Report of a one-day workshop organised by the
NASCO/North Atlantic salmon farming industry Liaison Group

Wild and Farmed Salmon -Working Together

In co-operation with the European Aquaculture Society (EAS)

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Background to the Liaison Group and the Workshop

The North Atlantic Salmon Conservation Organization (NASCO) and North Atlantic salmon farming industry Liaison Group is an advisory group established to provide an international forum for liaison between the salmon farming industry and the relevant authorities responsible for the wild Atlantic salmon stocks and aquaculture on issues of mutual interest. The Liaison Group includes representatives of NASCO, the International Salmon Farmers' Association (ISFA) and the salmon farming industry in Russia (Gigante Pechenga) and Scotland (Scottish Quality Salmon).

Through this Liaison Group, internationally endorsed Guidelines for Containment of Farm Salmon have been developed with the intention of preventing escapes in both the freshwater and marine environments. The Liaison Group receives reports from each country on the levels and causes of escapes, and the measures being taken to minimise them. Further information on the work of the Liaison Group is available on the NASCO website, www.nasco.int.

In 2003, the Liaison Group reviewed the extent of existing cooperative ventures between wild and farmed salmon interests, and identified future areas for cooperative work. This process was known as the SALCOOP project and the report is available on the NASCO website. In order to take forward the recommendations in this report, the Liaison Group decided to hold a one-day Workshop focusing on opportunities for cooperation between wild and farmed salmon interests, with the following themes:

- area management initiatives (local cooperation between wild and farmed salmon interests);
- pros and cons of using sterile salmon in farming and the possible opportunities for cooperative trials;
- restoration programmes (cooperative ventures in restoring wild Atlantic salmon).

The Steering Group for the Workshop comprised Drs Peter Hutchinson and Ken Whelan, Assistant Secretary and President of NASCO respectively, James Ryan, President of ISFA, and Kjell Maroni of FHL Aquaculture. The Workshop was held in Trondheim, Norway, on 9 August 2005 in cooperation with the European Aquaculture Society (EAS) and in conjunction with the Aquaculture Europe 2005 Conference and immediately preceding the AquaNor Fish Farming Exhibition. The Workshop was attended by 84 participants from 13 countries. It highlighted a number of important areas where there is existing cooperation between wild and farmed salmon interests and areas where cooperation might be developed or enhanced in future. The information presented at the Workshop and the valuable discussions that followed will be reviewed by the Liaison Group which will decide on appropriate actions. This report contains the presentations for the Workshop, together with the summary by each Session Chairman.

Introductory remarks

James Ryan, President, International Salmon Farmers' Association

Ladies and Gentlemen: Good morning and welcome to this NASCO Liaison Group Workshop entitled "Wild and Farmed Salmon – Working Together".

I am James Ryan and I am President of the International Salmon Farmers' Association (ISFA). Together with Scottish Quality Salmon and the Russian company, Gigante Pechenga, we represent the farming component of the Liaison Group. The wild fish interests are represented by the North Atlantic Salmon Conservation Organization (NASCO), an inter-governmental Commission based in Edinburgh. We have that Organization's President, Ken Whelan, and Secretary, Malcolm Windsor, with us today. Malcolm will be chairing one of the sessions and Ken will sum up and close the meeting this evening.

Following initial meetings in 1998, the Liaison Group was established in 2000 to provide a forum for cooperation on areas of mutual interest between the wild and farmed salmon sectors and to make recommendations for action. After a difficult birth, trust and understanding of each other's positions has developed and we have come to realise that there is a lot more that joins us than separates us. We are, after all, working with the same species and sharing the same environment. And we should remember that 30-40 years ago we were one and the same industry. Around that time the farming of salmon arose from the development of breeding techniques used by wild fishery managers.

Progress is being made on cooperative initiatives, most notably the development by the Liaison Group of its Guidelines for Containment of Farm Salmon – a document aimed at minimising fish escapes from salmon farms. In 2003 the Liaison Group carried out a study into cooperative projects between wild and farmed salmon interests and to identify potential areas for future cooperation. We called this the SALCOOP project and it identified a variety of cooperative ventures. For example, the industry has considerable expertise in hatchery techniques and on-growing that could benefit wild fish rebuilding programmes. Such cooperative ventures have been undertaken in the US, Canada and Scotland, for example. I believe this 'Working Together' approach will help both in the rejuvenation of wild stocks and in the ongoing sustainable development of the farming industry.

The SALCOOP project report included eighteen recommendations, too many to consider in detail during the annual meetings of the Liaison Group, so it was agreed that this Workshop be convened to focus on some specific issues. The focus today is on three issues:

- area management initiatives;
- the pros and cons of using sterile salmon in farming and the opportunities for cooperative trials;
- and restoration programmes for wild salmon.

These topics will be given a thorough airing in the three sessions that will follow. We have some excellent speakers and we have allocated an hour at the end of each session for discussion. We hope there will be an open and frank exchange of views and we welcome all contributions from the floor. We are allowing so much time for discussion because we would like to see recommendations arising from this meeting which result in new initiatives under all three headings.

Now before I hand over to our first session Chairman, I want to acknowledge with thanks the vital support of our sponsors without whom we simply would not be here today. On behalf of the Liaison Group I would like to thank them all most sincerely.

I would particularly like to thank all speakers for agreeing to contribute to the Workshop, our session Chairmen and the European Aquaculture Society, particularly Alistair Lane and Hilde Joncheere, who have made all the local arrangements. On my own behalf I would also like to thank both Peter

Hutchinson of NASCO and Kjell Maroni of FHL who did the bulk of the behind-the-scenes work in facilitating this event. The other members of the Steering Group are Ken Whelan and myself, so it is two for wild and two for farmed salmon interests. Assuming the success of this meeting, the work of this Steering Group will be a good example of the potential for cooperation between the two sectors.

Now without any further delay, I will hand over to our Chairman for the first session on Area Management Initiatives. Gordon Brown is an Assistant Secretary in the Scottish Executive's Environment and Rural Affairs Department. Gordon is the Head of the Freshwater Fisheries and Aquaculture Division with responsibilities for the wild Atlantic salmon, aquaculture policy and development and fish health and welfare. Another living example of wild and farmed salmon interests working together! Gordon, over to you.

Area Management Initiatives

Lessons learned in area management in New Brunswick and Maine

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Introduction

This paper refers to area management initiatives in both Atlantic Canada and Maine but its main focus is on New Brunswick, Canada, the hub of the east coast aquaculture industry. Representatives from the Maine Aquaculture Association, the National Marine Fisheries Service and the Maine Department of Marine Resources will offer separate presentations on the situation in Maine.

Shared environment

Both wild and farmed salmon require a pristine environment for their survival. They depend on their natural habitat, protection from disease, protection from predators and they must live in harmony with other marine users in order to survive.

Salmon farmers in Eastern Canada and Maine invest heavily in the site selection process in order to situate their farms in the best location from an environmental and fish health management point of view. The Canadian Environmental Assessment Act (CEAA) requires each applicant to demonstrate that the farm site will maintain a high environmental rating, that it will not interfere with other users of the marine resource, that it will not impede navigation and that it will not have a negative impact on fish habitat. Once these requirements are satisfied and a site is approved, the farmer is required by provincial and federal regulation to comply with strict fish health and environmental management regulations.

Common interests

In addition to sharing a common environment, wild and farmed salmon share a number of common interests such as fish health, genetics, and science and research.

Fish health

Farmed fish are certified disease-free when they are transferred from freshwater hatcheries to sea cages. Once they are placed in the open marine environment, they are vulnerable to the same diseases and parasites that challenge wild fish. Just like land-based farmers, salmon farmers must protect their animals from disease and when disease occurs they must act quickly to treat infections, eliminate parasites and, when necessary, cull fish to prevent the spread of disease to neighboring cages and farms or back to the wild stocks.

A significant body of science together with twenty years of management experience has led to the development of important management programs, codes of practice, government policies and regulations. These combined measures have led to measurable success in the management of parasites such as sea lice and diseases such as Infectious Salmon Anemia (ISA).

The ISA Control Program in New Brunswick requires mandatory veterinary involvement on each farm, a program of frequent testing, early detection, and eradication of fish (depopulation) in cages where ISA is detected, bio-security at all stages of the salmon's development, designated wharf usage, and controlled vessel traffic. The cost to the industry of implementing these measures has been significant but they have led to the reduction of the incidence of ISA as illustrated.

Since 1998, Infectious Salmon Anemia (ISA) has directly affected between 60% to 70% of the farms in the industry. Close to 8,500,000 salmon have been depopulated in an effort to control the spread of ISA within the industry. Over the past 5 years, ISA has infected a high of 17 farms (2002 year

Number of Farms Infected with ISA by Year Class in New Brunswick, Canada
updated August 2005

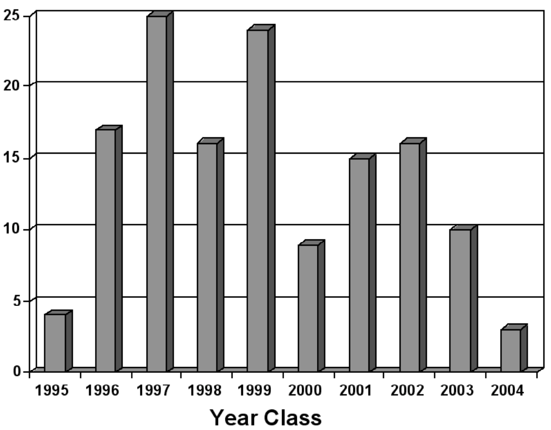


Figure 1

class) and low of 3 farms (2004 year class). This reduction has been attributed to a number of efforts by both industry and government. Reducing risk, biosecurity vigilance and the separation of year classes is the current focus for the ISA management and control program.

The objective of the New Brunswick ISA Management and Control Program is to provide industry, government, fish health professionals, and other stakeholder groups with a comprehensive and standardized approach to the management and control of ISA in New Brunswick. The legal framework for this program is under the New Brunswick Aquaculture Act, Chapter A-9.2. It is assumed by all parties that the effective management of ISA requires a multi-faceted and coordinated approach. If any of the critical components of this program are neglected or inadequate, the success of efforts in other areas of the program will be greatly diminished.

Critical components of the program include monitoring and surveillance requirements, determination of disease status and reporting and communication.

Standard Surveillance Requirements

The monitoring and surveillance of fish stocks is critical to the early detection and effective management of disease. The New Brunswick Marine Fish Health Surveillance Program (FHSP) provides a framework for the monitoring and surveillance of fish stocks at New Brunswick marine aquaculture sites. Each site is required to have an authorized veterinarian who shall carry out the responsibilities outlined in this program. In addition to those requirements established under the FHSP, prescribed sampling and submission protocols must be followed by the site's authorized veterinarian or a technician under the direct supervision of the authorized veterinarian, for the purposes of ISA. Surveillance visits at marine sites must be carried out by an authorized veterinarian at least once in each calendar month for the entire marine grow-out period. A minimum of five moribund or suitable dead fish should be collected and submitted from each site once every calendar month. The authorized veterinarian must conduct a gross post-mortem examination on a reasonable number of suitable samples from each cage, if such samples are available. If the five fish sample cannot be achieved, additional sampling will be required at the discretion of the New Brunswick Department of Agriculture, Fisheries and Aquaculture (DAFA) veterinarian. All samples must be collected and submitted to the DAFA laboratory for testing. The authorized veterinarian will have the discretion of submitting the whole fish or appropriate tissue samples (in priority kidney, spleen, liver). All samples will be routinely screened by both IFAT and PCR, unless otherwise directed.

The provincial veterinarian will circulate on a monthly basis site visitation and ISA testing results from the FHSP to all participating authorized veterinarians.

Role of the Fish Health Technical Committee

The Fish Health Technical Committee (FHTC) is a technical advisory committee, whose primary role is to provide advice to the Minister of Agriculture, Fisheries and Aquaculture for the management and control of diseases of concern. The DAFA Veterinarian may at any time consult with the FHTC or other experts on issues related to, but not limited to, depopulation, fallowing, biosecurity and surveillance.

Determination of Disease Status

The FHSP prescribes clear criteria for the determination of disease status as suspect or positive and requires sites with a suspect or positive status to follow set procedures for harvesting, disinfecting and fallowing sites.

The "holding over" of market fish at a site or in a bay where smolts are introduced is widely recognized as a practice that increases the risk of disease transfer between generations of fish. Although industry and government believe that true year-class separation must be the longer-term objective, it is recognized that, given the present structure of the industry, the practice of "holding over" fish is, at times, necessary. In cases where holdover fish are permitted by DAFA, the surveillance, testing and depopulation requirements for these fish is more aggressive and all additional testing costs are to be covered by the license holder.

General Control Measures

Unless otherwise required by the DAFA veterinarian, DAFA's *"Cleaning and Disinfection Guidelines for the Control of Infectious Salmon Anemia (ISA)"* will serve as the basis for all cleaning and disinfection that may be required under this program.

In order to minimize the risk of transferring ISAv between generations of fish at the same site or within the same bay area, fallowing of a site, sites or bay area may be required. The DAFA veterinarian will determine what sites or bay management areas will be required to fallow and the required fallow period. Fallowing may be required at ISAv-infected, suspect or negative sites, depending upon the circumstances at the time. The fallow period for a site commences once the site has been emptied of all fish and all cleaning and disinfection procedures for the site have been completed, inspected and approved by the DAFA veterinarian or technician. The fallow period for a site will end when new stocks are introduced back into the site or if a potentially contaminated item (e.g. vessel, equipment, personnel) enters the site. The DAFA veterinarian will determine both the start and end of the fallow period for the site. For infected farms or farms in an infected bay, a minimum of 6 weeks fallowing would be required. Farms in a non-infected area will be required to complete a minimum of 2 weeks fallow.

The fallow period for a bay area commences once all sites within the bay have been emptied of all fish and all cleaning and disinfection requirements have been completed at all sites. The fallow period for a bay will end when new stocks are introduced back into the bay area or if a potentially contaminated item (e.g. vessel, equipment, personnel) enters the bay area. The DAFA veterinarian shall determine the beginning and end of the fallow period for a bay.

Harvest vessels must be certified by the DAFA. The movement of equipment such as feed barges, cages, etc. from infected sites or bay areas must be approved by DAFA as per the Marine Equipment Transfer Request document.

Sites located in infected areas with alternate species will at the minimum follow the same cleaning and disinfection protocols. Any other special conditions will be determined by the DAFA veterinarian.

Centre for Aquatic Health Sciences (CAHS) at the Atlantic Veterinary College

The CAHS was initiated in 2003 using funding from multiple industry and government participants. The primary focus areas for CAHS include epidemiology of salmon health and disease intervention laboratory studies. Within the epidemiology focus, CAHS is developing better ways to monitor health and production, to assess health management methods, and to reduce the risk of unwanted disease events. CAHS researchers also take a step away from the farm and focus on assessments of new and alternative therapies for important diseases affecting fish farms in Atlantic Canada.

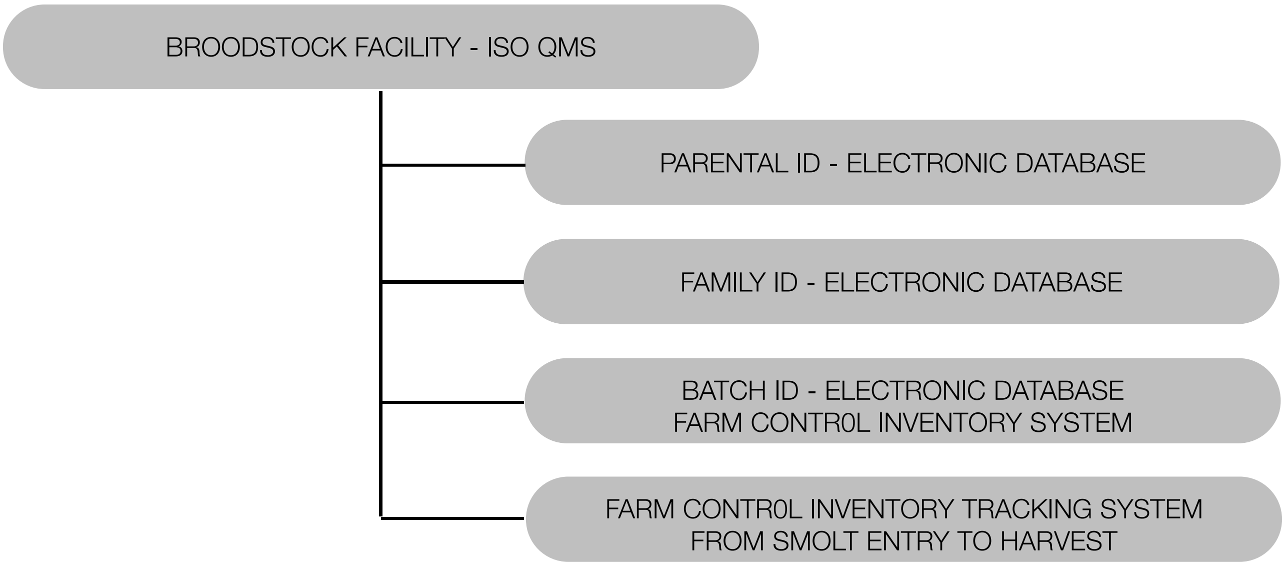
The Atlantic Veterinary College maintains a field office in the heart of salmon farming country in order for veterinary students to obtain hands-on experience in managing fish health.

Genetics

East Coast Salmon Farmers are constrained to the culturing of local strains of salmon on their farms. The goal of the farmer is to protect his inventory by keeping his salmon on the farm and to minimize the potential interaction between wild and farmed salmon.

Like other food-producing industries worldwide, salmon farmers are developing full traceability programs as illustrated in the following diagram, with some companies now developing a DNA-based tracking system.

Chain of Custody



Research

Aquaculture has substantially increased our body of knowledge in many areas related to our marine resource: oceanography and hydrographics, fish genetics, fish health, interactions between species and interactions with the environment. There are a number of science and funding organizations in Canada that continually generate and support aquaculture science and research.

One example is the large body of knowledge that has been accumulated concerning the various strains of the ISA virus as illustrated Table 2.

ISAv Strain	Distribution
European **HPR0**	2004 yc – Deer Island, Campobello, Grand Manan, Upshore
N. American **HPR2**	2004 yc – Deer Island (1 Clinical Site)
N. American **HPR4**	2003 yc – Clinical Sites
N. American **HPR4.a**	2003 yc – 1 Clinical Site only
N. American **HPR4.b**	2003 yc – 1 Clinical Site only
N. American-**HPR-RPC#1**	2004 yc – Deer Island (1 clinical site)
N. American-**HPR-RPC#2**	2003 yc – 1 Clinical Site only w/ HPR4

Table 2 *The different strains of ISA virus and their distribution.*

Joint projects

Because it provides consumers with a consistent supply of affordable fresh fish, salmon farming contributes to the conservation of wild salmon stocks by reducing the pressure on the wild fishery and on poaching. The expertise and resources of the industry can also be applied to specific conservation and restocking projects.

Several specific projects include:

1) Magaguadavic River Salmon Recovery Program, a partnership between the Magaguadavic River Salmon Association, the Atlantic Salmon Federation, the Huntsman Marine Science Centre and the New Brunswick Salmon Growers' Association and its member companies; http://asf.ca/Research/magaguadavic/broodstock.html

2) Genetic Profiling Project of farmed salmon in New Brunswick and Nova Scotia. (Fisheries and Oceans Canada, Research and Productivity Council – RPC, New Brunswick Salmon Growers' Association and member companies);

3) Discussions are underway between the Magaguadavic River Salmon Association and Cooke Aquaculture Inc. on the design of a joint project to hold wild salmon at Cooke's Tomaston Corner hatchery on the Magaguadavic River for release to the river at various life stages.

Formal interaction

A number of formal committees have been set up to provide formal interaction between the salmon farming industry and other users of the working waterfront. These include:

Bay of Fundy Stakeholder Forum
South West New Brunswick Marine Resource Group
Inner Bay of Fundy Salmon Recovery Group
Exclusion Zone Review Committee
NASCO/North Atlantic Salmon Farming Industry Liaison Group

Bay management

In 1997, the New Brunswick Salmon Growers initiated a Bay Management approach to the province's salmon farming industry. The industry was divided into Bay Management areas, with single year class farms having the same year class in each area. Bay Management Agreements were drawn up but were eventually replaced by an industry-wide Code of Practice supported by federal and provincial regulations.

The move to Bay Management areas allowed for fallowing of sites, for controlled and coordinated stocking, for the coordination of sea lice treatments and therapeutant use and for the designation of wharves for incoming and outgoing traffic, and for the designation of vessel traffic routes. All of these initiatives were designed to minimize the risk of cross-contamination and spread of disease and have achieved a significant measure of success. However, companies have been constrained by lack of available new sites in order to achieve true year class separation. At the same time they have had to harvest fish year round in order to supply the market on a consistent basis and stay in business.

In the fall of 2004, industry and government representatives formed a Task Force in order to assess the continued challenges facing the industry and to design a plan for change and for moving forward.

Atlantic Canada Sustainability Plan

The Atlantic Canada Salmon Farming Sustainability Plan was prepared by the New Brunswick Salmon Growers' Association this June in consultation with the Aquaculture Association of Nova Scotia and the Newfoundland Aquaculture Industry Alliance. The plan is a commitment by the salmon farming industry to implement the necessary changes to develop a profitable market-driven industry. It is the framework for moving forward.

The Sustainability Plan evolved as a response to the work of the Federal/Provincial Task Force on Fostering a Sustainable Salmon Farming Industry in Atlantic Canada. The report provided an update on the financial situation of the industry and the measures deemed necessary to ensure the long-term sustainability of salmon farming and for support of the market development of alternative finfish species. This includes changes to the Bay Management Area System (BMAS).

Industry and government are presently implementing the recommendations of the reports of the Task Force and the Sustainability Plan. A Steering Committee has been established to oversee the implementation of the farming system components of the Sustainability Plan. Under direction from its committee, industry has taken the lead on consultations by hosting several all-farmer meetings, distributing information packages, and facilitating discussions of smaller groups. Under recent changes to the Aquaculture Act the Minister of DAFA has authority to establish boundaries and operation parameters for BMASs.

The goal of these consultations is to reach consensus on a BMAS that divides the industry into three major areas: sites with smolts, sites with harvest fish and sites that are fallow. In order to achieve the best BMAS with true year class separation and adequate fallow periods, the industry will need to consolidate or relocate smaller farms, to have access to nursery sites and have access to new sites. Farmers will need access to enough sites to allow for a portion of their farms to lie fallow at any given time.

Maine Initiatives (details are provided in the papers by Lapointe and Bean and Belle in this volume)

- In 2001 Farmed Fish Containment Management System (CMS) agreement was signed with three Environmental NGOs;
- Farm stock health is monitored and tested regularly as part of a comprehensive state and federal management program. (Maine's fish farms are tested and monitored more frequently than any other form of farming in the United States.)

Lessons Learned

- Protecting Fish Health has become "a religion" to farmers;
- Industry efforts need to be mirrored by the "wild guys";
- Bay Management approach to farming requires adequate sites to allow for fallowing year class separation;
- Vast body of knowledge developed by aquaculture can be applied to conservation;
- Area management initiatives succeed when equal partners work together.

Area management initiatives in Norway

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Introduction

Salmon lice represent one of the most serious pathogens of wild and farmed Atlantic salmon and sea trout (Tully and Nolan, 2002; Heuch *et al*., 2005). Increased knowledge about migratory routes and speeds of wild Atlantic salmon and sea trout in fjord systems (Thorstad *et al*., 2004; Finstad *et al*., 2005), and the risk of infestation by salmon lice, is required in order for the aquaculture industry to continue its development, and at the same time reduce the environmental effects on the wild salmonid populations. In the present Hardanger fjord project, we have mapped the migratory behaviour of both wild and farmed salmonid post-smolts. By a combination of automatic and manual tracking, we will be able to map the migratory routes of wild and farmed salmonid post-smolts and combine this with hydrodynamic models. In addition, we have also monitored the lice burden in the fjord system at selected fish farms and sampled sea trout throughout the fjord system to map the lice burden on these fish. Smolt cages in the sea have been used as an indicator of the salmon lice pressure in the system.

Material and methods

To satisfy the main goal of the project, several work packages with specific sub-goals have been established:

Work package 1 - Registration of salmon lice abundance on wild, farmed and escaped salmonids

- Gather data on the abundance of salmon lice on all hosts in the fjord system: farmed salmon, escaped farmed salmon, wild salmon and sea trout;
- Evaluate the success of the local salmon lice management model in the Hardangerfjord system by examining infection levels on wild salmonids and correlating these with levels on farmed salmon;
- Develop and assess alternative strategies for increasing survival of sea-ward migrating post-smolts in critically affected areas.

Work package 2 - Optimised salmon lice monitoring and control strategies on farms

- Improve current procedures for using wrasse, in-feed and bath treatments for lice control;
- Improve salmon lice monitoring on individual farms and the region in general and investigate different approaches to lice counting;
- Investigate different strategies for using wrasse.

Work package 3 - Quality of farmed and wild smolts

- Check health status of farmed and wild smolts to assess their susceptibility to salmon lice infections.

Work package 4 - Migration speeds and routes of Atlantic salmon smolts

- Map the migratory route, swimming depth and rate of progression of Atlantic salmon post-smolts from one population located in the inner part of the Hardangerfjord system through the fjord areas to the sea.

Work package 5 - Spread of salmon lice larvae

- Investigate the abundance and origin of salmon lice larvae in the fjord system;
- Incorporate the ongoing scientific and commercial activities in the Hardangerfjord system with new and expanded activity to elucidate the connections between wild salmonids, fish farming

and the problems with salmon lice infestations in the area.

Work package 6 - Physical oceanographical factors on salmon lice distribution in the Hardangerfjord

- Quantify the distribution of salmon lice in the Hardangerfjord system based on the physical oceanographical and meteorological conditions for a given salmon lice production (number of lice and origin).

