These will variously interact in a myriad of ways within their local physical - chemical circumstances (e.g. loch size, isolation, depth, pH, alkalinity), including patterns of historical and seasonal environmental change (e.g. in temperature, solar input), to create a locally unique ecosystem. Each loch ecosystem can be expected to vary in its specific community composition and structure as well as biogeochemical and hydrological characteristics. This will include variation in the extent of intraspecific population structuring of salmonids as well as most probably other species. Certainly, multiple independent intraspecific populations and life-history stages are known to exist in some locations in respect to many salmonid species (e.g. Klemetsen et al. 2003)²², something that is not widely appreciated. In all such cases, the populations have been found to be ecologically different.

Ecological interactions, both direct and indirect, have the potential to impact the behaviour, survival and reproductive success of individuals, and impact abundance and recruitment in wild populations. As well as affecting the obvious characteristics, such as growth at age, body condition and survival, they can also lead to genetic change. Genetic changes may occur where interactions increase mortality and reduce abundance, leading over time to an increased relatedness of individuals in subsequent generations, increasing inbreeding and reducing overall genetic variability within the population. They may also result where heritable variation exists in relation to competitive ability, disease resistance, predator avoidance or habitat use, and induced mortality is differential among genetic types, with some suffering greater mortality or reduced reproductive success leading to changes in gene frequencies in the population in the next generation. Both pathways of genetic change may reduce population viability in the long term if they reduce the overall level of adaptation of a population to its local environment or the population's scope for coping with environmental change.

²² Klemetsen A., Amundsen P.A., Dempson J.B., Jonsson B., Jonsson N, O'Connell M.F. and Mortensen, E. (2003). Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and Arctic charr *Salvelinus alpinus* (L.): a review of aspects of their life histories. *Ecology of Freshwater Fish* 12:1-59.

3.1.3 Evidence for actual biological interactions and impacts

The general body of knowledge related to population biology and aquatic ecosystems makes clear there is a *prima facie* case for the potential for impacts. It also provides a general framework within which to consider the potential interaction pathways and general types of impacts that might occur on wild salmonid populations due to perturbations that might arise from local freshwater pen rearing of Atlantic salmon and rainbow trout. This does not mean that there will be interactions and impacts, only that they cannot be ruled out as biologically unrealistic. What general scientific evidence that bears on the likelihood of particular interactions occurring and having impacts is considered here in relation to each type of potential perturbation.

Feral Escapes

Direct reproductive interactions between populations of the six wild Scottish salmonid species and farmed Atlantic salmon and rainbow trout, will be limited by inherent barriers to successful interbreeding. These are incompatibilities between the genomes of the different species which have evolved over time. Artificial crosses of the different species suggest that only crosses where farm salmon interbreed with either wild salmon, or trout, have the possibility of producing viable offspring (Table 2), where sexually mature individuals spawn together in the wild. The success of crosses between salmon and grayling, powan or vendace has not been reported in the literature. However, it is reasonable to assume these to be zero based on the fact that the evolutionary divergence of these species is as great as or greater than between salmon and rainbow trout, which do not produce viable offspring, and that they are incapable of successful hybridization or back-crossing.

Hybridisation of any wild Scottish salmonids with rainbow trout can be more or less ruled out due to inherent incompatibilities between genomes even though fish escaping may be fertile and encompass both sexes (Walker, 2004)²³. This situation is further secured by the fact that rainbow trout are generally spring spawners, in contrast to most populations of Scottish salmonids which spawn in the autumn and early winter, making attempted interbreeding unlikely in most situations. The nature of the reproductive interaction will also be constrained where all female diploid stocks of rainbow trout, widely used, are farmed; where triploid females are used the risks of interbreeding could be assumed to be effectively eliminated.

²³ Walker, A. F. (2004). An investigation of escaped rainbow trout in the upper River Earn and Loch Earn during 2002/03. Scottish Fisheries Information Pamphlet 24.

Table 2: Summary of the potential reproductive interactions of the two farmed salmonid species and three species of wild salmonids found in Scottish lochs.

Native Species	Farmed species	
	Atlantic salmon	Rainbow trout
Atlantic salmon	IB, HV, IH	IB? H?
Brown trout	IB, HV, IH?	IB? H?
Arctic charr	IB? H?	IB??

IB – capable of interbreeding, H – capable of producing viable eggs, HV – capable of producing viable juveniles, IH - potential introgressive hybridization involving the backcrossing of first generation hybrids to the wild parental population so that DNA from the farm population is integrated into the wild gene pool; a “?” after acronym indicates uncertainty and suggests that it is probably unlikely to occur in most if not all situations but cannot be ruled out.

There is clear evidence of a realisable potential for impacts of interbreeding of escaped farmed salmon on wild brown/sea trout and Atlantic salmon populations. Atlantic salmon are known to hybridize naturally with brown trout (Jordan et al. 2007)²⁴. Additionally, levels of hybridization have been shown to be elevated where farmed escapes are present and feral farm and wild salmon shown to interbreed in the wild (Ferguson et al. 2007)²⁵. Reproductive interactions of wild salmon and trout populations with feral salmon can involve either early maturing juvenile males or returning anadromous adult fish. The existence of non-anadromous mature adult feral salmon in the wild has not been documented but cannot be ruled out as the maturation of both adult males and females is known to be possible if confined to freshwater. The interactions might be expected to be greatest in respect of interbreeding of early maturing feral juvenile males as juveniles will be more abundant than returning adults, although where feral adults do return their impact per individual may be greater. Evidence suggests the larger size of early maturing farm males can allow them to out-compete wild early maturing males giving them a higher relative reproductive success (Garant et al. 2003)²⁶. However, levels of early male maturation in farm fish may be lower due to selection against this trait in culture and greater straying and mortality of non-native feral farm fish is expected (Ferguson et al. 2007) such that their overall impact might be less than expected simply from numbers of escapes. Impacts will also depend on the degree of overlap of spawning times of feral and wild fish. Spawning times of local wild salmon and trout populations may be highly variable as may be the location of

²⁴ Jordan, W.A., Fleming, I.A. and Garant, D. (2007). Mating System and Social Structure. In *Atlantic Salmon: Genetics, Conservation and Management*. (Verspoor, E., Stradmeyer, L. & Nielsen, J. eds.). Chapter 6: pp 167-194. Blackwell, Oxford.

²⁵ Ferguson, A., Fleming, I.A., Hindar, K., Skaala, Ø., McGinnity, P., Cross, T. and Prodöhl, P. (2007). Farm escapes. In *Atlantic Salmon: Genetics, Conservation and Management*. (Verspoor, E., Stradmeyer, L. & Nielsen, J. eds.). Chapter 12: pp 357-398. Blackwell, Oxford.

²⁶ Garant, D., Fleming, I.A., Einum, S., Bernatchez, L., 2003. Alternative male life-history tactics as potential vehicles for speeding introgression of farm salmon traits into wild populations. *Ecology Letters* 6, 541–549.

spawning compared to feral farm fish. Atlantic salmon ascend rivers or burns to spawn, as probably do most stream resident, loch resident and sea trout, although the spawning behaviour of populations can be highly variable. Some trout populations may be lacustrine (loch) spawners (Klemetsen et al. 2003), and this would reduce the likelihood of reproductive interaction as would differences in spawning timing between farmed salmon and trout. Reproductive interactions will also be affected by behavioural differences between farm and wild fish, with farm fish generally reproductively inferior when it comes to spawning in the wild (Thorstad et al. 2008)²⁷. However, even if they are not as successful their presence could still be disruptive of the spawning success of wild fish.

The impact of interbreeding of feral salmon with brown trout will be largely confined to loss of gametes, which could be locally significant where spawning times overlap with feral fish and numbers of wild fish breeding are locally small. What evidence exists does not rule out the possibility of subsequent introgressive hybridization, but suggests that if it occurs it is likely to be rare (Verspoor and Hammar, 1991)²⁸. In contrast, the impact of interbreeding with wild salmon will encompass both a loss of gametes and the effects of introgressive hybridisation. The latter are expected in most, if not all situations, to be negative (Ferguson et al. 2007) as the available evidence indicates that most if not all wild salmon populations are locally adapted (Garcia de Leaniz et al. 2007)²⁹ and crossing with feral fish leads to depressed fitness of hybrid offspring (Ferguson et al. 2007; Houde et al. 2010). McGinnity et al. (2003)³⁰ – described in Ferguson et al. 2007) found the lifetime fitness of farm fish in the wild to be in the order of 2% of wild salmon.

The extent of the reproductive impact is predicted to depend on various factors including the extent of adaptive genetic differentiation between the feral and wild populations, the proportion of interpopulation crosses, the absolute abundance of the wild stock, and whether the wild population is at carrying capacity with regard to the local habitat (Ferguson et al. 2007). At one extreme, with low levels of sporadic interbreeding, and a highly abundant wild population at carrying capacity, modelling suggests the impacts would be limited and short-term. In contrast,

²⁷ Thorstad, E.B., Fleming, I.A., McGinnity, P., Soto, D., Wennevik, V. and Whoriskey, F. 2008. Incidence and impacts of escaped farmed Atlantic salmon *Salmo salar* in nature. NINA Special Report 36. 110 pp.

²⁸ Verspoor, E. & J. Hammar. (1991). Introgressive hybridization in fishes: the biochemical evidence. *Journal of Fish Biology* 39(Supplement A): 309-334.

²⁹ García de Leaniz, C., Fleming, I.A., Einum, S., Verspoor, E., Consuegra, S., Jordan, W.C., Aubin-Horth, N., Lajus, D. L., Villanueva, B., Ferguson, A., Youngson, A.F., & Quinn, T.P. (2007) Local Adaptation, Chapter 7, In *The Atlantic Salmon: Genetics, Conservation & Management* (Verspoor, E., Stradmeyer, L & Nielsen, J.L., eds). Blackwell Publishing, Oxford. pp 195-236. Houde et al. 2010

³⁰ McGinnity, P., P. Prodoehl, A. Ferguson, R. Hynes, N. O' Maoileidigh, N. Baker, D. Cotter et al. 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society of London. Series B: Biological Sciences* 270:2443–2450.

at the other extreme, with high levels of interbreeding and a numerically depressed wild population below the carrying capacity of its local environment, the impacts could be significant and long-term as regards the abundance character and viability of the wild stocks (Ferguson et al. 2007; Gilbey and Verspoor, submitted)³¹.

Studies of ecological and behavioural interactions of feral cultured fish with wild populations were reviewed recently by Thorstad et al. 2008. Understanding of this aspect of interaction is still largely incomplete. They point out that morphological differences between farmed and wild fish, some of which will be genetically determined such as growth and size at age, will affect their behaviour. However, wild and farm salmon born in the wild tend to feed on the same things in the wild such that it is likely that there will be competition for territories and food between the two. On the other hand escaped farmed fish may show different behaviours which carry over from their farm experience. Farm fish are generally more aggressive and less risk adverse. In general, large number of farm escapes might be expected to reduce food availability for wild fish through resource uptake and competitive displacement, particularly if they are larger than wild fish. They suggest that the outcome will often be context dependent but can be expected frequently to be negative based on general ecological principles. However, the nature and extent of ecological interactions and impacts remains largely unknown.

Physical Disruption

No studies were found that address the potential effects and impacts of the physical presence and operation of freshwater pens facilities containing farmed salmonids on wild fish populations, arising from the presence of physical structures, artificial light, noise, boating activity, etc. In principle, such activities could lead to hydrological perturbations which could damage fish habitat or affect fish behaviour that could have a possible downstream impact on population abundance, character and viability. For example, if pens are sited above a charr spawning area, spawning of fish might be disrupted. Fish may also be attracted to pens with fish for social reasons as well as by feeding opportunities associated with food and faeces falling through nets. Where the presence of pens attracts fish predators such as herons, there could be increased predation on those elements of the population attracted to a pen site.

There is a vast literature on the behaviour of salmonid fishes that is variously and tangentially relevant to the question of perturbation but no review has been carried out which considers this question specifically in the current context. A cursory consideration of this literature suggests the possibility of interactions cannot be dismissed entirely. However, it also suggests that,

³¹ Gilbey, J. and Verspoor, E. (submitted). Individual-based modelling of the demographic impacts of genetic introgression of farmed Atlantic salmon into wild populations. Aquaculture Environment Interactions.

impacts are likely to be highly dependent on the specific nature of a pen operation and the salmonid populations in the affected lochs, as well as the relative physical sizes of the pen groups and the overall loch.

A study by Lorang et al. (1993)³² of docks and walls structures in a lake in the USA found effects on the movements of gravels, changes to erosion patterns and knock-on effects on the development of riparian vegetation development: things that could affect inshore juvenile habitat quality as well as the quality of spawning habitat for shore spawning salmonids. A detailed analysis of the impact of lake shore developments carried out by Kahler et al. (2000)³³ included consideration of the effects of changes to shade and cover, lighting, removal of vegetation, and wave patterns from wharfs. They concluded, among other things, that there was potential for increased predation of wild salmonids from the loss of cover, reduced primary productivity, and a delay in migratory movements of juvenile salmonids, with also potential effects from boat activity. Southard et al. (2006)³⁴, in a study of marine inshore development associated with ferry terminals, found the effects were likely to be variable depending on the precise nature of the structure but that knowledge of salmonid behaviour was inadequate for determining impacts and recommending design changes to mitigate impacts. Toft et al. (2007)³⁵ state that the effects of retaining structures on ecological processes are poorly known especially as regards the implications for juvenile salmonid habitats. In their studies, juvenile salmonids did modify their behaviour and avoided swimming under overwater structures, probably due to increased predation risk.

Effects on fish behaviour have been reported in relation to changes in food availability (e.g. Alanara and Brannas, 1997)³⁶ and light (Gibson and Keenleyside, 1966³⁷; Ferno et al. 1995³⁸;

³² Lorang, M. S., J. A. Stanford, F. R. Hauer, and J. H. Jourdonnais. 1993. Dissipative and reflective beaches in a large lake and the physical effects of lake level regulation. *Ocean and Coastal Management* 19: 263-287.

³³ Kahler, Tom, Martin Grassley, and David Beauchamp. 2000. A summary of the effects of bulkheads, piers, and other artificial structures and shorezone development on ESA-listed salmonids in lakes. Final report, 13 July 2000. Prepared for the City of Bellevue, Washington by The Watershed Company, Kirkland, Washington, and Washington Cooperative Fish and Wildlife Research Unit, University of Washington, School of Fisheries, Seattle.

³⁴ <http://www.wsdot.wa.gov/research/reports/fullreports/648.1.pdf>

³⁵ Toft, J.D., J.R. Cordell, C.A. Simenstad, and L.A. Stamatiou. 2007. Fish distribution, abundance, and behavior along city shoreline types in Puget Sound. *North American Journal of Fisheries Management* 27:465-480.

³⁶ Alanärä, A. and Brännäs, E. (1993). A test of the individual feeding activity and food size preference in rainbow trout using demand feeders. *Aquaculture International* 1, 47–54.

³⁷ Gibson, R.J. and Keenleyside M.H.A. (1966). Responses to Light of Young Atlantic Salmon (*Salmo salar*) and Brook Trout (*Salvelinus fontinalis*). *Journal of the Fisheries Research Board of Canada*, 1966, 23:(7) 1007-1024.

³⁸ Fernö, A., Huseb, I. Jon-Erik Juell, J-E. and smund Bjordal, Å. (1995) Vertical distribution of Atlantic salmon (*Salmo solar* L.) in net pens: trade-off between surface light avoidance and food attraction. *Aquaculture* 132: 285–296.

Noble et al. 2007³⁹). Mazur and Beauchamp (2003)⁴⁰ found reactions of salmonids to prey in North American lakes to be affected by light intensity. Effects on behaviour, at least in respect of some perturbations at some life history stages, can vary among species (e.g Schutz and Northcote, 1972)⁴¹ and, within species, from one population to another (e.g. Valdimarsson et al. 2000)⁴², suggesting effects and potential impacts in any given situation will be difficult to predict with any accuracy.

The effect of factors such as increased light might be expected to be local as light attenuates quickly with distance, whereas other factors such as odours and sound may have a more distant impact. Alterations to behaviour caused by the presence of food may be more local where fish in a population are relatively sedentary or have relatively small home ranges, but be greater for those which move greater distances (e.g. migrating salmon smolts, predatory ferox trout). In some cases, such as noise or light changes, affected individuals may become habituated to changes over time with little long-term impact. In other cases, behavioural change could persist for the duration of a perturbation e.g. the presence of excess food or high levels of faeces. However, whether these types of effects on individuals lead to long term changes in the abundance, character or viability of a population has not been addressed. It is possible as changes in behaviour could conceivably affect, for example, exposure to predation, or change spawning behaviour and so affect reproductive success. These impacts would be difficult to assess against a background of normal demographic variation, particularly as accurately ascertaining the demographic status of a wild salmonid population in freshwater is extremely difficult, except possibly in relatively small and accessible parts of freshwater systems such as small burns.

Thus the general literature suggests physical perturbations of the environment associated with the presence or operation of freshwater pens could lead to interactions with wild salmonid populations. However, there are no studies that address this issue specifically in relation to freshwater pen operations, and the potential for impacts from this category of perturbations is

³⁹ Noble, C., Mizusawa, K., Suzuki, K. and Tabata, M. (2007). The effect of differing self-feeding regimes on the growth, behaviour and fin damage of rainbow trout held in groups. *Aquaculture* 264: 214–222.

⁴⁰ Mazur, M.M. and Beauchamp, D.A. (2003). A comparison of Visual Prey Detection Among Species of Piscivorous Salmonids: Effects of Light and Low Turbidities *Environmental Biology of Fishes* 67: 397-405.

⁴¹ D. C. Schutz, T. G. Northcote, T.G. (1972). An Experimental Study of Feeding Behavior and Interaction of Coastal Cutthroat Trout (*Salmo clarki clarki*) and Dolly Varden (*Salvelinus malma*). *Journal of the Fisheries Research Board of Canada*, 1972, 29:(5) 555-565,

⁴² Valdimarsson, S. K., Metcalfe, N. B. and Sku´ lason, S. (2000). Experimental demonstration of differences in sheltering behaviour between Icelandic populations of Atlantic salmon (*Salmo salar*) and Arctic char (*Salvelinus alpinus*). *Canadian Journal of Fisheries and Aquatic Sciences* 57, 719–724.

uncertain. It is suggested that specific research is required to inform this aspect of the debate in the current context.

Food and Faeces

Pen farming in open waters has the potential to cause large amounts of organic waste in the form of unconsumed feed and fecal matter to disperse into the water around and below pens and to accumulate in the bottom sediment. This organic waste can give rise to substantive changes in the benthic macrofauna and chemical structure of the sediment (Ackefors and Enell, 1990)⁴³. A large number of studies have been published on the effects of marine pen culturing on sediment (Karakassis et al., 1998⁴⁴; 1999⁴⁵; Dominguez et al., 2001⁴⁶; Pawar et al., 2001⁴⁷; 2002⁴⁸; Pearson and Black 2001⁴⁹; Carrol et al., 2003⁵⁰). However, there have been few published assessments of the environmental impacts of inland pen culturing (Cornel and Whoriskey, 1993⁵¹; Kelly, 1993⁵²; Troell and Berg, 1997⁵³; Temporetti et al., 2001⁵⁴). Pen culture has the potential to enrich sediments, alter community composition and population structure

⁴³ Ackefors, H., and M. Enell. 1990. Discharge of nutrients from Swedish fish farming into adjacent sea areas. *Ambio* 19: 28–35.

⁴⁴ Karakassis, I., Tsapakis, M. and Hatziyanni, E. (1998). Seasonal variability in sediment profiles beneath fish farm cages in the Mediterranean. *Marine Ecology Progress Series*, 162: 243-252.

⁴⁵ Karakassis, I., Hatziyami, E., Tsapakis, M. and Plaiti, W. (1999). Benthic recovery following cessation of fish farming: a series of successes and catastrophes. *Marine Ecology Progress Series*, 184: 205-218.

⁴⁶ Dominguez, M.L., Calero, L.G., Martin, V.M.J. and Robaina, R.L. 2001. A comparative study of sediments under a marine cage farm at Gran Canaria Island (Spain). *Aquaculture*, 192: 225-231

⁴⁷ Pawar, V., Matsuda, O., Yamamoto, T., Hashimoto, T. and Rajendran, N. 2001. Spatial and temporal variations of sediment quality in and around fish cage farms: A case study of aquaculture in the Seto Inland Sea, Japan. *Fisheries Science*, 67: 619-627.

⁴⁸ Pawar, V., Matsuda, O. and Fujisaka, N. 2002. Relationship between feed input and sediment quality of the fish cage farms. *Fisheries Science*, 68: 894-903.

⁴⁹ Pearson, H.T. and Black, K.D. 2001. The environmental impacts of marine fish cage culture. In: K.D. Black (Ed.), *Environmental Impacts of Aquaculture*, Sheffield Academic Press, UK: 32-51.

⁵⁰ Carrol, L.M., Cochrane, S., Fieler, R., Velvin, R. and White, P. 2003. Organic enrichment of sediments from salmon farming in Norway: environmental factors, management practices and monitoring techniques. *Aquaculture*, 226: 165-180.

⁵¹ Cornel, G.E. and Whoriskey, F.G. (1993). The effects of rainbow trout (*Oncorhynchus mykiss*) cage culture on the water quality, zooplankton, benthos and sediments of Lac du Passage, Quebec. *Aquaculture* 109: 101–117

⁵² Kelly, L.A. 1992. Dissolved reactive phosphorus release from sediments beneath a freshwater cage aquaculture development in West Scotland. *Hydrobiologia* 235–236: 569–572.

⁵³ Troell, M., and H. Berg. 1997. Cage fish farming in the tropical Lake Kariba, Zimbabwe: Impact and biogeochemical changes in sediment. *Aquaculture. Research* 28: 527–544.

⁵⁴ Temporetti, F.P., Alanso, F.M., Baffico G., Diaz M.M., Lopez, W., Pedrozo, L.F. and Vigliano, H.P. (2001). Trophic state, fish community and intensive production of salmonids in Alicura Reservoir (Patagonia, Argentina). *Lakes & Reservoirs: Research and Management*, 6: 259-267.

through the loss of excess food and fish faeces from pens (Phillips et al. 1985⁵⁵, Carss 1990⁵⁶; Cornel & Whoriskey 1993⁵⁷, Elberizon & Kelly 1998⁵⁸). Uneaten pellets, faeces, scales and mucus may be taken up by fish either through direct consumption or the consumption of lower trophic prey that have utilised the waste material themselves. This artificial resource may benefit local salmonid populations by increasing growth rates and survival. In the case of brown trout, increased food availability of food may lower the physiological drive to migrate to the marine environment (Pavlov and Savvaitova 2008)⁵⁹, which may increase number of resident trout and reduce the number of sea trout produced in a system.

The literature contains few reports of effects and the impacts of inland pen culture Atlantic salmon juveniles but there is now a significant literature related to the pen rearing of rainbow trout, much of it carried out under highly controlled experimental conditions in the Experimental Lakes Area in Canada. This work shows effects on the algal and bacterial communities, including spring and autumn blooms of chrysophytes and dinoflagellates, and that impacts accumulate over years (Findlay et al. 2009)⁶⁰. The effects relate primarily to increased levels of nutrients such as phosphates, whose effects will depend on natural levels in a system. Effects on zooplankton (crustacea and rotifers), invertebrates and fish predators have also been observed (Paterson et al. 2010) based on a study of 6 years pre-pen, 3 years during and 7 years post-pen data. The largest changes observed were to the phytoplankton community but there was also an overall change in crustacean zooplankton community structure, and the study results reinforced the need to monitor multiple variables when assessing ecosystem impacts of potential stressors. The studies, based on stable isotope analysis, also showed assimilation of waste by Mysis, chironomids and, particularly, minnows but not by littoral invertebrates or zooplankton, indicating that the waste can be a food source for the native biota. Additionally, Rooney et al. (2009)⁶¹ shows reductions in biodiversity in zoobenthos but variable effects on

⁵⁵ Phillips MJ, Beveridge MCM, Ross LG (1985) The environmental-impact of salmonid cage culture on inland fisheries - present status and future-trends. *Journal of Fish Biology* 27:123-137.

⁵⁶ Carss DN. 1990. Concentrations of wild and escaped fishes immediately adjacent to fish farm cages. *Aquaculture* 90(1): 29-40.

⁵⁷ Cornel, G.E. and Whoriskey, F.G. (1993). The effects of rainbow trout (*Oncorhynchus mykiss*) cage culture on the water quality, zooplankton, benthos and sediments of Lac du Passage, Quebec. *Aquaculture* 109: 101–117

⁵⁸ Elberizon, I.R. and Kelly, L.A. (1998). Empirical measurements of parameters critical to modelling benthic impacts of freshwater salmonid cage aquaculture. *Aquaculture Research* 29:669-677.

⁵⁹ Pavlov, D. S. and Savvaitova, K. A. (2008). On the problem of ratio of anadromy and residence in salmonids (Salmonidae). *Journal of Ichthyology* 48: 778-791

⁶⁰ Findlay, D.L., Podemski, C.L. and Kasian, S. E.M. (2009). Aquaculture impacts on the algal and bacterial communities in a small boreal forest lake. *Canadian Journal of Fisheries and Aquatic Sciences* 66: 1936-1948.

⁶¹ Rooney R. C. and Podemski C. L. (2009). Effects of an experimental rainbow trout (*Oncorhynchus mykiss*) farm on invertebrate community composition. *Canadian Journal of Fisheries and Aquatic Sciences* 66:1949-1964

biomass. They found effects were negatively correlated with distance from pen and water quality parameters, but disappeared within 15m of pens.

No studies were found which addressed the extent to which direct and indirect interactions associated with introduced food and faeces affect the character, abundance and viability of wild salmonid populations. However, such effects that might be expected, would be most pronounced locally, but be highly variable depending on location and the relative size of a pen-rearing operation compared to the size of a loch, also on the efficiency of feeding.

Unfortunately, no studies have addressed these issues in the freshwater context as regards salmonid pen rearing and what is known suggests impacts could, depending on the specific nature of a pen rearing operation, range from insignificant to very substantive. As such, situation specific studies will be required to determine if impacts are occurring and, if so, whether these relate to local salmonid populations.

Freshwater aquaculture is closely regulated by SEPA, according to new standards of water body classification as mentioned in Section 2. Cromey et al (2010)⁶² indicate a relatively stable trend in total phosphorous (TP) in Scottish lochs that have pen farming.

Chemicals and Pharmaceuticals

There are no specific studies published in the public domain on the use of chemicals and pharmaceuticals in freshwater salmonid pen-rearing operations and their environmental effects. In Canada the freshwater aquaculture industry is licensed to use various chemical agents to treat water, fish or pathogens e.g. fungicides, disinfectants, anesthetics, pigments, hormones and antibiotics⁶³. Based on discussions with the Scottish industry, it would appear that salmon and trout are not routinely treated with antibiotics or other therapeutants once in freshwater pens. As regards the use of chemical treatments, they indicate that fish are only treated occasionally with formalin to control fungal infection and external parasites, perhaps once for each cohort to control. It is a naturally occurring chemical which dissolves easily in water, breaks down rapidly, and it does not seem to build up in plants and animals. An FAO study of effects of formalin on fish⁶⁴ addresses only the immediate physiological impacts on treated fish. There are no specific studies which address the potential impact of formalin treatments on the environment and no studies have been published regarding its dispersal and breakdown following treatments; it does not appear to be routinely monitored following treatment. Results of the FAO study indicate that formalin at the therapeutic levels (25–50 mg/l) should be safe for fish unless continuously

⁶² <http://www.sarf.org.uk/cms-assets/documents/28925-497850.sarf055---final-report.pdf>

⁶³ (<http://www.dfo-mpo.gc.ca/science/enviro/aquaculture/sok-edc/volume3/scott-eng.htm>)

⁶⁴ (<http://www.fao.org/docrep/field/003/AC278E/AC278E00.htm>)

exposed for more than four weeks but that at higher levels (e.g. 75 mg/l) growth may be affected after exposure for more than two weeks. Given treatments are generally for periods of less than 1 hr, and formalin breaks down rapidly, the likelihood is that its impacts from treatments will be limited and transient in most normal situations, unless perhaps if there were a significant spill during its use. However, the FAO study recommends that studies are needed to look at the degradation rate of formalin in water of different temperature and the toxicity of formalin to bacteria, phytoplankton and zooplankton. It is known that formalin is toxic to algae at levels of ~1mg/litre, well below the levels used in treatments (Beveridge and Phillips, 1993)⁶⁵. This need is echoed in the recent review by Scott⁶⁶ who recommends research is needed into the fate and effect of therapeutants in freshwater systems, as well as monitoring of usage.

Disease (including parasites)

The general potential for direct disease interactions between wild and farmed fish populations in Europe has been recently reviewed by Bergh (2007)⁶⁷. A more detailed, specific review is that by Raynard et al. (2007)⁶⁸, carried out as part of the EU funded DIPNET project which includes a specific assessment in relation to the freshwater context. Additionally, Johansen et al. (2011) provides an overview of the specific situation in Norway, encompassing both the marine and freshwater contexts.

While a great deal of work has been carried out on diseases of salmonid fishes, Bergh (2007) comments that “... *little research has been undertaken on diseases of wild fish at the population level, and on the interactions between wild and farmed populations in terms of exchange of pathogens, with a few exceptions, for instance sea lice.*” Thus the only reasonably well studied example lies outside the current context. Bergh goes on to point out that what knowledge there is has been largely collected opportunistically from obvious but atypical outbreaks where large numbers of fish are involved. In respect of the few specific studies that have been carried out alternatively, reported work has involved the analysis of small numbers of fish with restricted geographical or temporal coverage so that little insight exists into the overall picture in space or time. These limitations of work on wild fish can be attributed to the substantive challenges that confront studies of disease in wild populations. Fish, by virtue of their hidden aquatic existence, are inherently difficult to study even if they are healthy. At the same time, diseased fish are not

⁶⁵ Beveridge, M.C.M and M.J. Phillips Environmental Impact of Tropical Inland Aquaculture. P.213-236. In R.S.V. Pullin, H. Rosenthal, and J.L. Maclean (eds). Environment and aquaculture in developing countries. ICLARM Conf. Proc. 31, 359pp.)

⁶⁶ (<http://www.dfo-mpo.gc.ca/science/enviro/aquaculture/sok-edc/volume3/scott-eng.htm>)

⁶⁷ Bergh, Ø. 2007. The dual myths of the healthy wild fish and the unhealthy farmed fish. Diseases of Aquatic Organisms, 75:169-164.

⁶⁸ <http://www.revistaaquatic.com/DIPNET/docs/doc.asp?id=48>

expected to persevere for long, either dying directly as a consequence of the disease and degrading or having a higher likelihood of succumbing to predators. This means that even if disease is present, the incidence of diseased individuals in the wild will be difficult to quantify.

Bergh (2007) argues that some diseases such as “... *vibriosis and furunculosis were commonly occurring in wild fish populations in North European waters prior to the development of modern aquaculture.*” However, it cannot be assumed that all disease vectors occur everywhere naturally. For example, until recently, the virulent monogenean salmon parasite *Gyrodactylus salaris* (Gs) was confined largely, if not exclusively, to the Baltic region where it had coevolved since the last ice age with local salmon stocks with whom they cohabit without detriment to the host. However, it was historically absent from rivers outside the Baltic. Unfortunately in 1975, Gs was introduced into Norway where it was formerly absent, most probably by movements of Baltic smolts from Sweden, with devastating impact on local wild salmon which are not resistant (Bakke et al. 2002⁶⁹; Johnsen and Jensen 1991⁷⁰). Even if the same nominal “species” is found in different geographical locations, it cannot be assumed that they are genetically the same. The virulence of each strain may vary depending on the local salmonid populations. Differences in virulence are seen among strains from different regions e.g. VHSV in fish (Benmansour et al. 1999)⁷¹.

Furthermore, conditions in fish farms have the potential to lead to the rapid evolution of disease vectors as has recently been indicated in relation to *Flavobacterium columnarum* in farmed salmon fingerlings in Finland, the vector underlying columnaris disease. Wild salmonids may not have inherent resistance to different or newly evolved strains, as with non-resistant populations of Atlantic salmon in relation to *G. salaris*, with the result that they can be highly negatively impacted to the point of extinction. Additionally, there is also the possibility that pathogens from one species may evolve the ability to infect other species, such as is observed for disease vectors in chickens in relation to humans (Ebert and Bull 2008)⁷² and is suggested may have

⁶⁹ Bakke, T.A., Harris, P.D. and Cable, J. (2002). Host specificity dynamics: observations on gyrodactylid monogeneans. *International Journal of Parasitology* 32:281–308.

⁷⁰ Johnsen, B.O. and Jensen, A.J (1991) The *Gyrodactylus* history in Norway. *Aquaculture* 98:289–302.

⁷¹ Benmansour, A., Basurco, B., Monnier, A.F., Vende, P., Winton, J.R. and de Kinkelin P (1997). Sequence variation of the glycoprotein gene identifies three distinct lineages within field isolates of viral haemorrhagic septicaemia virus, a fish rhabdovirus. *Journal of General Virology* 78:2837–2846

⁷² Ebert, D. and Bull, J.J. (2008) The evolution and expression of virulence. In: Stearns SC, Koella JC, editors. *Evolution in health and disease*. 2nd ed. New York: Oxford University Press; 2008. p. 153–67

occurred in respect of *G. salar*, which may originally have been a parasite of grayling (Meinila et al. 2004)⁷³.

Coutant (1998)⁷⁴ points out the challenge in determining whether the origin of infection and disease in a wild population was of farm origin or, for that matter, the converse. What is required is to establish what the 'normal' disease or pathogen status was or might be without the farm or wild contribution. This is difficult to do, particularly in the absence of a detailed assessment of the status of the interacting populations prior to their co-habitation.

Raynard et al. (2007) in their report on the EU DIPNET project have summarised the specific evidence for harmful impacts on wild or farmed fish and the evidence for interactions. They group these into proven and potentially harmful interactions, and potentially less harmful interactions. The review, carried out by leading fish disease specialists across Europe, concluded that diseased fish are seldom detected in wild fish populations unless there is a resulting mass mortality. Overall their review found only a few diseases where there is evidence of pathogen transmission from farmed to wild and even less evidence that this resulted in disease and that there was evidence of detrimental effects.

In their review they point out that planning scientific surveys of disease occurrence is problematic when the occurrence is rare, as large sample sizes are required from any given population if a disease that is present is to be detected with any statistical power and, in almost all cases, this involves the costly and unacceptable destructive sampling of large numbers of fish. They point out that techniques used for mass screening terrestrial animals such as seroprevalence tests are not proven or well established for fish. Evidence for transmission of some pathogens has been found and, for a few, evidence of impacts on wild fish. However, studies that find little or no evidence for transmission or impacts unless carried out on a large scale with large sample sizes will be equivocal on this question; scientifically it is not possible to prove that something does not exist. More extensive studies, even if they find no transmission or disease, as part of epidemiological modelling, may provide insight into the relative risks. The evidence from the review relating to salmonid fishes is set out in Table 3. In addition to this, no interactions are suspected in relation to Saprolegniosis and *Flavobacterium columnare*, though in respect of the latter, more research is indicated to be needed to evaluate potential impacts.