Work package 7 - Workshop, data implementation

- All relevant data from the different work packages in this project will be transferred into this work package and a knowledge base will be developed;
- Selected data from the knowledge base will be made publicly available through a pre-established Norwegian internet salmon lice page (http://www.fhl.no – and click “lusedata”);
- Experiences and methods from mathematical models used in the ongoing Norwegian Research Council project (Salmon lice as a population-regulating factor in Norwegian salmon: status, effects of measures taken and future management) from the Sognefjord and Altafjord systems will, as far as possible, be integrated into the project;
- The effects of an improved salmon lice strategy will be predicted through the base models and will be verified in nature by the work being done in work packages 1 and 2.

Results/Discussion

The Hardangerfjord contains the highest density of fish farms in Norway (approximately 60 fish farms in 2005) and the production of farmed fish in 2005 was approximately 60,000 tonnes of salmon and sea trout. A huge amount of data has been collected from this fjord system during field work in 2004 and 2005 and more will be collected in 2006. All this information will be gathered into a knowledge base for ecosystem modelling. The present project will be a joint venture for both Norwegian and international salmon lice research. Through broad cooperation between leading Norwegian research institutes, Canada’s Network of Centres of Excellence - AquaNet, the aquaculture industry and management, and experience gained from adjoining projects, we aim to develop a knowledge base for the Hardangerfjord system, and for other fjord systems globally, which can be used in management schemes aimed at minimising the risk of salmon lice infestation on wild and farmed fish stocks.

Acknowledgements

Additional partners in this project are described in the Hardangerfjord salmon lice project on NINA’s webpage: http://www.nina.no. The project has been funded by the Norwegian Fisheries and Aquaculture Research Fund, AquaNet – Canada, the Norwegian Research Council and the Norwegian Directorate for Nature Management.

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Loch Fyne - An example of successful area management in Scotland

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Background

The Tripartite Working Group (TWG)

What is the TWG? The purpose of the Group, set up in 1999, is to address problems common to salmonid farming and wild salmonid fisheries and to seek solutions for ensuring the maintenance of a healthy stock of wild fish whilst at the same time promoting a sustainable aquaculture industry. Membership of the TWG is drawn from the Scottish Executive Environment and Rural Affairs Department (SEERAD), the salmon farming industry and wild fisheries interest groups. Scottish Natural Heritage (SNH) and the Scottish Environment Protection Agency (SEPA) are also invited to participate. A number of recommendations were made in a Concordat and Report published in July 2000.

TWG Recommendations

The Concordat's principal conclusion is for close co-operation of the industry, wild fishery interests and other stakeholders, working at a local level in the form of Area Management Agreements (AMAs). The TWG Concordat emphasises synchronised fallowing and the use of single year class management, as key measures that AMAs should aim to incorporate.

The Area Management Agreement Process

The TWG implements its recommendations with respect to the development of AMAs through a National Development Officer, who in turn works with appointed Regional Development Officers, or their equivalents in some cases, in negotiating with local salmon farmers and wild fishery representatives to set up Area Management Groups (AMGs) in defined management areas. The wild fishery representatives include the local Fishery Trust, District Salmon Fishery Board and/or local river proprietors, but may also include angling clubs and scientific institutions. AMAs are proposed and drafted, generally by the Regional Development Officers, and signed when agreement has been reached by the local members of the AMGs. This may often be a protracted exercise, and is very dependent upon the willingness of participants to engage and recognise the benefits to be gained from the process, not least of which is the forum this presents for open discussion of matters of concern to the various parties.

AMAs cover issues such as:

- synchronised fallowing;
- co-ordinated and strategic sea lice treatments;
- monitoring of wild and farmed fish for sea lice infestation and diseases;
- containment policies and reporting of escapes;
- restoration efforts;
- predators;
- future stocking or equipment plans;
- biomass consents;
- wild fish stocking and hatchery plans.

The most pressing issue is the control of sea lice, and the key factor in setting up an AMA is always the local salmon farming company's ability to implement a stocking regime that incorporates a synchronous fallow of all sites within the management area.

Loch Fyne

Situated in Argyll to the west of the Firth of Clyde, Loch Fyne is Scotland's largest sealoch. Loch Fyne is 70km long from mouth to head, and is divided naturally into an upper and a lower basin. The significant rivers are the Fyne and Kinglas, which flow into the head of the loch, and the Aray and Shira which enter the loch 12km south of the head.

Loch Fyne has 13 individual marine cage sites, all operated by Pan Fish Scotland Ltd, 6 smaller sites (450 tonnes maximum biomass) in the upper loch, and 7 larger sites (900 tonnes maximum biomass) in the lower loch, all on S0 production (i.e. autumn sea transfer of smolts).

The Loch Fyne AMA was signed in 2002 with signatories comprising:

- Pan Fish Scotland Ltd – operating marine cage salmon farms;
- Otter Ferry Seafish Ltd – operating a pump-ashore production unit for halibut;
- Lakeland Smolt Ltd – operating a freshwater salmon hatchery and smolt production unit;
- Argyll Fisheries Trust;
- Loch Fyne District Salmon Fisheries Board.

The Area Management Commitment

This is primarily a Pan Fish Scotland Ltd commitment to single year class stocking of all operational areas, i.e. sites within defined management areas, with a synchronous fallowing period incorporated into the stocking regime. This policy was first implemented for the 2001 S0 generation in Loch Fyne, harvested out in 2003.

It has since been maintained in other Argyll S0 production areas, namely the west side of the Isle of Mull, Lower Lorne and the Isle of Gigha, all of which collectively comprise the company's S0 production capacity outside Loch Fyne. Pan Fish Scotland Ltd sites in each of these three areas are also subject to a synchronous fallow period. This means that harvesting operations of S0 fish switch between these areas in combination, and Loch Fyne, in alternative years.

A synchronous fallow period was achieved in Loch Fyne through sites being used in groups of, generally, two or three within the area, incorporating:

- a smolt nursery site – retaining (large grade) on-growers;
- a grade of the fish stock on the nursery site to split larger, faster-growing fish (large grade) from smaller, slower-growing fish (small grade). The large grade fish remain on the original site, while the small grade fish are transferred by well-boat to one or two other on-growing sites, within the management area;
- harvesting out all large grade sites within an area, followed by small grade sites, to set dates, to ensure synchronous overlap in fallow periods.

This is illustrated as a theoretical model in Figure 1, and the actual stocking and fallowing history of the Loch Fyne sites in achieving the synchronous fallow is illustrated diagrammatically in Figure 2.

The results of the synchronous fallow of all the Pan Fish Scotland Ltd sites in Loch Fyne in 2003 are illustrated in Figure 3. It can be seen that the net result of this fallow period was a period of 10 months, October 2003 to July 2004, when sea lice levels did not reach a level that triggered treatment. This compares with the same period in 2001/2002 when a number of treatments were required. The veterinary treatments available during both of the periods illustrated were the same, namely Excis™ and Hydrogen Peroxide. Slice™ became available in early July 2004 for Loch Fyne sites, and this was used in the first sea lice treatment necessary for the 2003 year-class later that month.

Figure 1

SITE AND AREA FALLOWING MODEL (S0 Production Cycle - Argyll sites)

Month	Site 1 Smolt & Large Grade (SLG)		Site 2 Small Grade (SG)		Site 3 Small Grade (SG)		
January	Harvest		Small Grade		Small Grade		
February	Harvest		Small Grade		Small Grade		
March	Fallow		Harvest		Harvest		
April	Fallow		Harvest		Harvest		
May	Fallow		Harvest		Harvest		
June	Fallow	1:3 Site Fallow	Harvest		Harvest		
July	Fallow		Fallow		Fallow		Area Fallow
August	Fallow		Fallow		Fallow		
September	Smolt transfer		Fallow		Fallow		
October	Stocked		Fallow	1:3 Site Fallow	Fallow	1:3 Site Fallow	
November	Stocked		Fallow		Fallow		
December	Stocked		Fallow		Fallow		
January	Stocked		Fallow		Fallow		
February	Stocked	Graded	Fallow		Fallow		
March	Large Grade		Small Grade		Small Grade		
April	Large Grade		Small Grade		Small Grade		
May	Large Grade		Small Grade		Small Grade		
June	Large Grade		Small Grade		Small Grade		
July	Large Grade		Small Grade		Small Grade		
August	Large Grade		Small Grade		Small Grade		24 Month Production Cycle
September	Large Grade		Small Grade		Small Grade		
October	Large Grade		Small Grade		Small Grade		
November	Large Grade		Small Grade		Small Grade		
December	Harvest		Small Grade		Small Grade		
January	Harvest		Small Grade		Small Grade		
February	Harvest		Small Grade		Small Grade		
March	Harvest		Harvest		Harvest		
April	Fallow		Harvest		Harvest		
May	Fallow		Harvest		Harvest		
June	Fallow	1:3 Site Fallow	Harvest		Harvest		
July	Fallow		Fallow		Fallow		Area Fallow
August	Fallow		Fallow		Fallow		
September	Smolt transfer		Fallow		Fallow		
October	Stocked		Fallow		Fallow		
November	Stocked		Fallow	1:3 Site Fallow	Fallow	1:3 Site Fallow	
December	Stocked		Fallow		Fallow		
January	Stocked		Fallow		Fallow		
February	Stocked	Graded	Fallow		Fallow		
March	Large Grade		Small Grade		Small Grade		
April	Large Grade		Small Grade		Small Grade		

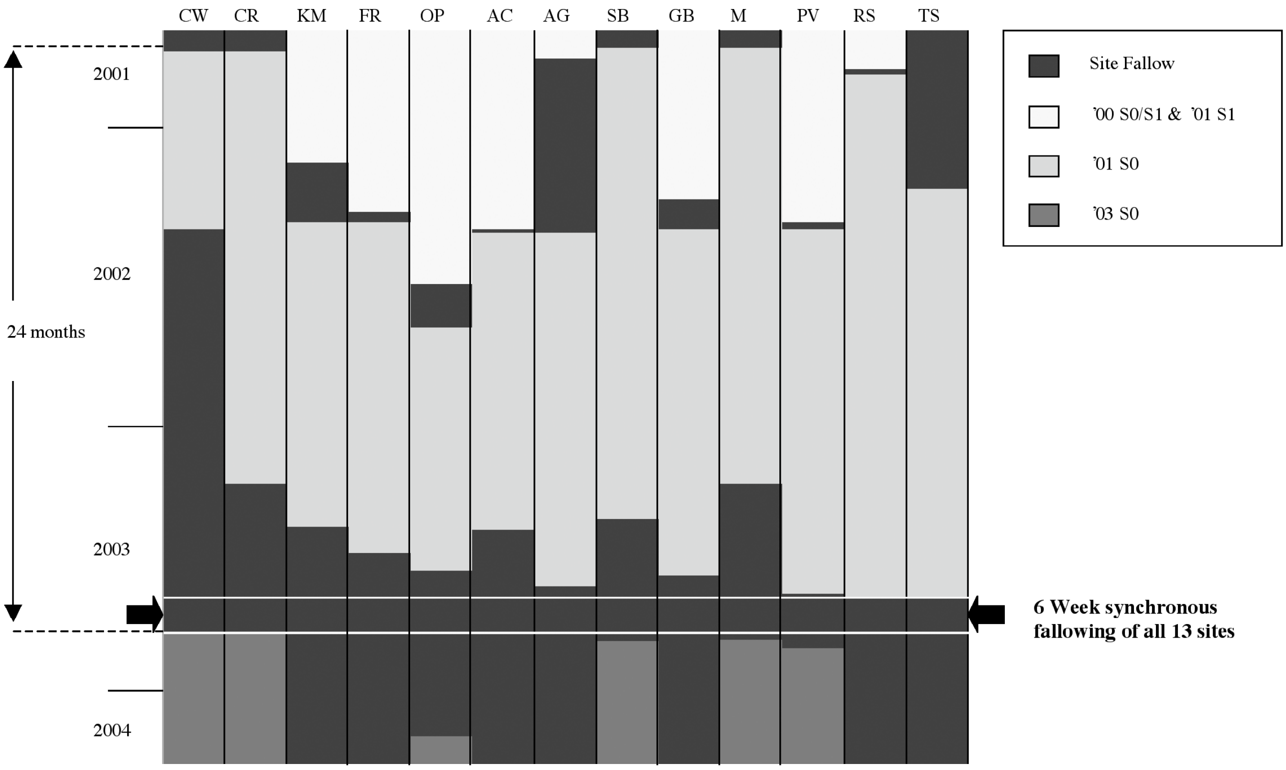
Several factors can be said to have assisted in achieving this result, namely:

- sole operator status of the loch for ease of operational management of the fallowing;
- the geography of Loch Fyne – a 'long bottle' shape means a relatively enclosed biological area (and an easily defined management area);
- there are few other salmon farms close to Loch Fyne – less potential for cross-infection between areas;
- relatively few significant wild salmonid fishery rivers – influence of wild fish vectors of lice may well be low;
- the weather over this particular period – a uni-directional flow of fresh water certainly assists the sites in the upper loch, and a wet autumn and winter improves this.

The practical significance of the results of the synchronous fallow to Pan Fish Scotland Ltd's Loch

Figure 2

LOCH FYNE STOCKING – 2001 TO 2004



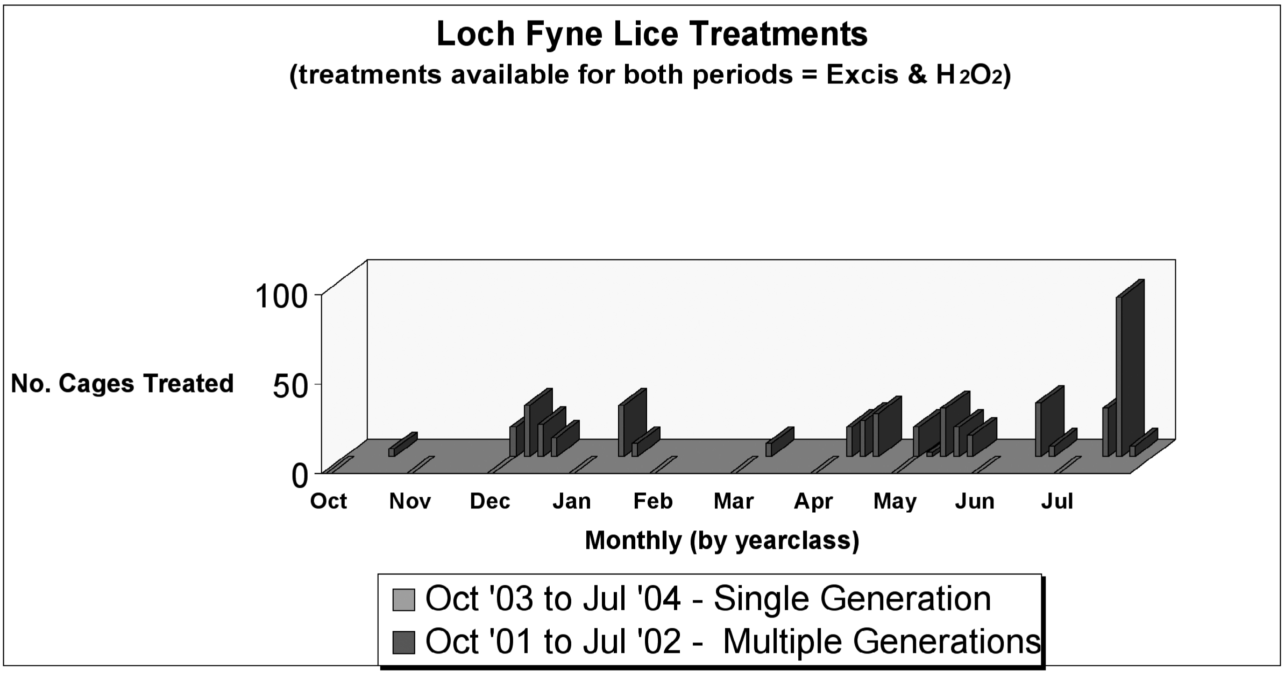
Fyne activities and production can be summarised as:

- for 10 months of a circa 22-month production cycle (and 13 months in total), lice levels at stocked sites within Loch Fyne did not reach treatment trigger levels (0 ovigerous females between February and June, and an average of 0.5 ovigerous females at other times). The production and performance losses associated with lice infestation, particularly in post-smolts, were avoided. The saving in economic terms, both in savings on cost of treatments and in not incurring the potential losses in growth, can be conservatively estimated to run to many £100,000s;
- this synchronous fallow has proved itself a major lice management tool in Loch Fyne, significant particularly in the light of the limited portfolio of lice treatments available for use in Scotland. The risk of resistance developing to these treatments is also lessened by the reduced usage of the treatments;
- together with the advent of Slice™ consents, synchronous fallowing enables lice control to become far more of a strategic pest management exercise than the 'fire-fighting' of the past – bath treatments are now generally limited to individual cage treatments, mostly carried out close to harvest.

Wider benefits to the Loch Fyne management area stakeholders, particularly wild fisheries, include the improvement in sea lice control in farmed stock, brought about by the synchronous fallow, which will certainly help to reduce any local 'lice pressure' on wild stocks. It is possibly too early yet to see if and how this might manifest itself in the local wild fishery.

The AMA does, however, address one of the factors considered at present to be most significant in local wild salmonid fishery status (i.e. sea lice), and through the participatory nature of the AMA, encourages other factors to be addressed. It is accepted within the AMA that such efforts on the part of Pan Fish Scotland Ltd should be matched by similar attention given to wild fishery issues by their representatives, for example development of Fishery Management Plans, habitat restoration, and re-stocking.

Figure 3



This all comes together to make the AMA a dynamic process. Members see themselves as participants in maintaining healthy and sustainable farmed and wild stocks in Loch Fyne, as demonstrated by their efforts. The Loch Fyne AMA can now be said to be "walking the walk".

Implementation of single-generation area stocking and synchronous fallowing of production areas present a variety of difficulties and obstacles to production policies and objectives. Having to harvest by a certain date can create pressure on harvest and sales, and reduces flexibility in being able to react to poor fish size and/or market price. Single-generation area stocking causes shifts in production effort with regard to grading and particularly harvesting, which creates logistical problems, particularly in terms of staff and equipment utilisation. Harvesting production from separate areas in alternate years means that costs rise if production from these distinct areas is not balanced. Pan Fish Scotland Ltd do not have this balance, and redressing this problem is a very long-term, frustrating, and not yet entirely successful undertaking. This is undoubtedly one of the most significant factors upon which the on-going success of widespread AMA implementation of single-generation stocking with synchronous fallowing will depend.

Finally, based on experience to date, a number of lessons from the AMA process have been learned. First, that the practical success of any AMA is obviously dependent upon positive contributions from all its participants. The degree to which this commitment is evident from the local members is central to making the process work – half-hearted isn't going to do it.

Second, frequent and open communication between AMA members has been a key success factor in building trust in the Loch Fyne AMA, particularly with regard to information sharing and distribution. Everyone feels informed.

Finally, the AMA requirement for single-generation stocking and synchronous fallowing changes farmed salmon production to far more of a strategic exercise in terms of geographical location. Industry regulation must recognise, address and support this for the AMA process to prosper.

Area management in Scotland: lessons and challenges

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Introduction

Background

The farming of Atlantic salmon has expanded exponentially since the 1960s and farmed production now greatly exceeds wild salmon biomass. Salmon farming has been implicated in declines of wild salmon populations, most particularly in Canada, Norway and Scotland, where declines have been dramatic and temporally and spatially linked to the development of the aquaculture industry (WWF, 2001). There are three primary areas of interaction by which salmon farming may affect wild stocks: parasites (mainly sea lice), escapes and communicable disease (Youngson *et al*., 1998). These threats and associated declines in wild populations provided the impetus for wild fish interests to become involved in area management initiatives for salmon farming in Scotland.

Sea lice on farmed and wild salmonids

Salmon lice (*Lepeophtheirus salmonis* L.) larvae are planktonic, moving with currents and tides for several days after hatching. The duration of the planktonic stages is between 2 and 10 days depending on water temperature (Johnson and Albright, 1991). After a number of moults the larvae become infectious copepodids. When a copepodid encounters a suitable host it settles, attaching itself to the skin of the fish, where it feeds and grows, moulting regularly. After a number of moults the louse becomes mobile, moving over and grazing the skin and mucus of its host. The biology and life cycle of sea lice have been reviewed by Pike and Wadsworth (2000).

Due to the large numbers of host fish concentrated in salmon farms, increased densities of louse larvae may occur in surrounding waters (Tully and Whelan, 1993). Lice infestation has been associated with declines and collapses of wild salmonid stocks in salmon farming areas of Ireland, Scotland and Norway (ICES, 1997; Tully *et al*., 1993 a, b; Whelan, 1991; Bjorn *et al*., 2001; Butler, 2002). Sea trout are particularly vulnerable to louse infestation since they remain in inshore waters where most fish farms are located, and where lice larvae are most abundant. Salmon, in contrast, move rapidly out to sea. Nevertheless, it has been demonstrated that in long fjords with multiple fish farms, an estimated 48-86% of emigrating wild salmon smolts may acquire lethal lice infestations (Holst *et al*., 2003).

Other pathogens

The movement of farmed salmon and trout between countries and regions has been strongly implicated in the transfer of disease and may lead to fish populations coming into contact with novel pathogens to which they have no immunity. The spread of *Gyrodactylus salaris* in Norwegian rivers is likely to have resulted from intentional fish transfers for farming and stock enhancement purposes. The parasite is thought to have originated in the Baltic. While Baltic salmon show high resistance to the parasite, it has proven devastating to Norwegian stocks. Similarly, furunculosis was spread to the Norwegian farming industry with infected smolts from Scotland in the mid-1980s. Escapes of infected salmon have since been implicated in spreading the disease to wild stocks where, in some rivers, infestations reached serious levels (Johnsen and Jensen, 1994; WWF, 2001).

Escaped farmed salmon

It is estimated that over 700,000 tonnes of Atlantic salmon are farmed in the North Atlantic. Farmed salmon are genetically different from wild salmon due to the processes involved in domestication (Fleming and Einum, 1997). Furthermore, the salmon grown at any farm site are often derived from non-local stocks, with Norwegian strains particularly common at farms throughout the North Atlantic. Escapes from both freshwater and marine farm sites are common. It is estimated that 2 million farmed salmon escape each year, representing 50% of the pre-fishery abundance of wild Atlantic salmon (McGinnity *et al*., 2003). As farmed fish have the capability to survive and breed in the wild, concerns arise over the potential changes to the genetic make-up of wild stocks from hybridisation. Ecological and behavioural interaction between farmed and wild stocks, from competition for space, may also lower wild production. Recent empirical studies support these concerns. McGinnity *et al*. (2003) show that wild salmon may be displaced in fresh water due to competition from juvenile farmed or hybrid stocks. Coupled with lower marine survival of farmed and hybrid groups, the result of ingress of farmed stocks to wild populations was reduced overall recruitment. Modelling of these data suggested that interactions with farmed stocks lowered fitness and in vulnerable populations might cause extinction in populations exposed to repeated escapes.

Area Management Agreements

During the late 1990s concerns over the potential impact of salmon farming on wild salmonid populations led to the establishment of the Tripartite Working Group (TWG). The TWG brought together farmed and wild fish interest groups under the chairmanship of the Scottish Executive. In July 2000 it published a Report and Concordat, stating that the purpose of the Group is to 'develop and promote the implementation of measures for the restoration and maintenance of healthy stocks of wild and farmed fish' (TWG, 2000). The focus of the TWG is fish health and the primary recommendation in the Concordat is the establishment of Area Management Agreements (AMAs) between neighbouring fish farms and local wild fish interests.

AMAs provide for local co-operation through the establishment of Area Management Groups (AMGs) to oversee the delivery of AMA objectives. These objectives are agreed locally, but should seek to meet the fish health objectives and principles as set out in the Concordat. Typical AMA objectives include:

- single year class management and synchronised production/fallowing cycles;
- zero ovigerous salmon lice before and during the wild smolt migration period (February – June);
- vaccination of smolts against furunculosis;
- preparation of containment and contingency plans to minimise escapes;
- adherence to industry Codes of Practice;
- regular monitoring and information exchange between AMA partners;
- preparation of catchment management plans;
- adherence to disease control mechanisms in wild fisheries.

Management areas are usually based on the biological areas for the management of farmed salmon proposed by the Joint Government/Industry Working Group Report on Infectious Salmon Anaemia (FRS, 2000), but are subject to local agreement. To date, 14 AMAs have been implemented from the 20 required to cover the main areas of Scottish marine salmonid farming in the mainland and the Western Isles. A further three AMGs have been set up, but without the formal signing of an AMA.

To date, little progress has been made in Orkney or Shetland where there are currently no AMAs or AMGs despite serious concerns over the impact of salmon farming on local sea trout fisheries. A further 15 AMAs may be required in Orkney and Shetland. The TWG continues to meet and the Scottish Executive is committed to continuing to sponsor the initiative.

Case Study

Background

The control of sea lice remains a major focus of wild fisheries organisations when working within the

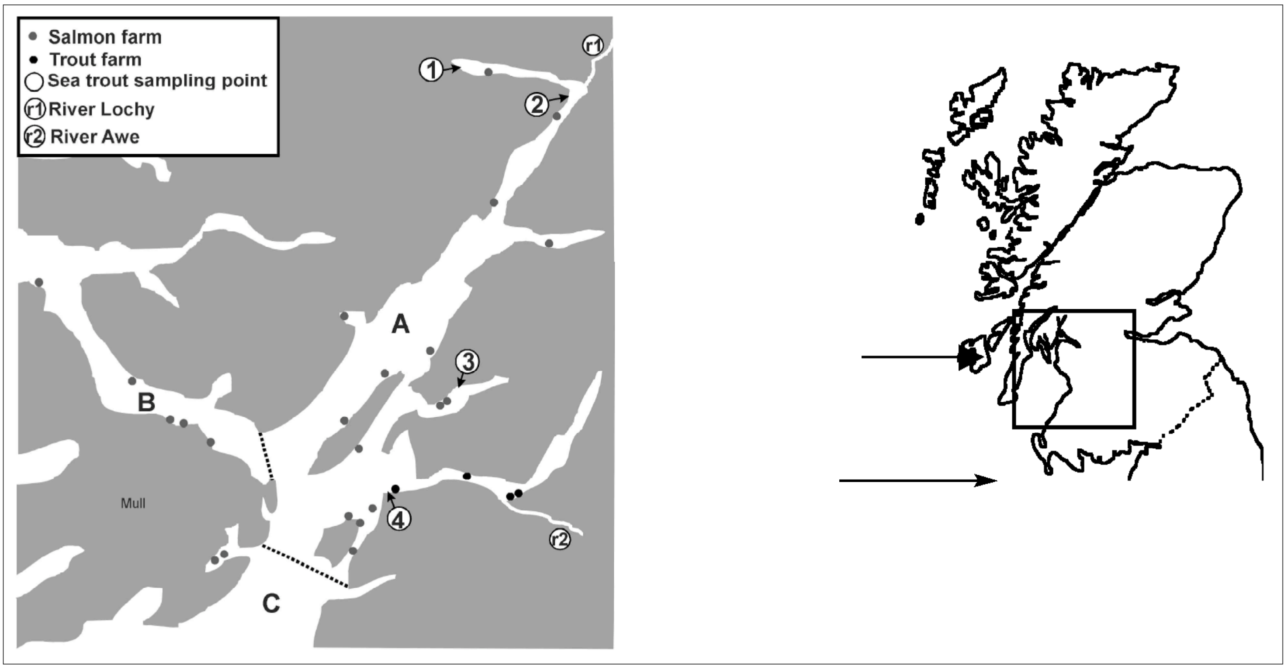
AMA framework. The reasons for this are fourfold. First, as sea lice originating from salmon farms pose a serious threat to wild stocks, louse control is a high priority in conserving and restoring wild stocks. Second, sea lice numbers and larval production are strongly influenced by treatment regimes and husbandry methods on farms (Revie *et al*., 2002). Third, sea lice numbers on both farmed and wild stocks can be routinely monitored, lending them to the setting, monitoring and modifying of target levels. Fourth, lice and lice control are not covered by any current UK or EU fish health or pollution regulations, making the AMA process the sole means by which wild fish organisations can attempt to influence lice control.

The TWG Concordat suggests that louse control within an AMA be achieved through the use of effective medicines and by developing fallowing and rotational strategies, helping to break the cycle of lice infestation across a management area. The following sections examine the effectiveness of such strategies in reducing lice burdens on wild sea trout within a very large sea loch system in western Scotland. The relationship between lice levels and the numbers of salmon returning to two large salmon fisheries in the same area is examined and the implications for louse control and the geography of AMAs is considered.

The study area and the AMA

The study was carried out in Linnhe and Lorne, straddling south Lochaber and north Argyll in the west Highlands (Figure 1), the heart of the salmon farming area of Scotland. The Linnhe sea loch system is one of the longest in Scotland, stretching some 75 km from the head of Loch Eil to the open sea. Following the outbreak of ISA in 1998 and 1999, an inter-company agreement covering farms in Linnhe and the Sound of Mull was signed, initiating single year class management for the 2000 production year (FRS, 2000). In 2002, an AMA was signed by all salmonid farmers using Linnhe, Firth of Lorne, Sound of Mull and Loch Etive. This AMA also brought in local Salmon Fisheries Boards, Fisheries Trusts and salmon fishery proprietors, with the objective of promoting improvements in the health of all salmonid stocks in the area. The Scottish Salmon Fishery Boards are statutory organisations, empowered to undertake works for the protection and improvement of salmon and sea trout stocks. Fisheries Trusts are local, charitable bodies. Typically, their remit is to undertake research, monitoring and education for the conservation and restoration of wild fish populations and the environments which support them. Salmon and sea trout fisheries in Scotland are privately owned, heritable assets.

Figure 1 Study area



The AMA recognises two production areas, shown as A and B on Figure 1. These two areas operate on different production cycles. Salmon farm sites in production area A (Linnhe, Lorn, Creran and Etive) stock during even years. Under the terms of the AMA, stocking is preceded by a co-ordinated fallow period covering all salmon farms in area A. Rainbow trout farms also present in the area are not required to fallow and remain in continual production. Salmon farm sites in production area B (Sound of Mull) stock during odd years, again preceded by a co-ordinated fallow period across the area. There are no rainbow trout sites in Area B.

To the south (Area C on Figure 1) is Lower Lorne, where there is currently no AMA. Salmon farm sites in this area are not on a synchronised production cycle and therefore there is no co-ordinated fallowing in this area. There are no rainbow trout sites in Area C.

Methods

Lice data from wild sea trout were collected from Kinlocheil (Loch Eil NM 97 78), Camasnagaul (upper Loch Linnhe NN 09 74), Loch Creran (An Iola NM 96 44) and Dunstaffnage Bay. These are referred to as sites 1, 2, 3 and 4 respectively. The location of the survey sites is shown on Figure 1. All fall within Production Area A.

Samples of sea trout were collected during May, June and early July using beach seines. Fish were anaesthetised, measured and placed in white trays to facilitate louse counting. The number of lice was recorded for each fish. Lice were classified into three stages: attached (copepodids and chalimus), mobile (sub-adults and adults excluding ovigerous females) and adult females with eggs (gravid or ovigerous females). After counting, fish were allowed to recover and were returned to the capture site. Data on louse numbers are presented as abundance, i.e. the mean number of salmon lice per fish in the whole sample, and maximum, i.e. the maximum number of lice found on any fish in the sample (Margolis *et al*., 1982).

Results and discussion

Lice infestations

Lice infestations on sea trout varied greatly between years and sites. Sites 1, 2 and 3 in the upper and middle part of the Linnhe system had a clear pattern of alternating years of low and high lice infestations, corresponding to first and second year of farm production respectively (Figures 2.1, 2.2, 2.3). Years of high and low infestation were consistent between sites 1,2 and 3 with high infestation levels on the sea trout only recorded when farms were in the second year of production. When farms were in the first year of production, i.e. following the fallow period, lice levels were very low on the wild fish during the spring.

This alternating pattern of years of low and high infestation was not found at site 4, in the lower loch, where between-year variation was not consistent with production cycles (Figure 2.4). Overall, annual fluctuations on fish sampled at site 4 were of lesser magnitude than of those observed in the upper loch.

Figure 2.1
Louse abundance and maximum infestation site 1 (Kinlocheil) 1999-2005 during first (open bars) and second (hatched bars) years of production after fallow period

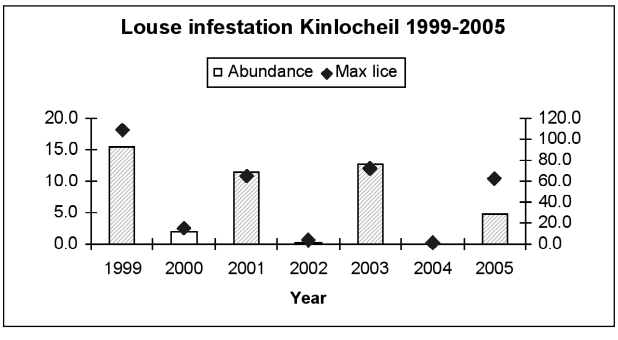


Figure 2.2
Louse abundance and maximum infestation site 2 (Camusnagaul) 2002-2005 during first (open bars) and second (hatched bars) years of production after fallow period

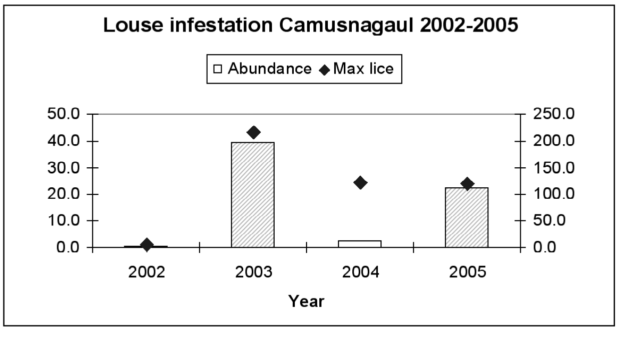


Figure 2.3
Louse abundance and maximum infestation site 3 (Loch Creran) 2003-2005 during first (open bars) and second (hatched bars) years of production after fallow period

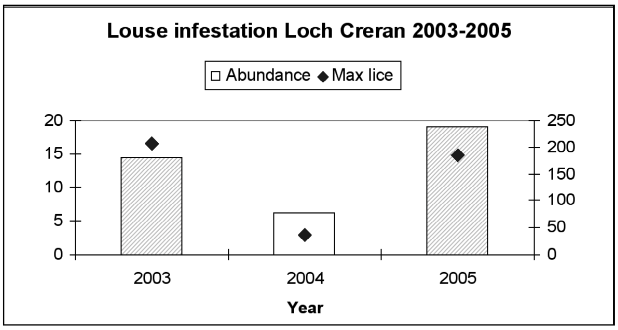
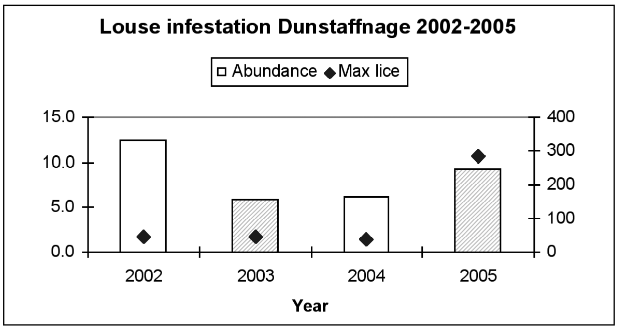


Figure 2.4
Louse abundance and maximum infestation site 4 (Dunstaffnage) 2003-2005 during first (open bars) and second (hatched bars) years of production after fallow period



The proportion of fish carrying ≥ 20 and ≥ 30 lice also varied among locations and years. The highest proportion of fish carrying high lice numbers was from site 2 in 2004, when more than 40% of the fish carried more than 30 lice (Table 1). High lice burdens in areas 1-3 were consistently associated with year 2 of farm production. At site 4 the proportion of fish carrying high lice burdens was highest in 2002, dropped in 2003 and 2004 but increased again in 2005. High lice levels were not consistently associated with the second year of production at this site. Site 4 is located close to rainbow trout farms on continuous production, and salmon farms in neighbouring management areas are on opposite production cycles.

Table 1
Percentage of fish carrying ≥ 20 and ≥ 30 lice when farms are in the 1st or 2nd year of production (FPY)

Year	FPA	Site 1 Kinlocheil		Site 2 Camusnagaul		Site 3 Loch Creran		Site 4 Dunstaffnage	
		% Fish with ≥ 20 lice	% Fish with ≥ 30 lice	% Fish with ≥ 20 lice	% Fish with ≥ 30 lice	% Fish with ≥ 20 lice	% Fish with ≥ 30 lice	% Fish with ≥ 20 lice	% Fish with ≥ 30 lice
1999	2	19.9	14.3	-	-	-	-	-	-
2000	1	0	0	-	-	-	-	-	-
2001	2	17.6	11.8	-	-	-	-	-	-
2002	1	0	0	0	0	-	-	26.9	11.2
2003	2	22.7	20.5	53.1	44.8	22.0	12.0	7.6	3.8
2004	1	0	0	2.6	1.3	3.3	3.3	9.8	4.9
2005	2	9.0	6.8	53.2	36.1	29.7	22.0	9.1	5.8

Potential impacts on wild sea trout and salmon

Studies on salmon post-smolts indicate that infestations of between 11 and 30 lice can cause fish mortality soon after the lice reach the pre-adult stage (Grimnes and Jakobsen, 1996; Finstad *et al.*, 2000). Lower levels may cause significant stress (Nolan *et al*., 1999). Studies of sea trout post-smolts suggest that sea trout express physiological stress at approximately 0.7 attached lice larvae per gramme of fish (Bjorn and Finstad, 1997). At such levels, fish are likely to die when the lice become mobile.

The results of this study suggest that in the second year of farm production 15–50% of sea trout post-smolts in upper Linnhe carried harmful, potentially lethal lice infestations. Less than 1% of the fish carried such infestations when the farms were in their first year of production following a fallow period (Table 1). These potential mortality levels are a snapshot in time. Actual mortality may be higher if infestation pressure continues through the summer. It has been suggested that survival of heavily infected fish may be promoted by de-lousing in fresh water (Pike and Wadsworth, 2000), as sea lice cause 'early returning' behaviour in sea trout (Birkeland and Jakobsen, 1997). However, empirical data show that where infected sea trout post-smolts do return to rivers, few return to sea and the growth of those which do is impaired, reducing fecundity (Birkeland, 1997).

Figure 3
Lochy Association grilse catches 1998 to 2005. The arrows show the timing of co-ordinated fallow periods. There was no all-area, co-ordinated fallow prior to 2000

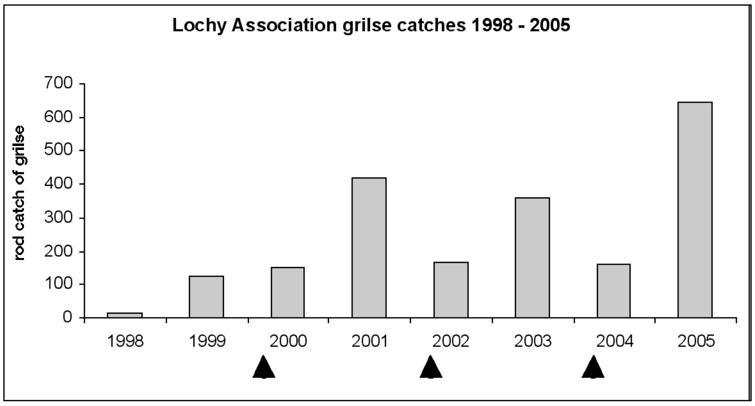
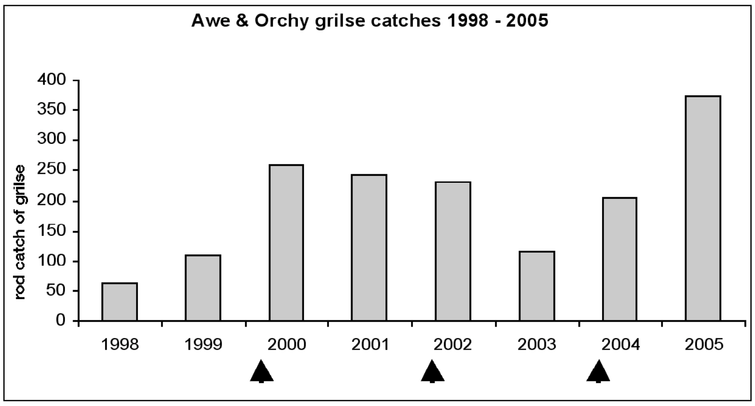


Figure 4
Awe catchment grilse catches, 1998 to 2005. The arrows show the timing of co-ordinated fallow periods for local salmon farm



Norwegian studies show that in long, fjord-like systems, salmon post-smolt mortality is significant during years of high lice abundance. The premier salmon fishery in the upper Linnhe area is the River Lochy, which enters the sea at the top of Loch Linnhe (Figure 1). Salmon smolts from the Lochy must pass through area A on their outward migration. Few data exist on lice burdens on these fish, with only very occasional salmon post-smolts captured during sea trout netting (these carried heavy infestations). If louse-induced mortality of post-smolt salmon occurs in Loch Linnhe, it would be expected that salmon post-smolt survival would be reduced in year 2 of production. Figure 3 shows the rod catch of grilse in the River Lochy over the past four production cycles (8 years). For the last three cycles, farm production and fallowing has been synchronised as a result of the 1999 inter-company agreement. Since the implementation of co-ordinated fallowing, years of high grilse abundance have consistently followed years of low spring louse infestation pressure in Loch Linnhe. Years of low infestation are correlated with fallowing of farm sites. The data are consistent with the hypothesis that salmon post-smolts from the River Lochy suffer significant louse-induced mortality on their outward migration and that co-ordinated late winter fallowing of farm sites reduces this mortality. The overall pattern of increasing catches indicates positive benefits from the move to area-based management.

The River Awe, another major salmon fishery, enters area A at the south end of the Linnhe system near survey site 4. Salmon smolts leaving the Awe will swim through a small section of area A on their migration towards the open sea. Lice infection recorded at site 4 indicates little between-year variation in louse infection pressure, contrary to the situation in the upper loch. Figure 4 shows the rod catch of grilse in the Rivers Awe and Orchy over the past four production cycles (8 years). Unlike the upper loch, there are no alternating years of high and low grilse returns.

Conclusions

The findings can be summarised as follows:

i) co-ordinated fallow breaks are effective in protecting wild fish where neighbouring farms are on the same production cycle;

ii) co-ordinated fallow breaks are less effective in areas where farms on opposite production cycles are in proximity, such as at the periphery of a management area;

iii) the lack of fallowing at rainbow trout farms may increase lice infection pressure during fallow breaks on salmon farm sites;

iv) louse infestations remain a serious threat during year 2 of production;

v) the overall impact of area management has been positive for wild salmon.

Lessons and challenges

The value of area management for wild salmonids

The results of the Linnhe study clearly suggest that the move to area management with synchronised production and co-ordinated fallowing has benefited wild salmon in rivers such as the Lochy. The recovery of the Lochy has been matched by improvements in salmon numbers in neighbouring rivers such as the Nevis, Coe, Scaddle and Cona (Lochaber Fisheries Trust, unpublished data). While problems for salmon post-smolts remain during year 2 of farm production, these are not of a magnitude which now threatens the viability of the salmon population. Mixed smolt and sea ages ensure that populations still continue to recover in the Lochy, even though a pattern of relatively weak and strong year classes may continue.

Problems encountered during year 2 of production suggest that from a wild salmon perspective, co-ordinated fallowing should encompass as large a part of the near-shore migratory route as possible. In long, fjord-like sea lochs it is essential that single year class management and co-ordinated fallowing are implemented throughout the full length of the loch system. Where such co-ordination is now in place, any move to fragment production or reduce the level of co-ordination potentially threatens wild salmonids and should be avoided.

The inadequate protection of wild fish in year 2 of production may partly be due to the poor efficiency of most medicines in killing louse egg-strings, permitting eggs to hatch even post-treatment. Furthermore, development time from egg to infectious larva (copepodid), when the louse must attach to a host, is from 12 to 22 days at 10ºC and longer at lower temperatures (Johnson and Albright, 1991). Hence, lice larvae can potentially infect wild fish for up to several weeks after farms treat. Co-ordinated treatments against lice should be conducted on all farms in their second year of production and this should be done sufficiently early to protect wild smolts.

At the periphery of the Linnhe AMA it was found that the fallow break was less effective in controlling lice infestations than in the inner loch. The reasons for the lack of consistent biennial variation at site 4 are unclear, but may relate to drift of lice larvae from production areas B and C, movements of sea trout between production areas or larval production from rainbow trout farms near site 4, which are never fallowed. The presence of rainbow trout farms should be considered in developing management agreements and, where necessary, they should be subject to spring louse treatments when fallowing cannot be implemented.

The protection of sea trout remains a serious challenge. Sea trout range along coasts and may move in and out of adjacent management areas during their time at sea. Furthermore, West Highland sea trout historically were slow-growing and long-lived (Nall, 1930). In order to reach a size at which significant numbers of eggs are being deposited, sea trout must experience more than one year of marine feeding. The collapse of West Highland sea trout resulted not only from reduced numbers of fish, but also from a near-total loss of older age classes (Walker, 1994). These older fish are still very scarce or absent from most systems. Evidence from Ireland suggests that only where low spring lice levels can be maintained for two or more years will sea trout populations begin to recover (Gargan, 2000).

Challenges

A recent review of the TWG process (TWG, 2005) concluded that:

"….progress has been made in many areas; but more could and should have been achieved by now. However, what is clear is that the process has been positive and should continue with renewed determination…".

The authors concur with this view. From a wild fisheries perspective, it seems clear that area-based management of fish farms is an essential tool in reducing impacts on wild stocks, and that it has shown significant benefits in some areas. It is only by co-ordination of activities across biological areas, in an integrated pest management strategy, that the salmon farming industry can hope to effectively tackle sea lice, which remain a serious threat to wild stocks. Wild fish interests should continue to encourage the development of area management across Scotland, based on principles of synchronised production, co-ordinated fallowing and optimal lice treatment strategies timed to protect migrating post-smolts.

While area-based management potentially offers benefits to wild fisheries and should be supported, it would be naive to assume that problems will disappear if AMAs are signed throughout Scotland. A number of serious technical, managerial and 'political' weaknesses in the process and structure of the initiative will continue to impede rapid progress and will compromise effectiveness. Some of the most commonly encountered issues are summarised in Tables 2 and 3. Resolution of these issues poses continued challenges for the future of the TWG process and for the development of individual AMAs.

There is no doubt that a number of the issues highlighted in Tables 2 and 3 result from a long history of sectoral animosity between farmed and wild fish interests, and the fact that the Scottish salmon farming industry grew rapidly with no area management structures in place. Imposing such structures on a mature industry where new sites are scarce, as in Scotland, poses very real problems for fish farmers. In countries such as Canada where the salmon farming industry is relatively small but growing, area-based management systems must be built into the planning and statutory framework governing developments. It is much easier to design area management into a growing industry than to try to implement it *post-hoc*.

Table 2
Technical challenges in the Scottish AMA process

Issue	Comment
Attainment of synchronous production	• Requires relocation of production in space and/or time, with associated costs; • Difficult for small, local producers with a limited number of sites in a single management area (mainland problem and especially a problem on Orkney and Shetland with numerous small producers).
Definition of management areas	• Differing views from fish farmers and wild fish interests. Small areas maximise flexibility for fish farmers while large areas maximise protection of wild fish; • Lack of scientific underpinning in determining biological areas, especially for sea louse control.
Reducing lice threat in year 2 of production	• Optimal timing of treatment to protect wild smolts may be earlier than desired by fish farms (especially use of Slice which farmers prefer to keep back to provide protection in summer); • Availability of effective medicines in adequate quantities may be limiting.

Target levels for lice treatments	• Extreme low levels of gravid lice may cause problems to wild fish, while not creating problem on individual farms. Tensions over the need to treat arise; • Target levels likely to vary between areas due to varying tonnages and local hydrography. Need for improved collection and collation of monitoring data; • In many areas, it remains unproven whether low enough lice levels can be maintained in order to allow recovery of sea trout.
Escapes	• AMAs provide forum for contingency planning, but recaptures are rarely effective; • AMAs should be used to help drive improved containment procedures, but enforceable codes of practice and industry standards likely to be more effective.
Broodstock sites	• Long production cycle (4 years) may increase threats to wild populations; • Difficult to integrate broodstock sites into synchronous management; • Strong case for relocation, if possible to shore-based sites.
Organic production	• Need for clear guidance on if and how organic production can be integrated to area management and integrated pest management strategies.

Table 3
Administrative and 'political' challenges in the Scottish AMA process

Issue	Comment
Confidentiality	• Data, e.g. sea louse levels collected within AMAs, are held confidentially by AMG, reducing the ability for AMGs to learn from experience in other areas; • No national or regional collation of data is possible, so detailed data from AMAs cannot be used to inform national policy or strategy; • Undermines public confidence and accountability (AMA process is publicly funded); • Isolates wild fish representation from those they represent.
Sectoral interests still prevail	• Most AMGs operate with representation only of fish farmers and wild fish organisations. Non-aligned, technically competent advice (e.g. from government scientists) is rarely sought or when it is, may not be forthcoming; • Concerns from farming industry re. confidentiality limit scope for bringing in wider representations or technical help.
Voluntary process	• Agreements are unenforceable and rely on goodwill – a potential weakness as well as a strength; • Uptake of AMAs cannot be enforced though planning or other controls; • Adherence to agreements cannot be enforced, even when signed; • 'Bad apple' effects – need for legislative and planning backup?
Education	• Fish farmers in some areas continue to maintain that their industry has no impact on wild stocks. This stance prevents realistic dialogue in AMA development; • Wild fish organisations may refuse to be involved, due to continued animosity and lack of understanding of potential AMA benefits; • Problems are often better publicised than solutions or successes.
Organisation and representation	• Fragmentation of wild fishery interests in areas without Fisheries Boards or Trusts creates problems in identifying representative parties; • Lack of progress in Shetland and Orkney is partly due to lack of organisational focus existing in wild or farmed fish farming sectors.

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Area Management Initiatives - Session Chairman's Summary

Gordon Brown, Scottish Executive Environment and Rural Affairs Department

I think we have had a very interesting session on area management initiatives and I must say I have been struck by the emphasis given in the presentations to the common interests of the wild and farmed salmon sectors, sharing as they do a common environment. There is clearly a need for commitments from all parties, on the basis of equal partnerships, if area management initiatives are to be successful and contribute to the conservation of the wild salmon and the continued development of a sustainable industry. I have also been struck by the different approaches being employed in the area management initiatives described which range from project- and research-based actions to full-blown area management agreements. However, it is clear that whatever the nature of the initiative, it is vital that it reflects the needs of the area in question.

During the lively discussion that followed the excellent presentations, we explored some of the concerns about area management initiatives and two main issues arose. These are whether area management initiatives should be voluntary or statutory and the transparency of the process (including the important issues of confidentiality of information and third party involvement). These are real issues that will need very careful consideration if we are to build on the early area management initiatives and develop the process into the future. However, what has been heartening to me has been the success of the initiatives described, which have in some cases led to dramatic declines in the need for sea lice treatments on the farms, and the co-operation locally between the parties when problems arise. The lessons that are emerging from these local cooperative initiatives will, I hope, inform future developments.

Area management is a process and while there have been some quick "wins" it is not always going to be like that and there may be a need to take a longer-term view. Building confidence and trust can take time but they are essential to the success of area management initiatives. We are looking for a "win-win" result in which both the wild and farmed salmon interests benefit. My take-home message is that wild and farmed salmon interests must work increasingly closely together for the future of both endeavours and that area management initiatives, involving as they do cooperation between these and other parties, are very worthwhile. They can deliver results that benefit both wild and farmed salmon and we should seek to enhance and expand such cooperative initiatives in the future.