⁷³ Meinilä, M., Kuusela, J., Zietara, M.S. and Lumme, J. 2004. Initial steps of speciation by eographic isolation and host switch in salmonid pathogen *Gyrodactylus salaris* Monogenea: Gyrodactylidae - International Journal for Parasitology, 2004 Mar 29, 34(4):515 - 526.

⁷⁴ Coutant CC. What is "Normative" for Fish Pathogens? A Perspective on the Controversy over Interactions between Wild and Cultured Fish. Journal of Aquatic Animal Health. 1998; 10: 101-6.

The DIPNET review concludes with the view that current understanding of disease interactions between wild and aquaculture populations, and its impacts on biodiversity, is inadequate to draw robust conclusions. They also raise the issues discussed above that the geographical scope of many existing studies is too limited, and that disease presence may be very contingent on local conditions relating to the environment (e.g. temperature, water quality) as well as host population size and density, both in culture and in the wild. They state that some exchange of pathogens is inevitable, particularly in net-pen culture, though the risk and extent can be minimised if husbandry practise is based on sound epidemiological principles for disease control.

Raynard et al. (2007) also conclude that “*The main source of infection for farmed fish is other farms and there are few diseases where there is sufficient evidence that infected farm populations pose a significant risk of infection to wild populations.*” They go on to say “*However, there are many more diseases for which there is circumstantial evidence or where transmission of infection is suspected and where a potential risk to wild fish exists.*” It must also be recognised, as Bergh (2007) points out, that disease, at least to some extent, is an integral part of natural ecosystems so a state of no disease on farms and in wild populations is likely to be unattainable for widespread and common vectors. They suggest that problems are most likely where exotic strains are introduced or are allowed to evolve locally because of conditions conducive to disease outbreaks and high pathogen loads, such as high rearing densities and high stress levels. They also point to the possibility that wild populations may generally be more resistant as they have more diversity of genes involved in fighting pathogens. Finally, they recognise that diseases that are non-problematic in one area may be problematic and damaging in another e.g. *G. salaris*. Though the problems of exotic disease may be attenuated over time by selection for resistance, this is likely to take decades at best to be realised and assumes the local wild populations have not been driven to extinction, as appears to happen in some cases with regard to *G. salaris*.

Table 3 Summary of evidence of viral and bacterial pathogens in salmonid fishes and their associated potential hazards.

Proven or potentially harmful interactions			
Infection by:	Harmful to:	Hazard posed through interactions	Scientific Evidence
IHNV	Farmed trout	Wild fish reservoir risk for trout farms	Circumstantial
VHSV	Farmed salmonids and escocids	Wild fish reservoir risk for fish farms	Yes
	Wild salmonids (grey literature)	Infected farmed fish - > risk of carrier status in wild fish	Yes
Aeromonas salmonicida	Farmed salmonids	Reservoir in wild fish	Yes
	Wild salmonids	Stocking of infected fish	Yes
Atypical Aeromonas salmonicida	Several farmed fish species	Carrier status of both wild and farmed fish	Circumstantial
	Different species of wild fish		
Motile Aeromonads	Different species of wild fish	Release of bacteria from infected farmed fish	Not available
Yersinia ruckeri	Farmed salmonids	Wild salmonids reservoir	Circumstantial evidence
Ichthyophthirius multifiliis	Farmed fish species	Wild fish reservoir, risk for fish farms	Circumstantial
Myxobolus cerebrakus	Farmed trout	Wild fish reservoir, risk for farms	Yes
	Wild trout	Infected farm fish - > risk of transmission	Yes
Potentially less harmful interactions			
Infection by:	Harmful to:	Hazard posed through interactions	Scientific Evidence
Alphavirus	Farmed trout	Wild fish reservoir risk for trout farms	Not available
Flavobacterium psychrophilum	Farmed trout	Wild fish reservoir risk for trout farms	Not available
Renibacterium salmoninarum	Farmed trout	Wild fish reservoir risk for trout farms	Yes
	Wild trout	Stocking of infected fish	Yes
Tetracapsuloides bryosalmonae	Wild trout Farmed trout	Shedding of infectious stages from infected fish	No evidence so far
Diplostomum sp.	Farmed fish (trout)	Wild fish reservoir risk for farmed fish (trout)	Demonstrated
Argulus sp.	Wide range of farmed and wild fish	Wild fish reservoir risk for farmed fish	Assumed

In addition to the direct impacts of disease, on mortality and abundance, there is also a potential for indirect effects on the genetic character of wild populations through differential mortality among genetic types. For example, there is a demonstrated association between immune gene variation and disease resistance or susceptibility in Atlantic salmon (Grimholt et al., 2003)⁷⁵ which could lead to an indirect genetic effect of cultured Atlantic salmon on wild conspecifics, congeneric brown trout, *Salmo trutta* L., or other salmonids (e.g. Arctic charr). The work of Coughlan et al. (2006)⁷⁶ indicates that diseases, introduced or increased in incidence by salmon aquaculture activities, can indirectly affect the genetics of cohabiting wild sea trout by reducing variability at an immune gene. In a study in the west of Ireland, allelic variation at a microsatellite marker tightly linked to a locus critical to the fishes immune response, showed a significant decline in allelic richness and gene diversity since the start of aquaculture not reflected by similar reductions at neutral loci, followed by a subsequent recovery of variability in post-aquaculture samples, probably due to gene flow with resident trout populations. The implications of the loss of variation are not certain but are likely to relate to a reduced ability of the population to cope with immune challenges more generally (De Eyto et al. 2011)⁷⁷.

3.1.4 Potential for interactions in Scotland

3.1.4.1 Physical co-occurrence

For interactions and impacts to occur, the farming of salmon and trout in freshwater pens must occur in lochs with wild salmonid populations such that the two are physically coincident. There are six salmonid species viewed as native to Scotland. Five of these occur in lochs and one is restricted to rivers. Three species, *Salmo salar* (Atlantic salmon), *Salmo trutta* (brown trout including sea trout) and *Salvelinus alpinus* (Arctic charr) are widespread and found in both rivers and lochs, though the latter is predominantly a fish reported to occur in lochs. However, populations in some lochs are known to use rivers for spawning and rivers may also provide habitat for early juveniles (Walker 2007)⁷⁸. For example, there is evidence that the Loch Insh charr spawn 15 km

⁷⁵ Grimholt, U., S. Larsen, R. Nordmo, P. Midtlyng, S. Kjoeglum, A. Storset, S. Saebø et al. 2003. MHC polymorphism and disease resistance in Atlantic salmon (*Salmo salar*); facing pathogens with single expressed major histocompatibility class I and class II loci. *Immunogenetics* 55:210–219.

⁷⁶ Coughlan, J., P. McGinnity, B. O'Farrell, E. Dillane, O. Diserud, E. de Eyto, K. Farrell et al. 2006. Temporal variation in an immune response gene (MHC I) in anadromous *Salmo trutta* in an Irish river before and during aquaculture activities. *ICES Journal of Marine Science* 63:1248–1255.

⁷⁷ de Eyto, E., McGinnity, P., Huisman, J., Coughlan, J., Consuegra, S., Farrell, K., O'Toole, C., Tufto, J., Megens, H.-J., Jordan, W., Cross, T. and Stet, R. J. M. (2011). Varying disease-mediated selection at different life-history stages of Atlantic salmon in fresh water. *Evolutionary Applications*, 4: 749–762.

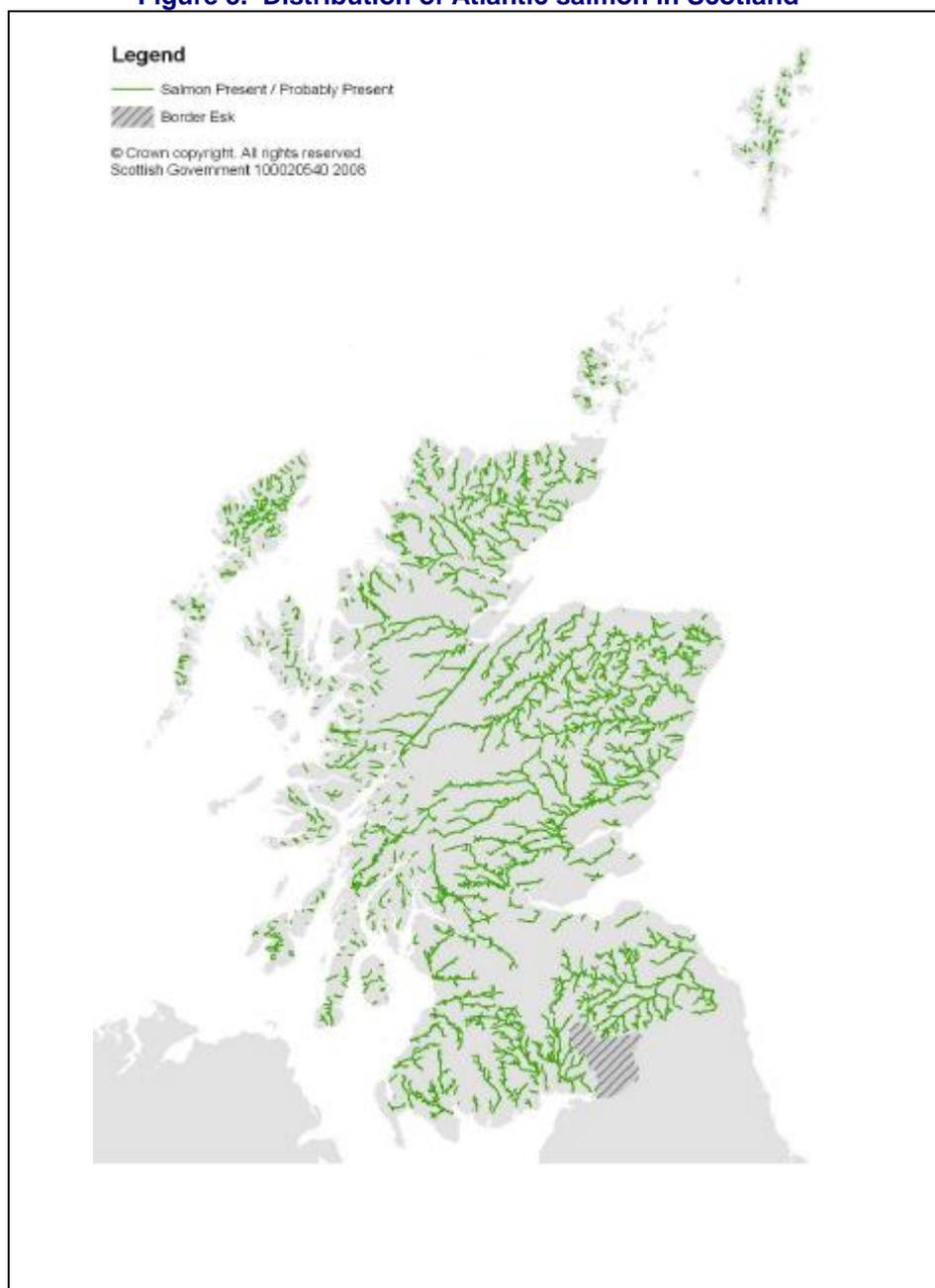
⁷⁸ Walker, A. F. (2007), Stream spawning of Arctic charr in Scotland. *Ecology of Freshwater Fish*, 16: 47–53.

up stream of the loch in a side stream of the River Spey. Rainbow trout is not native to Scotland and no self-sustaining feral populations are known to exist there.

Maps of distribution of different wild salmonid species vary in the origin and method of presentation. Set out with the discussion of each main species below are distribution maps that have been made available to the study team.

The most widely distributed Scottish salmonid is brown trout *Salmo trutta* (encompassing sea trout). This species occurs naturally in most rivers and lochs in Scotland. Additionally, they have been introduced into many stretches of rivers and small lochs that were not colonised naturally due to physical barriers to movement. In general, they are only absent from small, shallow high altitude lochs. There is no recent, detailed map available for this species and they can reasonably be assumed to be present in all lochs used for freshwater pen rearing.

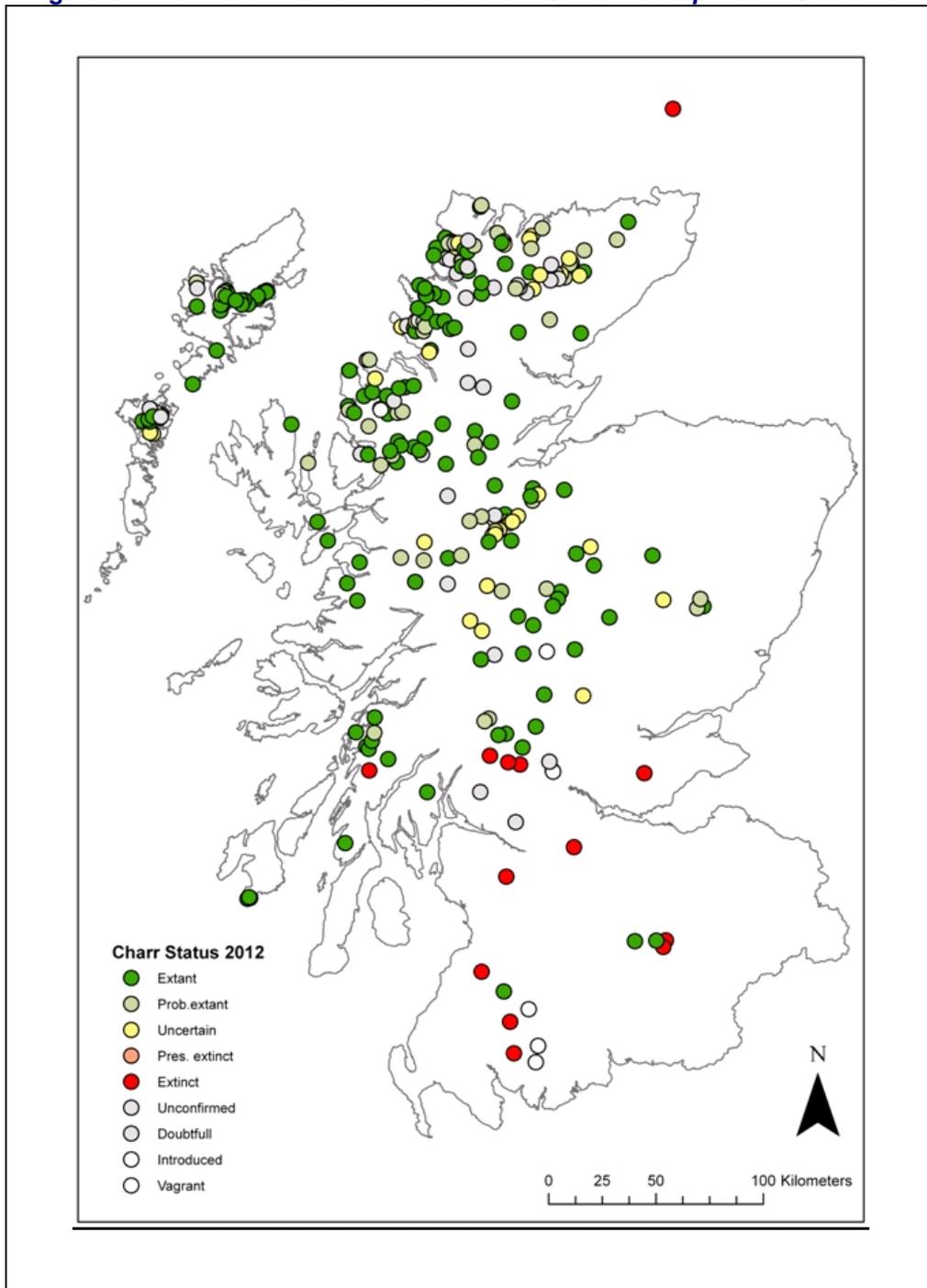
The Atlantic salmon is the second most widely distributed and found in all major river catchments where physical barriers to migration to and from salt water are absent, and habitat of a suitable nature and quality can be found. These requirements are met in most rivers. The distribution of salmon in lochs and rivers in Scotland has been extensively documented over the years by the Scottish government and the latest information is set out in Figure 5.

Figure 5. Distribution of Atlantic salmon in Scotland⁷⁹

The Arctic charr is the third most widespread Scottish salmonid but its distribution is not fully known. This is because it is generally found in deeper, colder parts of lochs outside its late autumn/ early winter spawning time, is not generally susceptible to capture by angling methods used for trout and salmon, and is not generally targeted by anglers. Thus its presence in lochs and rivers is often undetected and unknown. What is currently known about the distribution of the species in Scotland is being reviewed by Peter Maitland and Colin Adams (Figure 6). While it was formerly more widely distributed, its presence is for the most part confined to waters north of the central belt.

⁷⁹ http://www.nasco.int/pdf/far_habitat/HabitatFAR_Scotland.pdf

Figure 6: Known distribution of Arctic charr *Salvelinus alpinus* in Scotland⁸⁰

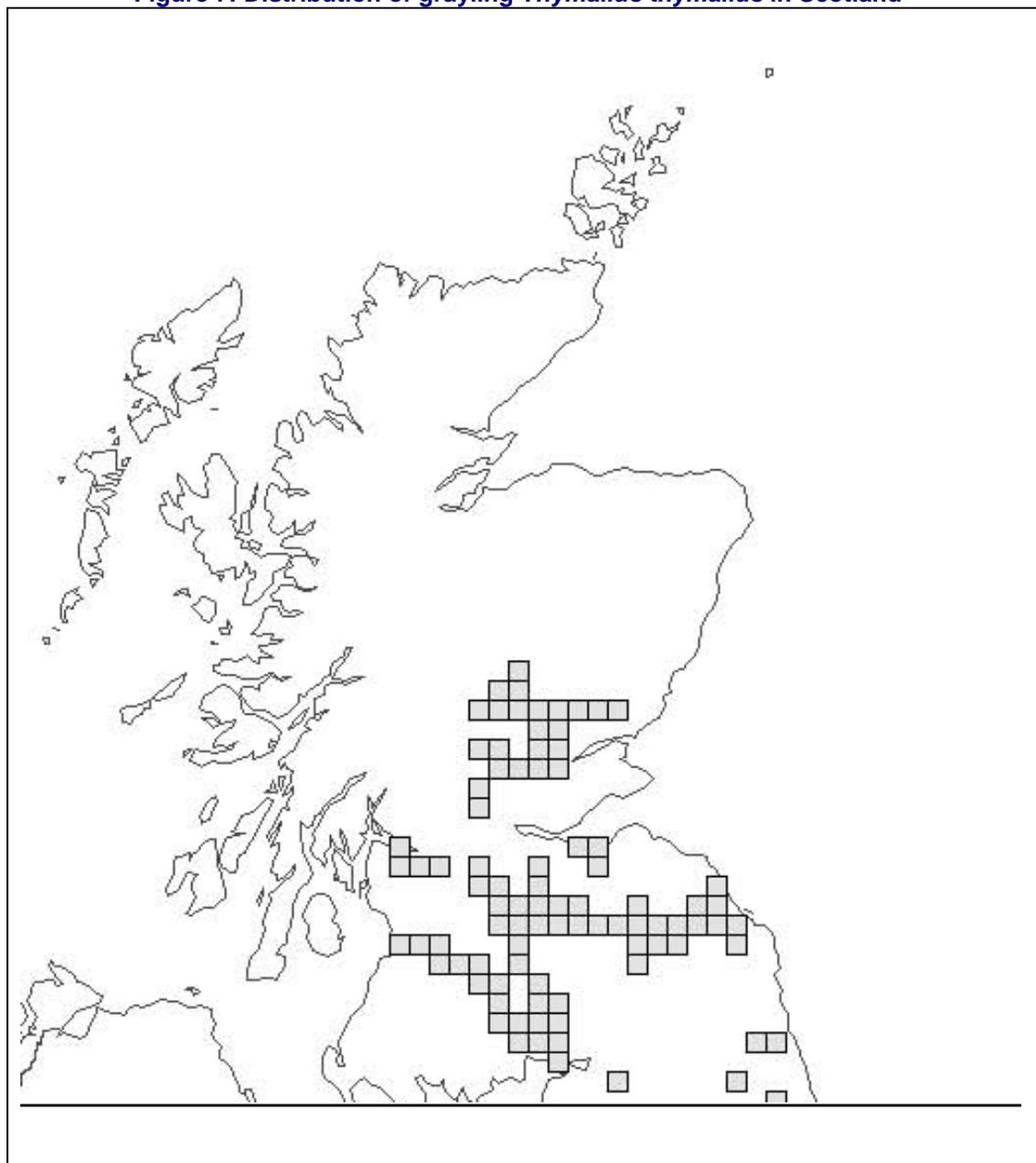


The distribution of the three remaining salmonid fishes is more restricted. The two whitefish *Coregonus albula* (vendace) and *Coregonus lavaretus* (powan) have a very limited distribution in Scotland. The former having become extinct but now reintroduced successfully into Loch Skeen. The latter are confined in their distribution to Lochs Eck and Lomond, where they are native, and to Loch Sloy and the Carron Valley Reservoir where they have been introduced. No freshwater pens are found at any of these locations. The European grayling *Thymallus thymallus* is more

⁸⁰ Colin Adams from Maitland and Adams (in prep) Charr in Lochs of Scotland: An Assessment of Distribution

widespread but it is largely confined to the southern half of the country (Figure 7). In Scotland it has only been reported to occur naturally in rivers, though it does occur in standing waters in other parts of Europe. Based on the published distribution of the species, it only occurs in one river system with freshwater pens (Tay).

Figure 7: Distribution of grayling *Thymallus thymallus* in Scotland⁸¹



The coincidence of freshwater pens used to rear farmed salmon or rainbow trout with wild populations of salmon, trout and charr in Scottish lochs has been assessed by comparison of the site location derived from the OS grid references for each site, (derived from the MSS site

⁸¹ Joint Nature Conservation Committee, 2007. Second Report by the UK under Article 17 on the implementation of the Habitats Directive from January 2001 to December 2006. JNCC, Peterborough

information), with the species distribution maps shown above. In addition it has been determined whether the pen sites also share catchments with Special Areas of Conservation (SAC's) for Atlantic salmon or freshwater mussel, based on site information from JNCC. This is set out in Tables 4a and 4b below.

Table 4a: Information on all of active freshwater pen sites used for rearing salmon smolts in Scotland as at late 2011, together with estimate of presence of wild salmonids and SAC's for Atlantic salmon and Freshwater pearl mussel in the same catchments

Reference	OS Location	Name of Site	Date registered	Holding Capacity (m3)	River system	River District	Within same catchment			
							Salmon present?	Charr present?	Salmon SAC?	Pearl muss SAC?
FS0069	NF806445	Loch Na Shibaigh Mhor	1991	870	Short river drains to Loch Carnan NE corner of S Uist	Howmore	Yes	No?	No	No
FS0149	NG049889	Loch Langavat	1986	9,216	Short river drains to SW Harris coast	Clayburn	Yes	Yes	No	No
FS0150	NN193853	Loch Lochy	1996	40,960	Lochy	Lochy	Yes	Yes	No	No
FS0195	NF906685	Loch Gierrean	1987	2,268	Short river drains into Loch Maddy, E side of N Uist	Mullanageren	Yes	No?	No	No
FS0255	NM683505	north west of Claggan in Loch Arienas Morvern High	1985	9,600	Aline	Aline	Yes	No?	No	No
FS0270	NM924146	near Kilmelford	1985	13,524	Awe	Awe	Yes	Yes	No	No
FS0300	NG860479	at the south end of Loch Damph Torridon Highland	1985	10,080	Balgay	Balgay	Yes	Yes	No	No
FS0302	NB188408	Loch an Duin	1993	840	Short river drains to outer part of Loch Carlabhagh, thence outer part of East loch Roag	Loch Roag	No?	No?	No	No
FS0330	NB334278	Loch Thota Bridein south east of Achmore	1992	1,215	Short river drains to Loch Liurboist, east coast Lewis	Creed	Yes	No?	No	No
FS0351	HU603905	Papil Water west of Tresta Fetlar Shetland	1987	2,262	Very short river on Fetlar, Shetland	Shetland	No	No?	No	No
FS0375	NG859520	in the north end of Loch Damph Torridon Highland	1991	15,840	Balgay	Balgay	Yes	No?	No	No
FS0428	NM468507	Loch Frisa	1988	8,640	Aros, drains to Sound of Mull	Penrygowan	Yes	No?	No	No
FS0429	NM564379	Loch Ba Mull	1989	7,200	Ba, Mull	Baa	Yes	No?	No	No
FS0434	NH591337	south west of Dores Loch Ness Highland	1987	24,460	Ness	Ness	Yes	Yes	Yes	Yes
FS0468	NM873169	south of Corrielorne in Loch Tralaig Argyll	1979	7,162	Oude, drains into Loch Melfort, Argyll	Awe	No	Yes	No	No
FS0471	NN10005	near Dunblane	1993	2,016	Wharry Burn drains into Forth catchment	Forth	Yes	No?	Yes	Yes
FS0506	NB354225	Keose Lochs Isle of Lewis	1994	2916	Drains via small lochs and short river to Loch Liurbost, east coast Lewis	Creed	Yes	No?	No	No
FS0542	HP568013	In the Loch of Snaravoe north of Belmont Unst Shet	1992	2,714	Very short river to Bluemull Sound, SW coast of Unst, Shetland	Shetland	Yes	No?	No	No
FS0612	NC396302	Loch Merkland	1994	8,125	Shin catchment drains to Dornoch Firth	Kyle of Sutherland	Yes	Yes	Yes	Yes
FS0627	NF761293	Loch A'Clachain South Uist	1988	1,058	Drains via small FW lochs and short river to Loch Aineort, east coast S Uist	Howmore	Yes	No?	No	No
FS0632	NF770303	Loch bayhead South Uist	1990	4,320	Drains via very short river to Loch Aineort, east coast S Uist	Howmore	Yes	No?	No	No
FS0649	NN136895	east of Inver Mallie in Loch Arkaig Highland	1991	25,600	Lochy	Lochy	Yes	Yes	No	No
FS0726	NF804435	Loch Druim An Iasgair	1991	870	Small loch system, south Uist, drainage route not clear from map	Howmore	no	No?	No	No
FS0737	NG085885	north north east of Ardvat in Loch Huamavat South H	1991	4,608	Short river to SE coast Harris	Clayburn	Yes	No?	No	No
FS0742	NM887792	Head of Loch Sheil	1992	31,360	Shiel	Shiel	Yes	No?	No	No
FS0756	NB235460	Carloway	1994	2,100	Drains via two small lochs to west coast Lewis	Loch Roag	No	No?	No	No
FS0762	NB365278	Loch Sandavat	1994	11,520	Ghlas catchment, drains to Loch Liurboist, east coast Lewis	Creed	Yes	No?	No	No
FS0769	NH637911	Loch Migdale	1992	3,375	Small catchment draining to Dornoch Firth	Kyle of Sutherland	No?	No?	No	No
FS0776	NM866120	near Kilmelford	1987	1,600	Small catchment draining to Loch Melfort, Argyll	Awe	No	No?	No	No
FS0816	NF768313	East Loch Ollay South Uist	1993	2,592	Drains via short river to Loch Aineort, east coast S Uist	Howmore	Yes	No?	No	No
FS0861	NB343240	in Loch Na Creige Fraoich west of Crosbost Western	1995	11,520	Complex of small lochs draining to Loch Erisort, East Lewis	Clayburn	Yes	No?	No	No
FS0862	NB338234	Loch An Eilean Liath Soval	1995	11,520	Complex of small lochs draining to Loch Erisort, East Lewis	Clayburn	Yes	No?	No	No
FS0866	NR765514	Tayinloan	1995	6,000	Loch Garasdale, small catchment draining to Sound of Gigha, Argyll	Ormsary	Yes	No?	No	No
FS0887	NC555084	Loch Shin	1996	18,720	Shin catchment	Kyle of Sutherland	Yes	Yes	Yes	Yes
FS0890	NC394242	Loch Shin	1996	24,460	Shin catchment	Kyle of Sutherland	Yes	Yes	Yes	Yes
FS0907	NC254502	Loch na Thull	1997	4,320	Small catchment draining to Loch Laxford, Sutherland	Laxford	Yes	Yes	No	No
FS0989	HU511798	Loch of Littlester	2000	242	Loch Tralaig, within Oude catchment, drains into Loch Melfort	Awe	No	No?	No	No
FS1000	HP563011	In the Loch of Belmont north west of Belmont Unst S	2000	904	Very short river to Bluemull Sound, SW coast of Unst, Shetland	Shetland	Yes	No?	No	No
FS1001	NB366293	Lochs road	2000	1,296	Complex of small lochs draining via Allna Craoibhe to E coast of Lewis	Creed	Yes	No?	No	No
FS1002	NB328305	Pentland Road Achmore Lochs	2000	1,296	Complex of small lochs draining via Abhainn Ghrioda, E coast Lewis	Creed	Yes	No?	No	No
FS1095	HP601115	Loch of Cliff Unst Shetland	2006	3,617	Within catchment on Unst, drains to north coast Unst.	Shetland	Yes	No?	No	No
FS1104	NH221016	Laddie Wood Loch Garry Inverness-shire	2007	22,275	Ness	Ness	Yes	Yes	Yes	Yes
Totals			42	365,081		0	Y=34	Y=12	Y=6	Y=6

Table 4b: Information on all of active freshwater pen sites used for rearing rainbow trout in Scotland as at late 2011, together with estimate of presence of wild salmonids and SAC's for Atlantic salmon and Freshwater pearl mussel in the same catchments

Reference	OS Location	Name of Site	Date registered	Holding Capacity (m3)	River system	River District	Within same catchment			
							Salmon present?	Charr present?	Salmon SAC?	Pearl muss SAC?
FS0023	NS077614	in Loch Fad Isle of Bute	1980	5580	Short river draining through Rothsay	Drummachloy	No	No?	No	No
FS0134	NX607907	Kendoon Loch east of Carminnows Dumfries and Galloway	1991	6,120	Dee, Galloway	Dee (Kirkcudbright)	Yes	No?	No	No
FS0180	NN620240	south of Ardeveich in Loch Earn Perthshire	1984	15,532	Earn	Tay	Yes	Yes	Yes	No
FS0260	NM956080	north east of Braevallich in Loch Awe	1985	32,378	Awe	Awe	Yes	Yes	No	No
FS0268	NN083263	south east of the power station in Loch Awe Argyll	1978	32,372	Awe	Awe	Yes	Yes	No	No
FS0432	NN762442	PH15 2HP	1980	24,500	Loch Tay	Tay	Yes	Yes	Yes	No
Totals			6	116,482			Y=5	Y=4	Y=2	

The detailed knowledge of the distribution of Atlantic salmon accumulated over the years makes it possible to say with confidence that the species is associated with most lochs with pens. 34 out of 42 salmon smolt pen sites share catchments with wild salmon (some 81%), and if trout pens are included, 40 out of 47 pen sites share catchments with wild salmon (85% overall). In most cases, salmon utilise inflow and outflow streams or use lochs during upstream (adults) or downstream (smolts) migration. However, in some river systems, lochs are important habitat for juveniles (Klemetsen et al. 2003); this is considered to be the case in some West Coast catchments such as those on the Hebrides but documentation of its extent is lacking.

The situation as regards Arctic charr is less certain. The species has historically been recorded in over 200 lochs but the actual number of locations is uncertain, though it is known that in some it has become extinct. No comprehensive survey for Arctic charr in Scottish lochs has been carried out and many records of their presence in lochs are historical and opportunistic. Thus their absence from lochs cannot be assumed in most cases. This view is supported by recent MSS studies of fish communities in an arbitrary selection of lochs which confirmed the presence of the species in some lochs for which there were no records of the species. However, the species has a more limited dispersal capacity as well as a general requirement for colder, deeper water, it is likely that it is not as widespread as either trout or salmon. That said Arctic charr do occur in some lochs, such as Loch Mealt on Skye where both salmon and trout are absent. The overlap figure must be taken as highly indicative.

There are three Scottish SACs primarily designated for Atlantic salmon and/or freshwater pearl mussels within which there are salmon smolt pen farms in the same catchment: Morriston, (within the Ness catchment) Teith (within the Forth catchment) and Oykel (within the Shin catchment). It should be noted that none of the smolt pen farms are within the boundaries of the SACs, but they are in a water catchment accessible for free-swimming animals. In the case of the Morriston there are 2 pen farms. In the case of the Oykel there are 3 pen farms, and in the case of the River Teith, 1 pen farm. In total, therefore, 6 salmon smolt farms out of 42 (14%) are located in the vicinity of 3 out of the 17 (16%) Scottish rivers designated as SACs for Atlantic salmon and/or freshwater pearl mussels. There are no salmon pen farms in catchments of SACs that are designated for freshwater pearl mussels but not salmon. The Teith SAC is designated for salmon, but not freshwater pearl mussels.

For rainbow trout pen farms, there are 2 within an SAC – the Tay. In this case one of the farms is physically located within the boundary of the SAC.

According to the SNH database (Sitelink.), all of the Atlantic salmon and freshwater pearl mussel SACs were designated on the 17th March 2005. All salmon and trout pen farms which are present in the catchment of a relevant SAC were already established when the area received its designation in 2005. The only apparent exception is the site at Laddie Wood, Loch Garry (FS1104) in the Ness catchment, which was registered in 2007, but which was an amalgamation of three historic sites which had been registered in the early 1990's.

It is appropriate to consider the relevance or otherwise of this co-incidence with SACs. The status of SACs in biological terms, referred to as its 'condition', can be obtained from the SNH website, and specifically Sitelink⁸². For the Morriston, Teith and Oykel the description given by SNH is 'unfavourable recovering' for Atlantic salmon, and for the Tay, 'favourable maintained'. Care should be exercised in interpreting the language used: 'unfavourable recovering' is generally seen as rather positive in terms of SAC condition. Of the 17 Scottish SAC rivers designated for Atlantic salmon, 15 are 'unfavourable recovering', and the other two are 'favourable maintained'. It does not seem that the presence of freshwater aquaculture pens has impacted on SAC condition compared with SACs without pens, or at least not in any way that can be assessed from the simple description of all SAC conditions.

Another analysis of Atlantic salmon river SAC status was undertaken by MSS for the Scottish Mixed Stock Salmon Fisheries Working Group in 2009/10 (already referenced). This entailed a

⁸² <http://gateway.snh.gov.uk/sitelink/index.jsp>

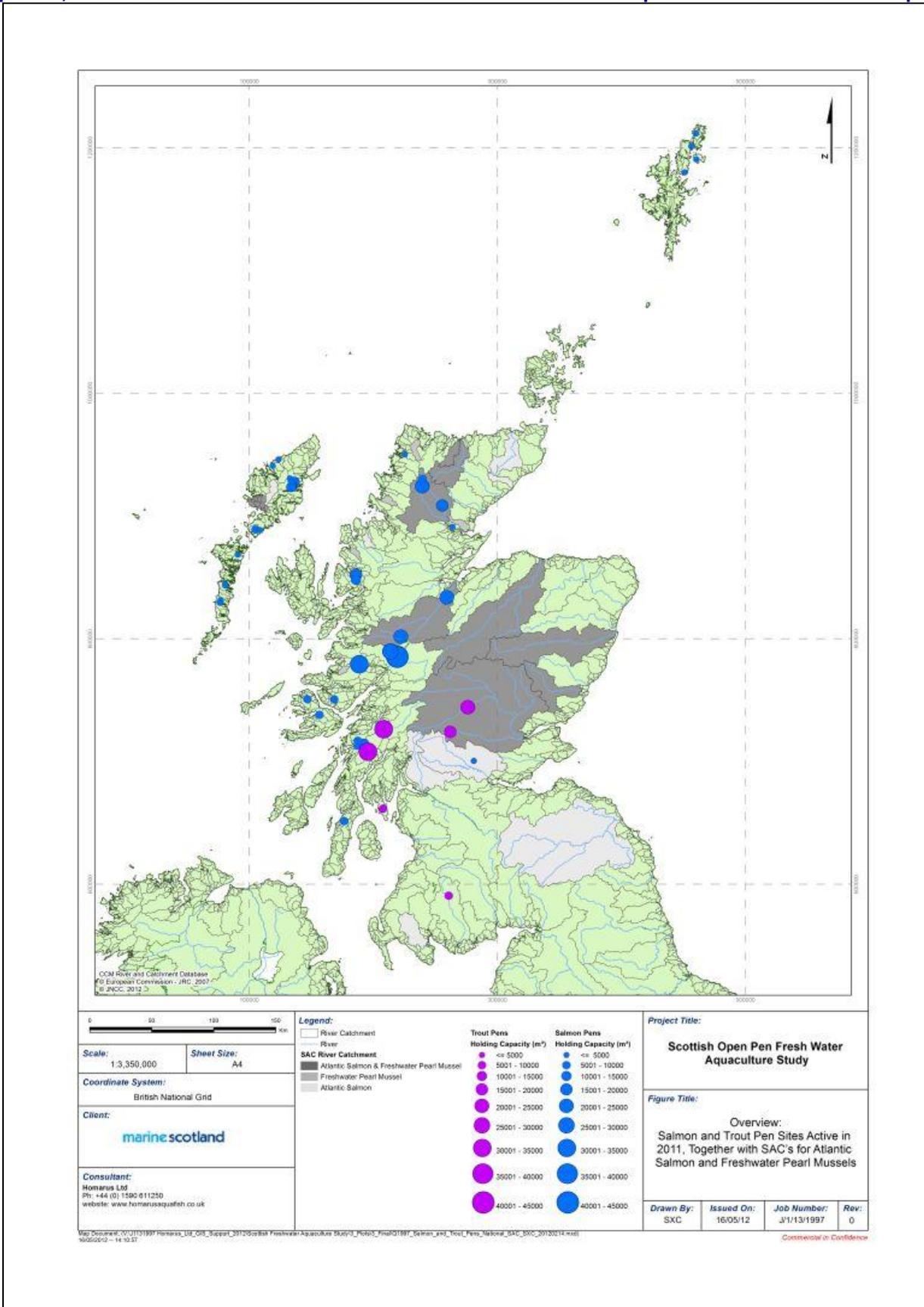
detailed analysis of the rolling 5 year average rod catch statistics for each river, and for the three main seasonal stock components of each river: spring, summer and autumn. The following summary information was presented (two small rivers were combined in the analysis, so the total number considered was 16 rather than 17):

- For the Spring stock component catches:
 - 94 % are declining (15 out of 16 rivers)
 - 0 % are increasing (0 out of 16 rivers)
 - 6 % are largely stable over the long term(1 out of 16 rivers)
- For the Summer stock component catches:
 - 19 % are declining (3 out of 16 rivers)
 - 72 % are increasing (10 out of 16 rivers)
 - 19 % are largely stable over the long term (3 out of 16 rivers)
- For the Autumn stock component catches:
 - 6 % are declining (1 out of 16 rivers)
 - 82 % are increasing (13 out of 16 rivers)
 - 12 % are largely stable over the long term (2 out of 16 rivers)

The details for the Morriston, Teith, Oykel and Tay catch trends are presented in an annex of the cited report, but in summary, the spring catch trends for the Morriston, Teith, Oykel and Tay all showed long term decline – but this was also true for most of the designated rivers. The Morriston was largely stable over summer and autumn (whilst some other rivers without freshwater pens showed declines in these seasons), and the Teith, Oykel and Tay were increasing in summer and autumn.

Pen site locations and capacities are shown by species on the following maps of river catchments. Those catchments containing SAC's for the species of interest are also shown.

Figure 8a: Catchment map showing locations and capacities of active freshwater pen sites, by species, also locations of SAC's for Atlantic salmon and freshwater pearl mussels: National map



Map template source: CCM River and Catchment Database © European Commission, JRC, Vogt, J.V. et al. (2007): A pan-European River and Catchment Database. European Commission - JRC, Luxembourg, (EUR 22920 EN) 120 pp

Figure 8b: Catchment map showing locations and capacities of active freshwater pen sites, by species, also locations of SAC's for Atlantic salmon and freshwater pearl mussels: Mainland & Shetland

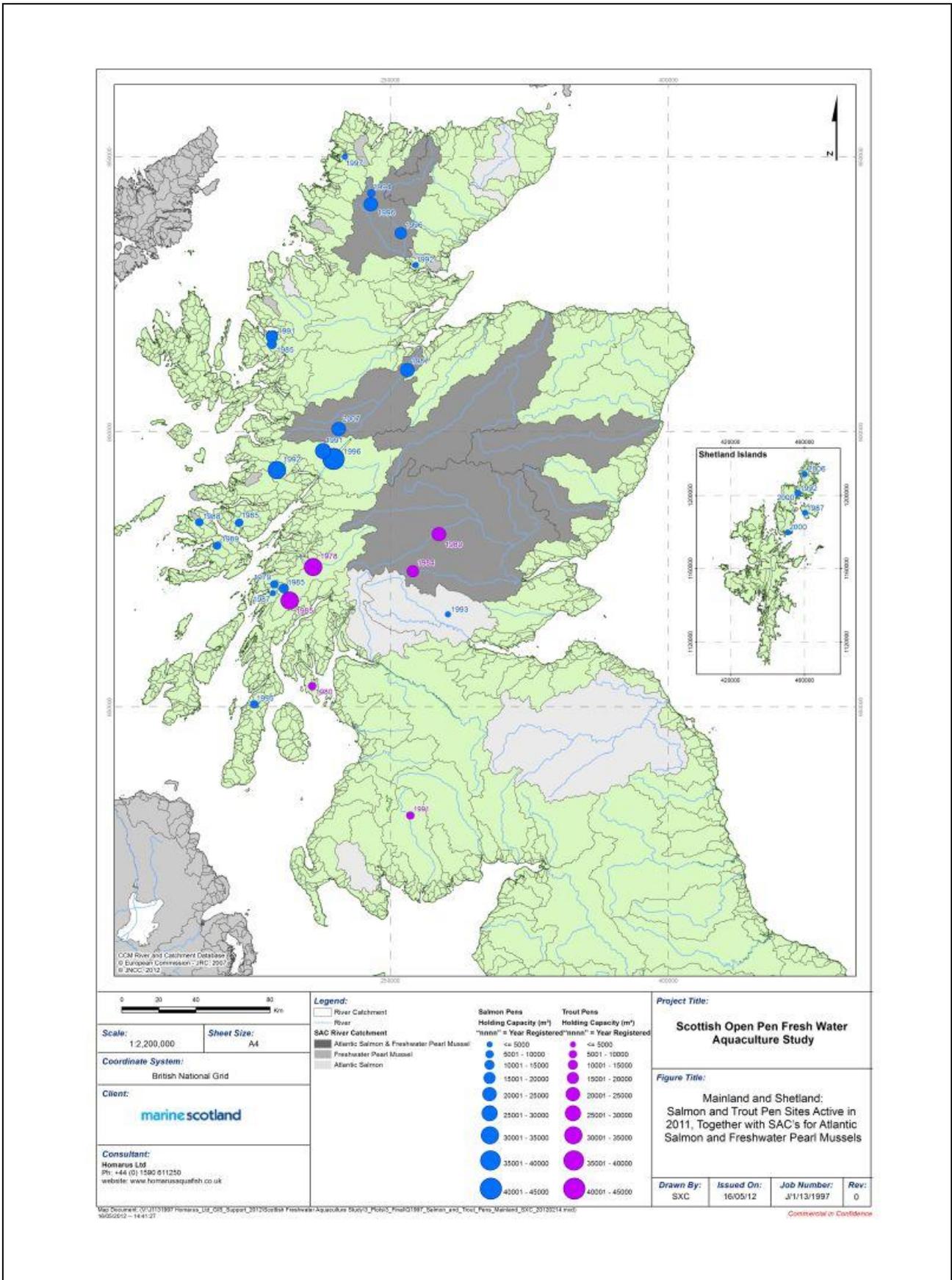
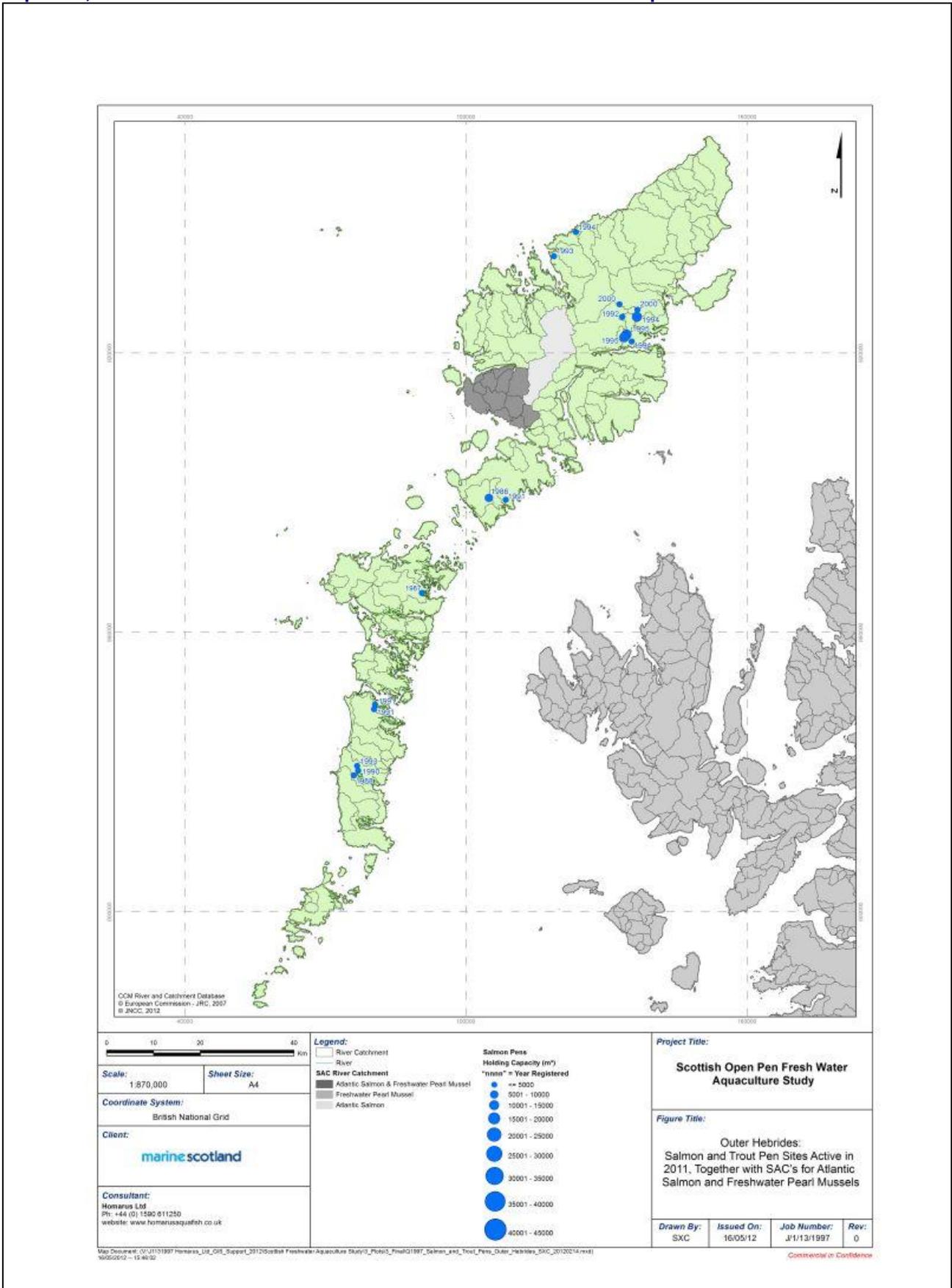


Figure 8c: Catchment map showing locations and capacities of active freshwater pen sites, by species, also locations of SAC's for Atlantic salmon and freshwater pearl mussels: Outer Hebrides



3.1.4.1.1 Trends in numbers and capacities of sites**Salmon smolt**

The following table sets out recent data on production systems for salmon smolts in Scotland.

Table 5: Summary of salmon smolt production in Scotland, showing numbers and types of sites, volumes and notional densities, 2000-2010

Year	Smolt output				Production sites							
	Pens (000's)	Tanks (000's)	Total (000's)	Pen share	Tanks				Pens			
					Number of sites (tanks)	Capacity (000's m3)	Av volume tanks (000's m3)	Notional density (smolt output / m3)	Number of sites (pens)	Capacity (000's m3)	Av volume pens (000's m3)	Notional density (smolt output / m3)
2000	21,531	24,052	45,583	53%	99	45	0.45	534	85	344	4.05	63
2001	22,309	25,237	47,546	53%	93	48	0.52	526	76	328	4.32	68
2002	20,085	27,076	47,161	57%	92	41	0.45	660	81	409	5.05	49
2003	20,320	24,094	44,414	54%	96	40	0.42	602	80	391	4.89	52
2004	22,424	17,575	39,999	44%	96	43	0.45	409	76	365	4.80	61
2005	15,380	20,946	36,326	58%	87	38	0.44	551	61	378	6.20	41
2006	18,700	22,127	40,827	54%	77	36	0.47	615	58	365	6.29	51
2007	19,440	18,685	38,125	49%	79	37	0.47	505	56	327	5.84	59
2008	17,065	19,385	36,450	53%	77	41	0.53	473	53	385	7.26	44
2009	17,041	19,827	36,868	54%	58	37	0.64	536	47	388	8.26	44
2010	20,333	16,539	36,872	45%	59	38	0.64	435	45	409	9.09	50

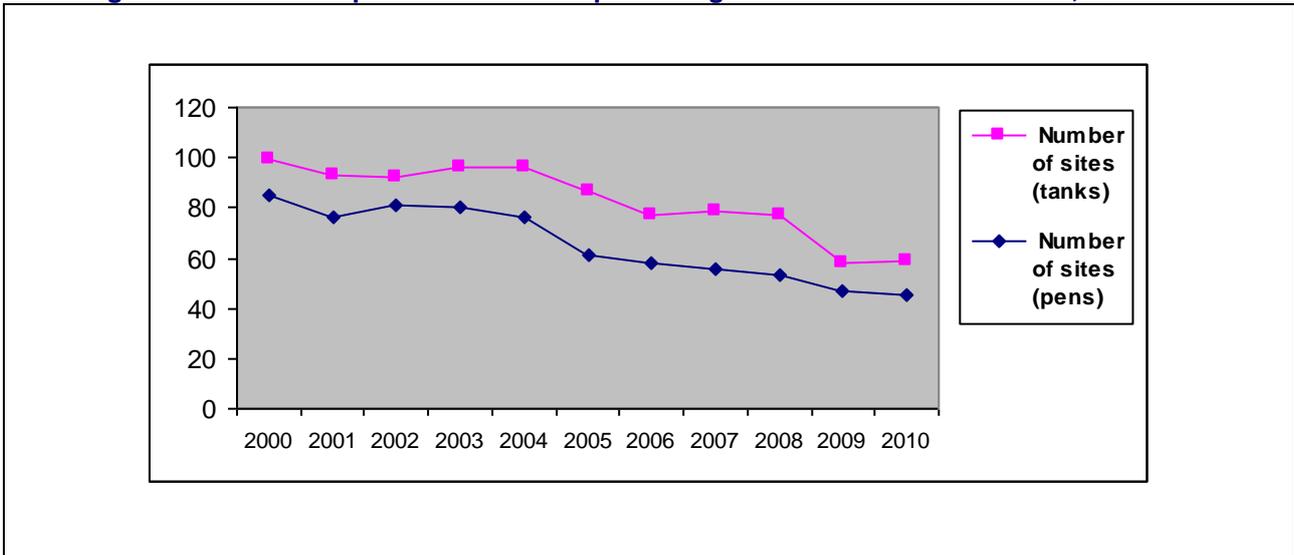
Data source: Marine Scotland Science, Scottish Fish Farm Production Surveys

The ten year time series shows some interesting trends. Overall smolt production has shown a variable but declining trend, with some 19% fewer smolts reared in 2010 compared to 2000, although projected production for 2012 is back over 40 million.

Finished salmon production tonnage has shown a rise from 129,000 tonnes to 154,000 tonnes over the decade, (with some shorter term variations), and so indicates an improvement in productivity per smolt. This is discussed further in Section 3.2.3.2 regarding future demand for smolts.

Freshwater pens have provided around 50% of the production, with no obvious trend in share. The number of sites in use has dropped markedly, as shown below.

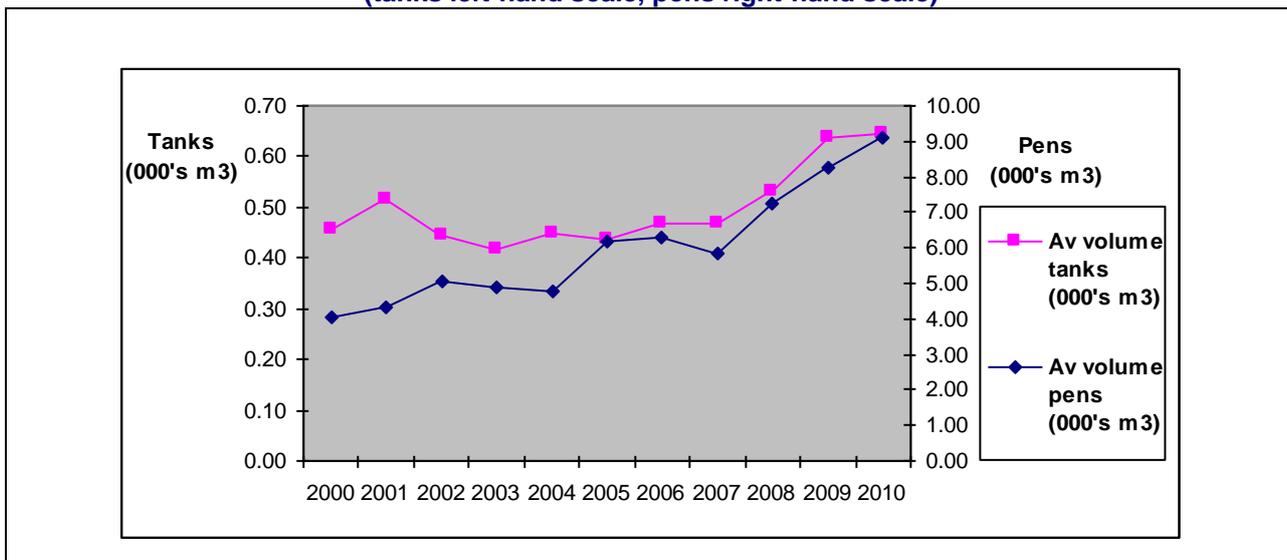
Figure 9: Number of pen and tank sites producing salmon smolts in Scotland, 2000-2010



Numbers of tank sites have dropped from 99 to 59 (40%), while numbers of pen sites have dropped from 85 to 45 (47%) over the decade. Note that the number shown in Table 4a is 42 in late 2011, three sites having dropped out of production compared to the 2010 figure derived from the MSS annual survey.

The average volume of each type of site has increased significantly, as shown below.

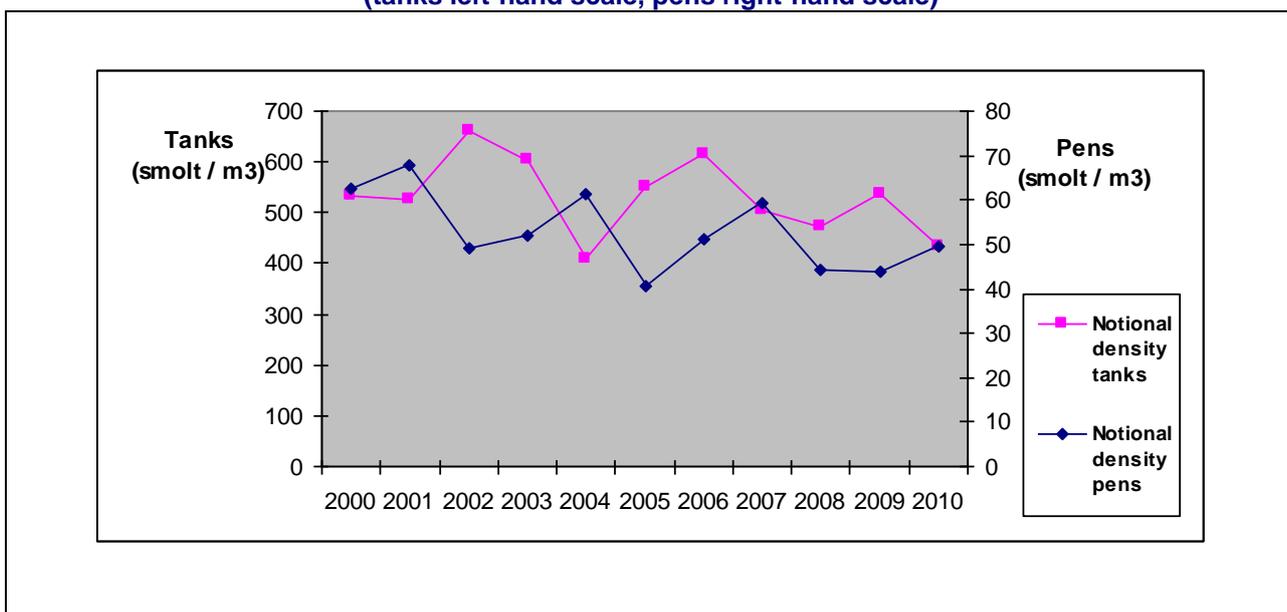
Figure 10: Average volume of sites in use for growing salmon smolts in Scotland, 2000-2010, (tanks left-hand scale, pens right-hand scale)



Average volume of tank sites have increased by about 42% in the decade, while the increase seen in average volume of pen sites is 125%.

These two opposing trends have meant that the total capacity in use has not changed very much. There is a slight fall in overall capacity of tank sites and a slight increase in that for pens. Comparing total output of fish with volume available gives a notional picture of intensity of use, in terms of smolts produced per unit volume of holding capacity in each year. Both systems have seen decreases in intensity of use of some 20%.

Figure 11: Notional density of salmon smolts in tank and pen systems in Scotland, 2000-2010, (tanks left-hand scale, pens right-hand scale)



The overall trends are therefore one of use of significantly fewer, larger freshwater sites and modest decreases in intensity of use. This follows the general trend in the marine growing phase of salmon which has also sought efficiency gains through use of fewer, larger sites and which has also moderately reduced overall stocking density.

Rainbow Trout

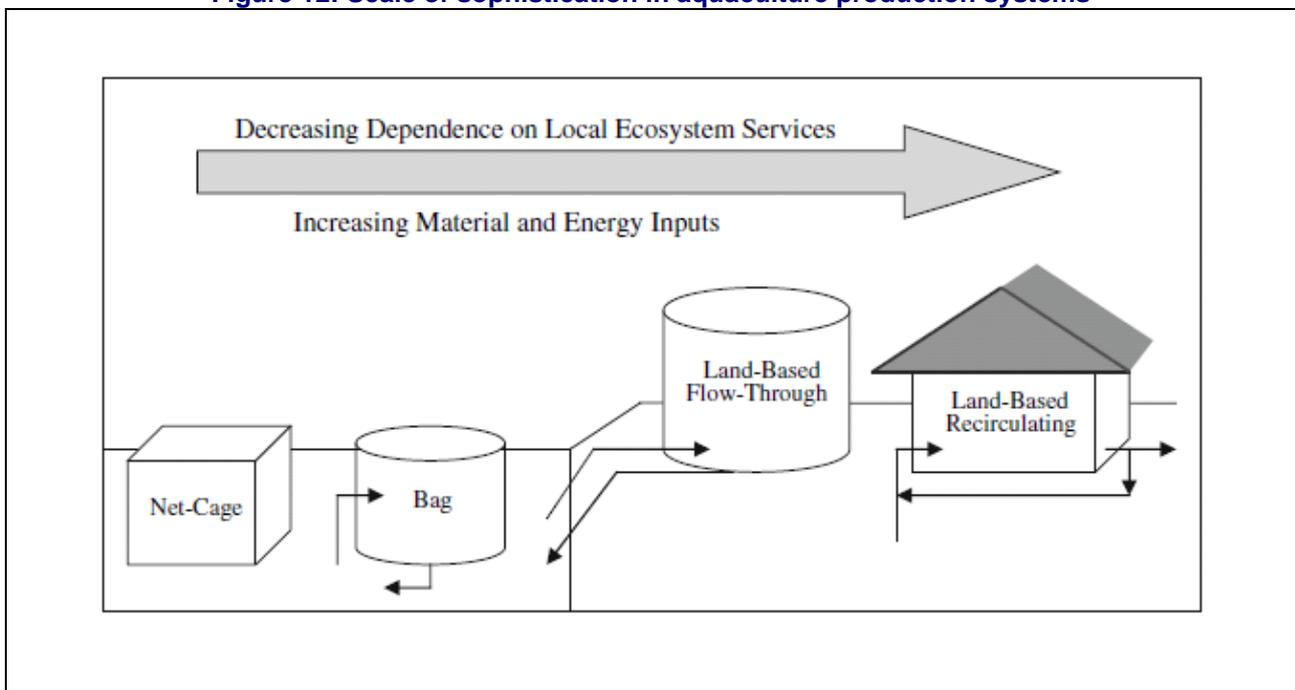
Freshwater pens are also an important contributor to rainbow trout production in Scotland, accounting for around 1600 tonnes, (32% of overall production), from five sites in 2010. This compares to around 2,300 tonnes, (44% of production) from nine sites in 2000. Here too, there seems to have been a trend toward using fewer, larger sites.

3.1.4.2 Current production practices

3.1.4.2.1 Introduction to Production Approaches

There are different ways of approaching production systems in aquaculture, and it is important to consider these when thinking about a transition from pen to tank production for large volumes of smolts. The review by Ayer and Tyedmers (2008)⁸³ provides a summary of the sliding scale of sophistication in aquaculture systems in terms of material and energy inputs and dependence on local ecosystem services, and Figure 12 illustrates this graphically.

Figure 12: Scale of sophistication in aquaculture production systems



The hierarchy of water interventions in land-based aquaculture is⁸⁴:

- Simple aeration (using air blowers) in the tanks, ponds or raceways

⁸³ http://sres.management.dal.ca/Files/Tyedmers/LC_Impacts.pdf

⁸⁴ See for example: Thorarensen and Farrell 2011 - http://people.landfood.ubc.ca/anthony.farrell/pubs/p307-Thorarensen_and_Farrell_2011.pdf

-
- Injection of additional oxygen (using pure gas – bought or generated on site) into the incoming ‘new’ water flow
 - Direct oxygenation (using pure gas and injectors/diffusers) into each individual fish-holding tank
 - Partial water re-use, where some of the water is recirculated around the farm without complex treatment, but with re-injection of oxygen. This approach provides oxygen, but also provides some additional flow characteristics, allowing for better solids removal
 - This approach may, in some cases, include a step to help drive off excess carbon dioxide, sometimes with the use of ozone gas injection
 - Complex recirculation, which introduces the idea of biological and other treatment systems (solids filtration, degassing, UV, ozone, denitrification, re-oxygenation) which also remove most of the other toxic metabolites, so that the same water can be used many times
 - With this degree of water retention in a system, artificial control of temperature becomes feasible.

The present study has to take account of all the possible types of sophistication in freshwater fish production, ranging from the most simple – pens - to the most complex – full recirculation with temperature control.

The study also has to take into account modern hybrid approaches. For example, a sophisticated recirculation system could be used to speedily grow salmon juveniles to an intermediate (but pre-smolt) size, when they could then be transferred to freshwater pens for a much shorter final grow-out-to-smolt phase, or alternatively to produce larger smolts for subsequent transfer to marine pens. This latter scenario is discussed in more detail later.

Ayer and Tyedmers (2008) observed that while the use of closed containment systems might reduce the pressure of pen-based systems on local environmental services, the increased material and energy requirements of such systems creates other environmental challenges.

3.1.4.2.2 Atlantic Salmon Smolts

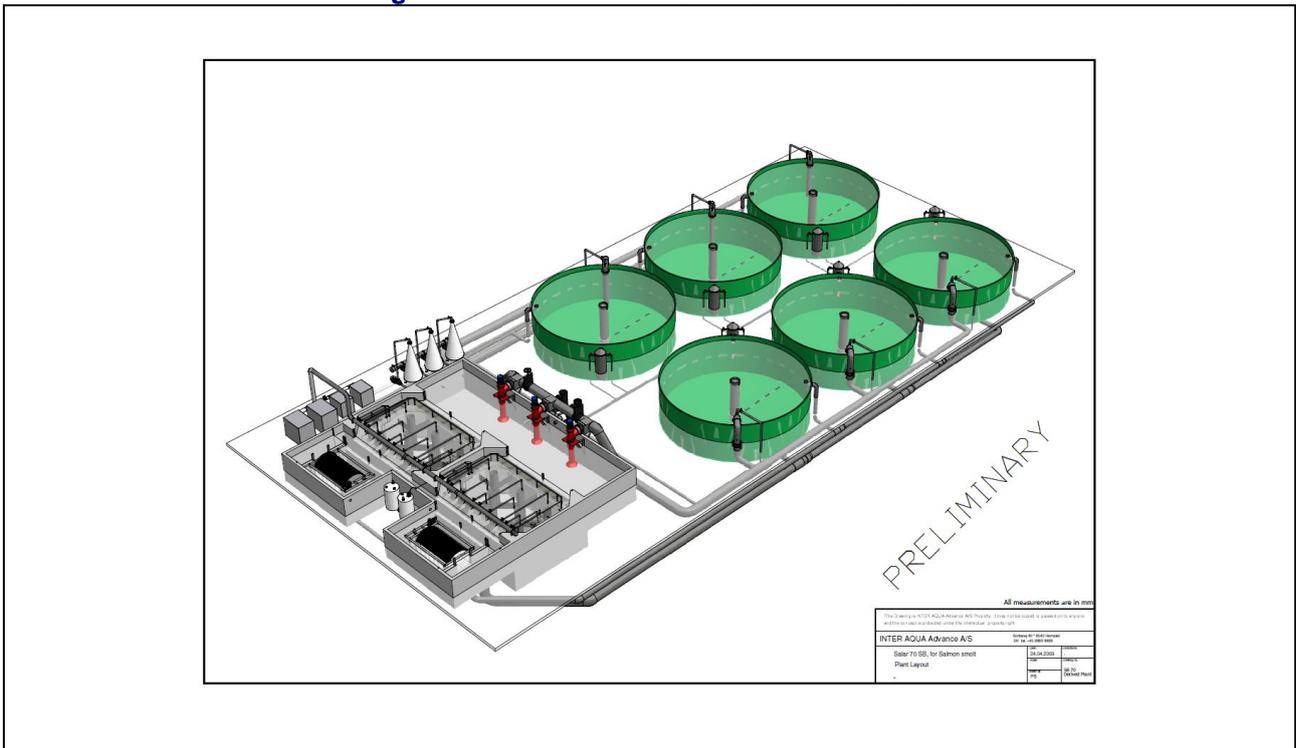
Atlantic salmon life cycle

A simple representation of the production cycle for Atlantic salmon is illustrated in Figure 16. The main focus of this study is the freshwater stage, although it is important to remember that the entire production cycle from egg to harvested adult fish is a continuum. Changes in practices in one part of the cycle will have impacts on other parts of the cycle, and this aspect is discussed in more detail later in the report.

Irrespective of subsequent production methodology, all farmers must have land-based hatchery, first-feeding and fry production units. Some companies keep their own broodstocks and obtain their own eggs, whilst others purchase fertilised eggs from specialist producers.

The freshwater parr to smolt phase of the cycle is the main focus for this study. The industry can choose to grow these in land-based tank systems of varying levels of sophistication (Figures 13 and 14) or in freshwater pens (Figure 15).

Figure 13: A modern recirculation smolt unit



Source: InterAqua

Figure 14: A traditional flow-through smolt unit



Source: Lakeland Smolt Ltd.