Pros and Cons of Using Sterile Salmon in Farming and Possible Opportunities for Cooperative Trials

An overview of methods of control of maturation in salmonids

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Introduction

When fish mature they experience lowered food conversion efficiency and suffer declines in flesh condition and appearance. Consequently, maturing fish have less sales value. Eliminating maturation in farmed stocks should make the rearing-cycle more predictable, thereby improving yields and increasing overall economic performance. Fish farmers first leant towards genetic selection for later maturity as the means to achieve better control of maturity but this was expected to have a long lead time. Accordingly, more direct interventionist methods were studied and it is these that are the subject of the current paper.

The drive towards reproductive control was initially farming-based and primarily economic. But with the growth of the industry in Europe into Atlantic salmon cultivation in sea cages, it soon became obvious that fish were escaping in large numbers. Wild populations of Atlantic salmon were at that time suffering declines throughout the geographical range and conservationists feared that farmed escapes were part of the threat to wild stocks since they had the potential to return to fresh water and breed with wild fish, thereby modifying their genetic make-up. The goal of sterility for farmed fish for growing in sea cages therefore came to be seen to be of additional advantage in minimising this introgression threat.

Direct control of maturity in salmonids has been attempted by physical, chemical and biological methods. The feasibility, efficacy, costs, societal and industry perceptions, and potential contribution to mitigation of the introgression threat of each of these is briefly summarised below.

Direct methods of maturity control

Surgical removal

Castration has a long history in farming practice. It is perhaps not therefore as surprising as might first be thought that attempts at fish gonadectomy were made by veterinarians early on in salmon farming practice in Scotland (Lydia Brown, personal communication). But in fish, the sexual organs are borne internally, and more radical surgical procedures are required to induce sterility than are typical of land animals. Experience showed that complete removal, consistent with short operating times and good recovery, was problematic. Survival rates were variable, the loss of growth following operation was considerable, and any gonadal material remaining after operation was capable of producing sufficient hormones later in development to bring about all the typical signs of maturity. In addition to these costs there are the costs of the veterinary service itself. Accordingly, the approach was never developed beyond the earliest stages, and, with the benefit of hindsight, we might now conclude that since, for welfare reasons, societal and industry concerns about its application might be considerable, it is an approach that is very unlikely to be reconsidered. It also follows that since the efficacy of the method is questionable, its effects on reducing the introgression threat would be correspondingly in doubt.

Immune castration

In the early stages of the application of immunology to aquaculture, immunologists thought it might be possible to immunise fish against their own sex cells with a view to controlling their reproduction. However, the experimental results of Laird and her associates based at Stirling and Aberdeen Universities in Scotland were disappointing (Laird *et al*., 1978). Although fish could be stimulated to form antibodies to some components of gonad cell suspensions, there was little evidence that this was sex-cell-specific or that inoculation caused material delay or alteration in actual maturation. Even today, when the administration of vaccines against specific diseases is commonplace in aquaculture, the logistics of administration is not without its problems. Animals must be given sufficient temperature/time to develop the necessary protection after inoculation and intra-peritoneal injection can cause adhesions between viscera and the belly wall, leading to the downgrading of some carcasses. Although there was earlier discussion of immunisation against the reproductive hormones produced by the pituitary, the immunisation route method has not, to this author's knowledge, been progressed further. As with surgical castration, it is imagined that it would be of doubtful benefit in reducing the introgression threat.

Irradiation

Rapidly-dividing cells are particularly susceptible to gamma irradiation. In the relatively late stage of embryological development, around the eyed ova stage, the primordial sex cells in salmonids rapidly increase in number and populate the primitive gonads. Thorpe and his co-workers in Scotland conducted experiments to ascertain to what degree exposure to irradiation might affect these processes (Thorpe *et al*., 1987). The results were of some encouragement but achievement of high levels of sterilisation required close attention to timing of administration, and optimal sterilisation doses had greater effects on growth and incidence of mortalities. In addition, there are likely to be logistical and, we can now imagine, societal difficulties with its application since consumers and welfare organisations might be less supportive of its use. If used, it would reduce, but is unlikely to eliminate, the introgression threat.

Androgen administration

Androgen administration was originally used for sex reversal purposes since it was noted that males mature earlier in the farming production cycle than females. It was hypothesised that if all-female stocks could be produced and reared, maturity might be delayed to overall economic gain. In the salmonids so far studied, the female is homozygous for sex (XX). Numerous studies have shown that if an appropriate dose of androgen is administered during a critical window, sexual development can be significantly altered and may be readily reversed. By these means, prospective genetic females can be turned into functional males and the male-determining Y chromosome thereby eliminated from subsequent male/female crosses. This in turn leads to the production of all-female stocks without administration of hormone to the stocks that are to be reared. All-female stocks are now commonplace in rainbow trout farming in Europe.

One limitation of sex reversal by androgenisation is that the doses used for reversal have sterilising as well as sex-reversing properties. This lowers the yields of usable reversed males, making the sex-reversal process itself comparatively inefficient. The sterilising effect is greatest at higher doses and this led Donaldson and his co-workers in west coast Canada to study the effects of androgen at doses higher than those required for sex reversal (Solar *et al*., 1986). When considered in isolation, the results of these studies were very encouraging. Sterility was sufficiently long-lasting and returns of released migratory animals back to fresh water were lower than in untreated stocks since animals stayed at sea to feed. But, in a wider view, there must be doubts about its feasibility since the method might not gain regulatory approval given societal concerns about food additives and residues, however poorly informed these might be. Overall then, although the cost of treatment itself might be low, the costs to farmers related to any adverse consumer perception of the product might be high. And, although its efficacy might be high and the introgression threat, should hormone-treated animals escape, be much reduced, it is unlikely to be eliminated.

All-female triploid using high hydrostatic pressure

Triploid salmonids have three, rather than the normal two, sets of chromosomes and occur very rarely in nature. At the moment of fertilisation, the salmonid egg contains two sets of maternal chromosomes, one of which is normally extruded when the sperm enters the ovum, thereby re-establishing the diploid condition. These events are orchestrated on a transient intracellular structure called the spindle. Both maternal chromosomal sets can be readily made to contribute to the embryonic genome by a variety of methods, all of which temporarily cause the spindle to dissolve. Subsequent mitotic divisions in triploids (a doubling of chromosome number followed by a reduction to two halves) are unaffected, since the spindle readily reforms after its artificial dissolution and balanced chromosomal sets can be produced (three is doubled to six then halved to three again). Subsequent meiotic divisions (a doubling followed by two reductions) are compromised because of the odd number of chromosomes present at the second reduction (three becomes six, becomes three, becomes ~ 1.5). Triploids are therefore reproductively sterile. Of the available methods (heat shock, anaesthetics, pressure) most would agree that pressure is the technique that most consistently generates the highest triploid rates at the highest survival rates. 100% triploid rates at high yield can be obtained if the correct treatment parameters are chosen. The mass production of triploid salmon using high pressure at high triploid yields requires specialised equipment but is readily feasible and affordable. Although triploids are reproductively sterile, most males, but only a very small proportion of females, become hormonally competent, a reflection, it is thought, of the different cellular architecture of testes and ovaries.

So, for Atlantic salmon aquaculture, all-female technologies must be combined with triploidisation if reproductive control is to be maximised. This adds an additional layer of complexity to the management task of ensuring that the right stocks are available for use in subsequent farming years, and the management costs of all-female triploidisation are not trivial. As regards their subsequent performance, industrial experience of rearing triploids has exposed additional concerns. Triploid Atlantic salmon grow little differently from diploids in fresh water and smolt yields are little affected. In sea water they grow like non-maturing diploids. However, in industry trials a greater incidence of mortalities and of deformities, including cataract formation, have been reported (see other contributions in this volume). For these reasons they have never become commonplace in Atlantic salmon aquaculture.

Although there has been minimal reported actual confirmation of triploid reproductive sterility, there is no reason to believe that the real triploid is reproductively competent. In the author's direct experience, the ova obtained from the very few eggs that were produced from maturing female triploids could not be fertilised with normal sperm. But the very few maturing female triploids that have been seen have produced near-normal levels of steroids. They can be expected to behave as if they were reproductively normal. They may therefore compete on spawning grounds with wild fish if they escaped from rearing facilities and returned to fresh water. When triploid Atlantics were released in Ireland fewer animals returned to fresh water (Wilkins *et al.*, 2001). Since it is only sensible to rear all-female triploids, the concern would be that hormonally competent, albeit reproductively incompetent, triploid females would consort with wild diploid males. This might be to the detriment of the stock in the sense that any diploid sperm so used would be wasted. Whilst this cannot be ruled out, it would be very infrequent since most triploid females never mature.

Overall then, although the use of triploids is expected to eliminate the introgression threat, triploids are not currently seen by farmers as being of equivalent aquaculture potential as diploids. It has been suggested that the underlying reason for the poorer industrial performance of triploids is that they have a reduced aerobic capacity. It is hypothesised that current rearing methodologies which are suitable for diploids are manifestly unsuitable for triploids and tailored rearing programmes need to be developed. The adverse perception by farmers of triploids might therefore be changed if the underlying reasons for their poorer performance could be understood and managed to match that of diploids. Although animal welfare lobbyists do not presently support the use of triploid technologies, because of the greater degree of deformity that has been observed, it is less clear what the overall societal opinion might be of their use. For some it may be a manipulation too far. For others it may be that they could appreciate that triploid use, and through it the mitigation of a potential threat to a charismatic wild species, was a balance that could be accepted.

Table 1

Illustrating and summarising the advantages and disadvantages of the different direct methods of maturity control in salmon (see text for additional explanation). The shading in each box is a representation of the relative worth of each technique where light grey is worst and dark grey is best. If the scoring in each cell is accepted, it can be seen at a glance that all-female triploid is the 'best' of the currently studied techniques.

Method	Feasibility	Efficacy	Overall Costs	Public Perception	Industry Perception	Interaction effect
Surgical castration	Uncertain	Low?	High?	Against?	Against?	Unknown No gain?
Immune castration	Uncertain	Low?	High?	Unknown?	Against?	Unknown No gain?
Irradiation	Uncertain	High?	Uncertain / High?	Against?	Against?	Reduced?
Androgen administration	Uncertain	High	Uncertain / High?	Against?	Against?	Much reduced
All Female Triploid by High Pressure	Ready	~100%	Affordable?	For?	Against?	Eliminated

- ve [shading scale] + ve

Conclusions and additional observations

The paragraphs above are summarised in Table 1. Of the presently available direct maturity control solutions, it is concluded that only the use of all-female triploids has the probable level of feasibility and efficacy to merit continuing consideration as a potential method of eliminating the introgression threat to wild Atlantic salmon posed by escapes of farmed salmon. If applied at its current level of understanding, however, it would reduce the economic efficiency of an industry that is already under economic strain. Whether wider societal opinion would be for or against such an approach is not known, not least because the issue continues, in this author's view, to be fairly low on the societal horizon. It may also be due to the lack of common metrics which might be used to evaluate the relative costs to industry on the one hand, and the costs to society if the wild salmon was lost from substantial parts of its former territory, on the other. The introgression threat is only one of the potential impacts that farmed escapes might have on wild stocks and triploid use would not mitigate any threats from disease or parasite burdens carried on farms. It has therefore been suggested that this is an area where the precautionary principle should be invoked, i.e. there is enough reason to believe that irreversible consequences might flow to stock diversity from continuing escapes from aquaculture, as to insist that aquaculture at sea ceases to operate, or is made to operate in a different way (NENT, 1997).

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Minimising the impact of farmed salmon on wild stocks

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The production of all-female triploid salmon

The process of sterilizing Atlantic salmon and other species of fish by triploidization is now well established. The major biological effects of the process are understood (see recent reviews by Benfey, 1999 and Tiwary *et al*., 2004), a number of different methodologies are available and the growth and performance of treated fish have been widely investigated.

To our knowledge the studies summarised here (from Cotter *et al*., 2000, Cotter *et al*., 2001 and Wilkins, Cotter and O'Maoiléidigh, 2001) are the only ones to have evaluated the migration to sea, and the return spawning migration, of ranched and cage-escaped triploid salmon at commercial and pilot-scale levels together with the comparative performance of triploids and diploids in sea cages. These studies were carried out in conjunction with colleagues in Scotland and Norway, with the support of the EC AIR programme.

The procedure we adopt in producing triploid salmon is illustrated in Figure 1. It involves two separate phases and requires almost four years for full evaluation. Firstly, sex-inverted (chromosomal XX) males are produced by feeding male hormone to first-feeding regular fry for a short period. The treated fry are then reared normally with no special diet or rearing conditions. Precociously mature males may occur, or can be induced, within the treated group towards the end of their first year. Two kinds of precocious males can then be identified, viz. sex-inverted (XX) and regular (XY) males. The sex-inverted, precociously mature males are used as sires to fertilize the eggs of regular females. Sex-inverted males held in fresh water for one or more additional years can also be used when they mature. All the eggs fertilized by the sex-inverted males will grow to be female salmon. This ends the first phase of the process after one year. Note that no chemical or hormone has been administered to the "all-female" eggs.

The "all-female" eggs are then triploidized by pressure shock. This involves subjecting them to high hydrostatic pressure in a special containment vessel for 10 minutes soon after fertilization. The eggs suffer very little adverse effect from the treatment and immediate mortality of treated eggs is not much greater than that of untreated controls. The pressure vessel we use can treat up to 12 litres of eggs at each pass (about 80,000 eggs), which takes about 15 minutes to complete. Over 250,000 eggs can be treated in one hour. In the experiments we also triploidize batches of ordinary mixed-sex eggs (i.e. eggs that will produce both males and females in the normal way) in order to provide proper controls with which to compare the all-female triploids.

The treated eggs are incubated and the resultant alevins grown in the routine manner; they require no special treatment or conditions. Triploidization is effectively 100% successful in our operations.

We have found the growth of triploid salmon in fresh water to be comparable to that of immature diploid siblings, an observation also made by others (e.g. Johnstone *et al*., 1991; Johnstone, 1998). As expected, some losses were observed due to the pressure treatment, incomplete triploidy induction (aneuploidy) and the occurrence of individuals made homozygous for deleterious alleles. At first feeding, triploid fry were slower to accept food and failure to feed was greater than with diploids. However, the majority of losses were sustained in the very earliest rearing stages and therefore did not have any economic or commercial consequences.

Triploids smolted as normal in spring of their second year and were either released in a ranching operation or transferred to sea cages at a commercial fish farm to be grown-on. This marked the end of year two of the cycle. The growth and performance of cage-cultured fish were examined

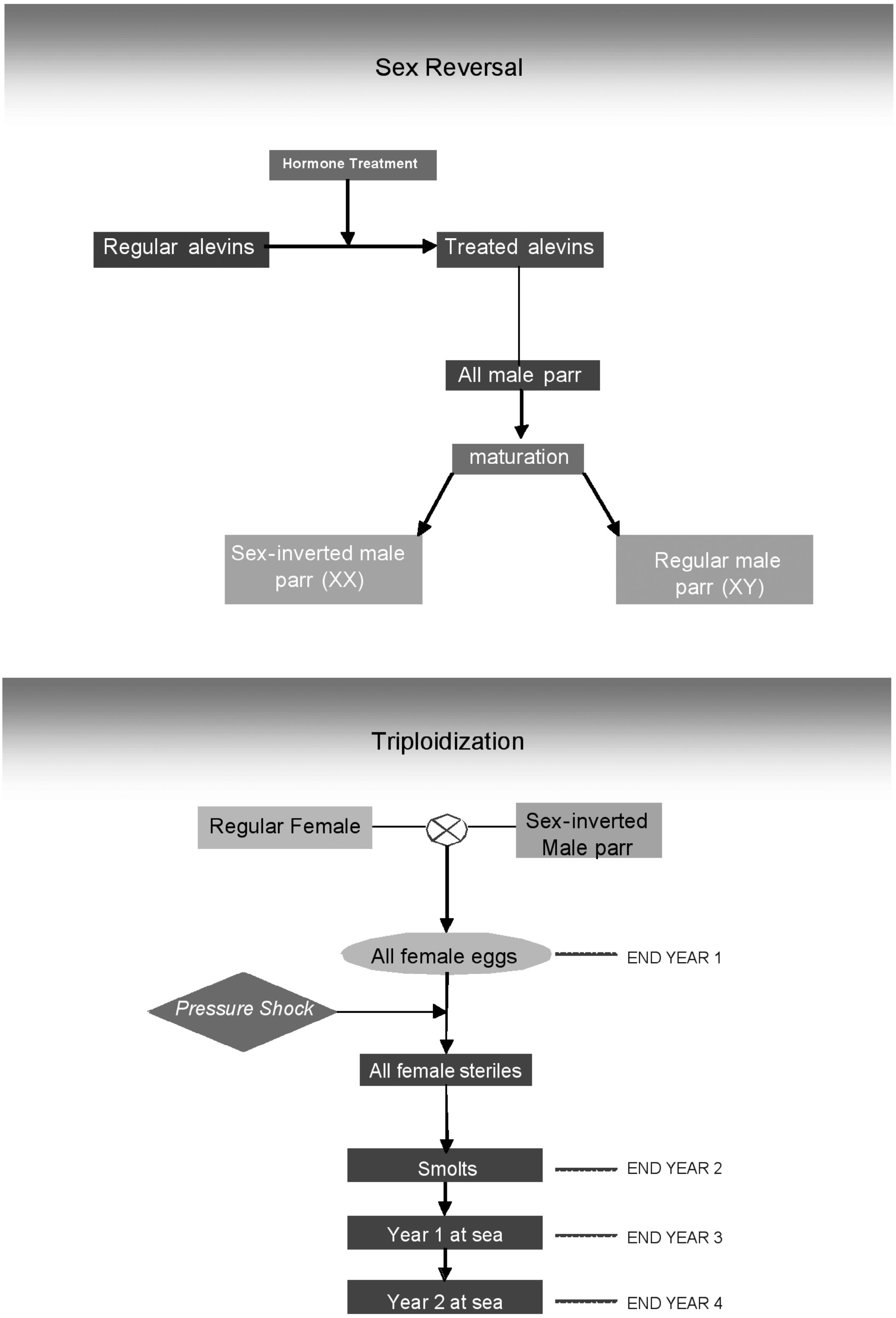

Figure 1
Protocols and timetable for production of all-female cohorts of salmon and subsequent triploidisation

during and at the end of their first year at sea; ranched fish migrated away from the release river and were not encountered again until they entered the commercial net fishery on the coast, or entered the hatchery trap, the following year. This marked the end of year three of the cycle. Some fish were released from the cages after a few months after transfer to sea. These, too, migrated away from the release site and could not be investigated until they returned, if they did so. The final examination of those fish that remain in cage cultivation, or those returning from the sea two years after release or escape, marks the fourth year of the cycle. The timescale of a complete cycle, as indicated in Figure 1, must be borne in mind when commencing the process: a decision taken at this meeting, for instance, to initiate a cycle of all-female triploid production and evaluation would not finish until December 2009 at the earliest.

Triploids and the wild stocks

Cultivated salmon can interact negatively with wild salmon in a number of serious ways: they can introgress with them (essentially spreading their genes by interbreeding with wild fish); they can interfere physically with wild fish on the redds, even if they do not interbreed successfully with them; and they can compete with wild salmon for resources like food and space either at the juvenile or the post-smolt and adult stages. Because triploids are sterile, their use in the salmon farming industry is often advocated as a way of reducing these negative interactions.

All the triploid females that we examined in the adult stage were fully sterile, with severely retarded ovarian development and consistently low gonadal steroid hormone levels. They could not interbreed with wild salmon, and their use in salmon farming would eliminate entirely the possibility of introgression with wild salmon at any stage of the life cycle.

However, not all the triploid adult males were sterile. Development of the testes was observed in some, their gonadal hormone levels were similar to normal diploid levels, and they showed the normal deteriorative carcass changes associated with sexual maturation. Triploid males therefore could, possibly, interbreed with wild salmon. But the milt produced by triploid males was sparse and dilute. When used to fertilize normal eggs it gave a greatly reduced number of hatched alevins, most of which exhibited “haploid syndrome” and none of which survived to first feeding. Therefore, the likelihood of significant introgression from triploid adult males is very small. The greater potential threat is that these reproductively inadequate males could disrupt the spawning of normal wild males on the redds (for example by competitively displacing the mature wild males, or mating unsuccessfully with wild females), thereby reducing the success of native salmon spawning. It is for this reason that we favour the use of “all-female” stocks if triploid salmon are to be used to minimise negative interactions with wild fish. This is especially important in instances where cultured juveniles may escape from freshwater facilities. There is good evidence that precocious male parr contribute in an important way to the total reproductive effort of a salmon stock by surreptitious participation in the spawning activities of adults. Such precociously mature male parr can be common in hatcheries, but very few were observed in our triploid mixed-sex groups.

The potential for adult triploid salmon to interact in any way with spawning adults requires, of course, the presence of such adult triploids in the freshwater environment. This is why it is important to know the likely migratory behaviour of triploids in the sea. If the fish are sterile, do they possess, and do they activate, the hormonal and other physiological mechanisms that induce normal diploid salmon to migrate back to fresh water? In our unique studies we have ranched micro-coded-wire-tagged triploids and their diploid siblings from fresh water, and we have released them from sea-cages, with a view to determining their return behaviour to fresh water. The results are shown in Tables 1 and 2.

The return of triploids to the coastal net fishery and to fresh water was greatly reduced relative to that of their diploid siblings. The number of all-female triploids that actually entered fresh water (maximum 0.31% of releases) was very low. All-female diploids had a return rate to fresh water up to three times greater. Up to 1.20% of mixed-sex triploids entered fresh water compared with 5.15% of diploids. Some of these mixed-sex triploids were males, so that there was some potential for interaction with wild fish on the redds, had these fish not been removed from the trap.

From these results we can conclude that triploid all-female salmon cannot introgress with wild fish and because of the considerably reduced numbers returning to fresh water the potential for negative competitive interactions between triploids and mature wild fish on the redds is greatly reduced; juvenile triploids present no genetic threat to wild fish.

	Number released	Number recovered at sea	Number recovered in fresh water	Total number recovered
Ranched 1				
Diploids	4,860	140 (2.880)	45 (0.93)	185 (3.81)
Triploids	4,801	35 (0.73)	10 (0.21)	45 (0.94)
Ranched 2				
Diploids	2,741	25 (0.91)	19 (0.69)	44 (1.61)
Triploids	2,856	8 (0.28)	0	8 (0.28)
Ranched 3				
Diploids	1,097	3 (0.27)	1 (0.09)	4 (0.36)
Triploids	1,279	3 (0.23)	4 (0.31)	7 (0.54)
Cage release 1				
Diploids	1,065	48 (4.51)	0	49 (4.60)
Triploids	1,086	6 (0.55)	1 (0.09)	7 (0.64)
Cage release 2				
Diploids	1,632	67 (4.11)	0	67 (4.11)
Triploids	2,290	10 (0.44)	0	10 (0.44)

Table 1
Release and recapture of tagged diploid and triploid all-female salmon. "Ranched 1" was released from Burrishoole, Co. Mayo; "Ranched 2" and "Ranched 3" were released from the River Shannon. "Cage releases 1 and 2" were released from sea-cages in Co. Donegal. Values in brackets are percentage returns from release. (Data from Cotter et al., 2000; Wilkins et al., 2001).

	Number released	Number recovered at sea	Number recovered in fresh water	Total number recovered
Ranched 1				
Diploids	4,897	109 (2.23)	110 (2.25)	219 (4.47)
Triploids	4,867	25 (0.51)	28 (0.58)	53 (1.09)
Ranched 2				
Diploids	9,405	447 (4.75)	484 (5.15)	931 (9.90)
Triploids	9,354	80 (0.86)	112 (1.20)	192 (2.06)
Ranched 3				
Diploids	2,865	26 (0.91)	10 (0.35)	36 (1.26)
Triploids	2,779	8 (0.29)	3 (0.11)	11 (0.40)
Ranched 4				
Diploids	1,320	17 (1.29)	7 (0.53)	24 (1.82)
Triploids	1,369	3 (0.22)	1 (0.07)	4 (0.29)
Cage release 1				
Diploids	1,061	28 (2.64)	0	28 (2.64)
Triploids	1,084	5 (0.46)	1 (0.09)	6 (0.55)

Table 2
Release and recapture of tagged diploid and triploid mixed-sex (male plus female) salmon. "Ranched 1 and 2" were released from Burrishoole, Co. Mayo. "Ranched 3 and 4" were released from the River Shannon. "Cage release 1" was released from sea-cages in Co. Donegal. Values in brackets are percentage recovery from release. (Data from Cotter et al., 2000; Wilkins et al., 2001).

Since so few of the triploids returned to the coast or the river their fate at sea is not known. They did not return in any later year either. If they remained alive in the feeding areas, then it is possible that the accumulation of non-returning triploids could present significant competition for wild salmon at sea, especially if the triploids remained close to the coast where migrating wild post-smolts are foraging immediately after entering the ocean. However, we speculate that the survival of triploids beyond the first year at sea is likely to be small. But the greatest potential for competition from triploids is that posed by the escape of juveniles in fresh water, where they will share the limited food resource with native wild parr and smolts. While triploidy will not reduce this competition should cultivated salmon juveniles escape, it will not increase it either, so that the effect of escaping triploids relative to diploids will be neutral at worst.

Triploids and the salmon farmer

The potential benefit to the wild stocks of using only triploid salmon in fish farms appears from these results to be significant. But do triploids present any benefit to the farmer that might recommend their use on commercial grounds, independent of their value for conservation purposes?