Figure 15: A freshwater salmon pen unit, Loch Arkaig



Source: Authors

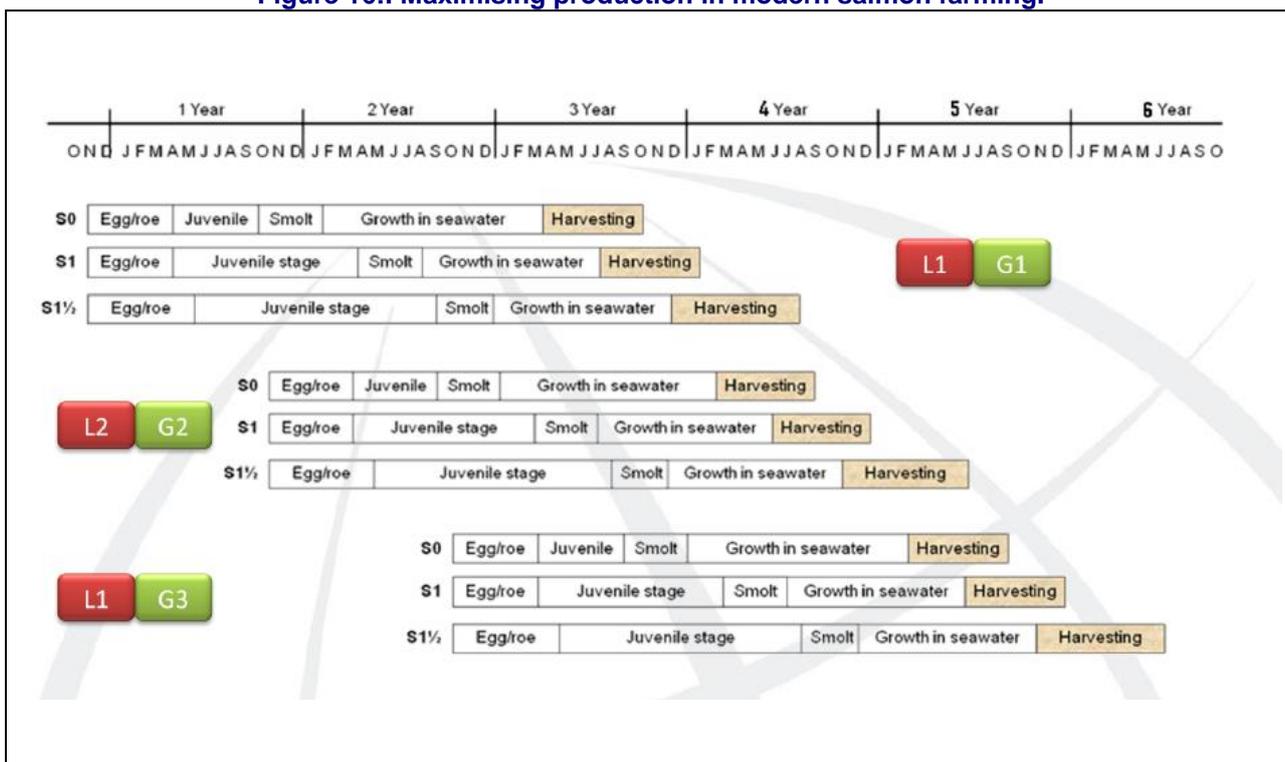
Extended Annual Production

Atlantic salmon reproduction is based on a natural annual cycle, with eggs being produced over one short season in the year. Unlike many farmed marine species, there has been no

development of out-of-season salmon spawning using photoperiod control. However, salmon production and harvesting for the market is now a year-round business. This has been achieved by a combination of management strategies and the development of so-called S0 or S1/2 smolts (see Figure 16), which can be put to sea earlier than traditional S1 smolts. These smolts are produced through a combination of heated water in the early stages of rearing leading to increased growth rates, and changes in the light regimes to trick the fish into thinking that a whole year has passed in a period of only 6 months. Figure 16 shows graphically how salmon stocking is best managed at two marine farm locations in order to achieve maximum possible year-round production.

Almost 40% of Scottish smolt production is S1/2s⁸⁵. Whilst the manipulation of photoperiod might be easier to achieve in a land-based production system, the industry has confirmed that S1/2s can also be produced in pen systems, using suitable shading and lights.

Figure 16:. Maximising production in modern salmon farming.



Source: Marine Harvest

⁸⁵ MSS Annual Survey 2010.

Husbandry in Freshwater Pens

Juvenile salmon are traditionally stocked into freshwater pens when their mean weight is 5-10 g, and they are grown in the pens until ready to be sent to marine sites, usually at 80-100 g. In order to optimise conditions for growth, the fish are graded and split between pens at least twice during this phase of production.

The number of smolts that can be held per unit pen volume (stocking density) is, in principle, a judgement that would be based on the biology of the species. However, in practise stocking densities are increasingly being dictated by quality scheme standards. A common one, Freedom Foods⁸⁶, limits the density to a maximum of 8 kg/ m³ (previously 12 kg/ m³).

Freedom Foods standards also apply to tank-based smolt densities, with the current maximum being 30 kg/ m³. Soil Association⁸⁷ organic standards for tank-based systems is set at a maximum of 20 kg/ m³.

It is important to consider the different husbandry procedures used in pen production, because some of these potentially represent risk points as far as escapes of fish are concerned.

Considering these in approximate chronological order:

- **Stocking pens with new fry.** There are two main approaches taken by industry. Either an empty pen can be towed to the shore pier for direct loading from the delivery lorry, or the fish can be placed into tanks on a raft, and that then towed to the empty pen in its normal location in the pen group.
- **Net size and new fry.** Pens have to be equipped with nets of an appropriate size to ensure that even the smallest fish in the pen cannot escape by swimming through. This is relevant to all stages of salmon production in pens, in freshwater and seawater. It is perceived to be particularly important when new small fry are first stocked into freshwater pens. Mesh sizes are small because the average weight of the fish is low. If the fry have been poorly graded when leaving the hatchery, there is a risk that some individuals are so small that they might escape through the net. Whilst this might have been an issue in the past, it is apparent from interviews that grading techniques and equipment have improved considerably over recent years. Furthermore, the industry development trend for stocking larger fry into freshwater pens (see later) reduces risks in this area.
- **Grading and moving fish between pens.** Typically there would be two periods during the freshwater pen phase, subsequent to initial stocking and before final harvesting, when fish are graded, counted and re-stocked in different pens. Exact techniques may vary from farm

⁸⁶ <http://www.rspca.org.uk/freedomfood>

⁸⁷ <http://www.soilassociation.org/whatisorganic/whatisorganic/oursymbolandstandards>

to farm, but broadly this activity is undertaken by moving a dedicated grading raft to the pen to be graded. The raft is floored with netting, so any fish that might jump out of the grader are caught. Fish are pumped into the grader, and then counted and piped to the appropriate receiving pen – which can be some distance away.

- **Vaccination.** There is generally a specialised vaccination raft that is towed up to the pen of fish to be vaccinated. It would have some sort of shed structure to house the vaccinating team and their equipment. Fish are pumped out of their pen, anaesthetised, vaccinated and then released back to a new pen (or pens).
- **Final harvesting.** Smolts ready to be transported to sea are harvested from freshwater pens by gently towing the pen towards the shore based pier or pontoon. Fish are pumped out of the pen, counted and deposited in the tanks of the transporter lorry. This then takes the fish to an appropriate marine port where they are loaded onto a well boat for final delivery to the sea site.

Taylor and Kelly (2010)⁸⁸ analysed the causes of fish farm escapes in Scotland for the period 2002 to 2008 and showed that the majority of these occurred as a result of holes in nets (32% of escaped fish numbers) or pen/mooring equipment failure (46% of escaped fish numbers). The number of fish that escaped as a result of handling and related operations directly was only 1% of total escaped fish, although holes in nets caused by snagging or chafing as a result of operations was 9% of total escaped fish.

The industry has been keen to stress that auditing procedures give a very accurate picture of stock numbers throughout the cycle. So called ‘drip’ escapes, whilst acknowledged to have been a problem in the past, are now seen as completely avoidable. Farmers are all independently audited against the industry’s Code of Good Practice⁸⁹, for which a new freshwater containment section has been written. Taylor et al (2012)⁹⁰ developed technical standards that might be applied to Scottish aquaculture, and although further work is required to fill some remaining knowledge gaps, such standards could be applied to the industry in due course.

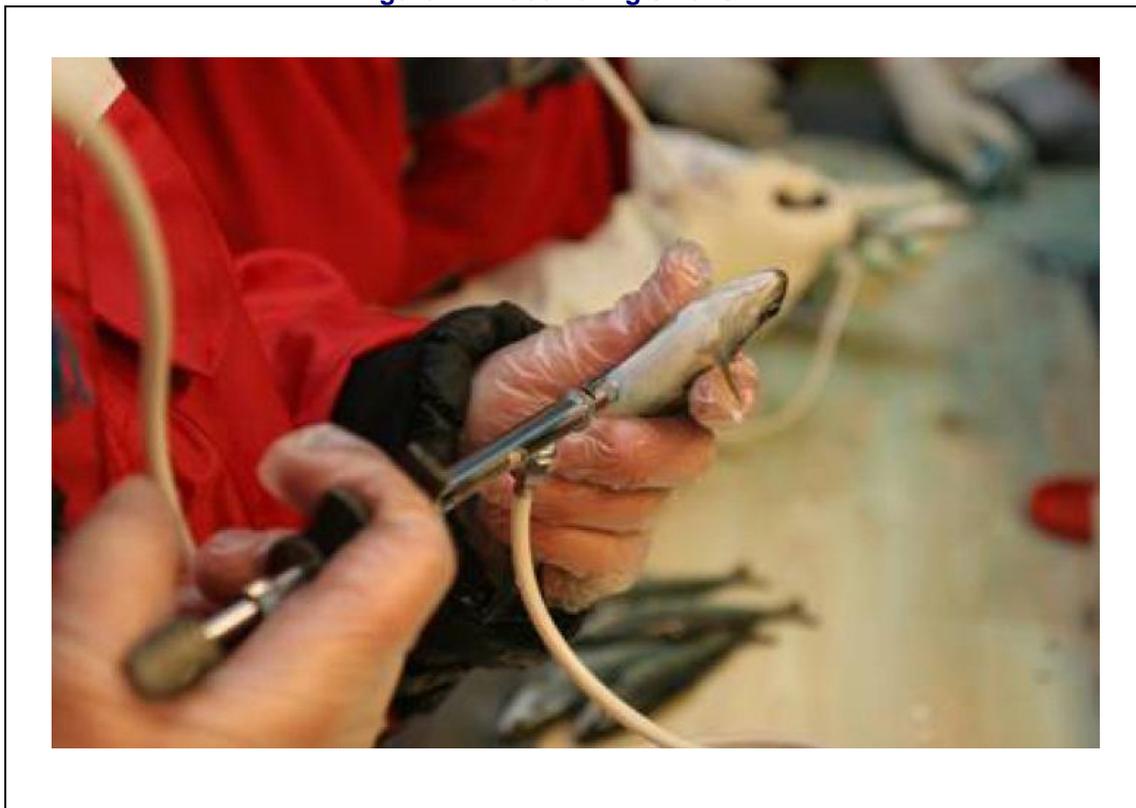
Vaccination and Pre-Treatment

Smolts are vaccinated for several disease threats before they are sent to sea, and this a significant cost element. Figure 17 illustrates a typical injection vaccination procedure.

⁸⁸ <http://www.sarf.org.uk/cms-assets/documents/28923-913107.sarf054---volume1.pdf>

⁸⁹ <http://www.thecodeofgoodpractice.co.uk/publish>

⁹⁰ <http://www.sarf.org.uk/cms-assets/documents/48448-527836.sarf073.pdf>

Figure 17: Vaccinating smolts⁹¹

One suggestion offered at the early stages of the current study was that if smolts were produced in tank-based systems located near the sea, they could also be given an initial prophylactic treatment with emamectin benzoate (Slice). The rationale would be to offer an early level of protection against sea lice. The reason for the location near seawater is that SEPA does not grant a discharge licence for the use of Slice in freshwater – but if the smolt unit could discharge its effluent directly to the sea, Slice could be used.

Discussion with industry experts suggests that this approach might not be of great use in practical terms. Use of any licensed therapeutic should be carefully targeted at situations where there is clear need, in order to reduce the risks of resistance development in parasite populations.

High-Specification Equipment

The current trend in freshwater pen farms is to upgrade them using modern plastic circular pens of the type originally developed for more exposed marine sites, as illustrated in Figure 18. To avoid risk of escapes from damage to nets, the industry is increasingly adopting the use of nets made from Ultra-High Molecular Weight Polyethylene⁹².

⁹¹ Source: Nofima, <http://www.nofima.no/marin/en/nyhet/2010/10/ipn-still-poses-a-challenge>

⁹² <http://dyneema.com/>

Figure 18: Freshwater pens recently installed in Loch Ness.



Source: Fusion Marine⁹³.

Non-Economic Advantages of Pen Production

The possibility of variable vigour of smolts put to sea depending upon their freshwater production method is discussed in Section 3.1.4. It is also possible that there are distinct water temperature advantages in pen-based production as opposed to traditional flow-through tank farms. The water temperature in large bodies of water such as lochs is much more stable on an hour to hour and day to day basis than the temperature in flowing rivers and burns. Stable temperatures are preferred for fish production.

This advantage would not be so marked when comparing pen and modern recirculation systems.

Future Trends

Several companies are already extending the complexity of the 'normal' production scenarios outlined above in order to achieve yet more efficiency in the overall production of salmon, or are considering doing so. One option is to grow parr quickly up to an intermediate size in land-based recirculation systems, and then finish them off in freshwater pens. This has the potential advantage of delivering larger smolts to the ongrowing sites: 150-160 g as opposed to 80-120g fish commonly stocked at present. The knock-on benefit is an overall reduction in time spent in

⁹³ http://www.fusionmarine.com/news_migdale_smolt.htm

seawater pens, from 22 months down to 16-18 months. This can allow increased following times by 25%, as part of the suite of techniques that can be applied to manage sea lice. The fact that Scotland has large, deep and well flushed freshwater lochs is seen by the industry as a distinct competitive advantage.

International Trends

In Norway smolts are almost all produced in land-based systems, because there is a rule that requires any discharge from a smolt unit to enter seawater⁹⁴. Most of these are grown in large flow-through farms with additional oxygenation, but there has been an increasing trend of installing large RAS farms. Some industry experts have speculated on a future trend to grow 1 kg 'smolts', transferring them to seawater pens where they will only have a one year growth cycle to harvest size. It has been suggested that RAS farms will be essential in this sort of development⁹⁵.

3.1.4.2.3 Smolt Vigour

The fish farming companies interviewed for this study provided anecdotal experience with respect to differential smolt vigour when transferred to sea, rather than results from scientific studies. There were divergent views about the hierarchy of smolt performance when put to sea, depending upon immediate origin. In one case, respondents suggested:

- **Recirculation Systems:** very poorly thought-of as a direct source of smolts going to sea. Anecdotes of up to 25% mortality post transfer.
- **Traditional Land Based Systems:** no obvious examples of increased mortality, but very clear experience of slow acclimation of the smolts to marine pens. It could take as much as two weeks for fish to come onto feed, and this means:
 - Some lost performance in the ongrowing phase
 - Some risk of susceptibility to disease challenge during the period of poor feeding
- **FW Pen Systems:** very positive, in the sense that transferred fish settle very quickly, and come onto feed almost immediately.

This suggestion about poor quality fish coming from RAS units was also made by an online commentator from Chile⁹⁶.

A different respondent in Scotland confirmed that in some of the earlier RAS units, or those that were badly managed, there might be some dangers on transfer to sea. These were attributed to

⁹⁴ In: The Atlantic salmon: genetics, conservation and management. By Eric Verspoor, Lee Stradmeyer, Jennifer L. Nielsen, Atlantic Salmon Trust

⁹⁵ https://www.was.org/documents/MeetingPresentations/AA2011/AA2011_0385.pdf

⁹⁶ <http://www.thefishsite.com/forums/showthread.php?t=2007>

poor maintenance of water quality (ammonia, oxygen, carbon dioxide) in the RAS unit. In well-run units, with high standards of water quality, there should be no problems with the transfer of fish to seawater.

This is clearly a topic that continues to engage proponents of one system or another, and there appears to be no peer-reviewed scientific work available.

3.1.4.2.4 Rainbow Trout

The rainbow trout sector in Scotland has not been growing as fast as the salmon sector, and production has actually declined since 2007. There are 6 freshwater pen trout farms, producing 32% of the total Scottish production, and 22 freshwater pond/tank farms, producing 38% of the total. The remaining production is taking place in seawater pen farms.

The sector has been through some consolidation over recent years, and it is clear that the current major producer now wishes to increase production. It views freshwater cages as a potentially useful resource in terms of future growth, but it is also considering taking many of the same approaches as modern smolt pen producers:

- New pens of high specification – plastic circles
- Ultra-High Molecular Weight Polyethylene nets
- Full compliance with the Code of Good Practice, and especially in the areas relevant to containment

Smaller independent producers, located on heavily modified water bodies with no natural wild salmonid populations, are likely to continue to use more traditional wooden pens, often manufactured on-site – Figure 19.

Figure 19: Freshwater pens used for trout production



Source: Authors.

Such producers have a good history of working with SEPA in terms of water quality and benthic impact, and report no concerns on the part of the regulator. Local salmonid angling is undertaken using stocked fish, and the farmer is active in that process. Local relationships are therefore positive.

Freshwater pens are generally used to produce the same 'table size' trout as freshwater tanks. Large trout production is generally undertaken in the seawater pen sites. Table trout are produced over a relatively short time period: 6-7 months at a mean weight of 300-400g⁹⁷. By stocking fry several times a year, and juggling fry sizes to accommodate seasonal water temperature variations, a farm as described above can produce market size fish all year round. The overall site is not fallowed as such, but groups of pens tend to be emptied and therefore fallowed for short periods every year.

Operations on a trout farm are not dissimilar to those described for salmon smolt production. Fish are graded and split twice or three times during the production cycle, and similar automatic graders and counting machines are used. Machinery integrity (hose connections, etc) is well maintained in order to avoid leaks and therefore potential escapes, and the grading pontoon is enclosed by a full net, so as to be able to recapture any fish if there were to be an accident.

3.1.4.3 Incidence of Escaped Farmed Fish in Scottish Lochs

Companies interviewed for this study stressed that their equipment and procedures for counting fry stocked into pens and smolts finally harvested from cages were extremely thorough, and that 'drip escapes' were not a current phenomenon. The use of smolt pen equipment that is now being upgraded to sea-pen standard, and particularly the increasing use of 100% Ultra-High Molecular Weight Polyethylene nets – which resist natural wear and predator damage – make inadvertent small scale regular escapes impossible in the view of industry personnel interviewed.

The official MSS register of escapes⁹⁸ shows numbers of salmon and rainbow trout escaping from farming operations into freshwater from 2002 to 2012, and these can be further analysed to provide information about reported escapes from pen farms, (Table 6). This shows farmed fish have escaped from freshwater pens into lochs in most years. Escapes of salmon have been recorded since 2002 and have been reported in freshwater every year except 2002 but, in a given year, have been limited to 1-4 escape events at 1-4 locations. Numbers of reported escaped salmon per event ranged from 1-194,000 and in size from 30-10,000g. Escapes of

⁹⁷ <http://www.britishtROUT.co.uk/explain.htm>

⁹⁸ (<http://www.scotland.gov.uk/Topics/marine/Fish-Shellfish/18364/18692/escapeStatistics>)

rainbow trout from freshwater pens have been reported every year except 2002 and 2004, with from 1-6 events each year. Numbers of reported escapes per event ranged from 12-80,000 with escaped fish ranging from 20-2,800g. The causes of escapes were not recorded prior to 2009 but since then the main listed causes are predator/hole in net, human error and weather; equipment failure and vandalism were also cited as causes.

Table 6: Reported escapes from freshwater pens by year and species since records were first kept.

Year	Salmon	Rainbow Trout
2002	-	-
2003	52,176	1,560
2004	1	-
2005	367,043	4,500
2006	5,803	240
2007	15,075	49,854
2008	1,700	5,381
2009	43,927	897
2010	10,885	97
2011	1,500	12,620

The official register does not encompass all cases of farm escapes in freshwater. For example, salmon identified as smolts of farm origin based on morphological traits, scale growth patterns and size, were netted in Loch na Thull in 2004 (Verspoor et al. 2009)⁹⁹, a known freshwater pen site, but there is no official record of an escape in this loch in that or any year. Similarly, in 2007, on one occasion putative farm salmon were sampled by gill net in the River Garry below the freshwater pen site on Loch Garry. They were confirmed by FRS to be of farm origin based in one case on scale growth patterns and size. Again, there is no official record of escapes, though in this case the size of the fish and their scale growth makes it unlikely that they escaped as small fish. Recent work under the RAFTS-MSS FASMOP project on Loch Shin, (the location of two freshwater pen operations), provide compelling evidence of further cases of unreported farm salmon escaped from freshwater pens (Mark Coulson, RAFTS, personal communication). In 2010, 77 fish were collected from lower Loch Shin and analysed for morphological and scale indicators of farm status of which 76 were deemed by MSS personnel to be of farm origin. In 2011, a further 33 fish were collected at Corrykinloch on Loch Shin which were of a similar appearance. In both cases, genetic testing indicated that they were of Norwegian ancestry supporting their farm origin; neither instance is associated with reported escapes. In contrast, all fish showing wild morphology and scale growth patterns and size, showed no evidence of Norwegian ancestry.

⁹⁹ Verspoor, E., Knox, D. and Marshall, S. (2009) Assessment of the Direct Genetic Impacts of Escaped Farm Salmon: a retrospective study of a wild Scottish stock. ICES CM2009/ Q:05.

It seems likely that the same situation may exist in respect of escaped rainbow trout. In an MSS review in 2003 (Anonymous 2003)¹⁰⁰, feral rainbow trout were reportedly observed in 54 rivers or streams and seven freshwater lochs where they had not been deliberately stocked. In all cases their origins were uncertain. However, given that freshwater pens are only found on relatively few sites, most of these will not have been from freshwater pens.

It can thus be concluded that the official MSS record of escapes under-represents the extent of escapes from pens in lochs, at least in the case of salmon. However, the extent to which it does so is unclear. Some unreported fish may represent “leakage”, something which is often cited as a problem.

The actual numbers that have escaped over the years must remain highly speculative. It could be quite low or quite high. It is also not known whether the numbers of escapes have declined over the years as technologies, such as net-pen construction and net quality, or rearing practises have changed, and there has been more accurate enumeration of fish such that losses can be identified and action taken to change practises to minimise them. One might presume that they have declined, but more research into this question is needed to define the true extent, and whether it is general or associated with specific sites. Also, it is important to note that the presence of feral fish in the wild does not imply that there is or will be a negative impact on wild salmonid populations in a loch.

Relative abundance

All else equal, the potential for negative interactions and impacts will be greater than if there is a higher relative abundance of farm fish compared to wild fish. The numbers of juvenile farm fish in pens could well exceed the numbers of wild fish of a given population or species. This will certainly be the case for smaller lochs but also be true for larger lochs with higher production capacities. However, numbers of wild salmonids in Scottish lochs are unknown and it is impossible to comment on this important variable beyond the probability that numbers of farm fish will exceed numbers of wild fish in many contexts. Even in the case of Atlantic salmon, where an extensive data base of electrofishing information is available, it is not possible to come up with total numbers of juvenile wild fish. Electrofishing data is highly variable from site to site and numbers of fish captured is highly dependent on flow conditions and season. In general, detailed repeat-pass electrofishing or mark-recapture experiments are required to get accurate estimates of juvenile densities. Because of habitat variability, these are difficult to extrapolate to an estimate for a whole stream or sub-catchment. Such surveys are rare and confined largely to

¹⁰⁰ Anonymous (2003) STATUS OF RAINBOW TROUT IN SCOTLAND: The Results from a Questionnaire Survey. Scottish Fisheries Information Pamphlet No. 23 2003

a few sub-catchments where intensive, long-term studies have been carried out by MSS scientists.

Adult salmon data is similarly problematic. In all but a few cases, where counters are in place such as on hydroelectric dams with ladders, the actual numbers of adults ascending rivers and individual sub-catchments are not known. Whole river estimates, based on catch statistics, can be calculated, but these require a large number of assumptions to be made regarding exploitation rates, effects of catch and release, etc, making catch statistics only a very rough and uncertain proxy for abundance in most situations. Obtaining estimates of abundance of trout and charr in lochs is even more problematic. To obtain even approximate estimates requires extensive and destructive netting using Nordic Gill Netting protocols and there are no good estimates of numbers of wild salmonids in Scottish lochs. When this is combined with uncertain data on numbers of escaped fish, it makes it impossible to comment on the abundance of feral farm fish in loch systems with pens relative to numbers of wild salmonids.

3.1.4.4 Other potential interactions in Scotland

Disease in farm and wild fish

No recent comprehensive review has been carried out specifically of the disease status of farmed and wild salmonids in Scotland as is available for Norway (Johansen et al. 2011)¹⁰¹. Understanding of the prevalence of pathogens is entirely dependent on official sampling of suspected farms and a very limited programme of sampling of wild populations. Therefore a clear view of the nature and extent of pathogens in farmed, and particularly wild, salmonids, which could provide a clear assessment of the potential for interaction and impacts, is lacking. However, what is known suggests that some fish pathogens are widespread and regularly lead to disease while those associated with other diseases e.g. ISA, are less widespread and cause only rare and sporadic cases of disease.

An example of a relatively widespread pathogen is *Renibacterium salmoninarum* which causes bacterial kidney disease (BKD; Murray et al. 2011)¹⁰². It occurs in both Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) farms and has been historically recorded in wild Atlantic salmon. A large survey of wild freshwater Atlantic salmon in the UK, including Scotland,

¹⁰¹ L.-H. Johansen, Jensen, I. Mikkelsen, H. Bjørn, P.-A. Jansen, P.A. and Bergh, Ø. (2011). Disease interaction and pathogens exchange between wild and farmed fish populations with special reference to Norway. *Aquaculture* 315: 167-186.

¹⁰² Murray, A.G., Munro, L.A., Wallace, I.S., Peeler, E.J., Thrush, M.A., 2011. Bacterial Kidney disease: an assessment of risk to Atlantic salmon from infection in trout farms and other sources. *Scottish Marine and Freshwater Science Vol 2 (3)*. Marine Scotland Science, Aberdeen UK.

in 2001 provided no evidence of clinical BKD in wild fish while a more recent survey of Scottish wild fish in 2005 to 2007 it was detected with low incidence in escaped rainbow trout and occasionally in 3-spined-stickleback (*Gasterosteus aculeatus*) and minnow (*Phoxinus phoxinus*) in association with infected fish farms. In 1993 and 1994, 28 of 288 salmon farms tests were *R. salmoninarum* positive but because of small sample sizes, the true incidence was likely to have been higher. The pathogen does not appear to be widely detected in the trout industry. Other diseases that appear widespread in farms are pancreas disease and infectious pancreatic necrosis.

Physical character of farm sites and pens

There are no studies which document the physical infrastructure of pen sites in Scotland relative to the physical and biological characteristics of lochs, which would give insight into the physical aspects of operations that would affect the potential for interactions and impacts. This makes it difficult to comment on whether particular aspects of the physical siting and operation of pen sites is particularly problematic as regards interactions with salmonids. What can be said is that a major factor influencing escapes will be the size of mesh used for pens relative to the size of fish placed in pens. No published study documents this relationship.

Use of Feeds and Faeces

Freshwater pens are open to the loch environment and feed is provided on a daily basis and fish produce faeces. The loss of excess feed through nets has been considerably reduced by the introduction of highly sophisticated on-demand feeding regimes. Past estimates of the amount of feed lost to the environment have ranged up to 30% and that 25-30% of the dry weight of feed is voided as faeces (cited in Carss, 1990). However, there are no recent studies of the amount of feed lost. The industry view is that the amount of food falling through nets is extremely small given modern feeding regimes. The main organic matter introduced into the environment will be faeces.

Use of chemicals and pharmaceuticals

Discussions with industry indicate that the use of chemical therapeutants is restricted to formalin treatments. No therapeutants such as antibiotics are used in feed.

3.1.5 Evidence of Impacts in Scotland

This section reviews available evidence of impacts from freshwater pens operations on wild salmonid populations in Scottish lochs. The impacts to the well-being of a wild population of fish, or any other species, are categorised, as previously set out, as pertaining to changes in one or all of the following non-exclusive biological facets:

-
- Morphological, physiological and behavioural character
 - Genetic character
 - Demographic abundance
 - Viability

Overview

A considerable amount of unpublished and anecdotal information exists that may bear on the impact on wild salmonid populations in Scottish lochs from interactions with freshwater pen operations. However, in the published literature there are only a few scientific studies that specifically address this question in the Scottish context.

Consideration of what is generally known about the state of wild salmonid populations indicates that the impact of salmon and trout farms on wild Atlantic salmon populations has not been demonstrated in the short-term. Based on familiarity with rod and line catch statistics, there is no dramatic differences in numbers over the last two decades between rivers with or without freshwater pens. There are no instances where rivers with freshwater pens have lost their salmon runs entirely or have even become severely depressed when compared to rivers without freshwater pens. While there is no data available at the sub-catchment level, there are no documented reports of dramatic differences between sub-catchments that can be ascribed to the presence of freshwater pens; in contrast there are cases where dramatic declines have been associated with hydroelectric developments.

Whether the same is true in respect of trout or charr populations is unknown as there is no monitoring of the abundance of wild populations of these species in lochs. However, where trout and sea trout are subject to angling fisheries, there is no anecdotal evidence that populations in lochs with pens have crashed while other neighbouring systems without any pens have maintained typical abundance trends; there is only evidence of a general decline in sea trout catches, particularly on the West Coast. As regards charr, the situation is totally opaque as their abundance is not subject to any monitoring, (not even informally by anglers), as the species is not generally targeted.

What is known about the potential for interactions and impacts strongly suggests that the outcome of their physical coincidence will be highly dependent on the specific circumstances prevailing in a given situation. This means that it will also not be possible to extrapolate findings from a study of one loch to what might happen in another loch. Modelling studies, such as those

relating to direct reproductive interactions (e.g. Gilbey and Verspoor, submitted)¹⁰³, make clear that factors that can be expected to vary from one situation to another (e.g. relative numbers of feral and wild fish) are likely to have a significant influence on the outcome. As such, extrapolation is only likely to be possible from robust empirical scientific studies of specific situations where there is a consistent outcome, positive, negative or neutral, across a range of interaction scenarios. In general, to make extrapolation possible, a significant proportion of studies would have to have the same outcome (i.e. at least 5 of 5, or 5 of 6 studies), to conclude that the outcome was likely in other lochs as well.

The absence of evidence for an interaction or impact does not mean that there is no interaction or impact; just that the state of affairs is equivocal and uninformative. If “There is no evidence” it may be that no robust studies have been carried out (or are in the public domain where they can be scientifically scrutinized). Alternatively, studies may exist but are insufficiently robust to draw conclusions, either because they were poorly designed or are based on poor quality data. Finally, it may be that a robust scientific analysis has been carried out and found no evidence of significant interactions or impacts. If there is “evidence” of interaction or impact, it is important to consider that it may be 1) inconclusive and equivocal, possibly because of its poor quality, 2) be inconclusive but appear to favour one hypothesis over the other, or 3) provide a compelling but not fool-proof case for one hypothesis or the other. Thus it is vital that the nature and quality of the evidence for or against interactions and impacts is critically assessed before drawing any conclusions one way or the other. In general, a robust case for or against impacts requires a number of independent lines of supporting evidence that can robustly reject potential alternative hypotheses.

Our limited understanding of interaction pathways and potential impacts means that the time frame for impacts is far from clear. Impacts may be transient, lasting only one or two generations, provided perturbations cease or are reduced while in other cases they may last for generations. Thus if there is evidence of an impact 5-10 years ago it cannot be assumed that an impact is still manifest, or that it has a legacy that is still being played out; this may or may not be the case based on what is known. Certainly, the salmon farming industry has changed dramatically, including in respect of its freshwater rearing practises. As such, current and future management and policy need to be supported by up-to-date scientific studies that address the impacts that are arising out of past as well as current freshwater rearing practises.

¹⁰³ Gilbey, J. and Verspoor, E. (submitted). Individual-based modelling of the demographic impacts of genetic introgression of farmed Atlantic salmon into wild populations. Aquaculture Environment Interactions

3.1.5.1 Confounding Factors

Morphological, physiological and behavioural character, genetic character, demographic abundance and viability, the biological characteristics of concern as regards impacts on wild salmonid populations, can be influenced by a range of natural and anthropogenic factors. For example, if a decline in catches of salmon begins at the same time as the introduction of a pen rearing operation into a river system, it cannot be assumed that the latter is the cause of the former.

Many factors in nature show correlated but functionally unrelated responses. This makes it crucial that studies of the impacts from freshwater pens also examine the possible effect from other factors which could account for observed changes or the absence of change. Unless plausible alternative explanations for observations can be ruled out, a study cannot provide a robust answer. After-the-fact correlative analyses of observational data, not collected specifically to address the question of impact (e.g. catch statistics) can be particularly problematic in this respect, even when strong correlations are observed. Correlations may occur by chance, reflect poor quality data, or poor study design. As such, the detection of a correlation between two factors will be equivocal unless other factors that might account for changes in wild populations can be reasonably ruled out. Disentangling the various possible causes of changes in levels of catches or numbers/densities of juvenile fish requires high-quality, long-term data sets (e.g. 20+ years) relating to all potentially relevant variables as well as sophisticated multivariate statistical approaches.

The possibility of confounding factors also needs to be taken into account in the design of directed field investigations specifically undertaken to assess impacts. Such studies by necessity are usually observational and correlational. Robust field studies of impacts generally require long time series of relevant data related to all potential factors affecting the population parameters being monitored. To be robust, they should encompass observations on variables from before and during pen rearing and, ideally, would include observations from when pen operation is followed or after it ceases operation. Without such observations, robust conclusions on impacts will be difficult to achieve. In any case, conclusions on impacts should be corroborated by independent lines of evidence.

Factors, other than the freshwater pen rearing of salmon and trout, may have impacts on wild salmonid populations and their effects may obscure actual associations or give rise to false associations. Particular factors that need to be taken into account in assessing the causal basis of impacts are changes in fishing pressure (both in amount and types of fish caught), environmentally induced changes in growth, mortality and reproductive success, and effects of deliberate stocking of cultured or wild fish. Doing so generally requires high quality, long term

data sets and sophisticated statistical procedures. It is generally known and acknowledged that stocking of cultured (including farmed) and wild fish has been widespread in rivers across much of Scotland over the last few decades. However, in the last five years, stocking has decreased and is almost exclusively carried out with native fish from the same river system and, increasingly in larger systems, with fish from the same sub-catchment within a river system.

3.1.5.2 Evidence of Impacts

The account presented below, demonstrates the limited extent of the actual scientific evidence in the public domain relating to impacts on wild salmonid populations in Scotland from freshwater pen rearing of salmon and trout. It encompasses only a few aspects of the potential interactions in a few specific situations. Furthermore, it is generally true that even those studies which have been done are compromised by a less than optimal analytical design and based on less than optimal data sets. None are corroborated by independent lines of evidence. As such their conclusions need to be considered as tentative and preliminary regarding the questions on impact that they set out to address.

Morphological, physiological and behavioural character

Beveridge (1984)¹⁰⁴ estimated that up to 30% of feed was uneaten and was wasted through pens. Carss (1990) found evidence of increased numbers and weights of wild fish near two freshwater pen sites in Loch Awe, although there was no evidence they were eating waste food; the majority of fish present at the pens, however, were feral escapes. Philips (1982; cited in Carss 1990) observed wild brown trout eating waste pellets around pens. In the case of some of the older studies mentioned above, it is important to recognise that aquaculture feeding practices, and specifically feed conversion ratios, have improved dramatically since the late 1980s and early 1990s: where it might have taken 3 kg of feed to produce 1 kg of salmon in the early years of the industry, this has now dropped to 1 kg of feed¹⁰⁵. At these levels of feeding efficiency, the amount of uneaten or wasted feed is likely to be much less. Freshwater diets have also been increasingly tailored to meet environmental concerns, e.g. lower phosphorous content.

A study of the ecto and endoparasite fauna of pen and wild fish communities in a Scottish loch cited in Beveridge (1984) found that the numbers and species of parasite present in the wild fish differ markedly from expected as a result of the presence of cultured rainbow trout. The reasons for this were not clear nor were the impacts on the fish populations aside from the elevated parasite levels.

¹⁰⁴ Beveridge, M.C.M., 1984 Cage and pen fish farming. Carrying capacity models and environmental impact. FAO Fish.Tech.Pap., (255) : 131 p.