The major features that may influence triploid acceptability to the industry include growth performance in sea-cages, frequency of abnormalities and deformities, disease susceptibility, general hardiness and market acceptability. Hardly a salmon farmer is without an opinion, based largely on anecdotal evidence, regarding these topics. We have examined the survival and growth of triploids compared to diploids in a commercial salmon farm in Ireland. Mortality was greater in triploids than in diploids under conditions that were far from suitable even for diploids (an infestation of a gill parasite occurred in August while temperatures exceeded 19°C and oxygen levels were low (<7 mg/l) causing severe mortalities in all groups) (Table 3). Weight at harvest was greater in diploids than in triploids but this was not sustained when dress-out weight was measured (Table 4) due to the differing degree of maturation of the gonads: all triploids were sterile with gonad weights less than 1g (gonadsomatic index <0.07), whereas 93% of the diploids were maturing sexually with gonad weights ranging from 13g to 90g. Their lower condition factor indicates that triploids were slimmer at harvest than diploids of equal length, a feature that makes them visually more streamlined and shapely.

Further comparative studies of triploids and their diploid siblings need to be carried out in sea-cages before the relative performances of the groups can be fully and adequately evaluated. Nevertheless, the relative performance of triploids and their final dress-out weights suggest that they may prove useful for production over 17 months in the sea – say up to December of year 2.

Period	Cumulative weeks	Cumulative % loss diploids	Cumulative % loss triploids
April - June	11	16.41	16.30
June - August	17	16.71	17.30
August - October	26	60.41	70.00
October - May (Harvest)	58	61.70	73.10

Table 3
Cumulative percentage mortalities of diploids and triploids under adverse sea-farm conditions in 1997 – 1998 (summarised from Cotter et al., 2001)

The greatest potential for commercial benefit lies in the sterility of female triploids that enables them to be retained in culture as long as desired without any appearance of the deteriorative carcass traits associated with sexual maturity. This benefit will accrue mainly during the second year of cage culture, after the non-sterile salmon have been harvested. To date it has not been possible to carry the evaluation into the second year of sea-cage culture.

The incidence of deformities in graded fish during the early months at sea was low, 0.3% in diploids (n=367) and 0.6% in triploids (n=360). Later, at harvest, 10% of diploids and 3% of triploids were recorded as deformed. Both groups exhibited cataracts, 27% of triploids and 9% of diploids being affected. Overall, the results suggest that the influence of triploidy on deformity may be stock-specific and deformity-specific, triploidy being beneficial in some cases and detrimental in others. In fact, studies at all life stages suggest that growth, conformation and performance are stock-specific traits in triploids just as they are in diploids, and it is necessary to evaluate each stock individually in order to obtain optimum production at any site. Indeed, inter-family variability is as marked in triploids as in diploids and this should be considered in any evaluation of triploidy. Such consideration is as essential with diploids as with triploids and does not constitute an insuperable barrier to the use of triploids.

	Diploid Mean ± S.E.	**Triploid** Mean ± S.E.
Whole weight (Kg)	2.76 ± 0.04	2.58 ± 0.05
Dressed weight (Kg)	2.49 ± 0.03	2.40 ± 0.04
Viscera weight (Kg)	0.27 ± 0.005	0.18 ± 0.005
Condition Factor	1.54 ± 0.016	1.22 ± 0.016

Table 4
Mean and standard errors of whole weight, dressed weight, viscera weight and condition factor in diploids (n=100) and triploids (n=100) at harvest after 58 weeks of growth in sea cages (Cotter et al., 2001)

Where to from here?

At this time a number of issues remain to be addressed and commercial-level trials need to be repeated. That the use of triploids in salmon farming would reduce the impact of farmed escapees on wild stocks seems established beyond reasonable doubt. A commercial benefit to the farming industry from the use of triploids is less clearly established to date. Of the outstanding issues, the most important is the growth and relative performance of triploids during the first and, more especially, the second year of culture in the sea. This latter period is the one when sterility offers its main commercial benefit. Despite many attempts, we have been unable to find any salmon farmers willing to retain triploids in sea cages into the second year and we conclude from this and other considerations that there is no real interest in the evaluation of triploids by the salmon farming industry at this time. Reasons why this may be so are not too difficult to suggest.

If fish farmers can increase growth rate, by husbandry or genetics, or a combination of these, so that bigger, non-maturing salmon are produced within one year or even less, then the need to retain fish for a second year becomes unnecessary, and triploidy becomes commercially irrelevant. This is the case with those who use multi-sea-winter stock. Secondly, where regulatory authorities insist on single-year culture at a site, with annual fallowing, triploids can be retained into the second year only if the farmer has access to more than a single site. This is a real disincentive to the use of triploids, especially by smaller operators. There is, too, uncertainty regarding the effects of other regulations, especially in the matter of product labelling. If, for example, regulators insist on the retail labelling of triploids as such, then consumer perceptions, rightly or wrongly, may turn negative towards the product, perceiving it to be “genetically altered”. Is it unreasonable to suggest that competitor producers from outside the EU, who may not face similar strict regulation, will quickly see a marketing advantage to themselves in such EU labelling requirements?

We believe that it is uncertainties like these that are causing the industry to hesitate in cooperating with the evaluation of triploids for commercial production. Unless the goodwill that is signalled by the NASCO/Industry Liaison Group is now translated into positive action and active cooperation in evaluation studies, the only reasonable conclusion will be that the industry is simply not interested in the triploid approach, notwithstanding its benefit to threatened wild stocks. If this is so, the industry needs to make its position absolutely clear; NASCO for its part needs to hear the message accurately. If we cannot agree to progress the necessary further trials at this meeting, then the timetable of the procedure (4 years) means that the full evaluation of triploids will not be completed until year 2010 at the earliest. It is beyond time to act or move on. The benefit to the NASCO/Industry Liaison Group parties themselves, especially to the industry, of continuing discussion and “verbal engagement” with triploidy is clear enough. But both parties need to interpret realistically the actions, not just the words, of the industry so that this issue can be relegated to the back burner if appropriate, and both parties can move on to other topics that show greater promise of agreement.

Before ever the industry will willingly undertake the culture of triploids it will need greater assurance regarding the regulatory environment that may be imposed on it. The regulators need to clarify the regulations regarding such topics as single-year/single-site operation, labelling of triploids and so on. The regulators may need to be the ones that commission the necessary further trials. NASCO will need to appreciate the real problem that triploidy may present to the industry: just as there is a price too high to pay to protect any threatened industry, there may be a price too high to pay to completely insulate wild salmon from all possible potential interactions with farmed fish. Industry will need to appreciate that triploids have significant conservation value even in the one-year production cycle. Getting the debate on triploidy clearly focussed and brought quickly to a long overdue conclusion will permit both parties to act or move on to other things. Biologists have long ago moved on from the expectation that triploidy will prove a realistic compulsory solution likely to be willingly embraced by the industry.

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An industry perspective of the pros and cons of using sterile salmon in farming

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Introduction

This paper presents some thoughts on the use of sterile salmon in aquaculture and the many challenges that triploid fish, in particular, have created for salmon farmers. Many of the scientific aspects of sterile fish production are covered in other presentations in this session, so this paper will focus mainly on the practical aspects and issues.

The relevance of sterile fish to salmon aquaculture

Salmon farming is now a significant and established part of the global food production business. The primary purpose of this business is to produce a high-quality food, containing high levels of nutritionally important elements, such as the essential omega-3 fatty acids EPA and DHA, in an efficient way, ensuring that salmon is available to consumers at an affordable price. The salmon farming business is internationally competitive and, over the course of the past thirty years or so, has become increasingly efficient according to a broad range of key performance indicators.

Sexual maturation in production fish is undesirable because it causes nutrients from the feed to be diverted into gonadal development instead of edible muscle and, as a consequence, reduces overall production efficiency and increases costs. It may also create health and welfare problems in fish which mature in pens, and give rise to concerns about possible interbreeding with wild salmon if maturing or sexually mature farmed fish are able to escape from captivity.

Suppressing maturation

In the early days of salmon farming, some of the stocks used routinely produced very high levels of grilse. In some cases, over 90% of the captive stocks matured in their first year at sea. Other stocks often routinely produced fairly low grilse levels but, from time to time, and sometimes unexpectedly, high levels of grilse appeared. High levels of grilse gave rise to welfare problems, for example because of the additional handling and grading required to remove overtly maturing fish from pens, and from bacterial infections which often affected the more stressed fish in the population. This also created problems with the continuity of supply of fish to the market when fish scheduled for harvest the following year matured in the first.

In response to these problems, a number of techniques to reduce or prevent maturation were assessed for effectiveness and practicability. These techniques included surgical castration; oral hormone treatment of juveniles to produce a high proportion of sterility in the treated population; chemical treatment, heat and pressure shocking of ova to produce all-female triploids; and the use of photoperiod manipulation coupled with the use of multi-sea-winter stocks. Of the various techniques examined, only one, pressure-induced triploidy, has been considered feasible for use in commercial production situations.

The use of sterile fish as a means of reducing concerns about escaped farmed salmon

Responding to concerns expressed about potential additional pressures on wild stocks of Atlantic salmon, already subject to various environmental and exploitation pressures, from interbreeding with escaped farmed salmon, NASCO's 1994 Oslo Resolution identified the possible benefits which might arise as a consequence of the use of sterile fish in aquaculture. The Resolution asserted that ***"The production of all-female, triploid salmon and other techniques which produce sterile fish could offer protection from genetic impacts. Practical methods have been developed to***

produce sterile fish; however, further research is needed on production characteristics, disease susceptibility and the marketing aspects of sterile salmon and on the ecological implications of escaped sterile salmon".

After almost a decade of applied research involving sterile salmon, NASCO's 2003 Williamsburg Resolution updated the Oslo Resolution to focus on the production of sterile fish which might be able to perform as well as conventionally produced diploid fish, stating that ***"Methodology and techniques for sterilization are now well developed; research should now focus on developing strains of sterile fish which could perform at a level similar to current strains of fish used in farm production. Trials should be encouraged to evaluate the performance of strains of sterile fish under production conditions".***

The use of triploid fish in commercial production

In the late 1980s and early 1990s many commercial salmon producers looked at the use of all-female triploids as a means of suppressing maturation in order to reduce welfare and production problems. In Scotland many of the marine producers in business at that time held triploid fish in pens alongside diploids to allow them to assess their potential to perform under farming conditions. However, their experiences, which will be described in more detail in the next section of this paper, were generally negative and, as a consequence, the use of triploids in commercial salmon production world-wide has since declined, almost to zero. While some academic research on triploids continues, the farmers have adopted alternative methods to control maturation, such as photoperiod manipulation and the use of multi-sea-winter fish.

Industry experience with triploids

One important general observation on triploidisation is that this is a procedure that can be applied to different stocks which, as diploids, are likely to exhibit different morphological, behavioural and performance characteristics. Because of this, it is unlikely that the characteristics of different triploid stocks will be the same, and it is, therefore, technically incorrect to refer to triploid salmon as a single entity, although this often happens.

Breeding and stock selection

Given the fact that, in many cases, selective breeding in the salmon industry is based on the principle of selecting the best performers in a population in respect of important characteristics such as growth, feed conversion or disease resistance, it is obvious that the use of sterile fish would create serious difficulties since one cannot easily breed from sterile animals. General production based on the use of sterile, triploid fish would, therefore, force the industry to be reliant upon a limited number of specialist breeding companies supplying triploid juveniles, thereby creating a supply bottleneck. It would also severely limit the options for stock selection.

Freshwater performance

Issues highlighted in the scientific literature, and the experiences of farmers who have produced triploid eggs and juveniles, largely coincide. These issues and experiences include reduced egg survival, higher incidence of non-feeding fry, reduced growth rates in fry and, overall in the freshwater phase, similar or even better growth rates for triploids compared with diploid siblings.

Seawater performance

There is also considerable coincidence between information presented in the scientific literature and the practical experience of marine ongrowers who have used triploid stocks. Key issues include inconsistency in growth rate; the 'best' triploids in the population sometimes exhibiting growth rates similar to those of immature diploids, but the growth spurt demonstrated by diploids from late winter onwards is absent; lower aggression, especially in the feeding response; and lower condition factor.

Overall performance

Taking freshwater and seawater performance together, both the farmers' experience and the scientific literature indicate that, when compared with diploid stocks, triploid stocks often exhibit poorer survival and performance, higher levels of downgrades due to body conformation problems and some physical abnormalities, and higher production costs.

Health and welfare

A number of concerns exist in relation to the health and welfare of triploid salmon. Some of the documented problems experienced in triploids arise as a consequence of physiological differences between diploids and triploids, for example the larger size and lower number of cells of certain types. Triploid salmon stocks have been shown to exhibit higher levels of runting, pinheads and deformities of the mouth, gills and spine; to have a reduced ability to deal with low dissolved oxygen levels and high temperatures; to have greater susceptibility to the effects of production stressors such as handling and grading; to have a higher than normal incidence of cataracts (in some stocks); to be more vulnerable to infection and disease, perhaps as a consequence of their greater susceptibility to the effects of stress; and lower survival rates (50-65%) when compared with similar diploid stocks.

Environment

While there have been pressures on salmon farmers to use triploid stocks specifically to minimise the likelihood of escaped farmed salmon interbreeding with wild salmon, a number of questions remain about potential impacts arising from the presence of triploid salmon in the environment. For example, the scientific literature describes lower rates of return to fresh water by triploid salmon. If triploid fish survive well outside farm pens and continue to feed and grow, the environmental implications of such fish inhabiting areas where salmon and sea trout smolts are present and their potential as predators most certainly need to be better understood. Similarly, if triploid fish are indeed more susceptible to certain fish pathogens than diploids, and if concerns about the transmission of pathogens from farmed fish to wild fish are real, captive triploids might potentially present an increased risk of transmitting pathogens to wild salmon.

Environmental organisations and other single-issue pressure groups continue to express concerns about the 'foolproof' nature of triploidy as a means of rendering fish sterile and some actively oppose the use of such techniques, claiming that the consequences for the environment are unknown.

The status of triploids is also under debate in relation to environmental legislation, and discussions within the EU on alien species in aquaculture have included consideration of polyploid selected strains as 'alien species'.

The marketplace

Bearing in mind the industry's role as a food producer and the obligations it is under to meet the requirements, specifications and standards applied by its retail customers who sell the fish it produces to the consumer, it is important that all of us engaged in this debate appreciate how this impacts on what we are able to do in practice. Put simply, we must continue to satisfy our customers' requirements if we are to remain in a position to trade with them.

Many of our trade customers and many consumers perceive that triploid salmon are subjected to unnatural treatment, treatment which has associations with genetic modification, engineering and manipulation. In general, the multiple retailers simply prefer not to be supplied with salmon which have been 'tampered with' genetically and most who have taken a formal position on this subject do not permit salmon farmers to supply them with triploid fish.

Organic standards for farmed fish production, against which many of our most vocal critics often judge the performance of conventional farmed fish production, proscribe the production of triploids.

Summing up the pros and cons

In preparing this paper, I consulted many salmon farmers, some of whom have been in the business for over thirty years. Most of them had reared triploids in the past (and a few still do), usually alongside diploids, because they quite genuinely wished to find a practical way of overcoming the welfare and production problems they had experienced when grilsing rates in the stocks upon which they depended for their livelihoods exceeded what their businesses were able to cope with. Two of the responses received from these farmers illustrate well the general attitude of the industry as a whole:

"They seemed to do fine in fresh water, but from the minute they went to sea, they were nothing but trouble".

"Your fish may survive and perform 364 days of the year, but on the 365th day, if the conditions aren't right it can kill them. This day came along much more often when we used triploids".

Preventing genetic interactions

To be completely effective, all farmed salmon would have to be triploids, although only a small proportion actually escape. A farmer would have to carry the penalties of poorer performance, survival, etc., even if none of his fish escaped.

Performance and survival

None of the evidence from laboratory trials, field trials or practical experience is sufficiently convincing to persuade farmers that triploids can replace diploids in general production.

Alternative approaches to the control of maturation

Practical measures other than triploidy have been adopted by farmers to address the grilse problem. Most farmers now use selected strains of multi-sea-winter salmon and apply photoperiod controls to manage and control maturation.

The breeding bottleneck

Specialist juvenile producers have insufficient capacity to supply the industry world-wide with triploid juveniles.

The marketplace

There are significant pressures from the marketplace for the use of conventionally produced mixed-sex diploids.

Taking these factors, and the many practical problems which clearly remain to be resolved, into consideration, it is difficult to foresee a situation in the near future where salmon farmers would be able to justify replacing selected diploid stocks, with proven performance characteristics, with triploid stocks.

Acknowledgements

I would like to thank NASCO and the Liaison Group for providing the salmon farming industry with the opportunity to present some thoughts on the use of sterile salmon in aquaculture and the challenge that triploid fish, in particular, have created for salmon farmers.

Improving the performance of sterile salmon for use in farming

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Introduction

The use of all-female triploids is currently the only suitable approach for the commercial-scale production of sterile salmon populations for aquaculture. (See contribution by Ray Johnstone in this volume). However, there has been limited interest from the aquaculture industry in using triploids because of real and perceived reductions in their performance compared to standard diploid industry stocks. This paper provides a brief overview of the biological effects of triploidy in fish and then outlines possible approaches for improving the performance of triploid Atlantic salmon in aquaculture.

Biological effects of triploidy

The biological effects of triploidy in fish have been reviewed in detail by Benfey (1999) and will therefore only be summarized briefly here. The induction of triploidy in a species which is normally diploid has several potentially profound biological effects that manifest themselves as genetic, physiological and behavioural differences from conspecific diploids. Diploid genomes are comprised of two chromosome sets: one of maternal origin and the other paternal. Triploids have a third set of chromosomes, and it is this odd number of chromosome sets that disrupts germ cell development and renders the fish sterile. Triploid germ cells generally fail to complete the two rounds of meiotic division necessary to yield mature eggs or spermatozoa, and those few cells which do occasionally complete meiosis in triploids generally have an unbalanced (aneuploid) chromosome number. It is the presence of this third chromosome set that is ultimately responsible for most of the basic genetic and physiological differences observed between triploids and diploids.

Triploids are usually produced by preventing extrusion of the second polar body from the egg. This represents a failure to complete meiosis, the process whereby eggs are normally left with a single (haploid) set of maternal chromosomes after shedding the haploid second polar body. These two maternal chromosome sets are not identical, due to a process of exchange among homologous chromosomes that occurs earlier in oocyte development, during the first meiotic division. As a result, retention of the second polar body provides some additional allelic variation to the resulting zygote, in addition to the much greater allelic variation provided by the fertilizing spermatozoon. Increases in heterozygosity are generally beneficial, so this should be a positive outcome for triploids. However, triploidy induction through retention of the second polar body also results in two maternal alleles for every paternal allele, and hence an unbalanced (2:1) gene dosage. Although the effects of this have not been investigated in triploid fish, a balanced (1:1) gene dosage is generally necessary for proper development in animals.

From a physiological perspective, the two principal effects of triploidy relate to changes in cell size and number, and to sterility. Triploid cell nuclei are larger than diploid nuclei because of the 50% increase in genomic DNA. As a result, triploid cells themselves also tend to be larger than diploid cells, at least when nuclei occupy a significant proportion of cell volume. Although largely unconfirmed, the decreases in cellular and nuclear surface area proportionate to volume that result from increased volume should affect, presumably negatively, all processes limited by surface area, such as nutrient uptake, metabolite release, signal transduction and respiratory gas exchange. On the other hand, triploid cells and nuclei have the advantage of requiring proportionately less membrane synthesis and maintenance compared to diploids. How, or even whether, these changes at the cellular level affect whole animal physiology is far from clear. They may, however, account for some of the limitations encountered by triploid salmonids under chronic stress.

The sterility of female triploids results in reduced or absent levels of reproductive hormones, some of which have growth-promoting effects. This likely explains why female triploid salmonids fail to exhibit the characteristic growth surges often seen in diploids prior to grilse maturation and after spawning. Female triploids retain the characteristics of immature fish throughout their lives. This includes greatly diminished ovarian development and the absence of secondary sexual characteristics. Adult aged/sized female triploids do not exhibit mating or spawning behaviours, presumably because of the lack of endocrine cues normally driving these processes. Apart from reproductive behaviours, there are no consistent behavioural differences between triploids and diploids. However, some studies have shown triploids to have reduced competitive abilities compared to diploids. Triploids also show a reduced freshwater return rate if released to the wild as smolts for seaward migration (Cotter *et al.,* 2000; Wilkins *et al.,* 2001).

Improving the performance of triploids in commercial aquaculture

Attempts to improve the performance of triploids are complicated by the fact that there is a paucity of information on what their true performance is. For instance, although a number of studies have investigated the production characteristics of triploid Atlantic salmon (Galbreath *et al*., 1994, Galbreath and Thorgaard, 1995; McGeachy *et al*., 1995; McCarthy *et al*., 1996; O'Flynn *et al*., 1997; Benfey, 2001; Cotter *et al*., 2002; Oppedal *et al*., 2003), comparisons among these studies are difficult because of differences in origin of stock (North American versus European), rearing environment (freshwater versus marine), rearing units (tanks versus cages), sex ratio (mixed-sex versus all-female) and scale (pilot versus commercial). However, as noted above, an underlying problem with triploids appears to be a reduced ability to withstand chronic stress. Some degree of chronic stress is always inherent in the captive rearing of fish for aquaculture, but it appears more critical to minimize these stresses for triploids in order for them to thrive. For instance, several studies have shown triploid salmonids to be less tolerant of elevated rearing temperature than diploids (Ojolick *et al*., 1995; Cotter *et al*., 2002; Hyndman *et al*., 2003), and it has recently been shown that the thermal optimum for triploid Atlantic salmon and brook trout is lower than for conspecific diploids (Atkins, 2005).

The genetic, cellular and physiological consequences of induced triploidy outlined above provide some context for why triploid performance might be different from that of diploids, but unfortunately allows little predictive strength. The fact that triploids look so similar to diploids makes it tempting to assume their biological requirements are the same. In many respects this is likely to be a safe assumption, and any evaluation of triploids should begin by using the best known rearing conditions for conspecific diploids. However, research should then be done to determine whether these truly are the best conditions of temperature, diet formulation, stocking density, etc. for triploids. A case in point is the differences in temperature tolerances and optima noted above. Such an approach is similar to that taken when developing a new species for culture.

Genetic improvement of triploid populations is also critical. Just as current aquaculture stocks out-perform wild stocks in culture situations because of genetic gains made through selection, triploid populations should also be amenable to genetic improvement. An immediate problem with this approach is that one cannot breed directly from the best-performing triploids, given that they are sterile. However, this is not an insurmountable problem with well-run breeding programs that can maintain diploid siblings of the triploid fish under evaluation. This is already standard procedure for diploids in some situations where broodstock are being retained in biosecure facilities while their siblings are evaluated under standard culture conditions. Direct evaluation of triploids is critical, since their culture characteristics cannot be adequately predicted from sibling diploid characteristics due to ploidy X family interactions (Friars *et al*., 2001).

It should also be borne in mind that most commercial evaluations of triploids have not even used the best-performing industry stocks, let alone taken into consideration possibilities for genetic improvement based on selection for triploid production traits. Our own recent research (C.F.D. Sacobie, T.J. Benfey and B.D. Glebe, unpublished data) has shown that triploid Atlantic salmon post-smolts survive and grow just as well as diploids within a stock, in comparisons done with both wild (St. John River, New Brunswick, Canada) and domesticated (Mowi) stocks, but diploids of neither stock perform as well as domesticated industry strains derived from wild St. John River stock when reared under local conditions. Thus, maximizing the performance of triploid fish requires both a clear understanding of their unique biology as well as a long-term commitment to selective breeding based on triploid production characteristics.

Acknowledgements

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Pros and Cons of Using Sterile Salmon in Farming and Possible Opportunities for Cooperative Trials - Session Chairman's Summary

Malcolm Windsor, Secretary, North Atlantic Salmon Conservation Organization

I thought we were privileged to have four excellent papers. Ray Johnstone gave us a masterly summing up of methods of sterilisation. He made it clear that, in his view, there is only one runner, triploidy. It is ready now and it is not expensive to produce triploids. But there are production problems, it seems, particularly with North American strains. Moreover, the salmon farming industry is against it because of these production problems and because they fear that the public might see triploids as being genetically modified. However, he felt that the public might well be for it if they knew that it would help to protect the genetic diversity of wild stocks; that public debate and explanation had not happened. Then Noel Wilkins showed clearly that triploidy can make a big contribution to solving the problems of genetic interactions and that the risks of other interactions was low because many fewer triploids came back to fresh water than did fertile fish. He threw down a challenge that this matter should be resolved, as there had been no progress at all in the last 7 or 8 years.

We heard next from John Webster, who gave us an industry view. It was a valuable review of the practical experiences of those producers that had tried triploidy. There were some advantages but the disadvantages were higher production costs, more deformities and more vulnerability to disease and stress. He felt that this could actually increase risks of transfer of diseases to wild stocks. There was the major problem of the market-place, where retailers preferred fish that have not been 'tampered with'. Moreover, organic producers could not use triploids.

Tilmann Benfey gave us a very good summary of how triploids actually differ from the fertile fish. He believed that triploids can do just as well as diploids for growth and other aspects of production. They would need to be selected just as the farmers selected their diploid fish. He said that it was best to think of them as a different species, for example they do well in cooler water. The comparison had never been done on a like-for-like basis so trials should establish which stocks were best suited to triploidy and what were the optimum growing conditions. He felt that there was no reason why triploids should not be farmed with similar productivity to diploids.

In the discussion, some basic questions were raised. Why is it that the public accepts triploid rainbow trout but we are told that it would not accept triploid salmon? Could the public be persuaded if they knew of the benefits to the genetic diversity of the wild stocks? Are the retailers aware of the arguments? Even if the farming costs are higher, what is the cost to the wild stocks, and the farmers, if genetic diversity is lost? Could farmed salmon be so domesticated that they could not interact with wild stocks?

Ladies and gentlemen, to me, this was a very interesting and valuable session. If I look back some years we were facing terrible impacts from sea lice. From what I have heard today, genuine progress has been made. I am very heartened by this. The next challenge is to make the same progress on stopping the genetic risks. It is certainly not precautionary to allow millions of fertile fish to escape and to interbreed with wild stocks. It is not precautionary to put millennia of evolution of genetic diversity at risk. It seems to me that we need to put much more energy and resources into trials to establish exactly how, e.g. using which strains, under which conditions, we can produce healthy triploids. At the same time we need to open up the debate with the retailers, with the consumer and with the public so that the benefits and the wisdom of this course of action can be understood. That way we may be able to say that we have also made real progress on the genetic risks.