¹⁰⁵ <http://www.ewos.com/portal/wps/wcm/connect/EwosCom/com/frontpage/news/nasf+2012+wathne>

MacKey (2009) reports a study on the diet, length-weight relationship, condition factor, and growth of brown trout in Loch Shiel, an oligotrophic loch in the west of Scotland, with freshwater pen rearing of salmon. Comparisons of wild fish captured adjacent to Atlantic salmon smolt pens and 8 km from the nearest pen showed those at the former to be made up of larger, older, fatter fish with a higher condition factor. Stomach content analysis showed that waste feed represented 33% of the immediate diet while an analysis of stable isotopes indicated the proportion of feed in the diet over the previous weeks to months to be closer to 48%, providing a compelling case that feed waste forms a significant part of the diet of trout in the vicinity of pens. At the same time, the analysis of scales showed they also had consistently higher growth rates. Additionally stable isotope analysis of benthic and pelagic organisms showed evidence of waste feed entering the local food web around pens. It was not clear whether the isotopic signatures arose directly from waste feed or from faeces. The author suggested that the increased growth and improved condition of trout around pens could be responsible for a decrease in the numbers of trout migrating to sea and account for local declines in sea trout abundance. However, no evidence was provided to confirm whether or not this was in fact the case.

Genetic character

Only one study has specifically addressed the question of the impact of freshwater pen operations on the genetic structure of wild salmonid populations (Verspoor et al. 2009)¹⁰⁶. This study reports a retrospective molecular genetic analysis to assess the direct genetic impacts in the Loch na Thull catchment in northwest Scotland containing a small wild stock and used for freshwater pen rearing of farm smolts from 1997-2004 of feral escapes. The study was based on an eclectic set of historical DNA sources and genetic data that precluded a simple comparison of the genetic character of the wild stock before and after freshwater pens were introduced. The study indicated significant genetic differences between wild and farm salmon and strongly suggested that farm escapes had contributed little to the genetic character of the current wild stock through interbreeding and introgression. However, the study was not able, by virtue of its design, to assess if indirect genetic impacts had occurred due to ecological interactions with farm escapes (e.g. competition for food and space or increased pathogen transfers). It was also uninformative as to whether direct and indirect mortality had any negative impacts on mortality and abundance in the wild stock and, thereby, led to a general loss of genetic variability or selective genetic changes.

Some recent baseline genetic studies carried out as part of the MSS-RAFTS collaborative FASMOP (Focusing Atlantic Salmon Management on Salmon) programme have found evidence

¹⁰⁶ Verspoor, E., Knox, D. and Marshall, S. (2009) Assessment of the Direct Genetic Impacts of Escaped Farm Salmon: a retrospective study of a wild Scottish stock. ICES CM2009/Q:05.

for the presence of feral farm salmon in three situations where freshwater pens with salmon were present (Coulson et al. unpublished-a). In Loch Shin fish of farm origin were identified to be present in Loch Shin and one tributary, based on morphological, scale age and molecular data. The molecular data also suggested that some genetic admixture of farm and wild fish may have occurred. In contrast, in the Ness River system, molecular analysis indicated juvenile salmon from the Green Field Burn, which flows into Loch Garry, to be of pure Norwegian ancestry (Coulson et al. unpublished-b), and genetically highly distinct from all other salmon analysed from other locations in the Ness and Beaully systems. This suggests that either they are unreported recent escapes or that they are the offspring of returning feral fish which had spawned in the burn. Unfortunately, there was no morphological or scale age data available to distinguish between these two hypotheses. The presence of salmon of Norwegian ancestry was also detected in the Slatach Burn which enters Loch Shiel where freshwater pen rearing of salmon is carried out on a large scale (Coulson et al. unpublished-b). These were detected in 2008 but not in 2005 when the salmon had a genetic profile typical of local wild Scottish salmon. However, there was no evidence of interbreeding or salmon of a mixed farm-wild genetic type.

Demographic abundance

No studies.

Viability

No studies

Overview of Available Evidence

The review of available literature shows that few objective scientific studies have been carried out in Scottish lochs, and published, that directly address the question of impacts on wild salmonid populations from interactions with freshwater pen operations. At the same time, a significant proportion of the limited literature that does exist is dated and may not be relevant to today's situation, given significant advances in farming practises. There is much anecdotal information that forms the basis for much conjecture as to whether or not impacts occur. This has not been included. While it may be helpful in defining research priorities and study design, it does not provide a robust basis for rejecting alternative hypotheses regarding impacts. Given the lack of published studies, it is a pity that it has not been possible to access unpublished information held by the Industry and studies carried out on their behalf by third parties. Some of this might be very useful for informing the debate. Though it is recognised that the use of such data may raise issues of scientific independence among some, this issue could be addressed by being vetted by the independent peer review process. While both sources of information are

unlikely to directly address the question of impact, they are likely to be useful for informing the direction and design of future scientific studies.

When studies are carried out, it will be crucial to address the potential impact of confounding factors such as changes in habitat quality due to other changes in land-use practise, the effects of stocking and other management interventions, and the effects of changing climatic and marine conditions on salmonid survival and growth. These will have to be addressed on a local basis for each individual study.

A review of the nature and extent of stocking as part of the management of wild fisheries, encompassing largely that of brown trout and salmon, was set out as part of the current study. This inclusion reflects the recognition that stocking, particularly when non-native fish are used, has the potential to have negative impacts on wild stocks in most situations, (Cross et al. 2007)¹⁰⁷ and could where coincident with pens be the cause of any observed impacts. Personal knowledge and discussions with local Trust and Board biologists, confirm that the practise was widespread in Scotland over the previous two decades, including in some areas the use of surplus farm fish, but has become much less widespread in the last five years. Furthermore, in those cases where it is carried out, it is largely based on stock from the same river, or where no native stock remains, on stock from a neighbouring river.

A meaningful review of stocking, relevant to the issues addressed by this report on impacts of freshwater pens, was not possible given available information on the numbers and origins of fish stocked out into Scottish rivers and lochs is incomplete and often anecdotal. As such, compilation and assessment of the information that was available on stocking was not carried out as it could not inform the debate addressed by this review. However, in light of the lack of evidence for impacts from freshwater pen rearing, whether there have been impacts from stocking is a moot point in respect of the current review. As previously discussed, there is no case where an effect of pen rearing has been demonstrated and so require consideration of the possibility that it is the result of stocking.

3.1.6 Current Research

There is currently no specific programme of research relating to the impact on wild salmonid populations in Scottish lochs of freshwater pen rearing operations. Some research related to this issue is incorporated into the MSS –RAFTS FASMOP research initiative, which is currently nearing completion. In collaboration with Norwegian researchers, a survey is being undertaken of the incidence of farmed salmon in the wild, using molecular markers to differentiate between farm and wild fish. It will also explore possible levels of introgression of farmed genes into wild

¹⁰⁷ Cross, T.F et al. (2007) Stocking and Ranching. Chapter 11, In *The Atlantic Salmon: Genetics, Conservation & Management* (Verspoor, E., Stradmeyer, L & Nielsen, J.L., eds). Blackwell Publishing, Oxford. pp 325-356.

populations and is due for completion June 2012. This will encompass parts of river systems with and without lochs with freshwater pens. There is no information on any other relevant research being carried out that addresses the research needs set out below.

3.1.7 Future Research

Sufficient general biological understanding exists to identify that there is a potential for interactions and impacts on wild salmonid populations from freshwater pen rearing operations in Scotland. However, the nature and extent of actual impacts on wild salmonid populations in Scottish lochs will be dependent on the specific way in which freshwater pen rearing is carried out in each loch as well as on a loch's particular physical, chemical and biological characteristics, including the specific nature of its salmonid community. Furthermore, situations in lochs with pens a decade or longer ago are unlikely to be the same today as pen rearing practises have changed markedly. At the same time, freshwater ecosystems in Scotland have also changed in response to natural cycles of environmental variation, as well as progressive changes associated with factors such as global warming. Thus the contribution that historical studies can make to informing management and policy needs for controlling impacts on lochs today is negligible. These needs can only be addressed by contemporary up-to-date assessments of impacts based on evidence gathered in relation to current freshwater pen operations. This does not deny the possibility that there may be a historical legacy of impacts from past perturbations that needs to be considered, as well as impacts arising from contemporary practises. However, it is the contemporary situation which needs to be managed.

The initial research need for such an assessment is to collect information on the nature and extent direct and indirect perturbation of salmonid populations in loch ecosystems containing freshwater pen rearing operations. To manage impacts, it is essential to know whether perturbations are in fact happening or not. Where potential perturbations can be ruled out, concern about their impacts can be allayed. Where significant perturbations are found to occur, then research can be focused on assessing their impacts, if any, and approaches to their mitigation identified. As such, based on what is known about the likely perturbations, the main focus of directed research should be on:

- Attraction of wild salmonids to nets and extent to which this exposes them to increased predation from bird, mammalian and fish predation
- Numbers and distribution of escaped farm fish, including how this changes overtime due to straying and natural mortality
- Interbreeding of feral farm salmon with wild salmon populations i.e. levels of introgression

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- Incidence of pathogens and disease wild fish in loch with pens compared to lochs without pens
 - Levels of feed and faecal matter wasted through nets into lochs and effects on different elements of the phytoplankton, zooplankton and benthic communities, focusing on comparisons of lochs with pens compared to lochs without pens
 - The extent of consumption direct consumption and indirect uptake through prey organisms of pen waste by salmonids

The development of detailed research programmes at certain index sites should be considered to gain an in depth insight. This should be supplemented by more widespread monitoring of a smaller set of key indices of perturbation such as levels of waste, numbers of escaped fish and incidence of pathogens, across a larger set of sites to provide insight into the general extent of perturbations.

Depending on the nature and extent of observed perturbations, to make an assessment of impact will require basic research into:

- the structuring of salmonid stocks in lochs with pens into distinct breeding populations,
- the basic population biology and dynamics of individual populations
- trophic relationships and interactions of salmonid communities with other components of the ecosystem in freshwater lochs
- the abundance of wild salmonid populations and how it changes over time and across seasons in Scottish lochs without and without pens
- the nature and extent of other anthropogenic influences such as stocking, land-use related pollution, hydroelectric development on salmonid populations
- fitness differences between feral farm salmon and wild salmon
- competitive interactions between feral farm fish and wild salmonids

Integration of this information and assessment of its likely implications for impacts on the character, abundance and viability of wild salmonid stocks will require the development of various quantitative ecosystem and demographic, or integrated demographic-genetic, population models. These will need to be developed as part of the above programme of basic research.

3.2 Costs, benefits and implications for industry

This section of the report assesses the economic costs and benefits that may arise from possible changes in use of freshwater lochs for farming fish. It also considers what the hypothetical financial and other related implications of such policy shifts might be, if they were to be contemplated in the future, perhaps on the basis of precaution or of new evidence.

As set out in the methodology, the only quantifiable cost from any policy change on permitted practices will be that to aquaculture industry. The section immediately below therefore examines what those costs might be in some detail. Other costs which are more difficult to quantify are discussed qualitatively in Section 3.2.1.6. Benefits, which can be both direct benefits, or in some cases avoided costs, are discussed and quantified to the extent possible in section 3.2.2

3.2.1 Aquaculture industry costs

3.2.1.1 Introduction to Costs

When considering the operating costs associated with either pen or land-based production, it is important to recognise that some elements could be:

Similar per unit. Irrespective of what type of production system is chosen, there will be some types of cost that are very similar per unit fish. These are likely to include: cost per egg/fry; cost of food; cost of vaccination; cost of transport to customer; and cost of administration. Of course there may be variability from site to site, but broadly these costs are likely to be relatively consistent.

Different per unit. Cost of water flow for the introduction of oxygen and the removal of waste might be different. In a simple gravity flow-through tank system it is also theoretically zero. However in practice this is not quite the case, because there is now a complex equation which relates to gravity head, bore/cost of pipelines and their friction losses, and the probable need to introduce at least extra oxygen/aeration in order to reduce flow requirements (and therefore reduce capital spent on larger pipeline bores). There is also a possible cost of installing (capital) and operating effluent treatment systems in order to meet environmental regulations. In a pen farm this latter cost is also zero – but only because the farm has been sited in a large water body, and is regulated by the relevant authority such that its waste stream is deemed to have been assimilated by the surrounding environment.

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- Cost of power (electricity) and/or oxygen gas will be different in land based units, at any degree of water-saving: from basic oxygen-boosting to full scale recirculation
 - Cost of staff may be different
 - Cost of adopting different standards such as Freedom Foods or Organic might lead to differences.

The purpose of setting out the basic elements of 'cost' above is to set the scene for the modelling that follows in subsequent sections, removing the need to describe first principles in each section. There are other considerations, such as whether or not smolt or trout production is developed in pen farms only for new production, or whether it is a displacement of current production.

Scale of production units is also a consideration, and assumptions on scale have to be made for the following modelling. The assumption is that for new production sites, and arguably for new 'displacement' sites that replace previous production capacity, it is likely that the modern salmon industry and trout industry would both choose to opt for larger single farming units, in order to achieve economy of scale.

In summary, the following modelling will:

- Consider Atlantic salmon farms capable of producing **2.5 or 5 million smolts per annum** (pen and land-based respectively)
- Consider rainbow trout farms capable of producing **500 tonnes per annum**¹⁰⁸

For each of these species categories, the modelling will consider:

- The **capital cost** of building a new pen unit based on high standard equipment
- The **capital cost** of building a new land based unit, in the following sub-categories:
 - Flow through with direct oxygen injection into intake water
 - Complex recirculation (RAS), with some capacity for temperature control
- The **unit cost of production** in:
 - Pen farms
 - Land based farms – according to the two categories shown above

¹⁰⁸ Refer to MSS 2010 Annual Survey: current freshwater cage farms produce an average of 326 tonnes per annum.

3.2.1.2 Literature Sources

Recent information obtained directly from industry and its suppliers for this study is presented in the following sections, but it is relevant to also consider published literature that pertains, directly or indirectly, to the issue of cost of production in different types of aquaculture facility.

One of the most directly relevant published studies in the area of different production economics, pen versus land-based, for salmon smolts was undertaken by Needham (1990) for the Ministry of Agriculture and Fisheries in British Columbia in 1990¹⁰⁹. Whilst now somewhat dated, it is important to understand that the basic biological needs of the fish have not changed since the study was conducted. Techniques might have changed, and inflation will have impacted on the quoted costs, but the basic comparisons remain relevant in 2012. Needham commented upon a difference of 11-15% between tank and pen produced salmon smolts (the former being the more expensive), and attributed quite a lot of that difference to the depreciation of expensive capital costs for building tank farms. It is important to note that if pen systems become more sophisticated – and more expensive – then this difference might be subjected to some erosion. On the other hand, the same might be said in relation to modern land-based systems.

Colt et al (2008)¹¹⁰ evaluated the resource and energy requirements of six different types of land-based, hatchery production systems located in the U.S. Pacific Northwest: flow-through with a gravity water supply, flow-through with a pumped water supply, flow-through with pure oxygen, partial reuse system, partial reuse with heating, and a reuse system for the production of Atlantic salmon smolts. Key parameters used in the evaluation include direct energy, indirect energy, transportation energy, greenhouse gas emissions, and pollutant discharges. They concluded that:

- Power (electricity and natural gas) and feed energy accounted for the majority of the required energy for all the rearing options evaluated
- The sum of the fixed capital and chemicals components accounted for less than 2–12% of the total energy budget for any rearing option
- The energy efficiency (energy output/energy input) of the six options ranges from 0.97% for flow-through with pumped supply to 3.49% for the flow-through with gravity supply.
- The rearing options with the three highest energy efficiencies were flow-through with gravity supply (3.49%), partial reuse (2.75%), and reuse (2.64%)
- On a kg of smolt produced basis, the six rearing options showed a wide range in performance

¹⁰⁹ <http://www.for.gov.bc.ca/hfd/library/documents/bib92977.pdf>

¹¹⁰ <http://www.sciencedirect.com/science/article/pii/S0044848608003438>

- The ranking of the six rearing options based on capital and operating costs are likely to be quite different from those based on energy, water, and greenhouse gas emissions.

Lisac and Muir (2000)¹¹¹ made a comparison between land-based and offshore pen-based ongrowing of seabass, choosing a scale of production of 400 tonnes per annum. The emphasis on the offshore aspect of the pen farm is important, since this implies a very high standard of equipment. Table 7 summarises their findings, and it is interesting to note that unit cost of production in a pen-based system was some 22% cheaper than in a land-based system..

Table 7: Lands-based v. Pen-Based Seabass Production

Parameter	Land Based	Pen Based
Capital Cost (Fixed Asset) – US\$ Mill.	1.415	0.943
Rearing volume – m ³	20,000	25,000
Cost of production – US\$ per kg.	7.77	6.33

Summerfelt and colleagues in the USA have published many papers on land-based production of salmonids, and whilst the bulk of their work focuses on land-based ongrowing, it is relevant in terms of assessment of design and energy characteristics of large scale land-based farms¹¹². They do not provide direct cost comparison information that is relevant to this study, but some of their work on tank hydrodynamics – especially with respect to dual drain systems – is of interest to any consideration of a modern efficient land-based system.

The development of ‘model farms’ in the Danish trout sector has arisen from a need to improve the industry’s environmental footprint in relation to freshwater systems. Whilst none of the literature sources investigated for this study provide direct evidence of cost comparison for smolt production, the farms themselves illustrate the type of modern land-based system that could be considered for salmon smolt production – or indeed for land-based trout production in Scotland¹¹³. It is worth pointing out that the BTA’s position is that such farms might have niche

¹¹¹ <http://ressources.ciheam.org/om/pdf/b30/00600661.pdf>

¹¹² See for example: <http://www.seafoodchoices.org/seafoodsummit/documents/Summerfelt,Steve.pdf>

¹¹³ See for example: http://www.aquamedia.org/FileLibrary/10/Aquaetreat_Modelfishfarms_Design.pdf

, <http://www.bioforsk.no/ikbViewer/Content/55627/Jokumsen%20Model%20trout%20farms.pdf>

, <http://www.danskakvakultur.dk/images/pdfdokumenter/rapporter/indhold-GB.pdf>

, <http://www.nordicras.net/upload/nordicras/per%20bovbjerg%202.pdf>

, <http://www.mendeley.com/research/water-quality-and-rainbow-trout-performance-in-a-danish-model-farm-recirculating-system-comparison-with-a-flow-through-system/>

, http://www.fao.org/fishery/countrysector/naso_denmark/en

, <http://www.nordicras.net/upload/nordicras/christina%20kongsted.pdf>

, <http://www.uwsp.edu/cols-ap/nadf/Workshops/Rainbow%20Trout%20in%20RAS.pdf>

, <http://archimer.ifremer.fr/doc/2009/publication-6506.pdf>

, http://www.matis.is/media/fodurradstefna-2011/2_Environment_efficient_production_rev.pdf

, http://www.ipfsad.ca/files/Documents/Reports/2008_-_Canadian_Model_Aqua_Farm_-_Technical_Report.pdf

application in the UK, but that broadly they do not suit the cost structure of the domestic trout industry¹¹⁴.

3.2.1.3 Current Experience – Capital Costs

Introduction

Both the aquaculture industry and some of its key equipment suppliers were asked to supply information on the capital costs of installing new smolt or trout production units. It should be noted that whilst there was good evidence of consistency across industry respondents, there was a disparity between industry views and those of one of the major equipment suppliers. This is largely unsurprising: capital cost estimates made by specialists can often translate into higher actual costs when projects are eventually completed¹¹⁵.

The other point that comes through very clearly from all respondents is the importance of economies of scale. This is particularly pertinent if one were to consider that a particular modest-scaled existing pen farm, producing just a few hundred thousand smolts per annum, could be somehow 'moved onshore'. Aside from the obvious difficulties of finding a suitable site, raising new finance and dealing with displaced production staff in remote communities, the economic implications are significant. The proposed 'onshore' equivalent farm would be a very small and inefficient land-based unit by modern standards, and would certainly not be able to take advantage of economies of scale.

Capital Costs – Pen Farms

a) Salmon smolts

There was some range in the estimates received from industry and other sources¹¹⁶, and the information gained about the possible capital cost of installing brand new pen farms capable of producing around **2.5 million** smolts per annum, requiring a pen volume of around 30,000 m³, suggested:

Maximum capital cost	£1,000,000
Minimum capital cost	£700,000
<u>Estimated mid-range cost</u>	<u>£900,000</u>

b) Rainbow trout

¹¹⁴ <http://www.cefas.co.uk/publications/finfishnews/FFN9.pdf>

¹¹⁵ http://www.northernaquafarms.com/knowledgelibrary/NAF_PDF_Files/RAS_minimum_standards.pdf

¹¹⁶ See for example: http://www.fusionmarine.com/news_migdale_smolt.htm

The capital cost of a freshwater pen unit to produce **500 tonnes** per annum of trout is likely to be more variable within the sector in Scotland. Some producers will wish to work with stocking densities that are likely to achieve Freedom Foods accreditation (15 kg/ m³), others do not have this requirement. Some producers, probably most, might choose to build a new large farm using current salmon smolt standards of equipment. Other producers in possibly less sensitive areas, and with good in-house expertise, might choose to use own-produced wooden pens. The range is assessed as :

Maximum capital cost	£700,000
Minimum capital cost	£375,000
<u>Estimated mid-range cost</u>	£538,000

It should be noted that these estimates include new shore-based facilities.

Capital Costs – Tank Farms

a) Salmon smolts – Recirculation

A range of cost estimates were provided for the construction of modern large scale RAS units for salmon smolt production:

- £16 million for a unit producing 10 million fish per annum
 - Industry experience
- £2.5 to £3 million for a unit producing 1 million fish per annum
 - Industry estimate (2 sources) – note poorer economy of scale
- £25 million for a unit producing 10 million fish per annum
 - Industry anecdote about a Norwegian unit – actual production has only reached 4 million smolts
- £7.3 million for a unit producing 8.4 million fish per annum
 - Supplier estimate
- £2.1 million for a unit producing 2 million fish per annum
 - Supplier estimate, smaller scale

It is appropriate to consider briefly why the supplier's theoretical estimate might be lower than the practical experience coming from the industry. For example, the supplier's model indicates that the required buildings to house all the tanks and equipment cost £200 per m². In practice UK building costs are considerably higher: £330 - £474 per m² for a simple industrial shell in Scotland (2006 prices)¹¹⁷. A purpose-built unit with electrical installation could cost as much as £771 per m². External works and items such as car parking would be additional costs: 20% on top of the building cost in the case of externals, and up to £1,500 per car parking space.

¹¹⁷ http://www.publicarchitecture.co.uk/knowledge-base/files/indicative_building_costs.pdf

One other key point to note is that in a RAS production unit, there are effectively 2 crops per year, i.e. productivity per unit tank volume is likely to be higher than for a standard flow-through farm. It is also very important to note that the equipment supplier's estimate was based upon a maximum stocking density of 60 kg/m³. If new smolts units in Scotland were aiming for Freedom Food accreditation, the maximum density allowed would be 30 kg/m³. One would have to potentially double the supplier's estimate in such cases.

Taking a balanced overview of all the capital costs indications, for the purpose of the subsequent modelling in this study, a capital cost of **£10 million** for a unit capable of producing **5 million smolts** per annum, mixed S0 and S1s, will be assumed.

b) Salmon smolts – flow-through

An outline budget for the construction of a more traditional flow-through land-based smolt unit, with oxygenation, is summarised in Table 8. This estimate is for a system designed to produce 1 million smolts per annum, based on the Freedom Foods land-based stocking density standard of 30 kg/ m³.

Table 8: Capital Cost for a One Million Smolt Flow-Through Farm

	Number	Each	Total
		(£)	(£)
Site excavation (moderate site)			20,000
40 m ³ concrete base tanks	60	6,494	389,640
Install			50,000
2 x 12 inch feed pipe (per m)	200	22	4,400
Install (x2)			10,000
Valves	60	60	3,600
Feeders	60	400	24,000
Feeder control (pc based)	1		2,000
Buildings	1	10,000	10,000
Walkways, covers etc	60	600	36,000
Vehicle	1	20,000	20,000
Alarm system probes	60	280	16,800
Alarm system electronics			10,000
Oxygenation system diffusers	60	300	18,000
Oxygen generator			20,000
Roads, gates, fences			10,000
Mains electric install			50,000
Drum filter	1	20,000	50,000
Graders, pumps etc			50,000
Inlet filter (concrete with steel)	1	5,000	5,000
TOTAL			799,440

This cost estimate is based on practical industry expertise, including a considerable amount of 'own management'. If contracted out completely to a specialist construction/equipment company, the cost would probably be higher. On the other hand, taking into account likely economies of

scale for a **5 million** smolt unit, a straight pro-rata multiplication might be realistic, i.e. a total capital cost of £4 million. Allowing for site development, planning and other consenting, and unforeseen costs, this could rise to perhaps **£5 million**.

c) Rainbow trout – ‘Model Farm’

The so-called Danish ‘model farm’ is essentially a type of RAS. They were introduced in Denmark because of environmental challenges to river water quality. For reasons of bio-security, they are largely based around borehole supplied water. It is important to note that the geological conditions over most of Scotland are unfavourable with respect to borehole freshwater, and it is also important to note that no ‘model farms’ have been built anywhere in the UK.

The capital cost of developing such a unit in the UK, based upon an understanding of the situation in Denmark, for a farm capable of producing 500 tonnes of trout per annum, is estimated at **£1 million**.

d) Rainbow trout – traditional flow-through

Scottish land based trout farms tend to be more traditional flow-through designs, with water supply coming from a river system upstream of the farm, and discharged back downstream of the farm after suitable treatment. Extra oxygen is commonly supplied, but it is interesting to note that at least one producer has abandoned the use of liquid oxygen and diffusion, and returned to the simpler – and cheaper – use of paddle wheel aerators.

The industry has stressed that there is currently no land based trout farm in Scotland large enough to produce 500 tonnes per annum, but has assisted this study by providing an estimate of what such a farm would cost to build, including site development, planning etc : **£800,000**.

3.2.1.4 Current Experience – Operating Costs

Salmon Smolts

It has been possible to access information about different aspects of operating costs, from a variety of sources. These are compiled in Table 9, which shows a range of estimated costs. It is important to note that an initial model of Table 9 was developed through consultation with key industry respondents, combined with first-principles calculations on major components. The results were then consulted-upon widely with all Scottish smolt producers. Responses were then collated and used to create the high-medium-low categories in Table 9.

Table 9: Cost models (with ranges) for various forms of Atlantic Salmon smolt production

Type of System	RAS	Flow Through With Oxygen			Pens		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
<i>All costs in £</i>							
Annual smolt production (N)	5,000,000	5,000,000	5,000,000	5,000,000	2,500,000	2,500,000	2,500,000
Capital Cost (£)	10,000,000	5,000,000	5,000,000	5,000,000	1,000,000	1,000,000	700,000
Operating costs							
Feed	548,936	548,936	548,936	548,936	274,468	218,000	275,000
Power (Fuel)	85,148	60,000	60,000	40,000	30,000	30,000	30,000
Oxygen	113,880	262,800	262,800	262,800	-	-	-
Chemicals, pH adj, denitrification	75,000	-	-	-	-	-	-
Maintenance	350,000	200,000	200,000	100,000	150,000	120,000	75,000
Labour	212,400	359,900	241,900	241,900	241,900	241,900	150,000
Fry	1,595,745	1,595,745	1,595,745	1,595,745	797,872	780,000	750,000
Vaccine	1,250,000	1,250,000	1,250,000	1,000,000	625,000	625,000	625,000
SEPA	12,000	20,000	20,000	20,000	10,000	10,000	10,000
Vet	10,000	20,000	20,000	20,000	6,000	6,000	6,000
Medicines	10,000	60,000	60,000	20,000	30,000	30,000	10,000
Water supply	20,000	20,000	20,000	20,000	-	-	-
Effluent plant	10,000	10,000	10,000	10,000	-	-	-
Insurance [3%; £0.75]	112,500	112,500	112,500	112,500	56,250	56,250	56,250
Rent (Estimates given)	250,000	300,000	250,000	300,000	45,000	45,000	25,000
Domestic costs	60,000	60,000	60,000	60,000	30,000	30,000	30,000
Misc	100,000	100,000	100,000	100,000	50,000	50,000	50,000
Operating costs total	4,815,609	4,979,881	4,811,881	4,451,881	2,346,490	2,242,150	2,092,250
Cost per smolt	0.96	1.00	0.96	0.89	0.94	0.90	0.84

Key Assumptions for the cost models in the above table are as follows:

- For all types of production system, 5g salmon fry are the initial starting point. This is necessary because comparisons have to be made between the cost of producing 80-100g smolts in different systems – and pen farms cannot, by themselves, produce smolts starting with salmon eggs. Some adjustments to land based system cost estimates have been made in order to accommodate production from fry rather than eggs, although it is possible that there is a slight remaining over-estimate of land based costs because capital and other fixed operating costs cannot be readily scaled. This possible over-estimate is likely to be small.
- Labour costs are based upon standard salary levels agreed with a range of respondents, and then varied according to the respondent's experience of actual manpower required.
- Salmon fry are assumed to cost £0.30 each, delivered to the smolt production unit.
- Feed costs are based upon a standard cost and feed conversion ratio agreed with respondents.
- Power and oxygen costs are based upon a range of feedback from respondents, and also upon some first-principles calculations of water pumping energy requirements and commercial gas costs.
- Delivery charges of smolts have been excluded. They are very variable, depending upon where the producer and receiving marine site are located.
- All other costs are based upon a summary of respondents' feedback for this study.

The main summary of Table 9, smolt cost vaccinated ex-smolt farm, is:

Average cost of pen produced smolts	£0.89
Average cost of RAS produced smolts	£0.96
Average cost of flow-through produced smolts	£0.95

Although it is a speculative assessment, if new or displaced smolt production were to be based on land, and include 50% RAS farms and 50% flow-through farms, the average unit smolt production cost would be £0.96, (rounded to the nearest £0.01).

Rainbow Trout

The Table below provides an estimate of the cost of production (£ per kg) for table size rainbow trout grown in different systems. It should be noted that in this analysis the lower capital cost estimate for a pen farm has been used.

Table 10: Possible Operating Budgets for Different Trout Units

Type of System	Danish 'Model Farm' system	Land based with oxygenation	Freshwater Pen
<i>All costs in £</i>			
Annual trout production (tonnes)	500	500	500
Capital Cost (£)	1,000,000	600,000	375,000
Operating costs			
Feed	550,000	550,000	600,000
Power (Fuel)	80,000	25,000	15,000
Oxygen	20,000	70,000	
Chemicals, pH adj, denitrification			
Maintenance	5,000	5,000	5,000
Labour	65,000	80,000	80,000
Fry Costs	166,000	166,000	178,500
Vaccine	10,000	10,000	12,000
SEPA	500	1,500	1,500
Vet	3,000	3,000	3,000
Medicines	6,000	6,000	3,000
Water supply			
Effluent plant	2,000	2,000	
Insurance			
Rent (Estimates given)	20,000	20,000	10,000
Domestic costs	5,000	5,000	5,000
Misc (central overhead)	80,000	80,000	80,000
Total operating costs	1,012,500	1,023,500	993,000
Cost per kg at farm gate	2.03	2.05	1.99

3.2.1.5 Other costs**Public sector**

Changes in production practices may need to be achieved through new regulation which will have a cost burden to generate and implement.

Angling sector

Costs to the angling sector are discussed in terms of possible changes to practices and to angler spend. Possible methods of quantifying angler spend and amounts involved are set out in the equivalent section below on benefits. Other aspects of fish wellbeing are covered under environmental costs as they are non-monetary conservation or non-use values.

Environment

Costs to the environment from changes in practices are described in terms of discharges to air, water or land, as well as aspects such as noise and traffic. They are also assessed as either short term or permanent.

Costs to the above categories can not be quantified in monetary terms and are scored in terms of relative costs of each Scenario on a 0 to 3 scale, (low to high).

3.2.2 Benefits**3.2.2.1 Aquaculture industry benefits**

Benefits to Scotland from salmon and trout farming include profit and employment generated in primary production, which for salmon includes marine and fresh water and phases. It also produces benefits related to upstream (supplier) and downstream (mostly processor) activities.

This analysis is restricted to primary production only, i.e. as far as the “farm gate”. For trout this covers the entire grow-out stage. For salmon smolt production, the profit produced is examined at the end of the marine grow-out stage. This is because the marine phase operations are entirely dependent on smolts: they have no alternate economic use if smolts became unavailable. Any change in smolt production method and costs will impact the overall production cycle as it represents a cost change to the marine grow-out phase. Employment benefits are excluded in this economic assessment, but are discussed later in Section 3.2.4 on financial implications of changes for the aquaculture industry.

Salmon

A measure of profitability of primary salmon production can be gained from quarterly or annual reports of the four large listed companies which make up the bulk of the production capacity in Scotland. These are available on the web. Three out of four of the companies involved are entities within multi-nationals. The parent companies report summary information for each business “segment”, usually a country of operation, of which Scotland is one. The only commonly used and reported measure of profit at “segment” level is EBIT (earnings before interest and tax) and this is often given, or can be calculated, on a unit weight (per kg gutted) basis. The reports of the four large companies have been assessed. These are:

- Scottish Sea Farms Ltd: (parent Salmar ASA and Leroy ASA)
- Scottish Salmon Company Ltd: (no parent)
- Grieg Seafood Hjalmland Ltd: (parent Grieg Seafood ASA)
- Marine Harvest (Scotland) Ltd: (parent Marine Harvest ASA)

Given that these companies together account for the majority of the production volume from Scotland, their average EBIT can be taken as reasonably representative of that for the whole industry.

Volume, sales value and EBIT have been extracted on an annual basis from 2006 to 2010 and for each quarter of 2011. These periods have been selected as they include a range of market price environments, with significant change within 2011. Also 2006 is as far back as accounts for most companies are available or can be reliably used due to ownership changes, changes in reporting methods etc. For some companies, data for 2006 and 2007 is incomplete.

EBIT has been identified as “Operational EBIT” or “EBIT before fair value adjustment on biomass, contracts etc”¹¹⁸. Three out of the four companies have values shown in Norwegian Kroner (NOK). In these cases the NOK values have been converted to Sterling using the average exchange rates for the period in question. These rates are derived from a foreign exchange information website¹¹⁹.

¹¹⁸ This is distinct from EBIT after adjustment for remaining biomass in the water and some non-farming issues such as values within contracts, restructuring costs, associated company profits and losses etc. This measure is a compliance requirement and is less relevant to profitability of the farming operation.

¹¹⁹ <http://www.oanda.com/currency/average>

The variables have been assessed for each company and each period and then aggregated. An overall weighted average was thus arrived at for each period. The average weighted EBIT has then been applied to the MSS annual survey all-industry harvest volume, which has been corrected to reach a gutted weight equivalent by deducting a rule-of-thumb conversion factor of 12%¹²⁰. Table 11 below thus shows that the companies examined covered between some 56% and 79% of total Scottish production in the period examined, and extrapolation gives an estimate of total industry EBIT ranging between some £20m to £140m per year over the period. On a unit basis, the average EBIT for the last six years for which data is available is £0.59/kg gutted, or £0.52/kg round.