Restoration Programmes

Practical aspects of the conserving and restoring of wild Atlantic salmon

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Conservation and restoration of Atlantic salmon are carried out through many different strategies. In developing a conservation and restoration programme one has to consider: what is the threat, when should the programme start, what strategy should be adopted, what is the time-frame for recovery? The Norwegian situation with acidification, the introduction of *Gyrodactylus salaris* and a fast-growing fish farm industry resulted in 1986 in the development of a programme for the cryopreservation of milt from threatened salmon stocks. The purpose of the programme was to preserve the genetic diversity and characteristics of natural salmon stocks by cryopreservation. The aim was to collect genetic material from 100 stocks, with a minimum of 50 individuals from each stock. This programme is now completed, with more than 6,500 samples from 165 wild salmon stocks.

The Living Gene Bank for Wild Atlantic Salmon was started in 1988. The purpose was to establish a living reservoir of genetic material which can be used for the re-establishment or enhancement of threatened stocks. The Living Gene Bank Programme (LGP) is considered to be a temporary measure.

What did we learn in implementing these programmes?:

- A late start is expensive and creates difficulties, and the genetic material available might be of a lower quality;
- Large numbers of escaped salmon will make it difficult to identify the original genetic material;
- The problem with escaped salmon may be compensated for by the use of genetic mapping of the original broodstock, which can be compared to the material in the gene bank;
- With removal of the threat, a Living Gene Bank Programme may be effective as a tool to restore genetic material to the river.

Choosing the concept for a conservation/restoration programme:

When starting a conservation/restoration programme it is necessary to consider the timeframe: how much time will be needed to eliminate the threat? You must consider how vulnerable a gene bank is with regard to vertically transmissible diseases, genetics and hatchery risks such as quality and stability of the freshwater supply. How do you ensure sufficient volume of genetic material for re-establishment/enhancement?

Examples of strategies are:

1. Traditional release of hatchery-reared fish (local stocks, various stages);
2. Releasing hatchery-reared broodstock;
3. Living Gene Bank based on river-caught juveniles;
4. Living Gene Bank based on eggs and milt from wild spawners;
5. Cryopreservation programme;
6. Combinations of 1-5.

In Norway, the environmental authorities chose a Living Gene Bank Programme with a strict focus on disease prevention and genetic preservation. The concept ensures large volumes of disease-free eyed eggs for the restoration programmes for many years. The time-frame for the Norwegian programme for the eradication of *Gyrodactylus salaris* is 20-40 years, depending on the success of the treatment of rivers.

The lessons learned during the early years are:

- When genetic resources are limited, one must ensure a good return of the material used. This can be done through a Living Gene Bank Programme;
- Ensuring a good return could involve the use of the same genetic material repeatedly. A Living Gene Bank Programme will allow this, and also allow a constant input of new genetic material.

The Living Gene Bank Strategy

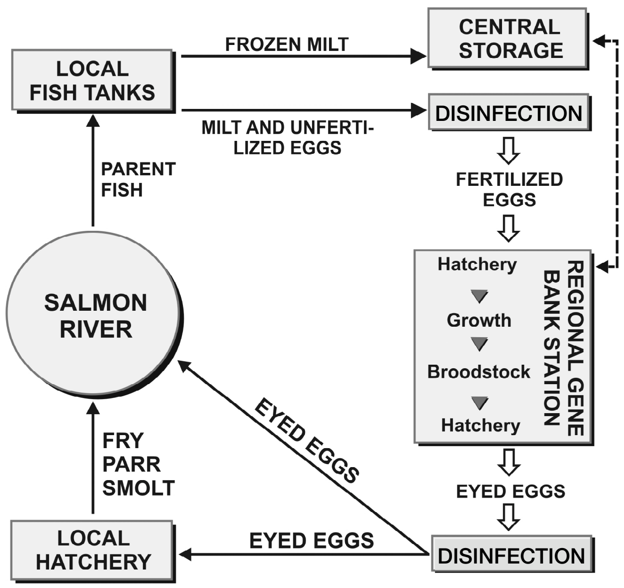

Figure 1
The Living Gene Bank Strategy for Wild Salmon Stocks

The concept is based on collecting milt and eggs from wild spawners. After scale sampling and disease control of the parents and sometimes DNA analysis, eyed eggs are accepted into the Gene Bank facility – an all-year and all-stages freshwater facility. Families are kept apart until the fish are large enough for individual marking (PIT tag), and then kept together as one year-class (different stocks kept apart in separate tanks) as long as space allows. Usually they are transported to large production tanks with older fish after 3-4 years. Each fish may be mated 4-6 times, and may reach an age of 10 years. Milt and eggs from Living Gene Bank produced fish are delivered to the respective rivers as disinfected, eyed eggs (see Figure 1).

At present 12 stocks are being re-established from the gene bank, 9 are completed and 7 stocks are waiting to be restored. The restoration history is given in Figure 2.

In addition to the stocks shown in Figure 2, there is one landlocked stock from the River Nansen which has been included in the gene bank programme to secure its genetic material in the event that the stock becomes threatened.

Lessons learned so far are:

- avoiding the introduction of disease is crucial to secure the genetic material;
- cryopreservation of milt is an effective tool when combined with a Living Gene Bank Programme;
- a Living Gene Bank Programme is a suitable tool for salmon stocks where the threats are eliminated.

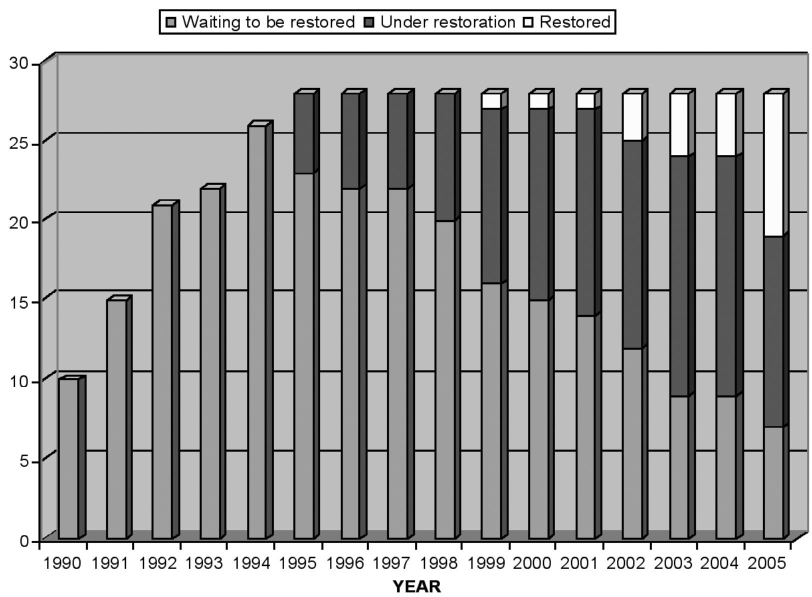

Figure 2
The restoration history of the Living Gene Bank Programme

The Steinkjer situation

To give an example of how the concept of a Living Gene Bank Programme might work, the situation in the Steinkjer region can be used as an example.

The size of the Living Gene Bank broodstock for the Bya, Figga and Ogna rivers are given in Table 1

Table 1 The size of the Living Gene Bank broodstock for Bya, Figga and Ogna rivers

River	No. of fish used 2004	No. of families	Ne
Bya	896	50	82.7
Figga	265	33	40.4
Ogna	864	36	67.3

The large number of mature broodfish gives a annual production of 1.5 – 3 million eyed eggs per year. These can be returned to the rivers as eyed eggs, or via a local hatchery to be returned to the rivers as fry (see Table 2).

Table 2 Stocking of eggs and fry from the Living Gene Bank

River	2003		2004		2005	
	Eyed eggs	**Fry**	**Eyed eggs**	**Fry**	**Eyed eggs**	**Fry**
Ogna R.	62,000	300,000	–	550,000	1,040,000	559,000
Steinkjer R.	60,000	480,000	–	232,000	78,000	97,500
Bya R.	60,000	240,000	450,000	137,000	702,000	390,000
Figga R.	–	120,000	–	65,000	97,500	97,500
Total	**282,000**	**1,020,000**	**450,000**	**983,000**	**1,917,500**	**1,144,000**

The eyed eggs are dyed in an alizarin solution to produce a distinct mark in the otoliths of the fish. This allows monitoring of the performance of Living Gene Bank material in the river. The results of electrofishing surveys in 2004 show that the Living Gene Bank material dominates the juvenile population in the rivers (Figure 3).

However, in July 2005, the parasite *G. salaris* was found in the Steinkjer rivers. For some reason, the rotenone treatment had again failed. The result is that the rivers must be treated once again, and much of the re-introduced material will be lost. This means that the Steinkjer river salmon stocks must be kept in the Living Gene Bank Programme for at least 5 more years after the treatment. For the rebuilding programme, the rivers can be declared free from the parasite after four years from the last treatment.

What we learned this year is that:

- a Living Gene Bank Programme with a large number of mature fish may result in genetic material in a river being dominated by stocked material following a rotenone treatment;
- failing to remove the threat will create problems.

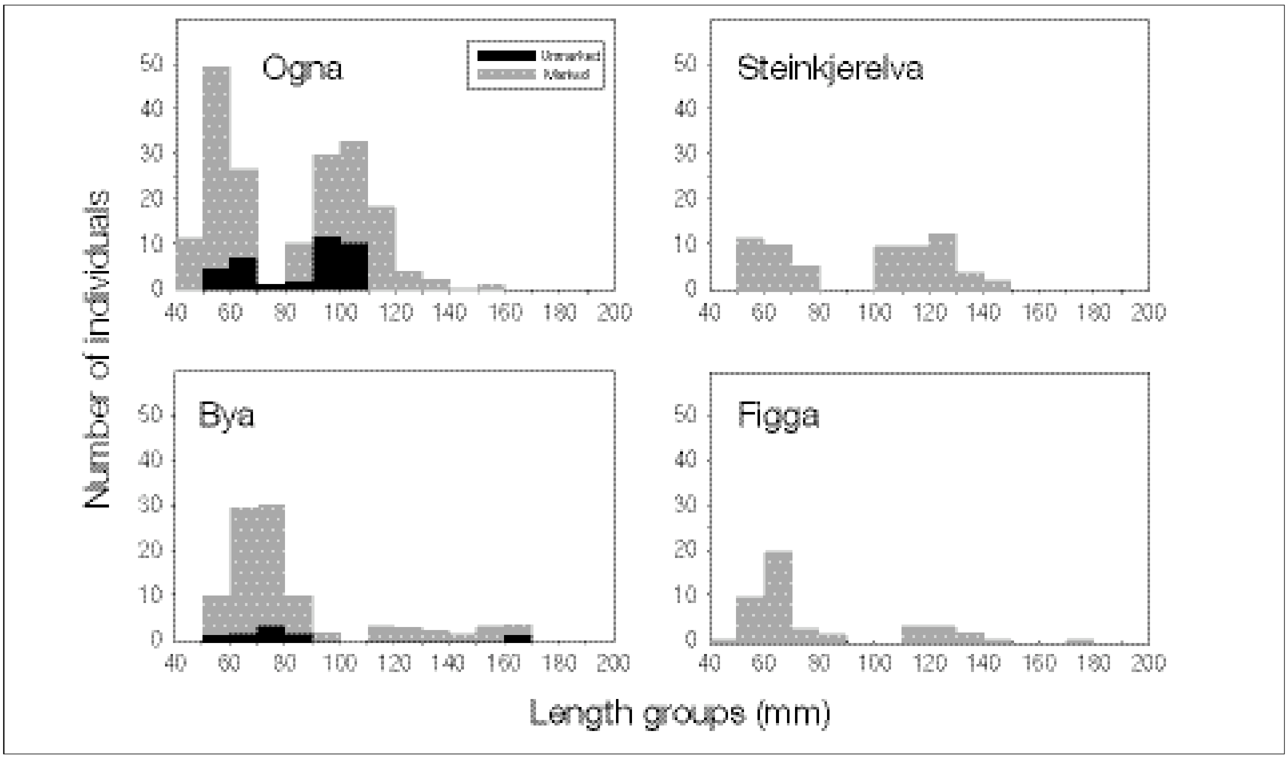

Figure 3 *Results from electrofishing in 2004 in the Steinkjer Rivers*

Summary

- Different situations (size of rivers, size of broodstock, disease situation, type of threat, economy) require different solutions regarding restocking/conservation;
- Starting a conservation programme when the fish numbers are low is difficult and expensive, and the quality of the genetic material is questionable;
- The threat to a given salmon stock must be removed for a Living Gene Bank Programme to be effective;
- In Norway, the combination of the Gene Bank Programme and the use of rotenone treatments against *Gyrodactylus salaris* is suitable for conservation and restocking;
- Working together will be useful in areas such as:
  - genetic mapping of stocks, cryopreservation programmes, hatchery management;
  - detecting escaped salmon in rivers and in broodstocks used for hatchery purposes;
  - a long list of projects evaluating the effect of escaped salmon;
  - a long list of projects regarding the serious interactions between wild and farmed salmon;
- Conservation programmes must be time-limited, and the threat removed. Therefore, the only sustainable long-term solution (regarding genetics) to save the wild salmon stocks is to prevent escaped salmon from spawning in the rivers.

The role of stocking in recovery of the River Tyne salmon fishery

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Introduction

This paper describes the role that stocking has played in the recovery of salmon stocks in the River Tyne. The Tyne salmon rod catch has increased from very low levels in the 1950s to 2,585 in 2002, being the single biggest in England and Wales. This increase has been attributed variously to a salmon stocking programme and to natural processes, but the relative importance of these mechanisms has never been objectively assessed. The demise of the Tyne salmon is attributed mainly to estuarine water quality decline, resulting from industrial and urban sewage pollution that was at its worst during the 1950s (Champion, 1991; Environment Agency, 1998). Water quality greatly improved following reduction in industrial activity and improvements to effluent treatment and disposal during the 1960s to 1980s. Fish deaths still occur intermittently in the estuary.

A hatchery was constructed and a salmon stocking programme started in 1979 by a legal agreement

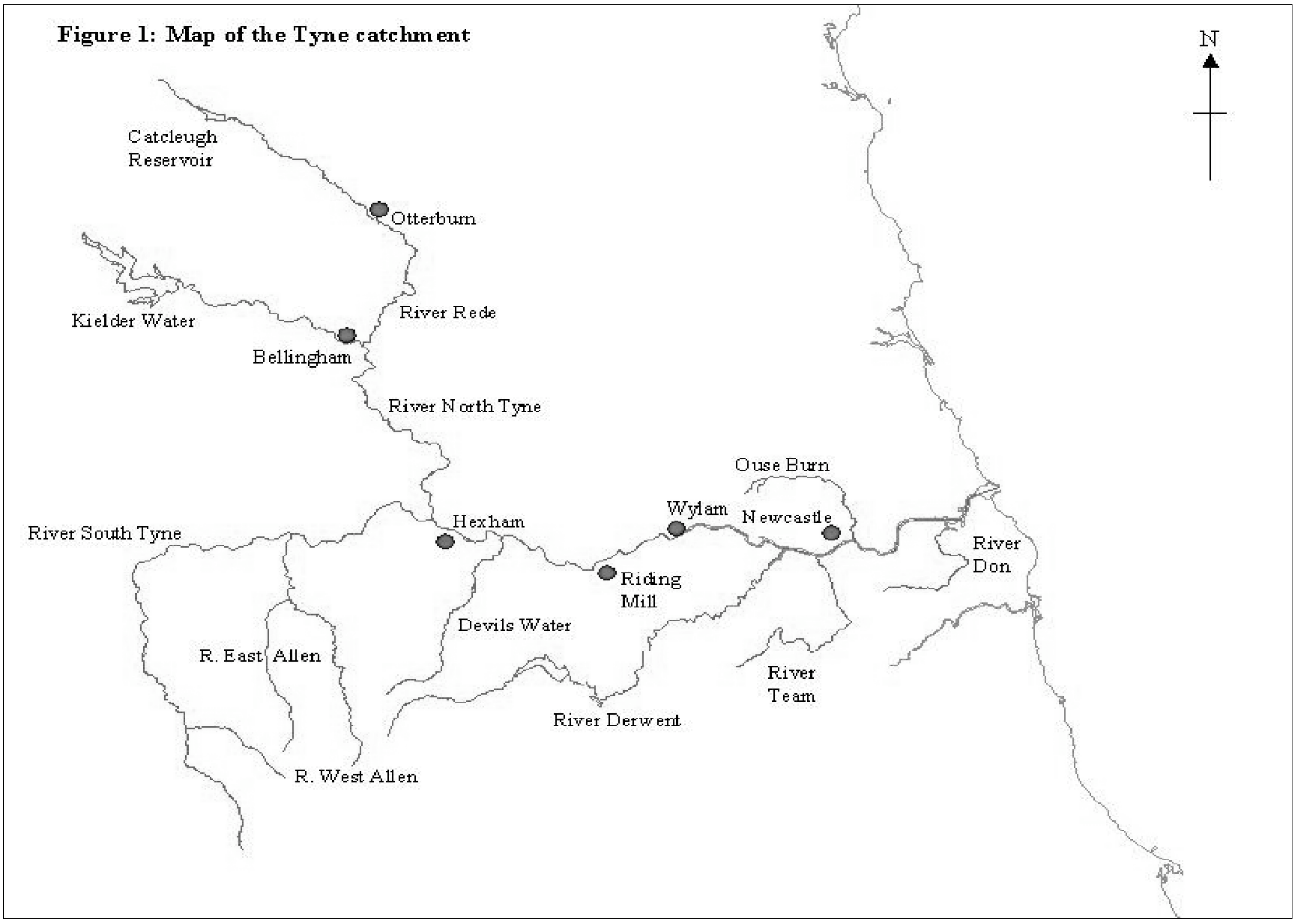


Figure 1
Map of the Tyne catchment

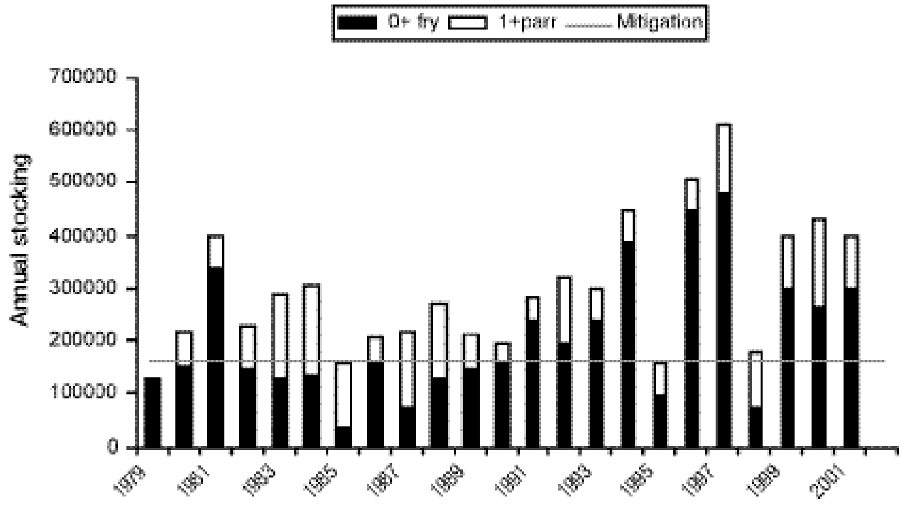


Figure 2
Salmon stocking into the River Tyne, 1979 – 2001. The mitigation level of 160,000 is shown

specifically to mitigate for the loss of salmon spawning and rearing area resulting from the construction of Kielder reservoir. Subsequent stock recovery has been attributed to a combination of factors, including water quality improvements, natural processes and stocking. However, some accounts have emphasised the role of stocking (Marshall, 1992; Charlton and Francis, 1992; Carrick and Gray, 2001); while others have suggested that its role may be less important than natural processes (Champion, 1991; Environment Agency, 1997). The objectives of this study were to establish the role of stocking in recovery by: 1) assessing the numerical contribution of stocking to Tyne salmon stocks and rod fisheries, including impacts on the timing and extent of the rod catch changes; and 2) assessing the return rates of stocked fish back to the major fisheries.

No formal monitoring of the stocking programme was carried out. Fortuitously, a Coded Wire Tag (microtag) marking programme was run between 1983 and 2000 (Jowitt and Russell, 1994) to study the marine return rates in the context of exploitation of salmon in distant-water fisheries. This

	Tyne					Wear				Tees				Coquet		
Year	0+	1+	Tagged 1+	Total 1+	Smolts	0+	1+	Tagged 1+	Total 1+	0+	1+	Tagged 1+	Total 1+	0+	1+	Tagged 1+
1979	135000	0	0	0	12500	40000	0	0	0	0	0	0	0	20000	0	0
1980	152000	70000	0	70000	0	30000	0	0	0	0	0	0	0	0	0	0
1981	340000	60000	0	60000	0	0	0	0	0	0	0	0	0	0	0	0
1982	150000	80000	0	80000	10000	0	0	0	0	0	0	0	0	0	0	0
1983	130000	160000	0	160000	0	0	0	0	0	0	0	0	0	0	0	0
1984	140000	153000	16912	169912	0	0	0	0	0	0	0	0	0	0	0	0
1985	40000	100000	20030	120030	0	0	0	20156	20156	0	0	10059	10059	0	0	10045
1986	160000	23000	25433	48433	0	22000	1400	0	1400	0	0	0	0	4000	0	10075
1987	80000	103000	34688	137688	0	0	0	0	0	0	0	0	0	25000	0	0
1988	135000	100000	42482	142482	0	25000	25000	10125	35125	25000	25000	10372	35372	25000	0	10222
1989	150000	25000	42096	67096	0	30000	30000	0	30000	30000	30000	0	30000	30000	30000	0
1990	165000	15000	16666	31666	0	0	0	10000	10000	0	0	11400	11400	0	0	14019
1991	240000	0	43947	43947	0	50000	0	5586	5586	50000	0	8329	8329	0	0	5178
1992	198000	80000	44295	124295	0	0	0	10050	10050	220000	0	30287	30287	35000	500	5185
1993	243000	30000	28369	58369	0	0	0	14802	14802	200000	32000	10112	42112	0	0	0
1994	390000	390000	20858	59858	0	0	3000	9014	12014	200000	32000	32194	64194	0	0	0
1995	100000	33000	29221	622210	0	0	0	0	0	180000	16000	14497	30497	0	0	0
1996	450000	32500	28624	61124	0	0	7500	7300	14800	100000	14000	10572	24572	0	0	0
1997	480000	80000	53095	133095	0	0	0	0	0	0	0	0	0	0	0	0
1998	80000	85000	15214	100214	0	0	0	0	0	0	0	0	0	0	0	0
1999	300000	80000	21591	101591	0	0	0	0	0	0	0	0	0	0	0	0
2000	270000	143000	21144	164144	0	0	0	0	0	0	0	0	0	0	0	0
2001	300000	100000	0	100000	0	0	0	0	0	0	0	0	0	0	0	0
2002	350000	100000	0	100000	0	0	0	0	0	0	0	0	0	0	0	0
Total	**5178000**	**1691500**	**504665**	**2196165**	**22500**	**197000**	**66900**	**87033**	**153933**	**1005000**	**149000**	**137822**	**286822**	**139000**	**30500**	**54724**

Table 1
Salmon stocking records for selected North East rivers

Rod_BESTes

Year	Stocking			Estimated recaps in rod fish, lagged to year						Hatchery fish in rod catch			Adjusted rod catch	% Hatchery fish in catch	Total H in run from stocking yr	% return to rivers	Total spawners
			%1+	From 1+ and 0+ stocking			From 0+ stocking			From 1+ and 0+ stocking							
	0+	1+	tagged	1SW	MSW	Total	1SW	MSW	Total	1SW	MSW	Total					
1979	135000	0	-										488		369	0.62	
1980	152000	70000	-							7	0	7	633	1.1	1271	0.62	6548
1981	340000	60000	-	9	0	9	0	0	0	9	0	9	393	2.3	1277	0.60	3842
1982	150000	80000	-	25	20	45	16	0	16	41	20	61	384	15.9	2283	0.54	3553
1983	130000	160000	-	25	55	80	18	35	53	43	90	140	395	35.4	2098	0.68	3470
1984	140000	169912	10	41	55	96	40	39	79	81	94	175	417	42.0	1705	0.57	3485
1985	40000	120030	17	60	88	148	18	88	105	78	176	253	1129	22.4	765	0.29	9009
1986	160000	48433	53	86	130	216	19	39	58	105	169	274	919	29.8	769	0.87	7000
1987	80000	137688	25	47	35	82	17	52	68	63	87	150	2048	7.3	573	0.19	14925
1988	135000	142482	30	41	10	51	5	11	16	46	21	67	2265	3.0	554	0.25	15809
1989	150000	67096	63	13	40	53	4	9	12	17	49	66	1161	5.7	695	0.34	7770
1990	165000	31666	53	29	36	65	6	28	34	35	65	99	1728	5.7	684	0.38	11113
1991	240000	43947	100	9	29	39	12	10	23	22	40	61	1064	5.7	864	0.41	6577
1992	198000	124295	36	18	35	53	10	49	59	28	84	112	2063	5.4	719	0.20	12277
1993	243000	58369	49	33	50	82	20	27	48	53	77	130	2305	5.6	375	0.15	13212
1994	390000	59858	35	22	49	71	21	28	49	44	77	120	1394	8.6	277	0.09	7705
1995	100000	62221	47	8	26	52	9	42	52	18	69	86	1360	6.4	635	0.14	7256
1996	450000	61124	47	5	16	21	4	28	33	9	45	53	1834	2.9	316	0.20	9454
1997	480000	133095	40	0	16	16	0	25	25	0	41	41	1606	2.5	683	0.12	8005
1998	80000	100214	15	20	36	56	5	89	93	25	124	149	1989	7.5	473	0.08	9592
1999	300000	101591	21	20	22	42	44	8	52	64	29	93	2088	4.5	269	0.15	9749
2000	270000	164144	13	10	8	17	11	44	55	21	52	73	2527	2.9	158	0.03	11431
2001	300000	100000	-	12	25	37	3	46	49	14	71	85	2764	3.1	nd	0.00	12125
2002	350000	100000	-	15	31	46	11	8	18	25	38	64	2844	2.2	nd	0.00	12098

NB 12.500 and 10,000 smolts stocked in 1979 and 1982 respectively

Variables	
Rod raising factor(Fr) =	2
scaling factor for untagged 1+(v	0.8
scaling factor for untagged 0+(w	0.25
proportional change in U =	0.5

	SPAWNERS cusum_1986
Total	36908
wild	29445
hatchery	7464
% hatchery	20.2

Max annual %=	42.0
Max 3yr mean %=	30.4
wtd return to river %=	0.27
wtd %H in rod catch%=	6.5

Table 2
Estimates of hatchery returns, based on microtag returns in rod fishery, using BEST parameters

present study was based upon observations of the patterns and timing of changes in environmental factors, stock size and catches, coupled with the estimated returns based upon the microtag data.

Site description and methods

The River Tyne (catchment area 2,930 km^2) is mainly a gravel bedded, upland spate river with land use dominated by agriculture, including a mixture of upland moor, forest, arable land and pasture (Environment Agency, 1998). The main river is fed by two major tributaries, the North Tyne and the South Tyne, and numerous smaller ones (Figure 1). The upper North Tyne has been impounded by Kielder reservoir since 1980, with the resulting loss of migratory salmonid spawning habitat over 12km of river. The operation of Kielder reservoir regulates river flows in the North Tyne and main Tyne. Most of the population of the Tyne catchment, estimated at 810,000 in the 1991 census, lives within in the Tyneside conurbation. Freshwater quality is generally very good in the river, but in localised upland areas there are still elevated levels of zinc and lead from historical mining. There are also still intermittent pollution incidents in the estuary, leading to fishkills due to oxygen problems at times of low flows and warm weather.

Stocking programme

Salmon

Small numbers of salmon eggs and, on one occasion, fry (5,000 in 1954, assumed to have been unfed), were stocked between 1954 and 1978. A total of 545,000 eyed ova, mostly from unspecified Scottish sources, was stocked between 1965 and 1977 at rates of 25,000 to 150,000 annually. The Kielder hatchery stocking programme began in 1978 and continues today. The mitigation agreement is for 160,000 0+ and 1+ salmon to be stocked annually. This number was estimated at the time from the loss of spawning and rearing area, rendered inaccessible by the Kielder dam (approximately 7 to 8% of the Tyne production). Through the main parr stocking programme up to 600,000 fish have been stocked annually (Figure 2). Overall, between 1979 and

2000, most (72%) have been 0+ fish and 1+ salmon have never formed more than 60% of the annual stocking. Smolts were stocked in two years, 1979 (12,500) and 1982 (10,000). Although most of the hatchery production went to the Tyne, some also went to adjacent rivers, the Coquet, Tees and Wear (Table 1).

At the start of the programme eggs were brought in from Scottish rivers. Between 1978 and 1983, 65% of the 2,465,000 ova laid down in Kielder hatchery were of Scottish origin, 26% from the Tyne and 9% from the Wear and Coquet. Thereafter, the increasing numbers of returning salmon allowed fish for the Tyne to be produced exclusively from Tyne broodstock.

Sea trout

Compared with salmon, very few sea trout have been stocked into the Tyne. 5,000 eggs were stocked in 1979; between 1986 and 1989, 27,500 0+ parr were introduced and a further 95,000 eyed ova were stocked in 1993. In addition, an unspecified number (thought to be small) of eggs left over from contract hatchery production were stocked in some years.

Year	Summarised extracts from annual reports
1951	Above-average numbers of migrating smolts seen in estuary… dead smolts seen in lower estuary
1955	Thousands seen in Tyne, N Tyne and S Tyne but lack of large spate led to high mortality. Hundreds found dead Blaydon - Elswick, also kelts
1957	Fairly large numbers at Wylam. Many seen dead at Elswick. Probable most died, due to lack of spates
1962	Large numbers of parr seen in upper Tyne
	...smolts die in tidal Tyne
1969	Good smolt run in May
1971	…good smolt run, few seen dead
1973	12,000 smolts killed in upper estuary by hypochlorite spillage

Table 3
Examples of accounts of salmon parr and smolts seen or found in the River Tyne reported in the Annual reports of the Northumberland and Tyne River Board and Northumbrian River Authority

Methods

The study used the following principal sources of information and data.

- Patterns of water quality improvement based on annual River Board and Water Authority Reports (1954 to 1979). Up to 1954 this evidence is largely anecdotal, from accounts in the historical reports, which do not give the original data. Thereafter data on dissolved oxygen and ammonia were available from various surveys (Northumbrian Water Authority, National Rivers Authority and Environment Agency);
- Observations of freshwater production, based on annual River Board and Water Authority Reports and electro-fishing surveys in 1978 and 1979 by the Freshwater Biological Association (Ottaway, 1979);
- Historical records of stocking based on Kielder hatchery records;
- Fishing effort based on data reported in Marshall (1992);
- Catch returns from the rod and net fisheries based on licence returns and reported through national statistics of the Environment Agency (1997 to present), National River Authority (1989

to 1996) and Northumberland Water Authority and its various River Board predecessors (before 1989). Adjustments were made to the rod catches to correct for underreporting based on the method of Small (1991), see Environment Agency (2003) for details. Rod catch data were obtained for the Tyne and two adjacent recovering rivers the Tees and Wear, both rivers recovering from serious pollution and stock collapses.

Estimation of run and escapement

Details of estimation methods are given elsewhere (Environment Agency, 2003). In brief, salmon run (R, the numbers of fish entering the river escapement during a calendar year) was estimated from rod catch using

$$R = C_t / U$$

Where: C_t = annual adjusted rod catch and U = exploitation rod rate (annual catch as proportion of annual run). U was estimated using methods outlined in Environment Agency (2003). Total escapement (S) was estimated using $S = [C_t ((1/U) - 1)]$. No correction was made for in-river natural mortality of adults.

Microtagging programme

Salmon were normally tagged at the hatchery during the winter, typically with one tagging period in November and a second in February. Only fish stocked as 1+ parr were tagged and these were partially graded by size to ensure that fish were large enough for microtagging (Jowitt and Russell, 1994). Fish were kept in the hatchery before release as parr in March and April. Yearling (0+) fish were normally stocked in late summer.

Tag loss rates were assessed prior to release of the 1+ parr, often after a period of some months in the hatchery. These were used to derive a best estimate of tagged fish actually released in each batch of fish (Jowitt and Russell, 1994).

Estimation of return rates

Tag returns were recorded from the Northeast Coast net fishery that operates off the Tyne coast and from the in-river rod fishery. Simple models were used to estimate the total numbers of returning stocked fish based on the microtag returns of sub-samples of 1+ stocked fish (Milner *et al*., 2004). (See Table 2). The MAFF/CEFAS microtagging programme (Jowitt and Russell, 1994) was designed to investigate exploitation in distant-water fisheries, not to address the contribution of Kielder-origin salmon to homewater net and rod fisheries. Nonetheless, the tagging data provide the only direct assessment of such contribution, but only for one component of the fish that are routinely stocked (the larger 1+ parr). It should also be noted that tagged fish have only been released for 17 (1984-2000) of the 24 years considered here (1979-2002). However, these tagged fish provide a core of data throughout most of the programme and a baseline against which data for the other two groups (0+ and the

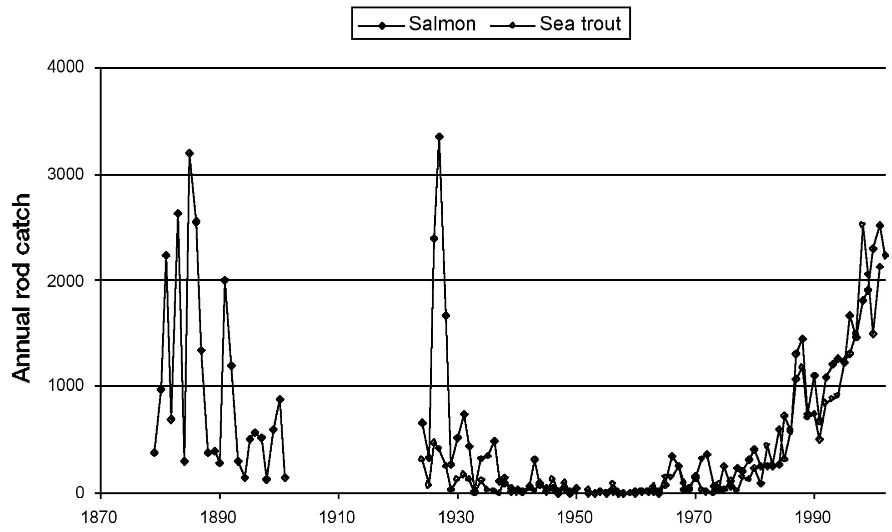


Figure 3
Salmon and sea trout declared rod catches in the river Tyne. No sea trout records were available for the period before 1924.

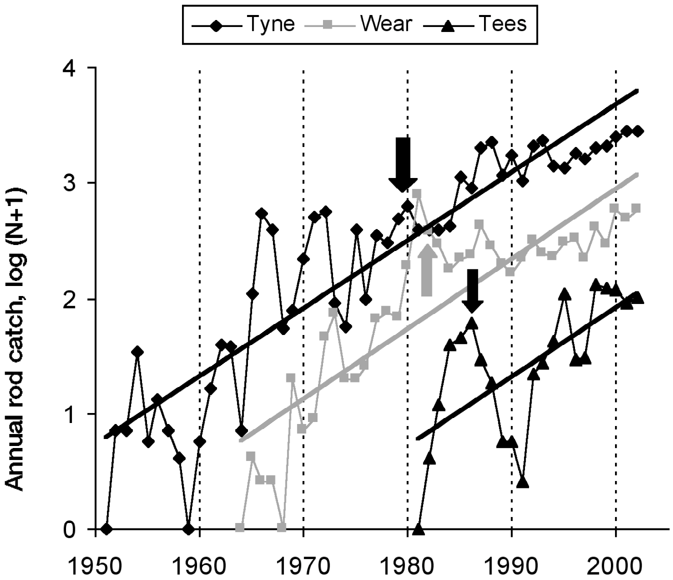


Figure 4
Change in rod catches, adjusted for return rate, as log10 (N+1), in three North East recovering rivers. Arrows show start of stocking returns, 1980, 1981 and 1986. Slopes fitted by linear regression.

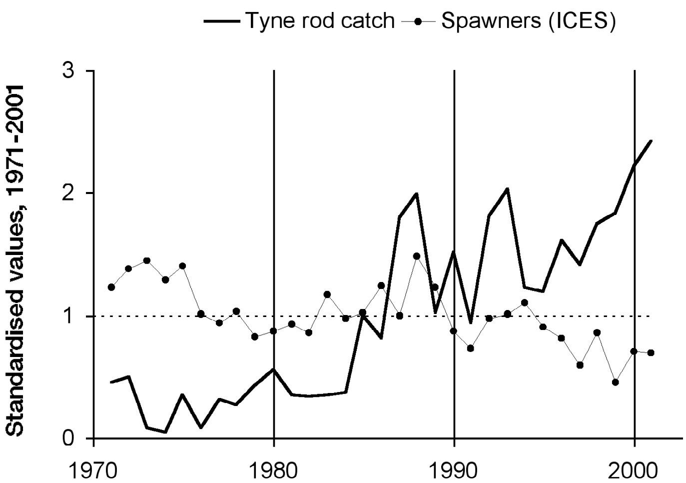


Figure 5
Standardised (values/long-term mean) return rates for ICES estimates of returning salmon spawners (1SW and MSW combined) in Southern area of the North-East Atlantic Commission area

smaller 1+) can be set. To extend these data from tagged fish to the entire hatchery contribution, it was necessary to incorporate estimates of returns of untagged 1+ and 0+ parr. This required assumptions to be made regarding the relative survival of these fish compared with the tagged batches. Because of grading prior to tagging, the tagged 1+ fish were larger, on average, than the untagged fish. Since survival will be size-dependent (e.g. Jowitt and Russell, 1994; Salminen, 1997) it has been assumed that the untagged 1+ parr will have survived less well than their tagged cohorts. A scaling factor (*v*) was used to adjust the return rates of these smaller fish, BEST=0.8 (i.e. 80 % of the tagged fish) range 0.7-0.9. For the substantially smaller 0+ fish released in the autumn, over-winter mortality will have been an additional and significant source of mortality compared with the tagged 1+ parr. The scaling factor for this (w) was BEST=0.25, range 0.1–0.5. The derivation of these values was based on published data for survival and is given in Milner *et al*. (2004). Estimates of return rates for untagged fish were based on the temporally nearest four-year runs of tag return observations. Thus, for example, the 1986-89 observations were applied to estimate 1981-1985 (1SW) returns and the 1994-97 observations were applied to estimate 1998-2002 (MSW) returns.

In addition, tag returns needed to be adjusted by raising factors to allow for reporting rates. In the net fishery these were estimated annually from market sampling (see Jowitt and Russell, 1994). No such systematic observations were available for the rod fishery and so various options for estimation were explored, including microtag returns in brood stock collection, tag returns seen in estuary fish kills and returns from wild and hatchery smolt tagging on the adjacent river Wear. For rod returns, a range of 1.2 to 3.0 was used (best 2.0, i.e. assumed 50% were not reported). There was uncertainty in the assumed parameters in the models, so minimum and maximum values were used to bracket the likely range about a best estimate, in order to illustrate the effect of the assumptions.

Results

Patterns of catch change

Very high catches were reported in the 19th century and early 20th century (Figure 3). Decline followed and annual reported Tyne salmon catches were zero in 1950 and 1959. From around the mid 1960s rod catches began to improve, but with big fluctuations (e.g. annual catch range 7 to

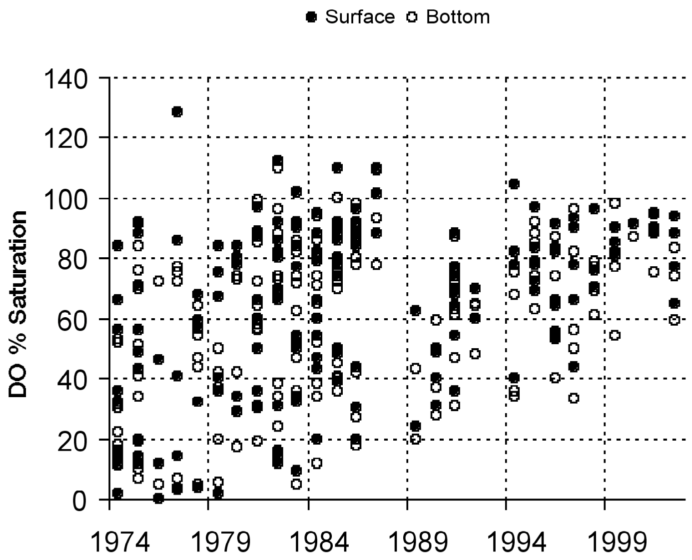


Figure 6a
Temporal change in DO % saturation at Tyne Bridge (mid Tyne estuary)

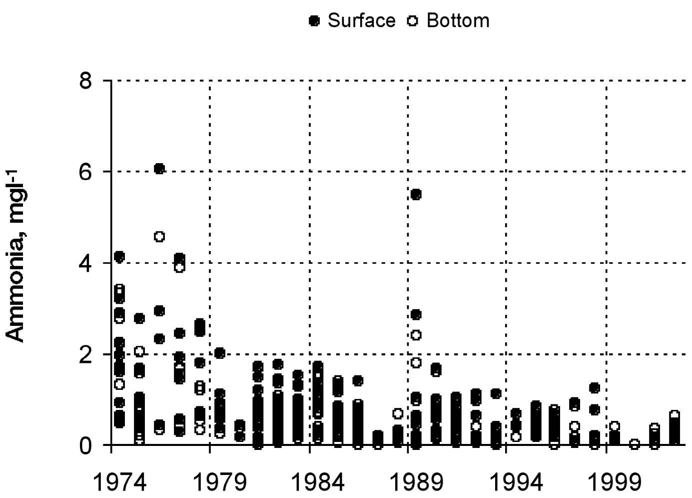


Figure 6b
Temporal change in Ammonia at Tyne Bridge (mid Tyne estuary)

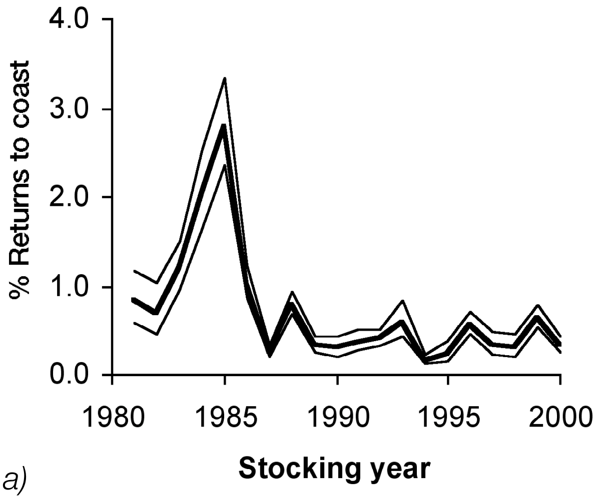
567) in the early stages particularly. In 2004 the adjusted catch was the highest recorded at 4,535. However it should be noted that the North East Coast drift net fishery was greatly reduced following a buy-out and that would have improved in-river catches. Assuming that the first returns from stocking will be 1SW fish one year after 1+ stocking, then salmon rod catch recovery pre-dated the first stocking returns by 15+, 16 and 3 years on the Tyne, Wear and Tees respectively (Figure 4).

A feature of the rod catch trajectory is the increase in the mid-1980s and following short-term downwards trend in the mid-1990s, giving the appearance of a blister on the general recovery trend, and the rising limb coincides with the peak of the hatchery returns (see below). This exemplifies the difficulties of separating the various factors confounding catch trends. All rivers in the Northeast Atlantic experienced fluctuations over this period. On a control river, the Coquet, the decline in catches between 1965 and 1975 indicates declining returns. Similarly, estimates of returning spawners to the ICES Northeast Atlantic Commission Southern Area confirms the general nature of this pattern and of the increasing returns in the 1980s to give the peaks in late 80s and early 90s, broadly corresponding to Tyne catch pattern over this period (Figure 5). A number of marine factors changed at this time and a major influence on all Northeast Atlantic salmon was the increase in the Greenland salmon fishery. For the Tyne and Coquet the emergence of the Northeast Coast drift net fishery in adjacent coastal waters would have coincidentally affected trends in return to the rivers and thus rod catches. The combined effect of these factors and possible changes in natural marine survival (Potter and Crozier, 2000) would have been to damp down the early recovery of the Tyne stocks and then speed it up at the same time as the hatchery returns started.

Juvenile abundance

For most of this period there were no systematic surveys of the freshwater populations. However, annual fisheries reports made regular reference to observations by fisheries staff of the presence of juveniles, often revealed by fishkills, in the lower reaches of the river. Table 3 illustrates some of these records and it is considered safe to assume that these are genuine accounts of smolts seen or recovered.

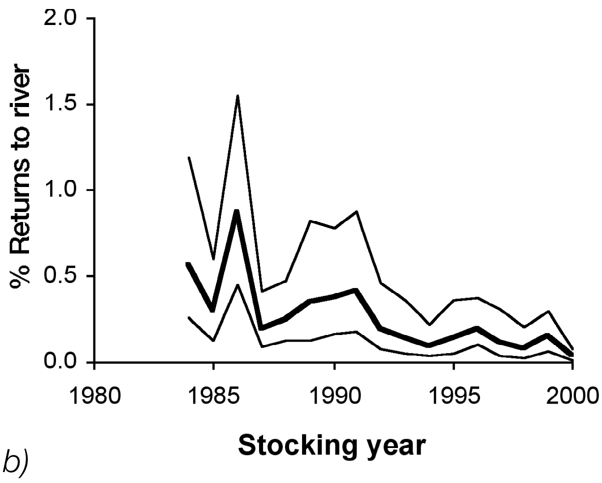
Further evidence of juvenile salmon in the river is given by the results of electro-fishing surveys carried out by the FBA in the North Tyne (Ottaway, 1979) which gave, in the area lost to the dam, minimum estimates of 26,809 fry and 11,567 parr. Taking uncertainty into account, the FBA estimated that the salmon population was equivalent to annual smolt production of between 2,305 and 17,245, equivalent to 0.6 to 4.7 smolts/100m^2. Such values lie within the “low” to “medium/high” categories of salmon smolt production, as reviewed by Symons (1979).



a)

Estuarine water quality

Anecdotal evidence from annual reports indicates that pollution in the estuary was serious during the 1950s and 1960s. There were numerous records of fishkills given in the Northumberland and Tyne River Board and Northumbrian River Authority reports, e.g. smolt mortalities reported in 1951, 1955, 1957, 1958, 1959, 1963, 1965 and 1973. It should be noted that lack of later reports does not demonstrate that fishkills did not occur. The causes of these kills is not known, but in six years the reports refer to high flows and cooler temperatures moderating losses, suggesting that low dissolved oxygen may have been implicated. In industrial and urbanised estuaries, lacking effective sewerage and pollution control measures, low dissolved oxygen and high ammonia are classical cause of fish deaths (Alabaster and Lloyd, 1980). Early data are not available, but samples from 1974 to the present show the time course of improvement (Figure 6). In spite of very high variability, the incidences of low dissolved oxygen (<20% saturation) and high ammonia (>2mgl^{-1} total ammoniacal nitrogen) had reduced by 1985 and 1980 respectively.



b)

Figure 7
Estimated return rates of stocked Tyne salmon to a) the coast, pre-North East Coast fishery and b) the river pre-rod fishery. Upper middle and lower lines are MAX, BEST and MIN estimates, respectively

Hatchery returns

Stocking began in 1979, first returns from hatchery-produced parr and smolts (the latter in 1979) were in 1980 and estimated returns peaked between 1984 and 1987 (Figure 7). Percentage returns of stocked parr to the coast and to the river have declined since the start of the programme. Estimates of the long term (1980-2000) weighted mean returns to the coast and river (Figure 7) were 0.6% (best estimate, with a range 0.5–0.8%) and 0.3% (range 0.1-0.6%) respectively. These rates were based on all fish (0+ and 1+) stocked and the values would have been different if expressed for fish stocked as 0+ or as 1+ separately, being lower and higher than these reported values, respectively. For example the overall return rate (releases 1984-1997) to the coast of just the microtagged (larger) 1+ fish was 1.21%. Adjusting these values for an average net exploitation rate of 0.375 gives a return to the river of 0.77%.

Over the same time the weighted contributions to the Northeast Coast fishery and the Tyne rod catch were 1.5% (range 1.2-2.0%) and 6% (range 3-14%) respectively. Current (post-1995) contributions to annual rod catch are mainly 2-7% (Figure 8). In the early years, estimated contributions to the run and escapement were higher because the natural recovery was in its early stages. Between 1983 and 1986, annual hatchery contributions peaked between 22 and 42%

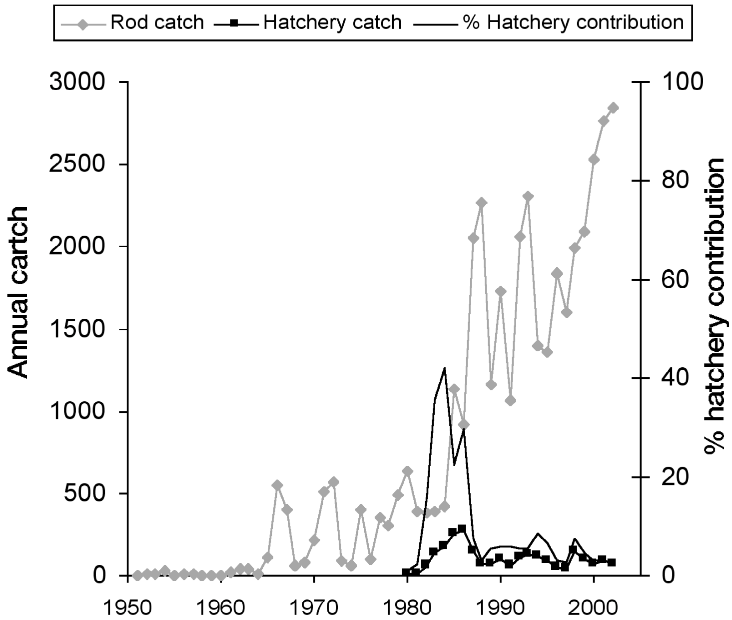


Figure 8
Adjusted Tyne salmon rod catch, estimates of hatchery-derived salmon in rod catch and % hatchery contribution

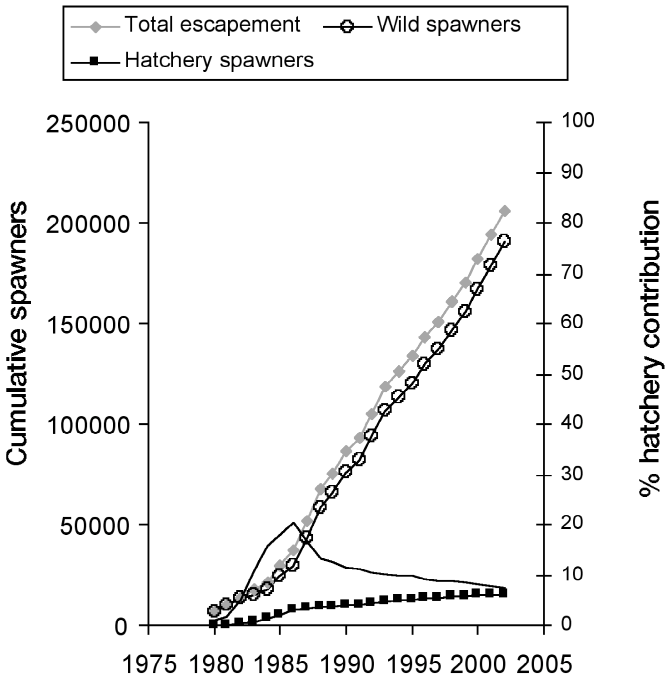


Figure 9
Estimates of annual cumulative spawning totals for hatchery, wild and total escapement, using BEST parameters

(Figure 8). However, annual contributions do not give a true impression of contribution to stock recovery, because the progeny of each year's breeding is dissipated in later returns over a three- to four-year period, owing to divided migration and return. Cumulative spawning over the period 1980 to 1986 is a better approximation of contribution to later generations, and the estimated total contribution from the hatchery was around 20% (9-43%) of the rod catch and by implication the in-river run (Figure 9).