Table 11: Calculation of all-industry EBIT based on data from specimen companies, 2006-2011

Year	Period	Aggregate volume (tonnes gutted)	Aggregate EBIT (£ '000's)	Overall EBIT (£/kg gutted)	Harvest volume per MSS (tonnes round)	Harvest volume per MSS (tonnes gutted)	Proportion of industry in selected co's	Overall industry EBIT (£ '000's)
2011	Q4	29,411	3,495	0.12				
2011	Q3	27,422	17,821	0.65				
2011	Q2	27,988	33,892	1.21				
2011	Q1	24,855	30,782	1.24				
2011	Year	109,753	85,993	0.78	157,385	138,499	79%	108,516
2010	Year	101,740	103,673	1.02	154,164	135,664	75%	138,242
2009	Year	96,649	55,216	0.57	144,247	126,937	76%	72,520
2008	Year	88,346	16,011	0.18	128,606	113,173	78%	20,511
2007	Year	63,551	21,559	0.34	129,930	114,338	56%	38,789
2006	Year	64,784	40,835	0.63	131,847	116,025	56%	73,134

Table 11 above is summary information only. The base data and analysis is on a large spreadsheet which is not presented to save bulk. Note that EBIT understates economic benefit as its calculation includes depreciation, a non-economic cost. Depreciation as a proportion of EBIT can be highly variable and is only reported in some company accounts for some years. A rough estimate from one company with a reasonable dataset suggests depreciation is generally between 10 and 50% of EBIT. More information on price and EBIT margins are given in section 3.2.4 on financial implications for industry.

¹²⁰ The statistical authority in Norway use 12.5%, see http://www.ssb.no/akvakultur_en/about.html, while anecdotally some processors estimate more and less than this

Trout

Detailed economic information is not available for the trout industry. None of the companies involved are listed. Various publicly available data sources have been examined to gain a view on farm-gate price in recent years, which can be compared to production cost estimates in Table 9 (further above) to arrive at an estimate of profit. However price data are not very refined and some aggregate large areas of production across Europe.

1. The Federation of European Aquaculture Producers (FEAP) / Aquamedia¹²¹ dataset suggests prices between 2006 and 2010 were in the range €1.94-2.28/kg for “pink” rainbow trout on an all Europe basis.
2. Infofish¹²² price reports suggest a range of approx € 2.50-2.80/kg in 2010-11 ex-farm in Italy, converting to £2.15 to £2.45/kg (using the average method described for salmon data).
3. Economic models from the Scottish Agriculture College (SAC)¹²³ suggest a range of £1.70-2.20/kg in 2008.
4. The FAO Fishstat datasets suggests UK rainbow trout produced in freshwater were in a price range £2.04-2.17/kg (after conversion from US Dollar values) over the period 2006-2009.

The FEAP data is thought to be too generalised and cover a wide variety of mostly low cost producers, also other prices within the dataset was unfeasibly low, so this estimate is ignored. As a rough estimate £2.15/kg is thus taken from the remaining estimates as an indicative sales value for portion-sized rainbow trout. Comparison with Table 10 suggests a margin before finance and tax costs of £0.10/kg for land based/oxygenation systems, £0.12/kg for the Danish model and £0.16/kg for pen rearing. Margins are significantly below those seen in salmon farming and these rather low levels perhaps explain the contraction in activity in recent years, from a peak output of some 7,500 tonnes in 2006 to 5,100 tonnes in 2010. Anecdotally the profit for the trout produced for restocking (13% of the total in 2010) is said by industry to be somewhat better than for portion fish, though the market is limited.

¹²¹ <http://www.aquamedia.info/pdf/flip/FEAPPROD2011/PriceAndSpecie/index.html>

¹²² FAO / Globefish European Fish Price Report, November 2011

¹²³ <http://www.sac.ac.uk/consulting/services/f-h/farmdiversification/database/fishfarming/trout>

3.2.2.2 Other benefits

Public sector

Some policy changes may result in a reduced regulatory burden or other avoided costs for the public sector and these will be discussed qualitatively.

Angling sector

All scenarios of change have the intention of removing risk of impact to wild fish populations. As already discussed it is not clear whether impacts have actually occurred. If they have, or might in future, there is no indication as to the extent impacts could disrupt populations to the point that they provide fewer fish for anglers or become unfishable and so economic benefit from angling is lost.

Even so, it is perhaps informative to at least consider the extremes, to assess the economic benefit that is currently derived from angling for salmon and sea trout in the catchments where pens are located.

An approximation of angler expenditure on salmon and sea trout fishing was established in a study on the economic benefits of freshwater angling in Scotland (already cited) in approximately 2002. The total expenditure of salmon and sea trout angling was £73.5m and covered the angling itself (rents for use of water, payments to ghillies etc) as well as relation expenditure such as food, accommodation and tackle. The data was collected in roughly 2002 and RPI tables¹²⁴ suggest this would equate to some £100m in 2012. A very crude estimate of the “value” of a certain catchment from salmon and sea trout angling can thus determined by:

1. assuming angler spend per fish caught (or caught and released) is the same in all Scottish rivers
2. Calculating the catch in a particular catchment as proportion of the national catch.
3. Applying this proportion to the national value

¹²⁴ <http://www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcn%3A77-223807>

Rod and line catch data is available at the Fishery District level. The catchments where each salmon or trout pen site is located as shown in Figure 8 and Table 4 earlier has been identified and allocated to a District. Five-year (2006-2010) average catches have then been calculated for each District for salmon (including grilse) and sea trout, based on catch and retained and catch and released combined, using catch data supplied by MSS, as shown in the tables below.

Table 12a: Five-year average rod and line catches of salmon and sea trout in those Districts containing smolt pen sites

District	District no	Salmon	Sea Trout
Aline	2	22	31
Baa	10	79	70
Balgay	12	35	9
Clayburn	21	27	89
Creed	25	404	542
Forth	44	2,430	728
Howmore	55	88	602
Kyle of Sutherland	66	3,406	534
Laxford	68	120	54
Loch Roag	73	947	479
Lochy	71	624	72
Mullanageren	79	30	214
Ness	83	1,167	50
Ormsary	85	25	30
Pennygowan	86	23	5
Shetland	108	1	195
Shiel	91	70	106
Total		9,498	3,809

Table 12b: Five-year average rod and line catches of salmon and sea trout in those Districts containing rainbow trout pen sites

District	District no	Salmon	Sea Trout
Awe	7	480	16
Dee (Kirkcudbright)	29	78	61
Drummachloy	33	0	0
Tay	98	9,725	1289
Total		10,283	1,366

For ease of reference, a map showing Fishery Districts within Scotland and their code numbers. is shown in Appendix 3.

The catch in the Districts containing either smolt or trout pens from tables 12a and 12b are compared to the national catch in 13 below.

Table 13: Comparison of five-year average catches of salmon and sea trout in Districts containing salmon smolt or trout pens with all-Scotland catches

Angling area	Rod & line catch			Overlap with Salmon	Overlap with Sea Trout	Overlap total
	Salmon	Sea Trout	Total S&ST			
All Scotland	89,181	22,178	111,358	100%	100%	100%
Districts with salmon pens	9,498	3,809	13,307	11%	17%	12%
Districts with trout pens	10,283	1,366	11,649	12%	6%	10%
Total	19,781	5,175	24,956	22%	23%	22%

The table shows that those Districts containing salmon smolt pens provide about 11% of the national catch for salmon and 17% of the national catch for sea trout. The equivalent figures for Districts containing trout pens are 12% and 6% respectively. No Districts contain both pen types and so overall Districts containing pens of any type account for 22% of salmon catches and 23% of sea trout catches, or 22% of catches of both species combined.

Great care needs to be taken when interpreting these data.

Firstly, it could be argued that the Districts concerned have already suffered from impacts of open pens and so catches from 2006-2010 are artificially depressed. The biological section of this study has found no clear evidence of damage however. Also, rod and line catch returns are felt unlikely to be particularly accurate and are at best a crude measure of the wild salmonid population size or health in a District.

Secondly the overlap of trout pens and salmon catches is somewhat artificial: there is a single pen site in Loch Tay within the Tay District which is a very large catchment with a very high catch and significant contributor to the national total.

Thirdly many of the Districts which contain pens are comprised of multiple and small catchments. Pens may be in only one, or occasionally two or more catchments within a District which may contain perhaps 10-20 small catchments. This is particularly the case

on the west coast sites and in the Outer Hebrides, also Shetland. On the other hand some Districts which contain pens comprise of principally single large catchments, for example Lochy, Ness, Kyle of Sutherland, which between them contribute some 43% of the total catches of all Districts containing salmon smolt pens. It would require a significant exercise (outside the scope of this study) to extract catch data and assess the position for all the small catchments in the 21 Districts which contain pens. On an overall basis, the authors roughly estimate that using Districts to assess the degree of overlap between pen farming and wild fish catch overestimates the position roughly two-fold.

The maximum value of angler spend under debate from the current array of freshwater pens including trout is thus 22% (from Table 13) x £100m = £22m. Taking into account the anomalies with trout pens, the figure where there is significant overlap is probably only slightly above the salmon total, say 13% of the national total or £13m. Allowing for the overstatement as a result of using District data and not catchments, the figure is perhaps £7m, but with a wide range of possibilities, say £2-12m.

Environment

Benefits to the environment from changes in practices are described in terms of discharges to air, water or land and short term or permanent.

3.2.3 Options analysis for mitigating impact

Before discussing the broad-scale options for mitigation, it is worth stressing that any action to mitigate possible impacts of freshwater pen use in future needs to be seen in context of the current uncertainty of the linkage between pen use and wild stocks, as set out in Section 3.1.

Broad scale-options to consider in relation to preventing further potential impacts thus appear to be:

- **No change**
- **Continue with open pens but improve existing practices**
- **Phase out open pens**

Under the **no change** option the aquaculture industry would continue to use open pens and in the same proportion as at present and may expand overall proportion to meet market demand. The potential risks to wild fish populations would gradually intensify with any expansion in freshwater pen use.

Improving practices aims to reduce incidence of escapes and subsequent interactions, primarily through improved containment equipment. However it does not remove indirect effects from the physical presence of pens in freshwater bodies and their associated waste streams, nor does it totally remove risk of escapes.

Phasing out of the use of pens has been called for by wild fish interests, the angling sector and environmental NGO's and assessment of this broad-scale option forms the second main workstream of this study.

3.2.3.1 Scenario construction

Based on the broad-scale options above, Scenarios have been constructed as follows:

High Level “Scenario 0”: This is the “do nothing” scenario under which the industry would gradually expand along present lines, retaining the present ratio of pen:tank production capacity. Given some variation in the ratio but no distinct pattern (please see Table 5 above), the pen:tank ratio is assumed to be the average value for the five most recent years, 2006 to 2010. That ratio is 49% pens, 51% tanks.

Scenario 0 is the base case for comparative purposes.

High Level “Scenario 1”: This is on the same basis as Scenario 0 but assumes that the aquaculture industry will be required to improve containment standards and practices at all pen sites.

High Level “Scenario 2”: This assumes that all freshwater pen farming is phased out and that there is no investment in tank-based capacity to replace it. It further assumes that the industry will continue gradual growth as per “Scenario

0”, but that smolt requirements which would have been derived from pen production will be met by imports instead.

High Level “Scenario 3”: This assumes that freshwater pen farming is constricted and as a result future demand for smolt will be met by new investment in tank capacity.

Sub-option 3a: assumes that freshwater pen farming will be capped at 2011 levels

Sub-option 3b: assumes that freshwater pen farming will be reduced to 50% of 2011 levels

Sub-option 3c: assumes that freshwater pen farming will be reduced to zero.

In addition, the possible costs of extreme but highly unlikely scenarios are considered for context, as described in the methodology. They encompass a) loss of smolt production from pens with no alternative sourcing, and b) total failure of salmon and sea trout angling in all catchments containing pens.

The timescale considered for change within each scenario is 10 years, i.e. by 2022. This is felt to be a realistic period needed to implement some of the more radical scenarios. Some of the simpler ones could possibly be implemented sooner. However this period is held across all scenarios for simplicity and comparability.

Economic costs and benefits, which may result from changes, will be gradually felt over the ten year transition phase, or a longer time period in the case of some potential benefits. It would be unnecessarily complex to try to disaggregate timing of all costs and benefits within this phase, as their exact timing is difficult to predict. Costs and benefits are therefore considered in terms of full implementation at the end of ten years, although intuitively it should be clear which will be felt earlier rather than later. Costs will be presented in capital or operational terms. Some scenarios involve significant capital expenditure.

The extent of the costs and benefits arising from the scenarios will be determined by comparison to what could be expected to happen in the normal course of events over the timescale, i.e. Scenario 0. Scenario 0 thus needs a reasonable range of projections

as to likely demand for smolt, so as to quantify the production capacity that would be subject to change under the other scenarios.

3.2.3.2 Demand for smolts

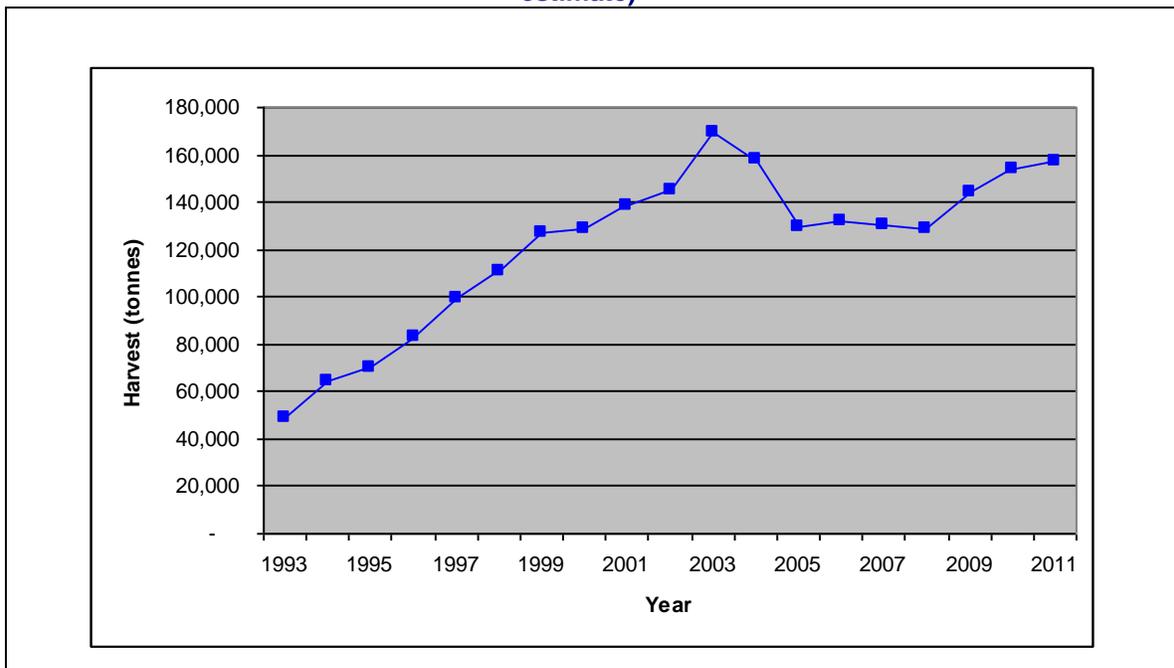
The likely future trends in demand for numbers of smolt required by the ongrowing industry is a complex intertwining of factors influencing the ongrowing industry such as demand for finished salmon, site availability, profitability, and access to capital, as well as factors determining yield of finished salmon per smolt stocked, such as smolt size at transfer to sea, seasonality, genetic origin, vaccination, or end customer requirements.

For this reason this study will assess the numbers of smolts likely to be needed in the future based on a best estimates of the key variables of the future capacity of the ongrowing industry and the yield per smolt put to sea, with some discussion as to possible ranges.

Ongrowing

The pattern of expansion of the Scottish farmed salmon industry will be familiar to most users of this report.

Figure 20: Harvest volume of farmed salmon in Scotland, 1993-2010 (round weight, 2011 estimate)¹²⁵



¹²⁵ Data source: MSS Annual Fish Farm Surveys

Production in the last 20 or so years has been split into two distinct phases: before 2003 growth was quite rapid with compound annual growth of around 13%, while after 2003 growth has reversed slightly overall. Arithmetic projection would be virtually meaningless as the outcome would vary considerably based on the period selected. There are many complex factors at play and there is no reason to suppose that future growth will adhere to any particular historic trend.

The on-growing industry in Scotland has medium to longer term aspirations for growth in output. The main drivers appear to be increasing demand for aquaculture products at the global level and, more locally, increased uptake of salmon products throughout UK and Europe as a year-round available meal choice, with positive health attributes and able to compete on price with red meats and many wild-caught fish. The constraints from the business perspective are further increases in production from Norway and Chile, so depressing prices as seen in 2002-03, together with the many issues surrounding expansion in sea water production capacity, as well as possibly some issues related to feed ingredients.

One estimate of growth from the Scottish Salmon Producers' Organisation (SSPO) is stated as: "In the next 5 years production is anticipated to increase by a minimum of 30,000 tonnes"¹²⁶. This statement refers to 2010, when production was 154,000 tonnes, so implies around 185,000 tonnes output by 2015, or a 20% increase over four years. Two of Scotland's leading producers have public statements of intent to expand production volume. One recently announced an intention to expand from around 23,000 tonnes per year at present to 40,000 tonnes per year by 2015¹²⁷. This represents a 74% increase over four years. Another has a stated intention to increase from some 33,000 tonnes in 2010 to 50,000 tonnes, (both gutted weights) an increase of 52%, though without a date for this target¹²⁸. One of the latest estimates available from government is within the Key Challenges for aquaculture within the National Marine Plan Pre-consultation report¹²⁹. That suggests 4% compound growth and gives a possible outcome of around 220,000 tonnes by 2020.

¹²⁶ <http://www.scotland.gov.uk/Topics/marine/Fish-Shellfish/international/ukaf/071010/UKAFPresentations>
¹²⁷

http://www.fishupdate.com/news/fullstory.php/aid/16998/The_Scottish_Salmon_Company_unveils_expansion_plans.html

¹²⁸ <http://hugin.info/209/R/1507169/442027.pdf>

¹²⁹ <http://www.scotland.gov.uk/Publications/2011/03/21114728/0>

For the purposes of this study and to use round figures for ease of illustration, it is assumed that the estimate in the National Marine Plan Pre-consultation report of 220,000 tonnes will apply in 2022 and is used as a central projection. This path of growth is less steep than the shorter estimates provided by SSPO and the company estimates, but is still higher than that seen in the last decade. Very late in the preparation of this study, the First Minister of Scotland provided a view as to the future production output (in the context of an announcement of new investment in production capacity by Marine Harvest) as follows: “...including our aim of increasing production by 50 per cent on 2009 levels to 210,000 tonnes by 2020”¹³⁰. This is very close to the central estimate suggested for this study.

The company statements of intent perhaps tend to be optimistic (for example one company had the stated target output for 2015 as occurring in 2013 in an earlier company report). The two statements give an average growth forecast of 63%, with short or medium time scales. An upper likely limit of expansion is therefore taken as this growth rate applied to the whole industry, but to be realised by 2022, not the shorter forecasts given. This would imply an upper realistic output of 257,000 tonnes by 2022.

A lower growth scenario is taken as no change from 2011. This would continue the trend seen in the last eight or so years and assumes difficult market conditions through re-emergence of Chile as a dominant global force, also possibly a restrictive environment on marine site use in Scotland.

In summary, the bounds are rounded and assumed are as follows:

Low: Static growth, i.e. 160,000 tonnes in 2022

Central: ~4% annual growth, i.e. 220,000 tonnes in 2022

High: ~63% overall growth from 2011, i.e. 260,000 tonnes in 2022

Yield per smolt

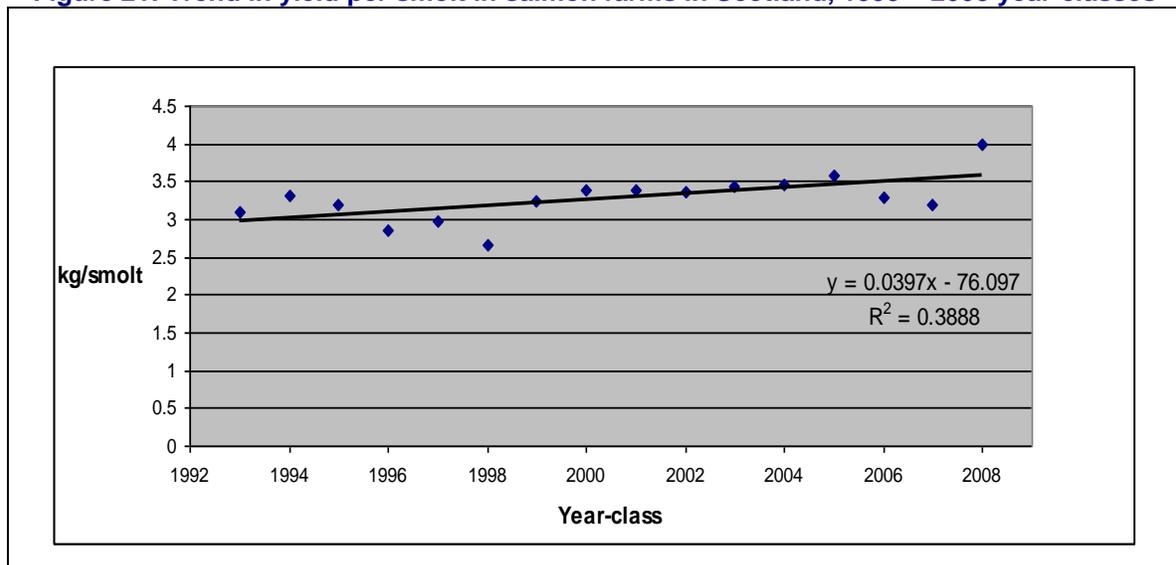
The numbers of smolt needed to supply the projected output is determined by yield per smolt put to sea. The MSS annual survey reports provide a useful summary of performance of each year class of smolts stocked in on-growing farms. Final harvest

¹³⁰ <http://www.fishupdate.com/news/fullstory.php/aid/17593>

weight achieved per smolt input is obviously a function of growth rate and survival of smolts post-transfer, also farmers' choice as to weight at which to harvest. These have all been trending upwards in recent years through a range of technological improvements in smolt quality and the on-growing process, as well as market preference as regards size.

The graph below sets out the long term trend in smolt yield.

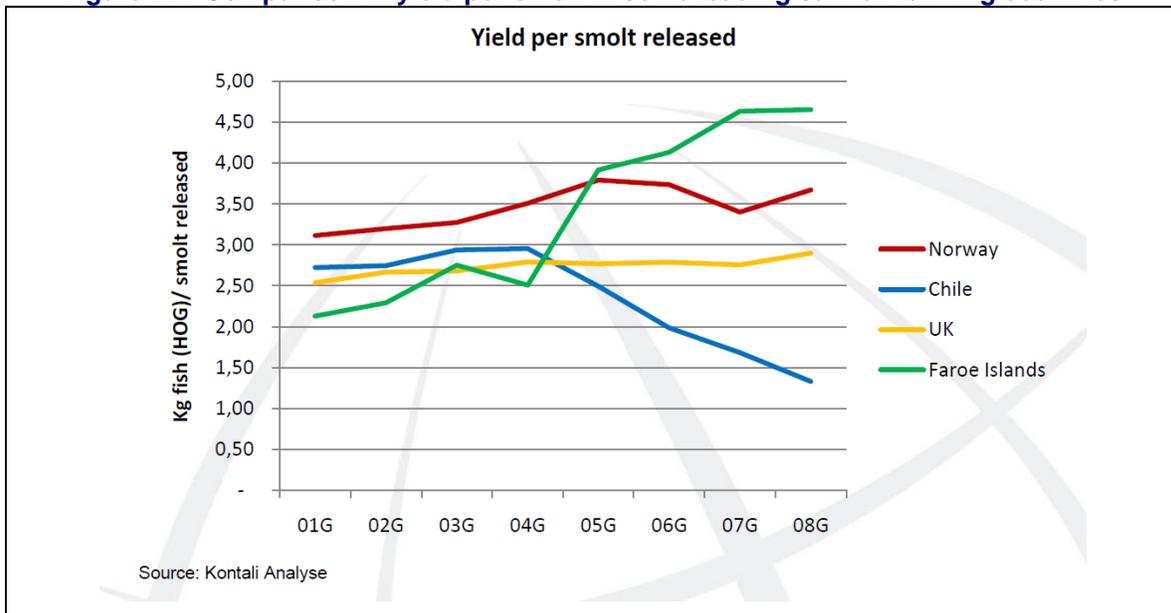
Figure 21: Trend in yield per smolt in salmon farms in Scotland, 1993 – 2008 year-classes



The yield per smolt appears to be improving over time, although the R^2 value suggests the relationship is not particularly close. If the formula is resolved for the year 2022 the yield per smolt at that time calculates at 4.18kg. However it is not at all certain that yield can continue improving *ad infinitum*. It is worth noting that if the graph is plotted and the formula resolved on the recent (i.e. 2000 to 2008) year classes only, the forecast yield in 2022 drops to 3.99kg. Some of the variables driving yield will be at or near their optimum level already. There have been some periods when yield has drifted downwards, possibly through ISA related problems in the late 1990's, also lice problems may have had a part to play at other times.

The following graph makes an international comparison of the situation for year classes 2001 to 2008, albeit on a different measure (head-on gutted weight).

Figure 22: Comparison in yield per smolt in some leading salmon farming countries



Source: Kontali Analyse within Marine Harvest Salmon Farming Industry Handbook, 2010

UK (i.e. Scotland's) position is relatively stable compared to some other countries which show stronger upward trends but with significant variations. (It is assumed that the raw data is derived from the MSS Annual Survey reports as well). The very poor situation in Chile is assumed to be as a result of the major ISA outbreak in that country.

To take a middle path therefore, and to provide some round figures for onward scenario testing, it is assumed that yield in Scotland will average 4.00kg whole salmon per smolt input in 2022. Again, to provide a range so the effects of this variable can be examined, the following estimates are considered on the following assumptions:

Low: average of the last 5 complete year classes, 3.50 kg/smolt.

High: projection based on the 1993-2008 year class trend, 4.18kg/smolt

The possible outcomes for future demand for smolt are shown in the table below.

Table 14: Projected demand for salmon smolt in Scotland in 2022 under various combinations of finished salmon production and yield per smolt

Forecast production (t)		Yield (kg / smolt)		
		Low 3.50	Mid 4.00	High 4.18
Low	160,000	45,714,286	40,000,000	38,277,512
Mid	220,000	62,857,143	55,000,000	52,631,579
High	260,000	74,285,714	65,000,000	62,200,957

With a projected harvest of 220,000 tonnes, the central projection of the number of smolt needed in 2022 is therefore estimated at **55 million per year**. This is some 19 million above 2010 production, and 10 million above that in 2000.

This predicted demand can then be applied to those scenarios requiring changes in production method, as summarised in the following table. Note that the starting value used is 2011 and is based on the estimated number of smolts placed in the sea in 2011 according to the MMS 2010 annual survey. The pen:tanks ratio is 49:51 as mentioned above. It is also assumed for simplicity in these scenarios that in 2022 all smolt used for on-growing in Scotland will be domestically produced, with the exception of Scenario 2.

Table 15: Predicted pen and tank capacity changes required by 2022 under Scenario 0, 3a, 3b and 3c, (all numbers 000's of smolts)

		OVERALL DEMAND	SCENARIO 0		SCENARIO 3a		SCENARIO 3b		SCENARIO 3c	
SUB-OPTION			NO POLICY CHANGE		NO EXPANSION OF PENS PERMITTED		MODERATE REDUCTION IN PENS		MAJOR REDUCTION IN PENS	
DESCRIPTION			MAINTAIN SHARE OF PEN PRODUCTION AT AVERAGE OF 2006-2010 SHARE		NO CHANGE IN PEN PRODUCTION FROM 2011		REDUCE PEN CAPACITY TO 50% OF 2010 LEVELS BY 2022		REDUCE PEN CAPACITY TO ZERO BY 2022	
Production capacity			pens	tanks	pens	tanks	pens	tanks	pens	tanks
	2011	35,900	17,589	18,311	17,589	18,311	17,589	18,311	17,589	18,311
Range										
Mid	Projected demand 2022	55,000	26,947	28,053	17,589	37,411	8,795	46,205	0	55,000
	Change from 2011	19,100	9,358	9,742	0	19,100	-8,795	27,895	-17,589	36,689
	Change as a result of policy		0	0	0	9,358	-8,795	18,153	-17,589	26,947
High	Projected demand 2022	74,286	36,397	37,889	17,589	56,696	8,795	65,491	0	74,286
	Change from 2011	38,386	18,807	19,578	0	38,386	-8,795	47,180	-17,589	55,975
	Change as a result of policy		0	0	0	18,807	-8,795	27,602	-17,589	36,397
Low	Projected demand 2022	38,278	18,754	19,523	17,589	20,688	8,795	29,483	0	38,278
	Change from 2011	2,378	1,165	1,213	0	2,378	-8,795	11,172	-17,589	19,967
	Change as a result of policy		0	0	0	1,165	-8,795	9,960	-17,589	18,754

The table shows that on the central projection for smolt demand, capacity will be needed to grow a further 19.1 million smolts by 2022. Assuming the tank:pen ratio seen in recent years holds, the new capacity will be provided almost equally by pen and tank based production.

If no new pen production is permitted beyond 2011 levels, as assumed in Scenario 3a, then 19.1 million of the additional capacity will need to be met by new tank units. Of this, some 9.4 million capacity will be additional to that which is assumed would occur anyway, i.e. is policy-driven. There will be avoided costs from not needing to install the equivalent pen capacity.

If pen production were to be scaled back to half of 2011 levels by 2022, as per Scenario 3b, to meet demand, tank capacity for an extra 27.9 million smolt will be needed, of which 18.1 million would be policy related. As with Scenario 3a, there will be the avoided cost of installing 9.4 million pen capacity.

If pen production were to be phased out entirely by 2022, as per Scenario 3c, to meet demand, tank capacity for an extra 36.7 million smolt will be needed, of which 26.9 million would be policy related. Again, there will be the avoided cost of installing 9.4 million pen capacity.

The rows in pink in the table above illustrate the situation given highest plausible demand, using the combination of high production and low yield per smolt shown in Table 14.

The rows in brown show the situation given the lowest plausible demand, using the combination of low production and high yield per smolt. The change in demand by 2022 is barely significant, being within fluctuations seen in recent years. It is thus only in Scenarios 3b or 3c where any significant policy related increase in land-based capacity would be needed in a low demand situation.

The assumptions used for the possible range in the variables of production and yield are somewhat arbitrary and so should be taken as illustrative only. The extreme combinations used to calculate smolt demand may not be as likely to occur as some of the intermediaries. For example, the high assumptions on growth in output of finished salmon would infer a profitable industry, which would be able to invest in smolt production technology, genetics and so on, which would tend to increase yield per smolt. Conversely static production may see no increase in smolt yield, so the most extreme predictions may not play out. Users of this report may have differing views on the likely situation for either of these variables in 2022. The smolt capacity needed using differing assumptions can be interpolated between the high and low range figures shown in Table 14, and indeed between Scenarios, if necessary.

3.2.3.3 Demand for trout

Trout production has stagnated in Scotland in recent years and it is difficult to predict likely future direction of the industry and so need for freshwater pen capacity. The relationship with salmon production is complex with both synergistic and competitive pressures at play. The common

factors are perhaps gradual increase in demand for aquaculture products generally with increasing population. However trout appears to have less mass-consumer appeal. A reasonable central estimate for 2022 would appear to be a return to the levels seen the mid 2000's, i.e. 7,500 tonnes. Pen production accounted for an average of 34% of output over the period 2006-2010. Assuming this share will hold, then capacity for $(7,500 \text{ tonnes} \times 34\%) = 2,250$ tonnes will be needed in 2022, compared to 1630 tonnes in 2010.

3.2.3.4 Costs of scenarios

The tables below set out predicted costs under each Scenario of change, compared to Scenario 0. Capital and recurrent costs are considered separately. For the aquaculture industry, capital costs are mainly associated with investment in new equipment, particularly in land based production facilities. Operational costs are mainly associated with differential production costs between rearing methods.

Costs that may accrue to the public sector, angling sector and the environment can not be quantified and are discussed qualitatively. The summary of costs in Tables 16 and 17 below allocates these a notional relative score of 0-3, low to high.

For both types of cost it is important to stress that the residual cost of the Scenario or policy option is measured, i.e. it is an estimate of the difference between what would have happened anyway and what may happen as the result of a possible policy intervention.

Each Scenario provides a summary description of the possible policy intervention, with calculations showing the basis for capital and recurrent cost estimates. For each scenario, calculations of costs to the aquaculture industry show variables and assumptions in each case. They also show range values of estimated costs depending on future size of the industry: the best estimate or "central" projections are shown with white backgrounds while those for high and low expansion projections are shown with pink and light brown shading respectively. Commentary is also given on non-quantifiable costs and where appropriate notes regarding assumptions or knowledge gaps.

Scenario	1																																														
High level change	No restriction on pen use																																														
Sub-option change	Improved containment																																														
Description	<p>This policy would oblige all freshwater pen site operations to adopt best equipment available and best practice regarding fish transfers and site operation.</p> <p>Industry currently operates a Code of Good Practice on containment.</p> <p>The trends for equipment replacement at current sites are toward use of high quality nets and collar designs developed for exposed marine sites, as discussed in section 3.1.4.2 on current practices.</p> <p>Consideration is currently being given to a Scottish Technical Standard regarding containment which would apply to both fresh and sea water pens.</p> <p>The extent of transfer to high quality equipment has not been formally surveyed for this project. From the team’s knowledge and discussions with industry it is estimated very approximately that one third of smolt pen production capacity currently uses equipment to this high specification and is probably in line with a possible future Scottish Technical Standard.</p> <p>This proportion will probably increase over the transition period to reach two thirds by 2022, without any policy intervention. Therefore the additional cost to industry, if obliged to make a full transfer to this technology by 2022 is one third of pen capacity then assumed to be in use at that time.</p> <p>For trout is assumed that one half of projected capacity for 2022 will use the new technology without policy intervention. Additional cost will be upgrading of the remaining of capacity.</p>																																														
Costs																																															
Aquaculture industry	<p>Salmon: capital</p> <table border="1"> <thead> <tr> <th>Variable</th> <th>amount</th> <th>units</th> <th>calc</th> </tr> </thead> <tbody> <tr> <td>Projected pen production 2022 (central)</td> <td>26,947,495</td> <td>smolts</td> <td>A</td> </tr> <tr> <td>Projected pen production 2022 (high)</td> <td>36,396,616</td> <td>smolts</td> <td>B</td> </tr> <tr> <td>Projected pen production 2022 (low)</td> <td>18,754,237</td> <td>smolts</td> <td>C</td> </tr> <tr> <td>Proportion requiring upgrade</td> <td>33.3</td> <td>%</td> <td>D</td> </tr> <tr> <td>Capital cost new high spec site</td> <td>700,000</td> <td>£</td> <td>E</td> </tr> <tr> <td>Capacity new high spec site</td> <td>2,500,000</td> <td>smolts</td> <td>F</td> </tr> <tr> <td>Unit capital cost new high spec site</td> <td>0.28</td> <td>£/smolt</td> <td>G=E/F</td> </tr> <tr> <td>Total capex required (central)</td> <td>2,515,100</td> <td>£</td> <td>H=AxDxG</td> </tr> <tr> <td>Total capex required (high)</td> <td>3,397,018</td> <td>£</td> <td>I=BxDxG</td> </tr> <tr> <td>Total capex required (low)</td> <td>1,750,395</td> <td>£</td> <td>J=CxDxG</td> </tr> </tbody> </table>			Variable	amount	units	calc	Projected pen production 2022 (central)	26,947,495	smolts	A	Projected pen production 2022 (high)	36,396,616	smolts	B	Projected pen production 2022 (low)	18,754,237	smolts	C	Proportion requiring upgrade	33.3	%	D	Capital cost new high spec site	700,000	£	E	Capacity new high spec site	2,500,000	smolts	F	Unit capital cost new high spec site	0.28	£/smolt	G=E/F	Total capex required (central)	2,515,100	£	H=AxDxG	Total capex required (high)	3,397,018	£	I=BxDxG	Total capex required (low)	1,750,395	£	J=CxDxG
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Total capex required (low)	1,750,395	£	J=CxDxG																																												

	Trout: capital			
	Variable	amount	units	calc
	Projected production 2022	7,500	tonnes	A
	Share from pens	34	%	B
	Proportion requiring upgrade	50	%	C
	Capital cost new high spec site	700,000	£	D
	Capacity new high spec site	500	tonnes	E
	Unit capital cost new high spec site	1400	£/tonne	F
Total capex required	1,785,000	£	G=AxBxCxF	
	<p>Capital costs: The upgrade to new equipment is estimated at £700,000 based on estimates given in section 3.2.1.3 and covers new pens and associated equipment but not a new shore base, i.e. costs are lower than in the case of creating new sites from scratch.</p> <p>Operational costs: Assumed unchanged</p>			
Public Sector	Minor relating to policy introduction and enforcement.			
Angling Sector	None			
Environment	<p>Natural resource use and discharges to air, land and water arising from equipment manufacture and installation.</p> <p>Artificially early disposal of existing pen equipment (landfill), also discharges arising from removal operations.</p>			
Notes	The proportion of industry using various types of technology in freshwater pen production at present is unclear. Proportions discussed are rough estimates and should be treated as illustrative only. Primary research on this topic is recommended.			

Scenario	2																																																												
High level change	Full restriction on freshwater pen use																																																												
Sub-option change	No replacement capacity, substitution by import																																																												
Description	<p>This scenario would involve phasing out of all domestic pen production of smolt and assumes demand for smolts would be met through import from areas outside Scotland with equivalent health status. Parts of Norway are the only such potential supplier area with potential capacity to replace pen based production in Scotland.</p> <p>It is envisaged that production would be met from large tank-based farms in Norway. Costs of such production are assumed to be similar to those in Scotland, or possibly slightly lower, which would be balanced by slightly higher delivery costs. The cost to the Scottish industry is thus assumed to be the difference between average unit costs for pen production and an average of the land based costs shown in Table 10, for those numbers of smolts which would normally have come from Scottish pens by 2022.</p> <p>For rainbow trout, the cost to the Scottish industry would be the difference between average unit costs for pen production shown in Table 11 and an estimate of the wholesale value of imported fish for the tonnage of trout which would normally have come from Scottish pens by 2022. This is notionally taken to be the farm-gate price shown in Section 3.2.2.1 of £2.15/kg plus £0.10/kg to cover freight, i.e. £2.25/kg.</p>																																																												
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Public Sector	Significant: increased health surveillance costs on imported smolts.																																																												
Angling Sector	Risk of ISA and other disease introduction to wild stock in Scotland.																																																												

	<p><i>Gyrodactylus salaris</i> (Gs) is only minor risk as the parasite can not tolerate marine conditions which would be experienced in well-boat transport. Possible increased risk of VHSV introduction in additional trout carcasses for processing in Scotland.</p>
Environment	<ul style="list-style-type: none"> ○ Increased emissions to air relating to transport by well boat ○ Increased sea traffic ○ Increased emissions and traffic relating to trout substitution <p>Artificially early disposal of existing equipment, (landfill), also discharges arising from removal operations.</p>
Notes	<p>The option of importing smolt from an area of equivalent health status is one that has been available for many years. However the Scottish industry has consistently opted to retain the sourcing from within Scotland, with small amounts from England and Ireland.</p>

Scenario	3a				
High level change	Partial restriction of freshwater pen use				
Sub-option change	No expansion of pen capacity beyond 2011 levels, demand to be met through additional tank-based capacity				
Description	<p>This option involves both capital and recurrent expenditure for both salmon smolt and trout.</p> <p>Additional capital costs are derived from the difference between pen and tank based facilities. Additional recurrent costs are derived from the difference in operating such facilities.</p> <p>Salmon For salmon smolt, it is assumed that in order to fill the capacity which might otherwise be met through pen production, the industry will employ high-tech RAS systems and flow through systems in equal proportion for the land-based expansion required.</p> <p>Additional operational cost is assumed to be the difference between the average land-based cost and the average pen cost from Table 9. (note these tables have ranges of possible costs, however they are quite narrow (11% high to low in both cases) and incorporating these into the calculations and results below would add clutter while only widening the range of outcomes slightly). Average values are therefore used.</p> <p>Trout For trout it is assumed that the land-based expansion required to meet demand will employ only flow-through systems with oxygenation. The cost of a large scale unit is £800,000 with a capacity to produce 500 tonnes per annum.</p> <p>Additional operational costs are assumed to be the difference between the flow-through systems the pen cost from Table 10.</p>				
Costs					
Aquaculture industry	Salmon: capital				
	Variable	amount	units	calc	
	Projected additional tank production (central)	9,358,130	smolts	A	
	Projected additional tank production (high)	18,807,252	smolts	B	
	Projected additional tank production (low)	1,164,873	smolts	C	
	Land based	Capital cost RAS	10,000,000	£	D
		Capital cost Flow through	5,000,000	£	E
		Capacity	5,000,000	smolt/yr	F
		Average capital cost unitised	1.50	£/smolt cap	$G=(D+E)/2/F$
	Pens	Capital cost	900,000	£	H
		Capacity	2,500,000	smolt/yr	I
		Cost unitised	0.36	£/smolt cap	$J=H/I$
	Additional capex (central)	10,668,268	£	$K=A \times (G-J)$	
	Additional capex (high)	21,440,267	£	$L=B \times (G-J)$	
	Additional capex (low)	1,327,955	£	$M=C \times (G-J)$	
	Salmon: recurrent				

Variable	amount	units	calc
Projected additional tank production (central)	9,358,130	smolts	A
Projected additional tank production (high)	18,807,252	smolts	B
Projected additional tank production (low)	1,164,873	smolts	C
Operational cost RAS	0.96	£/smolt	D
Operational cost flow-through	0.95	£/smolt	E
Average operational cost land based	0.96	£/smolt	F
Operational cost pens	0.89	£/smolt	G
Additional recurrent	613,553	£/year	H=Ax(F-G)
Additional recurrent	1,233,071	£/year	I=Bx(F-G)
Additional recurrent	76,373	£/year	J=Cx(F-G)

Trout: capital

Variable	amount	units	calc
Current total output	5,100	tonnes	A
Proportion pens	34	%	B
Current output from pens	1,734	tonnes	C=(AxB)
Projected total output 2022	7,500	tonnes	D
Projected output from pens Scen 0	2,550	tonnes	E=BxD
Additional tank capacity needed	816	tonnes/yr	F=E-C
Land based			
Capital cost new flow through	800,000	£	G
Capacity new flow through	500	tonnes/yr	H
Capital cost unitised	1,600	£/tonne cap	I=G/H
Pens			
Capital cost	538,000	£	J
Capacity	500	tonnes/yr	K
Cost unitised	1076	£/tonne cap	L=J/K
Additional capex	427,584	£	N=Fx(I-L)

Trout: recurrent

Variable	amount	units	calc
Additional tank capacity needed	816	tonnes/yr	A
Operational cost flow through	2.05	£/kg	B
Operational cost pen	1.99	£/kg	C
Differential	0.06	£/kg	D=B-C
Additional cost	48,960	£	E=AxD

Public Sector	None. No additional policy or enforcement activity foreseen.
Angling Sector	None
Environment	One off: Land take for additional tank based facilities Natural resource use and discharges to air, land and water arising from equipment manufacture and installation. Traffic, noise, etc related to construction of additional facilities Recurrent: Energy use for land based production

Scenario	3b																																																																																																																																												
High level change	Partial restriction of freshwater pen use																																																																																																																																												
Sub-option change	Reduction of pen capacity to 50% of 2011 levels, demand to be met through additional tank-based capacity																																																																																																																																												
Description	<p>This option involves both capital and recurrent expenditure for both salmon smolt and trout.</p> <p>Additional capital costs are derived from installation of the tank based capacity above that which would have occurred anyway, less the avoided cost of installing pen facilities which would have been installed. Additional recurrent costs are derived from the difference in cost of operating the additional tank facilities compared to their pen counterparts.</p>																																																																																																																																												
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(low)	652,984	£	HF=Cx(D-E)	Variable	amount	units	calc	Projected total output 2022	7,500	tonnes	A	Current output from pens	1,734	tonnes	B	Projected output from pens this Scen	867	tonnes	C=B/2	Projected output from pens Scen 0	2,550	tonnes	D = Scen 3a "E"	Projected additional tank production	1,683	tonnes	E=D-C	Tank cost unitised	1600	£/tonne cap	F = Scen 3a "I"	Projected avoided pen production	816	tonnes	G=D-B	Pen cost unitised	1,076	£/tonne cap	H= Scen3a "L"	Additional capex	1,814,784	£	I=(ExF)-GxH)	Variable	amount	units	calc	Additional tank capacity needed	1,683	tonnes/yr	A	Differential	0.06	£/kg	B = Scen 3a "D"	Additional cost	100,980	£	D = Ax(B-C)
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Public Sector	Moderate relating to policy introduction and enforcement.
Angling Sector	None
Environment	One off: Land take for additional tank based facilities Natural resource use and discharges to air, land and water arising from equipment manufacture and installation. Traffic, noise, etc related to construction of additional facilities Recurrent: Energy use for land based production

Scenario	3c		
High level change	Full restriction on freshwater pen use		
Sub-option change	Demand to be met through additional tank-based capacity		
Description	<p>This option involves both capital and recurrent expenditure for both salmon smolt and trout.</p> <p>As with Scenario 3b, additional capital costs are derived from installation of the tank based capacity above that which would have occurred anyway, which in this case is greater than in Scenario 3b, less the avoided cost of installing pen facilities which would have been installed. Additional recurrent costs are derived from the difference in cost of operating the additional tank facilities compared to their pen counterparts.</p>		
Costs			
Aquaculture industry	Salmon: capital		
	Variable	amount	units
	Projected additional tank production (central)	26,947,495	smolts
	Projected additional tank production (high)	36,396,616	smolts
	Projected additional tank production (low)	18,754,237	smolts
	Tank cost unitised	1.50	£/smolt cap
	Projected avoided pen production (central)	9,358,130	smolts
	Projected avoided pen production (high)	18,807,252	smolts
	Projected avoided pen production (low)	1,164,873	smolts
	Pen cost unitised	0.36	£/smolt cap
	Additional capex (central)	37,052,315	£
	Additional capex (high)	47,824,314	£
	Additional capex (low)	27,712,002	£
	Salmon: recurrent		
	Variable	amount	units
	Projected additional tank production (central)	26,947,495	smolts
	Projected additional tank production (high)	36,396,616	smolts
	Projected additional tank production (low)	18,754,237	smolts
	Average operational cost land based	0.96	£/smolt
	Operational cost pens	0.89	£/smolt
	Additional operational costs (central)	1,766,775	£
	Additional operational costs (high)	2,386,293	£
	Additional operational costs (low)	1,229,595	£
	Trout: capital		
	Variable	amount	units
	Projected total output 2022	7,500	tonnes
	Current output from pens	1,734	tonnes
Projected output from pens this Scen	0	tonnes	
Projected output from pens Scen 0	2,550	tonnes	
Projected additional tank production	2,550	tonnes	
Tank cost unitised	1600	£/tonne cap	
Projected avoided pen production	816	tonnes	
Pen cost unitised	1,076	£/tonne cap	
Additional capex	3,201,984	£	

	Trout: recurrent		
	Variable	amount	units
	Additional tank capacity needed	2,550	tonnes/yr
	Differential	0.06	£/kg
	Additional cost	153,000	£
Public Sector	Moderate relating to policy introduction and enforcement.		
Angling Sector	None		
Environment	<p>One off: Land take for additional tank based facilities Natural resource use and discharges to air, land and water arising from equipment manufacture and installation. Traffic, noise, etc related to construction of additional facilities</p> <p>Recurrent: Energy use for land based production</p>		

Extreme scenarios

Although very unlikely to occur, the changes in costs and benefits which could result through the total loss of one activity or another are worth considering, to illustrate the total economic contribution of different uses of freshwater bodies in isolation. As set out in the methodology, these are:

- a) if freshwater pens were totally removed and their capacity not replaced with land based facilities or imports
- b) if freshwater pen use continued, but so was so damaging that all angling in the affected catchments were to cease.

Permanent loss of smolt capacity

This extreme scenario assumes that all smolt production currently available from pens is prohibited and that land-based production can not be used to replace it, possibly through a lack of suitable sites or inability to source capital. Imports are not used as biosecurity risks are considered too high, or for other reasons. The loss that would result would be from the inability of the ongrowing industry to produce finished fish from smolt normally derived from pens. There would be an annual loss of profit for this volume of finished fish, calculated as follows:

Estimated production in 2011: 160,000 tonnes round
 Proportion of smolt from pens: 49%
 EBIT £0.52/kg round
 Loss = 160,000,000kg x 49% x £0.52 = **£40.8m**

Note that EBIT includes depreciation costs. Without depreciation operating profits would be some 10-50% higher than shown.

Permanent loss of angling potential

In the extreme, if negative impacts of pen rearing on wild salmonids were so severe as to make angling in the affected catchments unviable, angling spend would be lost in these areas.

Angling spend in those catchments which overlap with pen production is crudely estimated at £7m annually, with likely range £2m to £12m, as set out in Section 3.2.2. Even if the fishing in these catchments ceased to exist, all angler expenditure would not necessarily be lost. Radford (already cited) discusses substitution possibilities, based on a questionnaire which established anglers' choices in the event of total failure of certain categories of fishing in certain regions. If salmon and sea trout fishing ceased to exist in Highland, the species and area of interest for most pen sites, Radford estimates some 59% of expenditure would be lost, equating to about £4.2m in the catchments in question, based on the rough estimates above, with possible range, say, £1m to £8m.

These extreme values are based on current production levels for finished salmon, and the current array of pen sites which supply almost half of smolt needs. It is worth noting at this point that the average profit margin used to make these estimates is derived from six recent years for which information is reasonably available, (2006-2011). This period saw reasonably buoyant market prices and so profit margins. The cost to the industry of this scenario could be lower in periods of lower prices and this is discussed in more detail in the section on implications for the industry below.

It also bears repeating that the estimates of angler spend in the relevant catchments is extremely rough.

The main scenarios above consider the position in 2022, when demand for smolt would be higher. If the current ratio of pen:tank ratio held in future, as in Scenario 0, the base case, then some 9.4 million additional smolt would be derived from pens to meet the central projection. It is uncertain at present where these would be located, so it is not possible to predict angler expenditure which would overlap and potentially be lost with expanded pen production. Aquaculture production loss of profit in the central projection would be some £56m in 2022 on the same basis as above. Angling losses would also be somewhat higher than in the projection made on current pen distribution, it is impossible to say by how much, but it is reasonable to expect that the relative proportion of values of the two activities would not change greatly.

Summary of costs

The following tables set out and compare the capital and recurrent costs associated with the main Scenarios of change considered, i.e. 1,2 and 3a-c.

Table 16: Summary of estimated capital costs associated with Scenarios for change in freshwater pen production

Scenario	Description	Aquaculture (£m)							Other (relative score)				
		Salmon			Trout	Total			Public	Angling	Env	Total	
		Central	High	Low		Central	High	Low					
Capital	1	Improved containment	2.5	3.4	1.8	1.8	4.3	5.2	3.5	1	0	1	2
	2	No FW pens, no new land-based capacity, replace with imports	0	0	0	0	0	0	0	2	2	2	6
	3a	Hold pens at 2011 levels, expand using new land-based capacity	10.7	21.4	1.3	0.4	11.1	21.9	1.8	2	0	2	4
	3b	Reduce pens to half 2011 levels, replace and expand using new land-based capacity	23.9	34.6	14.5	1.8	25.7	36.4	16.3	2	0	3	5
	3c	Reduce pens to zero, replace and expand using new land-based capacity	37.1	47.8	27.7	3.2	40.3	51.0	30.9	2	0	3	5

Table 17: Summary of estimated recurrent costs associated with Scenarios for change in freshwater pen production

Scenario	Description	Aquaculture (£m / year)							Other (relative score)				
		Salmon			Trout	Total			Public	Angling	Env	Total	
		Central	High	Low		Central	High	Low					
Recurrent	1	Improved containment	0	0	0	0	0	0	0	1	0	1	2
	2	No FW pens, no new land-based capacity, replace with imports	1.8	2.4	1.2	0.7	2.4	3.0	1.9	3	2	2	7
	3a	Hold pens at 2011 levels, expand using new land-based capacity	0.6	1.2	0.1	0	0.7	1.3	0.1	0	0	2	2
	3b	Reduce pens to half 2011 levels, replace and expand using new land-based capacity	1.2	1.8	0.7	0.1	1.3	1.9	0.8	1	0	3	4
	3c	Reduce pens to zero, replace and expand using new land-based capacity	1.8	2.4	1.2	0.2	1.9	2.5	1.4	2	0	3	5

These costs can be combined to establish the overall economic cost of the different policy options for the different projects of aquaculture growth.

These are shown in Table 18 below and have been derived using the following assumptions:

- Capital expenditure will be spread evenly over a ten year transition period.
- Recurrent expenditure is phased in evenly in the same way as capital expenditure.
- The total expenditure required each year is subject to discounting at 3.5% (derived from HM Treasury Green Book guidelines)
- Non quantifiable relative costs scores to other sectors are summed

Table 18: Summary of estimated costs associated with Scenarios for change in freshwater pen production expressed as net present costs and relative cost scores

Scenario	Description	Aquaculture Industry Net Present Cost (£m)			Other (relative score)			
		Central	High	Low	Public	Angling	Env	Total
1	Improved containment	3.6	4.3	2.9	2	0	2	4
2	No FW pens, no new land-based capacity, replace with imports	10.5	13.2	8.2	5	4	4	13
3a	Hold pens at 2011 levels, expand using new land-based capacity	11.9	23.7	2.0	2	0	4	6
3b	Reduce pens to half 2011 levels, replace and expand using new land-based capacity	27.0	38.6	16.9	3	0	6	9
3c	Reduce pens to zero, replace and expand using new land-based capacity	41.8	53.5	31.7	4	0	6	10

3.2.3.5 Discussion of costs and benefits

Costs

Scenario 1, improved containment, shows a moderate level of capital expenditure (in relative terms) needed and no additional operational costs. It is the lowest cost solution compared to all other options apart from Scenario 3a, (restricting pens at 2011 levels combined with the low aquaculture growth projection). This is because growth is assumed to be very small and hardly any capital expenditure is required in land based capacity. Costs to the public sector, angling sector and environment are also relatively modest.

Scenario 2, prohibition of pens and importing smolts (and trout) to make up the shortfall shows moderate cost levels over 10 years. The main cost is recurrent at some £2m in the central smolt demand estimate, reflecting the higher cost of imported stock produced in tank farms. Note this cost estimate is approximate from discussion with industry and is indicative only. It is doubtful that there is sufficient capacity to meet Scottish needs from outside in the short term, either in smolt availability or well-boat capacity, though this could probably be overcome within ten years of a policy change in Scotland. The major aspect of this scenario is of course the risks to biosecurity and strategic supply chain capacity within Scotland. It also seems unlikely that in practice Scottish processors would buy in trout from outside Scotland to meet customer demand for the shortfall grown in pens.

Scenarios 3a-3c are the core considerations under the study and show costs under varying degrees of restriction of use of cages whereby their capacity is replaced with land-based

facilities. The most significant costs are in capital expenditure for additional land based facilities. Clearly this increases with the projected size of the industry and the degree of restriction on pen use. Restricting pens to the existing levels of some 18m smolts/year and 1,700 tonnes of trout per year (3a) would cost between £2m and £24m in current terms in order to maintain the varying projections of growth. This increases with greater removal of pen capacity (Scenario 3b). Removing freshwater pen production altogether would cost between £32m to £54m in current terms at the varying industry growth projections.

Costs to the other sectors are lowest overall under Scenario 1, improved containment. Scenario 2, prohibition of pens and import of smolt is considered to place a the highest cost burden on other sectors: public sector health monitoring is likely to be increased for imported stock, risks to angling and conservation value of wild stocks is considered higher through the additional biosecurity risk of this Scenario. For Scenario 3, other costs increase with increasing pen removal. This is through costs to the public sector of introducing additional legislation. Similarly environmental costs increase with increasing disposal of pen hardware, land take and construction of new land-based facilities, and additional energy use once they are running.

Benefits

As discussed earlier, the actual impacts of freshwater pens on populations of wild salmonids is more or less unknown. It is thus not appropriate to directly compare the costs which might be needed to protect these stocks, with benefits which might arise from such protection. Nevertheless for the sake of completeness the possible benefits which may arise from the Scenarios set out is discussed here.

Scenario 1, improved containment, is likely to bring about some minor benefits to the aquaculture industry as escapes would be reduced. However on an industry-wide basis, the value saved is likely to be well below the cost of upgrading cages. It may also bring about some cost savings in both the public, aquaculture and angling sectors in dealing with escape incidents, and in dealing with both legal challenges and general media involvement costs. There will be some moderate benefits to the aquaculture supply industry, as a result of equipment being upgraded earlier and to a greater extent that it would have been otherwise.

Scenario 2, import of smolt, could have some environmental benefits in terms of avoided costs of land take and construction of necessary land-based facilities in Scotland, however these kinds of impacts would be in effect externalised to Norway or other supply areas.

All of the variants of Scenario 3 involve investment in new land-based facilities. This would offer significant short-term opportunities for supply companies and construction contractors in Scotland, which increase in proportion to degree of restriction on cage use across the scenarios. Most of the capital expenditure identified would remain in Scotland, though some equipment is likely to be imported.

The total value of angler spend in catchments currently containing pen facilities is estimated very roughly at some £2-12m, as shown in the general discussion on benefits. In order to completely remove the potential risk to the economic value gained from angling, the aquaculture industry would have to either:

1. implement a programme of capital investment in, and operation of, new land based facilities estimated at some £32m at today's scale in current terms, per Scenario 3c, or
2. continue without the input of smolts from freshwater pens at a recurrent loss of £41m at today's scale, per the extreme scenario analysis shown earlier, or
3. Import smolt from areas of equivalent health status, at recurrent cost of some £1.9m but with significant biosecurity risk, per Scenario 2.

When considering the two activities as alternates, it is also worth noting:

1. Reduced activity in both smolt farming and on-growing of salmonids will cause significant relational losses in supplier, processor, transport, retail etc activities, which are additional to the primary impacts discussed. Angler spend includes estimates of upstream and downstream activity.
2. If either activity ceased, business suffering relational losses may be able to mitigate these to some extent, for example processors may be able to adapt to process other foodstuffs, while hotels might try to attract birdwatchers as opposed to anglers.

Other benefits associated with removal of risk to wild salmonids include non-use values, i.e the benefit enjoyed by the public of knowing that wild salmonid stocks were not becoming damaged. As mentioned in the methodology, such a value would have to be determined by a "Stated Preference" survey, which would be a significant undertaking. Trying to fill this knowledge gap is of doubtful merit, given the state of knowledge of the primary linkage between use of freshwater pens and health of wild stocks. Freshwater bodies without pen facilities may add visual value, although new land-based facilities in rural settings can reduce visual value locally.

3.2.4 Implications for aquaculture industry

Discussions so far have focussed on the economic aspects of the various scenarios for change. This section deals with the financial implications for industry of having to implement changes to production methods which could arise from the degrees of restriction of freshwater pen use described in the Scenarios, possibly brought in as a result of new information, or as a precaution. It also discusses implications in terms of locating and constructing sites, as well as possible impacts on employment.

3.2.4.1 Financial implications

The implications to the industry, and importantly its shareholders and investors, of any particular policy choice will be considered by the industry in financial terms. Salmon production is a global industry with international markets, and potential increased costs have to be considered.

The additional costs associated with a change in production method will be assessed in terms of industry profitability, both on a unit weight (per kg) basis and a whole industry basis.

Capital issues

If faced with the need to invest several million pounds in new smolt production facilities, the companies involved will either source this from financial markets or from within their own cash reserves, or a combination of the two. In either case there is a cost of using that capital. For the purposes of this study it is assumed that the cost of using internal funds is the same as borrowing externally. Discussions with commercial lenders in the UK for this study as well as industry sources suggest that interest rates on loans over 10-20 years for facilities such as smolt units would be in the range from 4% to 7.5% per annum. The lower value could apply to large multinationals with a strong balance sheet and borrowing record, while the higher rate might apply to less secure companies or start-ups. The majority of the companies involved are multi-national and so might expect to have access to funds at the lower end of the range. However it is worth bearing in mind that interest rates are at a historic low and that they are likely to rise in the outlook period for this study. One potential lender suggested that they would structure a loan with a re-pricing provision after five years, which would inevitably mean a higher rate of interest in the latter part of the loan. For these reasons 6% is taken as a safe estimate for the cost of capital.

The cost of finance has generally been simplistically estimated by assuming that the full capital cost has been funded by a term loan. In real terms this cost element will be different for every company, but the 6% debt capital cost used provides a consistent basis for subsequent analysis.

It is also worth bearing in mind that access to capital is not as simple as it once was. The banking crisis in 2008 has meant that the attitude of banks is more restrictive and this could place constraints on potential borrowers. Loans have to be secured, and the ability of some of the smaller companies to provide such security could be problematic. However it is impossible to model in these uncertainties.

Depreciation issues

Depreciation rates are often a matter of company policy as much as a reflection of the lifespan of the assets being depreciated. After discussions with industry the following rates are assumed:

- 20 years for salmon smolt RAS farms
- 15 salmon smolt flow-through farms
- 15 years for salmon smolt pen farms
- 15 years for trout flow-through farms
- 10 years for trout pen farms

The annual finance costs associated with changes under the Scenarios can thus be assessed by applying the above interest costs and depreciation rates to the capital and recurrent expenditure set out in Tables 16 and 17. These calculations assume capital cost of installation and operation of new facilities only. They do not include the early write-off of existing pen assets, as although their early disposal amounts to an economic cost, in financial terms they would have devalued anyway. This assessment is of the *additional* costs which would result from an enforced change in production method.

Table 19: Financial costs of Scenarios of change of smolt production techniques under central (no shading) and high (pink shading) projections of demand for salmon smolt

		Salmon								
Scenario	Description	Key Parameters								
		Annual production			220,000	tonnes round / year				
		Interest rates			6%	per annum				
		Capital required (£m)	Depreciation period (years)	Depreciation amount (£/ year)	Interest (£/year)	Total finance costs (£/year)	Finance costs (pence/kg round)	Recurrent cost (£m/year)	Recurrent cost (pence/kg round)	Total cost (pence/kg round)
1	Improved containment	2.5	15	167,673	150,906	318,579	0.14	0	0	0.14
2	No FW pens, no new cap, imports	0	0	0	0	0	0.00	1.8	0.80	0.80
3a	Hold pens at 2011 levels, new cap	10.7	17.5	609,615	640,096	1,249,711	0.57	0.6	0.28	0.85
3b	Reduce pens to half 2011 levels, new cap	23.9	17.5	1,363,445	1,431,618	2,795,063	1.27	1.2	0.54	1.81
3c	Reduce pens to zero, new cap	37.1	17.5	2,117,275	2,223,139	4,340,414	1.97	1.8	0.80	2.78

		Salmon								
Scenario	Description	Key Parameters								
		Annual production			260,000	tonnes round / year				
		Interest rates			6%	per annum				
		Capital required (£m)	Depreciation period (years)	Depreciation amount (£/ year)	Interest (£/year)	Total finance costs (£/year)	Finance costs (pence/kg round)	Recurrent cost (£m/year)	Recurrent cost (pence/kg round)	Total cost (pence/kg round)
1	Improved containment	3.4	15	226,468	203,821	430,289	0.17	0.0	0	0.17
2	No FW pens, no new cap, imports	0.0	0	0	0	0	0.00	2.4	0.92	0.92
3a	Hold pens at 2011 levels, new cap	21.4	17.5	1,225,158	1,286,416	2,511,574	0.97	1.2	0.47	1.44
3b	Reduce pens to half 2011 levels, new cap	34.6	17.5	1,978,988	2,077,937	4,056,925	1.56	1.8	0.70	2.26
3c	Reduce pens to zero, new cap	47.8	17.5	2,732,818	2,869,459	5,602,277	2.15	2.4	0.92	3.07

Table 19 (continued) : Financial costs of Scenarios of change of smolt production techniques under low (brown shading) projections of demand for salmon smolt, also rainbow trout

		Salmon								
Scenario	Description	Key Parameters								
		Annual production			tonnes round / year					
		Interest rates			6% per annum					
		Capital required (£m)	Depreciation period (years)	Depreciation amount (£/ year)	Interest (£/year)	Total finance costs (£/year)	Finance costs (pence/kg round)	Recurrent cost (£m/year)	Recurrent cost (pence/kg round)	Total cost (pence/kg round)
1	Improved containment	1.8	15	116,693	105,024	221,717	0.14	0.0	0	0.14
2	No FW pens, no new cap, imports	0.0	0	0	0	0	0.00	1.2	0.77	0.77
3a	Hold pens at 2011 levels, new cap	1.3	17.5	75,883	79,677	155,560	0.10	0.1	0.05	0.14
3b	Reduce pens to half 2011 levels, new cap	14.5	17.5	829,713	871,199	1,700,912	1.06	0.7	0.41	1.47
3c	Reduce pens to zero, new cap	27.7	17.5	1,583,543	1,662,720	3,246,263	2.03	1.2	0.77	2.80

		Trout								
Scenario	Description	Key Parameters								
		Annual production			7,500 tonnes round / year					
		Interest rates			6% per annum					
		Capital required (£m)	Depreciation period (years)	Depreciation amount (£/ year)	Interest (£/year)	Total finance costs (£/year)	Finance costs (pence/kg round)	Recurrent cost (£m/year)	Recurrent cost (pence/kg round)	Total cost (pence/kg round)
1	Improved containment	1.8	15	119,000	107,100	226,100	3.01	0.0	0	3.01
2	No FW pens, no new cap, imports	0.0	0	0	0	0	0.00	0.7	na	na
3a	Hold pens at 2011 levels, new cap	0.4	15	28,506	25,655	54,161	0.72	0.0	0.65	1.37
3b	Reduce pens to half 2011 levels, new cap	1.8	15	120,986	108,887	229,873	3.06	0.1	1.35	4.41
3c	Reduce pens to zero, new cap	3.2	15	213,466	192,119	405,585	5.41	0.2	2.04	7.45

The depreciation period for land based salmon smolt facilities is a simple average of those for RAS and flow through systems. For Scenario 2 applied to trout, it is not very meaningful to divide the economic cost of importing trout into Scotland around an existing industry as importing fish for re-sale would be very unlikely in practice.

It is impossible to be certain what the actual implications of this would be for individual companies, but some theoretical estimates could be made based on the information obtained for this study. The assumptions might be:

- That all the different current pen farms are at different stages in their straight-line depreciation of their fixed assets, depending upon when they were built or renewed
- It is theoretically possible that across the entire sector the farms are on average 50% through their depreciation cycle
- The average capital cost for a pen farm producing 2.5 million smolts per annum is £900,000, which after 50% depreciation means a current book value of £450,000
- However some current units will be older, lower specification facilities with lower original capital cost
- Book value across industry therefore assumed to be £350,000 per 2.5 million smolts per annum capacity

Using the central estimate, Scenario 1, improving containment, produces a cost burden of 0.14 pence / kg. As discussed in the analysis of this cost, this makes some very broad assumptions as to the extent to which the industry has already adopted these practices, and might do so in the outlook period without compulsion. If the proportion which would need to be upgraded through introduction of regulation were to double from one third to two-thirds, then this cost would also double, but it seems unlikely that this cost could go much higher than this, given existing progress in this area.

The estimate of 0.80 pence / kg in Scenario 2, import of smolts, also needs treating with caution. Views from the industry were not very clear on costs of imported smolt: it is a contentious issue with a presumption against import, so the question of relative costs is not under routine consideration.

The costs under Scenario 3, involving varying degrees of constraint in pen use, largely speak for themselves. The cost is very low under the low growth estimate and allowing current pen capacity to remain, (3a) as only a very minor amount of additional land-based capacity would need to be built. Costs escalate with increasing degrees of substitution of pens with land based

farms at all projections of industry size. It is worth noting that in all cases the main cost element is that related to capital expenditure, as opposed to operational costs. Operating cost differential estimates originate in Table 9, which bears out industry views that once running, operating costs of the two types of facility are not markedly different.

The costs to the trout sector are generally much higher. This is because the additional costs affect the whole grow-out phase of the fish, while additional costs associated with smolt are in effect shared by the ongrowing process and much diluted when considered on a whole industry basis. The cost burden of upgrading pens is also higher as a result of an estimate of a higher proportion (half) of the pen capacity is assumed to be subject of an upgrade under any new containment regulations.

Significance to industry

It goes without saying that the industry is very cost conscious and any additional cost is unwelcome. For comparison with the standard industry measure of profit, EBIT / kg gutted, the costs from the Tables above need to be converted to a gutted basis. The following table shows the increased costs as a proportion to the EBIT reported by the majority of the industry in recent years.

Table 20: Annualised costs of Scenarios 1 & 3a-c, (central projection), and as proportions of average industry EBIT

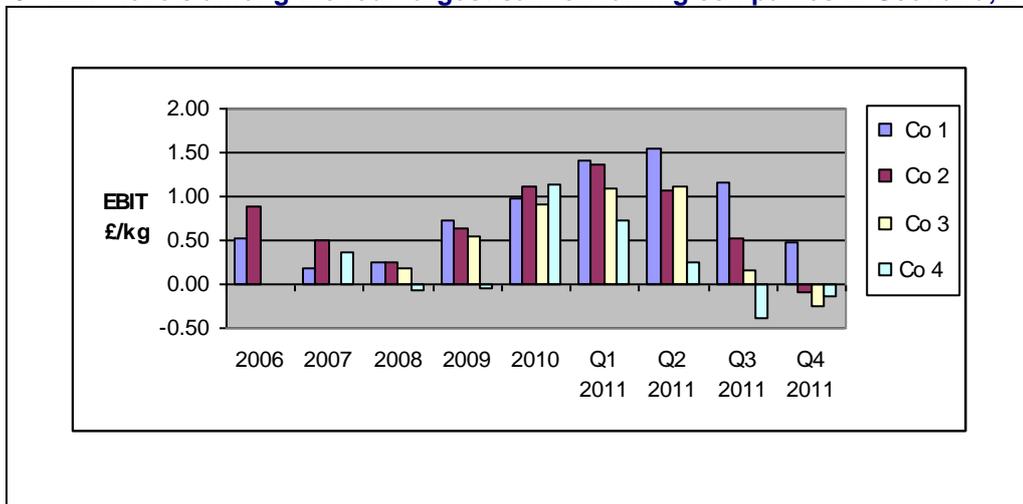
			Additional cost			
			Scen 1	Scen 3a	Scen 3b	Scen 3c
0.88	conversion	pence /kg round	0.14	0.85	1.81	2.78
		£ / kg gutted	0.002	0.010	0.021	0.032
Year	Period	Overall EBIT (£/kg gutted)	Proportion overall EBIT	Proportion overall EBIT	Proportion overall EBIT	Proportion overall EBIT
2011	Q4	0.12	1.4%	8.1%	17.3%	26.5%
2011	Q3	0.65	0.3%	1.5%	3.2%	4.9%
2011	Q2	1.21	0.1%	0.8%	1.7%	2.6%
2011	Q1	1.24	0.1%	0.8%	1.7%	2.5%
2011	Year	0.78	0.2%	1.2%	2.6%	4.0%
2010	Year	1.02	0.2%	0.9%	2.0%	3.1%
2009	Year	0.57	0.3%	1.7%	3.6%	5.5%
2008	Year	0.18	0.9%	5.3%	11.4%	17.4%
2007	Year	0.34	0.5%	2.8%	6.1%	9.3%
2006	Year	0.63	0.3%	1.5%	3.3%	5.0%

The table shows that for the most part the incremental cost will be quite small compared to overall profit in the period assessed, particularly in the case of Scenario 1. Costs would be relatively lower at the low rate of industry growth and high smolt yield assumption, and relatively higher at the high growth and low yield combination.

It is difficult to say at what point increased costs might become a serious concern or prohibitive. Any erosion will be unwelcome to industry, as these EBIT level profits are of course needed in the normal course of events to pay interest on loans and bonds, meet corporation tax obligations, contribute to central company overhead and shareholder dividends, as well as building reserves, funding investments in expansion or efficiency improvements. By way of illustration, any measure that has a cost of over 5% of EBIT is shaded orange. Unsurprisingly, relative costs increase with the degree of substitution of freshwater pens and at periods of lower EBIT.

The above analysis shows the average position for the four large companies assessed. It is worth noting that individual performances differ.

Figure 23: EBIT levels among the four largest salmon farming companies in Scotland, 2006-2011



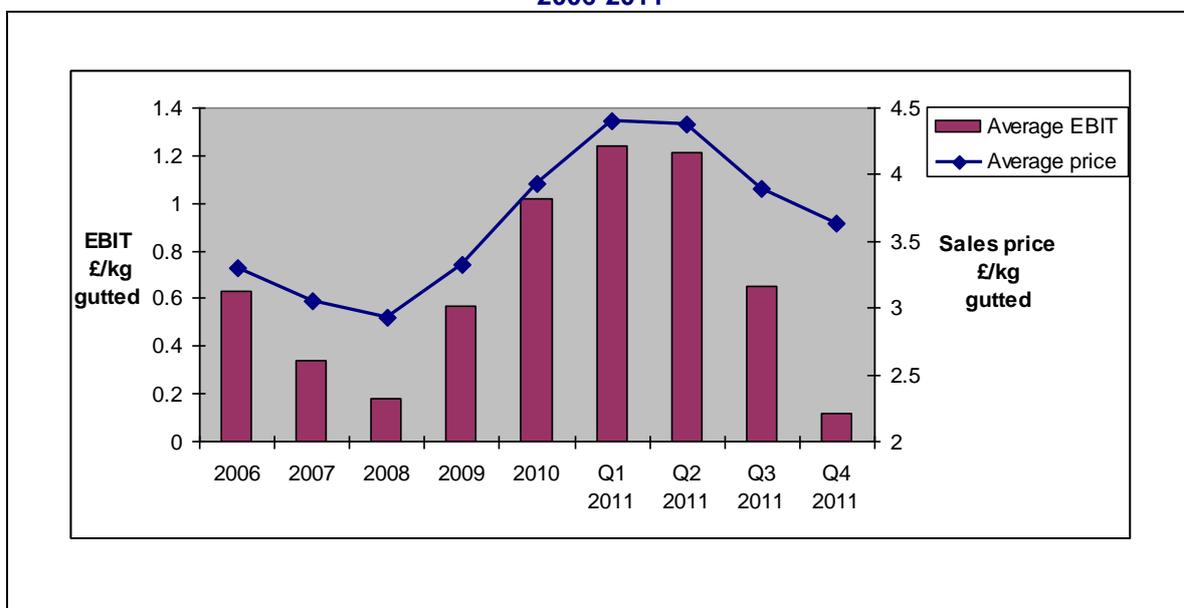
Inter-company variations are greater within the quarter years of 2011 than the whole years, which is not surprising, but even in complete years there can be a difference of £0.78/kg from highest to lowest at most (in 2009). Also different companies have different arrangements as regards existing smolt facilities, so they would all be affected by policy change differently.

The situation for trout production is fairly dire. Earlier this study assessed a margin before finance and tax costs of £0.10/kg for land based/oxygenation systems, £0.12/kg for the Danish model and £0.16/kg for pen rearing. Assuming an overall average industry profit of some £0.12/kg at present, additional costs associated with improved containment of £0.03/kg (Scenario 1) would erode some 25% of industry profits. Capping pen use at current levels (Scenario 3a) would only use around 10% of profits, as the amount of additional capacity needed would be very small, due to modest expectations of industry expansion. Increasing levels of cage substitution would mean profit erosion by one third in Scenario 3b and by over

one half in Scenario 3c, where pens are totally removed. These figures provide only general guidance as profit figures are not very clear to begin with. Also the industry is quite heterogeneous: different companies will be affected to different degrees. However with these indicative levels of impact on profitability, and knowledge of the industry, there has to be significant doubt whether the industry could raise funds to make the investment needed in land based farms, should regulation remove pen capacity.

Returning to salmon, it bears repetition that this analysis covers periods of relatively high selling price for salmon. EBIT is very closely correlated to market price. A weighted average harvest price has been established from the company reports using the same methods as described earlier for EBIT. They are shown on the same graph below.

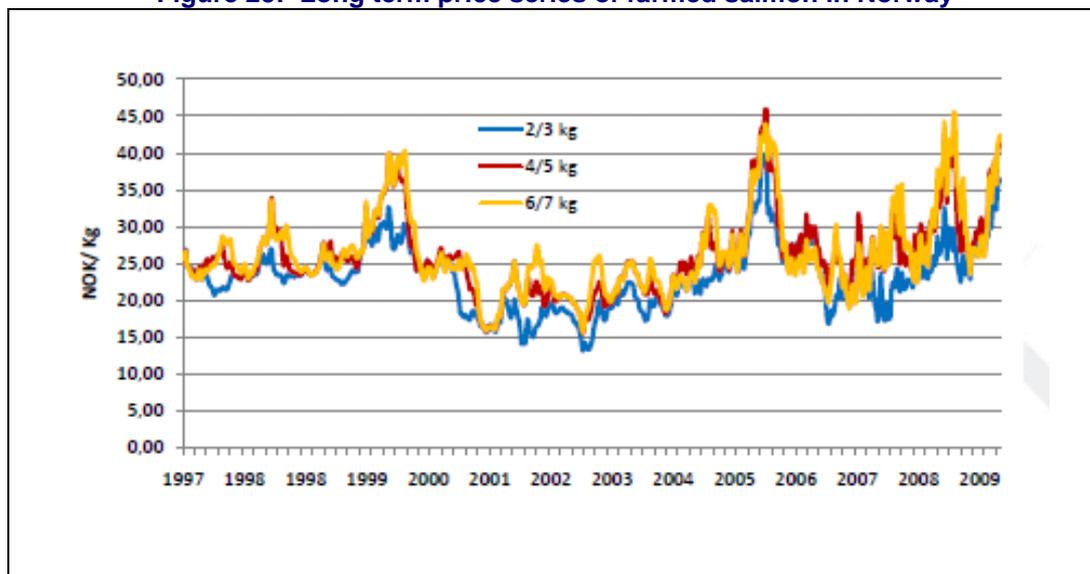
Figure 24: Weighted average EBIT and sales prices of the four largest salmon farming companies, 2006-2011



Clearly every change in price is copied by a change in EBIT in the same direction, whether by quarter of 2011 or by complete year. 2008 shows the lowest prices in the series and an average EBIT of £0.18/kg. At this level, additional cost burdens of £0.01 to £0.03 become very significant. The poorest performer in the group was making a loss of £0.08 / kg in that year.

A longer time series of prices is shown below. Although based on Norwegian salmon, the prices for Scottish product will have followed these trends closely.

Figure 25: Long term price series of farmed salmon in Norway



Source: Kontali Analyse within Marine Harvest Salmon Farming Industry Handbook, 2010

The graph illustrates the variable nature of market price trends and in particular shows the situation in some years before we have detailed data, i.e before 2006. The period 2001 to 2003 was very poor from a price perspective due to global over-production, with high volumes from Chile. Scottish output also peaked in 2003. Several operators in Scotland failed or were taken over in this period. Some limited information to compare profits with prices is available through the Marine Harvest website for this era, the only company to keep early reports available. It is derived from reports of the Scottish segment of Pan Fish ASA¹³¹. This has been corrected through average currency conversion as described before, also to gutted weights from round values. Reporting at the country level is also less detailed in the earlier reports. Harvest volumes for this single company are obviously quite low compared to the whole industry but they are felt large enough to be reasonably representative.

¹³¹ Pan Fish were at that time separate from Marine Harvest, but merged with Marine Harvest in 2006. The Pan Fish assets in Scotland, a range of sites around Loch Fyne, Mull, Skye and the Outer Hebrides, were then “spun off” from the merged grouping and became Lighthouse Caledonia.

Table 21: Harvest volume, sales price and EBIT for Pan Fish ASA operations in Scotland, selected years 2000-2005

Year	Harvest volume (tonnes gutted)	Price (£/kg gutted)	EBIT (£/kg gutted)
2005	13,692	2.40	0.11
2004	14,001	2.02	0.00
2003	19,538	1.95	-0.34
2002	nd	nd	nd
2001	nd	nd	nd
2000	9,328	2.72	0.43

This data gives an indication of industry profitability in ranging from small profit to moderate loss years 2003-2005 which experienced moderately low prices. Unfortunately no data is available for 2001 and 2002, but by comparing the graph in Figure 25 with the data above and from recollections at the time, margins would have been substantially negative. The benefits of the price spike in 2000 are clear.

Overall therefore there is a picture of very variable profitability in the salmon industry in Scotland which is largely driven by sales price and which responds to global supply and demand. As mentioned already, it is difficult to say what additional burden from not using freshwater pens could be considered as “affordable”. In the last 12 years for which we have data or an indication, there have been six years when EBIT margins have been small or negative (under £0.20/kg): 2001, 2002, 2003, 2004, 2005 and 2008. In these years additional costs of £0.03 / kg or so would have had a significant impact on business performance and would have made difficult situations worse, though it is impossible to say if such costs would have been the deciding factor between business success or failure. All businesses will be affected differently. In the remaining six years profit was higher and variable and extra costs are minor to moderate in relation to background variation and so could probably be absorbed more easily.

It is of course impossible to predict trends in finished salmon prices and profitability out to 2022 and so comment with any certainty on the effect of costs associated with restrictions on use of freshwater pens. However in broad terms, Chile is recovering from ISA problems and is thought to be more sustainably managed, and still has considerable physical potential for the long term. Norway seems to be set on a continuing path of moderate growth. The large operators in Scotland seem to have a desire to expand. The sharp price declines (in relative terms) seen in

the second half of 2011 are perhaps a warning sign that markets are still very sensitive to supply/demand balance changes. They have been severe enough to push three out of four large companies into losses in the final quarter. Prices in the spot market in Norway dropped below NOK 20 / kg gutted¹³², a situation not seen in a protracted way since the 2001-2004 era, when the industry was loss-making on a wide scale. However prices in early 2012 have recovered quite well to the NOK 25-30 /kg band. Forward contract prices for 2013 are in the band NOK 24 to 28 /kg according to Fishpool data, suggesting a price environment similar to 2005, 2007 and 2008 (from Figure 25), when profits in Scotland were low to moderate, range £0.11 to £0.34 / kg, (Tables 20 and 21). Data assessed for this study (not presented) suggest that average costs of production in Scotland have been on a rising trend in recent years, most probably through rising feed prices, also fuel, transport and other costs subject to inflation. The effects of ISA in Shetland and sea lice issues also probably contribute to the overall picture. These rises will have more than eroded the profit margins achieved in 2007-08 era. Some of these factors may turn out to be reversible and ISA was hopefully an isolated event. There could yet be opportunity to gain significant benefit of scale as seen in Chile and Norway. Feed prices may be driven down through greater marine ingredient substitution, (but this in turn could negatively affect price, and is by no means certain as the cost of substitute raw materials may increase in the future). However these potential gains are somewhat speculative and as a reasonably cautious view, outlook for profitability in Scotland appears no better than moderate. The ability to absorb these extra costs in the coming years is thus seen as mixed and could differ significantly between companies and between years.

Comparison to “regulatory” costs

As well as examining implications on profitability, the potential additional costs associated with changes in smolt production technique can be examined in context of existing “regulatory” costs to the salmon farming industry in Scotland. “Regulatory” costs can suffer from definitional problems and can include those involving setting up and operating a fish farm, as opposed to wider costs which are still “regulatory” and can differ between countries, for example employment regulations, generalised environmental regulations, duties, tax regimes etc. Also some regulatory costs are indirect and are not easy to measure. Many regulatory factors influence size of ongrowing sites for example, and these can influence cost of production through scale factors. Costs associated with restrictions on smolt production technique are perhaps one such indirect cost, but have nevertheless been quantified in the current study.

¹³² <http://fishpool.eu/index.aspx>

An earlier study examined “regulatory” costs to salmon farming companies in Scotland in 2007¹³³. The aim of the study was to compare “regulatory” costs in Scotland with those of the main competitor countries of Norway and Chile. The costs which were quantified encompassed costs of compliance with planning and buildings regulations, staff training costs, also environmental and operational costs. The study found that these “regulatory” costs in Scotland averaged some 3.7 pence / kg on a round fish basis, with some differences according to scale of operation. This equates to 4.3 pence / kg gutted using the conversion factor discussed earlier. Of this 1.7 pence / kg gutted was from Crown Estate rental cost, some 40% of the total. This is a slight overestimate as farms on the main island groups enjoy a 10% discount in rent. Note also that rents will increase to 2.25 pence /kg gutted from 2013¹³⁴.

Costs associated with the Scenarios of change in production practice are shown below as a proportion of 2007 regulatory costs.

	Cost / kg gutted	Proportion regulatory costs
Scen 1 Improved containment	0.2 pence	4%
Scen 3a Restrict pens to 2011 levels	1.0 pence	23%
Scen 3b Reduce pens to 50% 2011 levels	2.1 pence	48%
Scen 3c Phase out pens entirely	3.2 pence	74%

On this basis, costs associated with improved containment will hardly add to the regulatory burden. By contrast, those relating to restriction in pen use will add significantly to this kind of cost, adding roughly one quarter if pen use is restricted to current levels, or adding three-quarters if pen use is phased out. Put another way, they will range from roughly 0.5 to 1.9 times the cost of current Crown Estate rents, or 0.4 to 1.4 times rents after 2013.

It is worth noting that the regulatory costs assessed in 2007 will have increased somewhat with inflation in the interim and will slightly dilute the relative cost of new regulation shown above. It is also worth remembering that these costs are approximate and will vary from company to company according to their cost of capital and other factors.

New Capital

¹³³ Detailed Investigation of Range of Issues to Assess the Cost Structure and Competitiveness of the Salmon Growing Industry in Scotland, Report to Scottish Government CR / 2007 / 24, Poseidon Aquatic Resource Management, 2008

¹³⁴ <http://www.thecrownestate.co.uk/news-media/news/2011/aquaculture-rent-review-includes-funding-boost/>

The salmon industry is multi-national and Scottish-based subsidiaries compete with those in other countries for investment. A requirement to find an additional £11m to 37m, depending on severity of pen prohibition, for Scotland might negatively impact on decision-making in international boardrooms. These figures are capital requirements for additional land based investment to achieve the central projection of 220,000 tonnes in 2022. More new capital would be needed to fulfil the higher growth assumptions, and less for slow/static growth. It is perhaps this latter combination, of having to find between £1m and £28m to invest with almost no growth, which the industry may find the least appealing. Instead of spending in the sums identified, the Scottish industry could simply decide to import salmon smolts, a strategy that has thus far been seen as undesirable.

In respect of trout, at least for the smaller independent companies, it seems unlikely that the industry will be able to raise the new capital which would be required for new land-based farms. The industry would probably therefore decline significantly.

3.2.4.2 Strategic change in production

Earlier in the report, the potential for a trend to hold fish in freshwater pens to a larger size was discussed. This provides an opportunity for a shorter seawater phase and so helps to combat sea-lice. The industry's suggestion that this approach could lead to production cost savings of 15% is significant and could help to reverse recent production cost rises. Loss of the opportunity to rear fish in freshwater pens would remove this possible advantage.

3.2.4.3 Site Availability

There are some concerns about site availability in general. A successful and satisfactory location for a new, modern, large scale smolt recirculation unit has certain key requirements:

- It needs to have access to a suitable flowing freshwater source, with no risk of industrial or other pollution
- It needs to have an adequate area of land, which should be relatively flat and easy to develop
- It has to be relatively close to existing road links
- It has to be close to a source of high-tension electricity – for which the network in the more rural parts of West Scotland is somewhat limited
- It has to be close enough to a community of sufficient size to offer housing for staff, and in the case of staff with families, issues such as schools and medical services would be important
- The landowner has to grant a lease for the area required

-
- Planning permission has to be obtained, as does a CAR licence from SEPA

Industry experts are concerned about whether there are actually sufficient completely suitable locations for such units in Scotland. Planning permission might be especially difficult, because the sizes of buildings required for a modern large scale recirculation unit are unlikely to be in keeping with local authority development plans in rural areas.

In the context of the central projection of expansion, Scenario 0 in Table 15 shows that land-based capacity of just under 10 million smolts will be needed between now and 2022 in the normal course of events. This would require the equivalent to two large modern smolt units of the 5 million capacity used for modelling in this study.

Total requirements for new sites on this basis where pen use is restricted are as follows (to the nearest whole number) :

Pen use restriction	Base	Policy	Total new sites
Capped at 2011 levels	2	2	4
Reduced to 50% 2011 levels	2	4	6
Totally removed	2	5	7

At the low demand projection, the base need would be 0.25 of a site, with total needs under the restrictions of 0.5, 2 and 4 new sites respectively.

At the high demand projection, the base need would be 4 new sites, with total requirements 8, 9 and 11 new sites respectively.

The extent to which suitable sites are available is very unclear at present. It is recommended that if there is to be consideration of a policy change regarding pen use, then the issue of potential sites for land based production is researched to fill this knowledge gap. Implementing policy without this information might in practice be obliging industry to make changes that are not possible in practical terms, and so cause economic damage through industry contraction.

The above estimates for site requirements work on the assumption that cage and land based smolt production capacity will expand in the same proportion as employed in the last ten years or so, i.e. roughly equal. On this simplistic basis, additional freshwater pen capacity will be needed under normal circumstances. Under the central demand projection, Scenario 0 suggests that some 9.3m additional smolts would be produced in freshwater pens by 2022.

Again using the same capacity as in the models, this would require four new modern sites each with an annual capacity of 2.5 million smolts. At the high demand projection, eight sites would be needed, and with low demand, 0.5 of a site.

The situation is obviously more complex. Hatcheries and fry units are needed to produce early stages in either production system and industry appears to be looking at new ways to integrate both types of production more efficiently. The possibility of growing smolts to a larger size will need more cage and biomass capacity for a given output of smolt. The choice is thus not a simplistic either / or approach. There will have to be consideration as to where additional capacity would be located if pen use is to be allowed to expand.

3.2.4.4 Employment considerations

Changes in production technique will lead through to changes in employment patterns. The estimate of employment needed to produce smolt based on the central projection of demand (55 million fish) for 2022 has been calculated as follows:

1. The productivity of labour in both systems in 2022 is assumed to be the same as the peak level in the last 10 years according to the MSS survey, but corrected so that one part time post equated to 0.5 full time equivalent (FTE).
2. The relative productivity between pens and land based systems is assumed to be the same as the relative labour costs shown in the costs models at Table 9. The land based value is taken as the average of RAS and flow-through labour costs.
3. The productivity disaggregated in this way is then applied to the numbers of smolts assumed to be produced by each method under the various scenarios.

The following table shows estimates of labour engaged in producing smolt and changes from the base Scenario.

Table 22: Estimated employment in smolt production in 2022 based on the central projection of demand for smolt, and estimated changes from different Scenarios.

Scenario	Description	Central projection 2022 (FTE's)			Change from Scenario 0 (FTE's)		
		Pens	Tanks	Total	Pens	Tanks	Total
0	Maintain pen:tank ratio	207	116	323	0	0	0
1	Improved containment	207	116	323	0	0	0
2a	No FW pens, no new cap, no imports	0	116	116	-207	0	-207
2b	No FW pens, no new cap, imports	0	116	116	-207	0	-207
3a	Hold pens at 2011 levels, new cap	135	155	290	-72	39	-33
3b	Reduce pens to half 2011 levels, new cap	68	191	259	-140	75	-64
3c	Reduce pens to zero, new cap	0	228	228	-207	112	-96

Employment in pen-based activity is higher than for tanks as labour efficiencies are lower in pen farms. Loss of pen activity in scenario 2 would therefore lead to a loss of some 200 FTE's. It is

also worth noting that there would be a significant loss of labour in seawater farming under the extreme scenario, where pen use is phased out and no replacement smolt production capacity is built or imports occur. Again assuming peak productivity from the MSS surveys, the labour employed at sea in 2022 to produce 220,000 tonnes will be some 1400 FTE's. Loss of 49% of capacity to produce smolt is assumed to cause a pro-rata reduction in labour, i.e. some 700 FTE's. This situation is somewhat academic as mentioned earlier, but is included for completeness.

Scenario 3 which applies varying restriction on pen use shows a shedding of labour in pen activities which is faster than labour increases in the replacement tank capacity, purely as a function of relative productivity. Labour numbers therefore drop as substitution increases. This model has not been run for the high and low projections for smolt demand. Obviously the higher demand will have higher labour needs and the lower demand model will have labour needs which are not much different from today. The same overall patterns will occur, with total cage labour loss in Scenario 2 and increasing net loss of labour with progressive substitution of tank based farms in Scenario 3.

The changes to labour costs have already been considered under alterations to cost of production. The labour use in 2010 was some 260 FTE's according to the MSS survey and modelling here suggests that some 320 FTE's will be needed to produce 55 million smolts in 2022, an increase of around 60. The net loss under Scenario 3c, the most severe, is some 96 FTE's and so labour numbers would fall to some 40 below the today's level if this policy was followed. Loss of labour under Scenario 2 would be more significant and depress numbers to some 140 or so below 2010 levels, i.e. the smolt labour force would be less than 50% of what it is currently.

As well as dealing with labour reduction through redundancies or natural wastage, there would be some residual issues for the industry regarding labour management. Less or no use of pens would mean moving labour from those sites and redeploying them at land based tank units. There is no certainty where this might be located and so these changes could involve significant re-location of personnel, which has costs to companies in financial terms and social costs to the individuals concerned, depending on circumstances. Industry would also need to engage in a significant amount of re-training, as production methods and skills needed are different between pen and tank-based systems.

4 Conclusions

Several key points have emerged from this study:

- The theoretical potential for negative impacts on wild salmonids as a result of the presence of freshwater aquaculture is clear where they are physically coincident
- At a national level the large majority of the wild salmon and trout populations in Scotland are not physically coincident with freshwater pen sites
- The actual impacts on wild salmonid populations in Scotland from freshwater pen rearing of salmon and rainbow trout remain more or less unknown. Only a few studies, many quite old, have been carried out to date which address the question of actual interactions and impacts. These studies are restricted in the scope of their investigation on the question of impacts and are confined to investigations of single lochs
- There is no evidence of broad-scale impacts in terms of catch statistics and other obvious measures of wild salmonid stock/population health
- Freshwater pen aquaculture is only one of the several factors that might affect the health of wild salmonid stocks/populations
- Pen-farmed salmonids still escape, and therefore still offer a potential threat to wild salmonids – no matter how remote or how equivocal in terms of current scientific evidence
- There is evidence that some pen escapes have not been reported through the Marine Scotland mandatory self-declaration system
- The benefits of a change of policy now are by no means clear, taking into account current scientific knowledge
- The impact of financial costs on salmon production arising from restrictions in freshwater pen use to rear smolts range from minor to moderate in years of strong market prices and good profitability, to major or possibly prohibitive in years with poor prices and profitability. The impact on trout production is considered major or prohibitive throughout.

On the basis of the above key points and the other wide range of evidence gathered for this study, the authors conclude that:

- There does not appear to be a robust evidential case for suggesting radical and potentially expensive policy change regarding freshwater pen use.
- The least radical option in terms of costs would be mandatory improvement of containment. This would reduce but not eliminate most of the potential risks to wild stocks in those catchments in which pens are located. Tightening of the regulatory regime in this regard would not be unreasonable given the current state of knowledge regarding impacts. It would

be logical for improvements in freshwater containment to go hand-in-hand with that for marine pens.

- Associated with improvements in containment, it is recommended that
 - A formalised regime of sampling for escaped fish in catchments containing pens should be established, independent of the industry self-reporting system that currently exists. Details of such a scheme require further consideration: scope of sampling, how much it would cost, and how it would be funded
 - Scientific Assessment of Impacts of Escapes. There should be a robust scientific assessment, probably on a specific catchment/project basis, of the *actual* impacts of farmed escapes, if and when they occur.

Appendix 1

STUDY BRIEF

OBJECTIVES

In order to meet the aims of this study the following objectives should be considered:

- Provide an assessment of the evidence on what is known about the impact and impact pathways of the production of salmon smolts and rainbow trout in freshwater lochs on wild salmonids, both from international experience and within Scotland;
- Identify and provide a synthesis of information on the farm sites in Scotland including:
 - A geographical representation.
 - Information on the river systems¹³⁵ where farm sites are located.
 - Highlight sites where there is a SAC designation for Atlantic salmon or freshwater pearl mussel.
 - Detail farm output, structure and working practices.
 - What is known about the current and historical restocking practices on those same river systems including restocking with ex farm reared sources.
 - What is the current knowledge on the frequency, cause and timing of drip escapes from these facilities and any documented impact on wild salmonids.
 - What is known about hybridisation in the systems and how much is due to (a) smolt production and (b) restocking practices?
- Using the synthesis of information on farmed sites and knowledge of salmonid population health in river systems where there are no farm sites, is there any evidence to demonstrate that there is a lesser impact on wild stocks within river systems where there are no open pens compared to those with open pens?
- Provide information on what work is being carried out in this field both in the UK and globally and identify gaps in our understanding. Provide an assessment of what future research would need to be carried out to fill these gaps with reference to possible methodologies to address specific problems.
- What are the options for mitigating against any identified impacts and impact pathways and their applicability in Scotland.
- Specifically carry out an investigation of the economic costs and benefits to Scotland, of replacing open pen production, either completely or on all future developments with closed containment systems. Including:
 - the cost implications for the industry, in terms of alternative production methods and supply of smolts.
 - consideration of the benefits or avoided costs, for example in terms of enhanced ecosystem services.

¹³⁵ The term river system is inclusive of freshwater lochs and other bodies of standing freshwater

-
- an operational timeframe for a phased move away from open pen production to closed/land-based production.
 - Identify whether there is any evidence to support the belief that smolts raised via the closed containment system exhibit lower vigour when transplanted to marine site when compared with open pen produced smolts.

METHODS

It is anticipated that this study will involve a combination of desk based research including a detailed literature review drawing information from all appropriate sources and consultation with experts and stakeholders including scientists, wild fish interests and industry representatives both in Scotland and elsewhere.

- Specifically support will be required from Marine Scotland Science to identify locations of smolt production facilities and status of salmonid populations on relevant river systems.
- Some travel throughout Scotland will be necessary to meet with stakeholders this should be undertaken in a sustainable way making use of audio and video conferencing facilities where appropriate.

Appendix 2

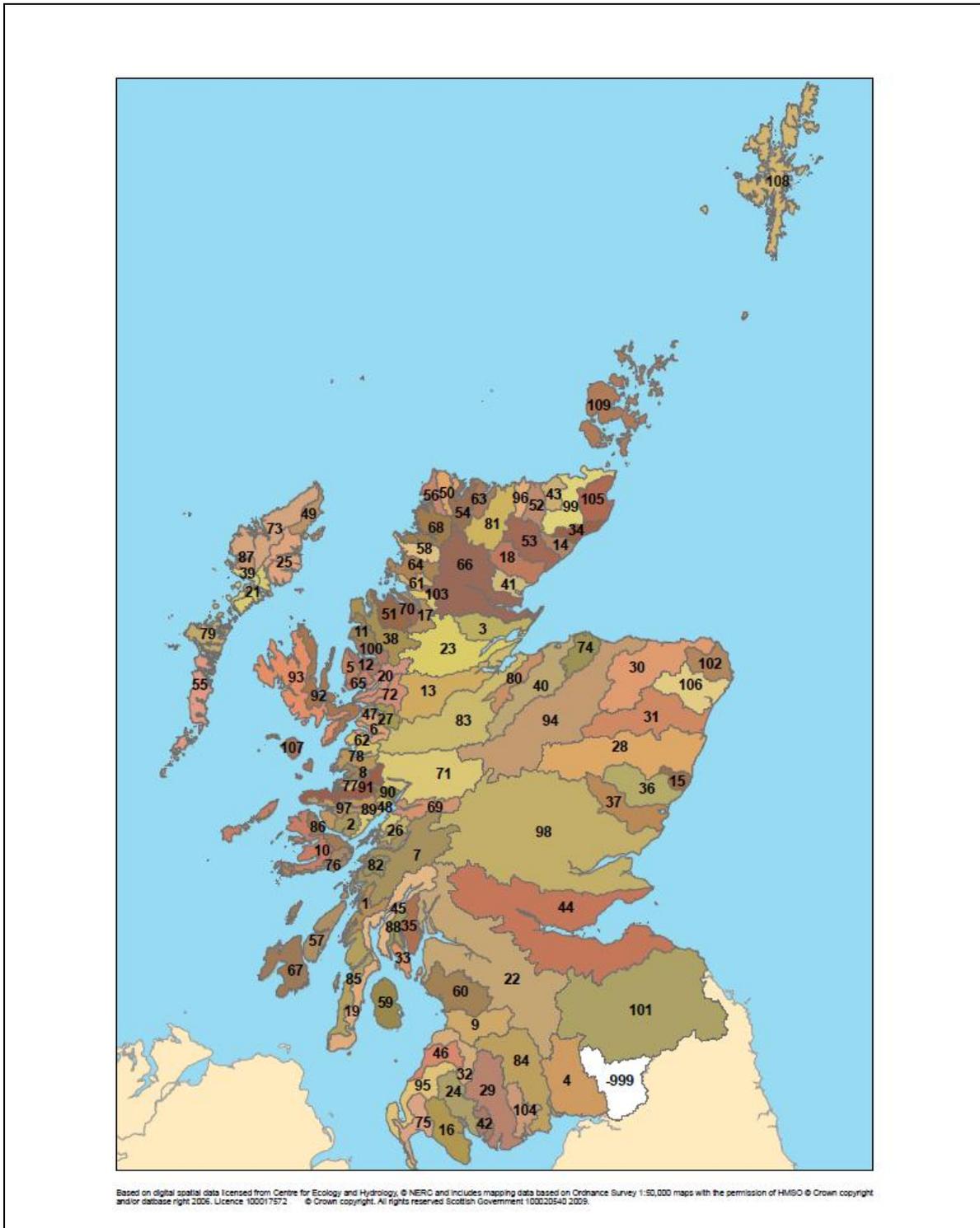
LIST OF CONSULTEES

The following people were consulted during the course of this study, either by telephone, email or face-to-face, (* indicates also on project Steering Group). Their time, input and assistance is appreciated by the authors.

Charles Allen - Marine Scotland Science
Alan Anderson – Loch Duart
Steve Bracken – Marine Harvest (Scotland) Ltd
Grant Cumming – Hjaltland
Stuart Cannon – Kames Fish Farming
David Catto - Migdale Smolt Ltd
Mark Coulson - Rivers and Fisheries Trust Scotland
Hugh Currie – Landcatch
Mark Davies – Torhouse Trout
Rebecca Dean Migdale Smolts Ltd
Paul Haddon – Marine Scotland*
Ben Hadfield – Marine Harvest (Scotland) Ltd
Paul Irving – Lakeland Smolts
Darren Jordan – Torhouse Trout
Alan Kettle-White - Argyll Fisheries Trust
Eivind Lygren - Kruger Kaldnes
Sasha Maguire – Marine Scotland*
David McEwan – Marine Harvest (Scotland) Ltd
Duncan McLeod – Scottish Salmon Company
Iain McMyn - Kyle of Sutherland District Fishery Board
Stuart Middlemas - Marine Scotland Science*
Hugh Murray – Migdale Smolts
Gideon Pringle – Dawnfresh
John Rae – Scottish Sea Farms
Hugh Richards – Wester Ross Salmon
Peter Richardson – Kames Fish Farming
Derek Robertson – Howietoun
Gordon Smith - Marine Scotland Science
Ronald Smith - Marine Scotland Science*
Damien Steel – Hebridean Smolts
Dave Tierney – Yorkshire Salmon
Ivar Warrer-Hansen – InterAqua
John Webster - Scottish Salmon Producers Organisation
Keith Williams - Ness and Beaully Fisheries Trust
Mark Woods – Loch Duart
Manson Wright - Marine Scotland Science*

Appendix 3

FISHERIES DISTRICTS WITHIN SCOTLAND



Source: MSS



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