Discussion

The Tyne salmon recovery has been dramatic and continues today. It is not certain what the production capacity of the river is, but a regression of the ten-year mean rod catch against catchment area in rivers of England and Wales indicates that a ten-year mean catch of up to 4,600 might be expected (Milner *et al*., 2004). Incorporating Scottish rivers into the analysis, which are more productive per unit area (see Crozier *et al*., 2003), but may be more representative of the Tyne than the majority of other rivers in England Wales, suggests it could be as high as around 6,000 to 6,500 fish.

Restoration of good water quality, in the Tyne's case in the estuary, is an essential prerequisite for recovery of any self-sustaining salmon river, irrespective of the origins of the fish. On the Tyne, improvements in estuarine water quality have been the result of major changes in industrial and domestic discharges and waste treatment over many years. Closure of coke ovens and chemical plants began in the 1960s and concluded in 1985. The introduction of the Pollution Control Act in 1974, introducing powerful regulation, and the installation of a major sewage interception system between 1973 and 1993, were key events reflected in water quality.

The key issue is this: as water quality improved in the Tyne what caused the increase in its salmon stock? There are two candidate mechanisms, natural processes and artificial stocking. These are not mutually exclusive, both require good water quality and are subject to a range of other influences, such as survival at sea and carrying capacity in fresh water. The actual pattern of catch recovery was evidently complex and influenced by several factors, mostly acting simultaneously, e.g. UDN, marine survival, stocking and natural recovery.

Evidence of natural recovery

Salmon were always present in the Tyne, even during its worst condition, as evidenced by observations of juveniles and adults, albeit in low abundance. Natural recovery is thought to have been some combination of production from the residual stock in the Tyne and straying into the river by salmon from other rivers. Although predominantly a homing species, straying is a normal property of salmon, enabling them to colonise new rivers and to maintain a low level of gene flow (Quinn, 1993). The extent of straying, which is always very low, seems to be variable and dependent upon the source of the strays, proximity and similarity of the donor and receiving rivers and the population size in the colonised river. Sea migration routes bring salmon close into the Northeast coastal zone, which is why the drift net fishery was so productive (it was mostly bought out in 2003). Many of these fish are destined for Scottish rivers (Anon., 1996). Straying rate studies are rather few and normally consider straying *from* rivers rather than straying *into* rivers. Tag returns to the Tyne from salmon stocked into other Northeast rivers indicates that straying *from* those releases to the Tyne could be of the order of 1.5 to 3% (Potter and Russell, 1974). Thorpe (1988) has suggested that straying rates, *into* stocks, of 1-2% would be acceptable for retaining genetic variation as well as sustaining a low level of gene flow. He was referring to well-populated rivers; but in a seriously depleted river, with unoccupied habitats, such as the Tyne would have been in the 1960s and 1970s, effective straying rates are likely to be higher for reasons noted above (Vasemagi *et al*., 2001; Thorpe, 1994). A range of straying rate of 1-5% (into the river) can be taken for illustrative purposes. At such straying rates and a conservative notional run size of say 20,000, in a normal pristine state, the Tyne salmon stock might have received around 200 to 1,000 fish annually. Such potential for straying would be present even when environmental conditions were poor, but would not be effective until estuarine water quality improved to the extent that fish would survive passage through it.

No direct estimates of adult stock size were available for the time of lowest stocks, but adjusted annual salmon rod catches averaged 12 (max. 39) between 1951 and 1964. Acknowledging the caution necessary with such small counts and the potential inaccuracy of records (probably tending to under-record catch), at a notional exploitation rate of 5%, this indicates an average run size of 200-300, ranging up to around 800. The provenance of these fish cannot be determined; they could be residual Tyne stock or strays, but distinguishing between these is impossible retrospectively. The key point is that run numbers indicate the presence of an actual spawning stock available and capable to generate recovery as water quality improvement allowed.

Sea trout catch recovery occurred at rates similar to those of salmon, but with very little stocking. This demonstrates that a species with a broadly similar migratory life history to salmon, and crucially dependent upon estuarine water quality, did recover by largely natural processes. In summary, the argument for natural recovery is based on:

- existence of a plausible mechanism (re-colonisation by some combination of a residual population and inward straying);
- observations of water quality improvement broadly corresponding to timing of catch and fishing effort recovery;
- the timing of catch and effort changes, which pre-date hatchery returns;
- the observation of moderate populations of salmon juveniles in the Tyne in the late 1970s, which pre-date hatchery returns;
- the majority of escapement has always been wild fish, based on microtag data; and
- the simultaneous recovery, without significant stocking, of a cohabiting migratory species, sea trout, with broadly similar life-cycle.

Time course and relative role of hatchery returns

Egg stocking was carried out at very low levels during the 1950s to 1970s. Using literature values of 1SW adult returns from eggs (Harris, 1994) gives a total of 31 adults, with a maximum of 6 in any one year (1976). Accordingly, given the evidence of natural run size from the rod catches it is inconceivable that this egg stocking would have had any detectable effect on run sizes. First returns from the main Kielder programme would have occurred in 1980 and annual contributions would have peaked in 1986. It was not possible to detect an impact of stocking on catches, because other confounding factors were also tending to increase runs. Principal amongst these was the improvement in estuarine water quality that would have allowed natural recovery to increase. Coupled with that is the potential for exponential increase in salmon as typical of animals in the early stages of colonising under-utilised habitats (Krebs, 1978). Finally, marine return rates, increasing because of reducing exploitation of interceptory fisheries, or fluctuations in natural survival, would also have acted on Tyne salmon as they did across the Northeast Atlantic. Thus, natural processes alone could explain the temporal pattern of the Tyne salmon recovery. Nevertheless, annual hatchery contributions to runs were estimated to be up to 42% annually; although these annual values would have over-estimated direct contribution to later production because of divided migration and return. Annual spawning is dissipated over later years by divided migration and return. Therefore, a better index of the relative contributions to spawning and thus recovery is given by the respective cumulative totals up to the time of any significant potential second-generation returns (i.e. natural progeny of stocked fish which could not be distinguished from the progeny of wild fish). This value peaked for hatchery fish at 20% (range 9 to 43%) between 1983 and 1986.

Return rates (Figure 9) were pooled for all the 0+ and 1+ stocked fish, thus giving the average returns, 0.6% and 0.3% respectively, from the annual stocking. Comparisons with other studies are best made using separate return rates. Because the 1+ microtagged (larger fish) return values are based on direct returns to the nets and involve fewer assumptions, they are probably the most robust of the estimates. Return rates of 1.2% and 0.8% of the microtagged 1+ fish to the coast and rivers respectively are similar to those reported for other studies (Aprahamian *et al*., 2003). Even allowing for greatly reduced exploitation after the 2003 net buy-out it is most unlikely that return rates to the river would exceed 1.5%. This value should be contrasted with the value of 13% previously given for the Tyne (Carrick and Gray, 2001), which is shown to be a considerable over-estimate.

It is probable that the overall hatchery contribution of up to 20% to the cumulative run, would have played a useful role in accelerating and stabilising stock recovery in its early stages, when water quality improvements were still inconsistent annually. An interesting question is what might have happened without the stocking. It is not possible to model this with any reliability, but the relative proportions of natural to hatchery spawning effort (80:20) over the first few years may indicate the level of difference in recovery rate. The original intention of stocking was to mitigate for lost salmon production upstream of the Kielder dam, and that has been consistently achieved. Its contribution to pump-priming was moderated by its relative scale compared against natural production. Pump-priming, as a fishery restoration practice, is therefore dependent upon the circumstances of each river. In the case of the Tyne, which had both a residual stock and a huge potential source of strays in the large salmon migration through its coastal waters, pump-priming was not the major factor. In contrast, on a river such as the Dove, a tributary of the River Trent that drains from the English midlands to the North Sea, the scope for natural recovery is virtually zero because of no residual stock and low likelihood of strays. Under those circumstances pump-priming is essential and current stocking is proving successful in establishing salmon runs (Tim Jacklin, pers comm.).

There remains an unresolved difficulty in identifying or evaluating the long-term sustainable benefits of the stocking programme, resulting from the later generations of the progeny of hatchery-origin parents. In this account, second-generation and beyond hatchery fish have been assumed to have had the same fitness and lifetime success levels (e.g. Fleming *et al*., 2000) as wild-origin fish. This may not be a safe assumption and, if flawed, makes the estimates of hatchery contributions conservative in favour of the hatchery. There have been concerns expressed about the effects of outbreeding depression at F2 and beyond (e.g. McGinnity *et al*., 2003) resulting from the breeding of natives and non-native (but wild) salmon. The scale of this effect is presumably dependent upon the genetic divergence and the relative fitness of the breeding groups. On the Tyne, after the first six years when Scottish-origin ova were used, the brood stock were mostly returning hatchery-reared fish, which may have been more genetically adapted. No genetic information was available for the Tyne, but studies on this using historical material may be feasible and are being explored.

The study has put the Tyne stocking programme into perspective. There are plenty of circumstances where stocking is an important and sometimes essential tool in fisheries management. On the Tyne itself the reservoir mitigation was only practicable through stocking. Continuing intermittent fish deaths in the Tyne estuary present the need to have restoration-stocking facilities routinely available. Other rivers in England and Wales may need, variously, short-term pump-priming or restoration stocking to support stocks. Stocking brings both risks and benefits, but when and how to stock are fishery management questions that can best be answered when informed by quantitative assessment of the type reported here. Targeted studies to assess the outcomes of operational stocking are still rare and more are needed to cover the range of stocking operations and circumstances.

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Experience in conserving and restoring salmon rivers in Maine

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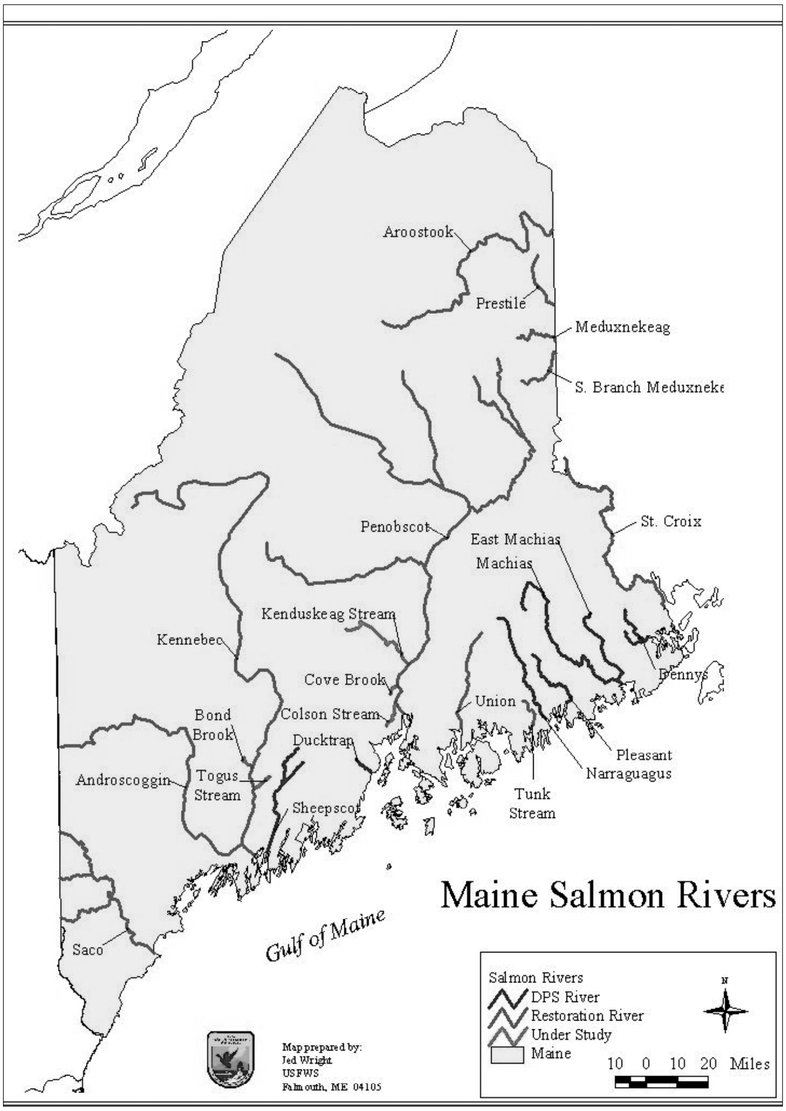

Figure 1
Salmon rivers in Maine

This paper highlights the efforts at cooperation between wild and farmed salmon interests in restoring salmon to Maine's rivers. This is a critical issue in Maine where the two interests share a limited amount of coast. Furthermore, sharing the expertise found in wild and farmed salmon interests pools critical personnel and funding resources in times of limited budgets.

At meetings of the North Atlantic Salmon Conservation Organization (NASCO), representatives for other countries speak of hundreds of rivers and returns in individual rivers that number in the thousands and tens of thousands of salmon. Similarly, farmed production is noted in the high tens of thousands of tonnes.

By contrast, the State of Maine has about 10 salmon rivers along a couple of hundred miles of coast (Figure 1). Virtually all of the US Atlantic salmon resource is found in Maine. One river in the state, the Penobscot River, has runs of over 1,000 fish; slightly more than 1,300 fish returned to the Penobscot in 2004. The other Maine rivers, particularly those covered by the Endangered Species Act, have salmon returns in single or low tens of fish, and a few rivers do not have returns every year. The salmon resource and farming industry in the US is comparable to one sea loch in Scotland or fjord in Norway. Nonetheless, this small amount of salmon is incredibly important to the US.

With respect to salmon farming, marine lease sites occur primarily in the eastern portion of the state with a couple of sites further to the west. This is important because we have a small, stressed wild salmon resource which occupies nearly the same area of the state in which salmon farming also occurs.

The factors affecting wild salmon abundance, as identified in the Endangered Species Act listing of Atlantic salmon in Maine, are documented below. Clearly, the interaction between wild and farmed salmon is a significant issue in the listing of Atlantic salmon.

- Many rivers no longer support salmon;

- Low number of spawners in rivers;
- Habitat quality and quantity limits smolts;
- Populations dependent on hatcheries;
- Interactions between wild and farm-raised salmon;
- Low ocean survival.

Table 1 *Major events in the history of salmon conservation and restoration in Maine*

Year	Event
1865	Regional Fishery Commission
1867	Maine Fishery Commissioner
1872	Hatchery at Craig Brook
1939	Maine General Salmon Commission
1946	Maine Sea Run Salmon Commission
1993	ESA Petition for Atlantic Salmon
1995	Maine Salmon Conservation Plan
1996	Maine Atlantic Salmon Authority
1999	Maine Atlantic Salmon Commission
2001	ESA listing

Table 1 outlines some of the history of salmon management and restoration efforts that have taken place in Maine starting in the 1860s. The first salmon hatchery in Maine was built in the 1870s and there has been a succession of state and federal efforts to manage salmon since that time. An important modern date in this timeline is the listing of Atlantic salmon in a number of Maine's rivers, under the federal Endangered Species Act in 2001. Table 2 is a timeline for salmon farming in Maine, with the first marine cage site in 1973 and the state farming leasing law in the early 1980s. There are currently about 40 finfish leases that produced about 6,700 tonnes in 2004. It is also important to note the passage of state salmonid fish health regulations in 1999 and the presence of infectious salmon anemia virus (ISAv) in 2001.

Table 2 *Timeline for salmon aquaculture in Maine*

Year	Event
1973	First marine salmon site
1980	First salmon lease site
1990	20+ marine sites, 5,689 tonnes of production
1999	State salmonid Fish Health Regulations
2000	ISAv detected in Maine
2004	44 sites, 6,760 tonnes of production

When the farming and conservation timelines are combined (Table 3), it shows much activity since 1990. The concern over the status of Maine's wild Atlantic salmon shown on the bottom of the figure has been the catalyst for having wild salmon and farmed salmon interests working together to restore wild salmon.

Table 3 *Combined timeline of wild salmon and salmon farming in Maine*

Year	Event
1974	First salmon marine site
1981	First salmon lease site
1991	20+ marine sites, 5,689 tonnes of production
1993	Endangered Species Act petition
1997	State Salmon Conservation Plan
1999	State salmonid Fish Health Regulations
2000	Endangered Species Act listing
2001	ISAv detected in Maine
2003	Clean Water Act discharge permit
2004	44 sites, 6,760 tonnes of production
2004	First marking requirement for farmed fish

Major components of Atlantic salmon protection efforts in Maine have included:

- The petition to list Atlantic salmon in Maine under the Endangered Species Act;
- The state Atlantic Salmon Conservation Plan, a document for planning and management in an attempt to avoid listing salmon under the Endangered Species Act;
- Federal listing of Atlantic salmon in selected rivers in Maine;
- Federal Clean Water Act permit provisions that impact salmon farming sites and business operations.

These efforts and requirements have prompted discussions on cooperation in restoring salmon. Concurrently, the multiple efforts and timelines made it harder to come to closure because of the fast pace of change and changing requirements under these laws and plans.

The following list provides examples of the farming industry and wild salmon interests working together. The list is not meant to be comprehensive; efforts that others would deem important may have been omitted.

- Rearing wild salmon;
- Salmonid fish health regulations;
- Weirs in salmon rivers;
- Containment management systems;
- Fish marking.

Bringing farming industry experience to bear in the raising of wild fish is an obvious place to start this discussion and remains an obvious area for continued cooperation. Clearly, the salmon farming industry knows how to produce volumes of fish while minimizing production costs, some of the very attributes important to the restoration hatchery program. If salmon farmers rear wild fish, it is important to pay attention to the different goals and specifications for rearing farmed and restoration fish.

Fish health regulations were a state effort that involved industry and wild salmon interests to protect both farmed and wild salmon from diseases of regulatory concern such as ISAv or IPNv (Infectious Pancreatic Necrosis virus). These regulations took a few years to draft and promulgate but provide a successful example of working together. All parties put much time and effort into developing these regulations. The fish health regulations have allowed flexibility and quick response in addressing issues such as the occurrence of ISAv in Maine.

The use of weirs in some of Maine's Atlantic salmon rivers is an effort to physically separate farmed fish from wild Atlantic salmon as fish move upriver to spawn. There has also been industry cooperation with escape reporting and pen inventory monitoring. All these factors together ensure that fish that have escaped from farmed pens do not interact with wild salmon on spawning redds and potentially dilute the genetics of wild salmon. Weirs have allowed an assessment of the numbers of farmed fish entering some rivers. Overall, however, they have been of limited utility because it has not been possible to put weirs on enough rivers.

Containment management systems were developed cooperatively by industry, conservation interests, and government agencies. Importantly from the perspective of working together, attention was paid to the needs of all interests in the development and implementation of containment management systems. The work on containment management systems has been a success, giving confidence in how sites are performing and allowing corrective action that focuses on real problems.

The issue of marking fish has been, and remains, controversial. Permits under the US Clean Water Act require the marking of farmed fish, with a requirement for site-specific marks in 2007. An important issue to consider with regard to marking is the relative advantage or disadvantage of having one portion of the industry mark when another portion does not have this requirement. As was discussed at the NASCO meeting on marking in late 2004, physical and genetic markers should be considered. In the US, attempts at industry/wild salmon dialogue have been on again and off again, with much work remaining on this issue before declaring the marking issue a success or failure.

The last example is the watershed councils which are groups of interested, local people who work on the local issues surrounding wild salmon on a particular watershed. There has been some industry involvement on watershed councils. However, I believe that this type of locally directed council still has much potential for co-operation between wild and farmed salmon interests. From the experience coming from the examples provided above, I believe that we can draw key elements of having wild and farmed salmon interests working together. These are:

- Develop clear objectives
- Outline clear expectations

These two bullets are linked, so will be discussed together. The development of clear objectives and expectations is critical to wild and farmed salmon interests working together. Our experience in Maine is that without the foundation provided by clear objectives and expectations, participants are far more likely to assume what the objectives of an interaction are, and it is likely that the assumptions of one party will not match the assumptions of another. The result of differing objectives and expectations will be disappointment, mistrust, and lack of progress.

- Real listening and understanding is critical

To be successful, working together with parties who have different goals and measures of success takes real listening and understanding. When discussions about hatchery techniques have taken place in Maine, you would think it would be an easy matter of comparing notes and moving forward. However, if one thinks about the different way in which production hatcheries and restoration/wild fish hatcheries are operated, it is easy to see how a misunderstanding can occur.

- Build trust

A good working relationship requires trust; trust that must be built among the parties that are working together. Without trust, parties will participate because they think there is some type of obligation. They will participate from a position of making sure that their interest is not harmed, rather than trying to co-operate with another party to work together towards a mutually agreed outcome. The trust element is extremely important, and hard to achieve when the past actions of individuals or parties have eroded trust. In Maine, some of these relationships go back twenty years with little trust involved. Making up for these past perceptions is tough work.

- Use adaptive management

When trying to achieve a working partnership between wild and farmed salmon interests, the need for adaptive management must be understood and built in to any agreements. The way we look at salmon restoration or farming changes rapidly with an evolving understanding of the ecological, social, legal, and economic conditions affecting all parties. Our working arrangements must acknowledge and embrace adaptive management. To do otherwise will damn all parties to the maintenance of obsolete agreements and to certain failure.

- Follow through on commitments

Simply stated, successful cooperative working arrangements require a follow-through on commitments among all Parties. Otherwise, why work together?

- Establish regular communication

With the distances among NASCO Parties and among the wild and farmed salmon interests within the NASCO Parties, and the time commitments that we all have in our respective positions, regular communication is a vital element in a good working relationship. Regular communication demonstrates a commitment to the working relationship, can demonstrate progress toward meeting objectives, and can relay reasons for not meeting objectives. Regular communication does not allow problems or perceptions to build into significant barriers to working together.

Not surprisingly, these elements are central to most interactions that we all have in our personal and work lives but they are important nonetheless. The experience that we have had in Maine is that these critical elements must be committed to, and followed through, to maximize the benefit of having wild and farmed salmon working together toward the mutual goal of conserving and restoring wild Atlantic salmon throughout its range.

Salmon restoration – pooling skills and resources

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Atlantic salmon populations in Maine's Downeast Rivers are well below historic levels and in need of rehabilitation. Inadequate spawning escapement is one of the primary factors limiting population levels. Therefore increasing the number of adult spawners is an important step in conserving and rehabilitating these stocks.

The US Fish and Wildlife Service, NOAA's National Marine Fisheries Service, the State of Maine Atlantic Salmon Commission, St. Croix International Waterway Commission and representatives of three salmon aquaculture companies in Maine (Atlantic Salmon of Maine, Heritage Salmon, and Stolt Sea Farms) implemented a cooperative program to assist in rebuilding endangered Atlantic salmon populations in Maine. Atlantic salmon in eight Maine Rivers are listed as a Distinct Population Segment (DPS) within the Gulf of Maine that warrant protection under the Endangered Species Act. The program utilized eyed eggs from selected DPS river-specific stocks to rear to maturity in private industry hatcheries and marine net pens.

The State of Maine, through the Maine Atlantic Salmon Task Force, requested that eyed Atlantic salmon eggs be transferred from the Craig Brook National Fish Hatchery in East Orland, Maine, to aquaculture industry fish culture facilities in February 1997 and 1998. These eggs were derived from the DPS river-specific Atlantic salmon captive broodstock program at the Craig Brook National Fish Hatchery and were reared to various life-stages by the industry for the purpose of augmenting salmon populations in rivers supporting extant populations of wild Atlantic salmon.

In 1997, 60,000 eyed eggs were transferred from the Craig Brook National Fish Hatchery to two commercial hatcheries supporting the Maine aquaculture industry. These eggs originated from the Dennys, East Machias and Machias captive broodstock populations. In 1998, 70,000 eyed eggs were transferred; these eggs originated from the Dennys, East Machias, Machias, and Narraguagus captive broodstock populations. Eggs transferred in 1997 reached the smolt stage in 1998 and were transferred to industry marine net pens to rear to maturity. Approximately one thousand smolts from each stock were placed at two industry marine sites located at Cross Island in Machias Bay and Deep Cove in Cobscook Bay. The balance of the juvenile fish, approximately 60,000, was stocked into their river of origin as parr and smolts. The second transfer of eggs reached the smolt stage in 1999 and was transferred to three industry marine sites located at Starboard Island in Machias Bay and Broad Cove and Prince Cove located in Cobscook Bay. Again, approximately 50,000 juvenile fish were stocked into their rivers of origin as parr and smolts during the spring of 1999 prior to the marine transfer.

In 2000, 1,038 adult Atlantic salmon were stocked into the Dennys (112), Machias (176), and St. Croix (750) rivers. In 2001, a total of 703 adult Atlantic salmon was stocked into the Dennys (75), Machias (104), and St. Croix (524) rivers. The 2001 totals were well below the desired stocking levels due to disease concerns (ISAv) and over-winter mortality experienced at some of the marine sites. The fish were sampled for disease prior to stocking to ensure that only healthy fish were stocked.

The numbers of adult fish to be stocked into natal rivers were determined based on target egg deposition rates (240 eggs per square metre of juvenile rearing habitat) believed to optimally utilize available habitat. Fecundity estimates were conducted on 111 females in an effort to accurately determine egg deposition potential for stocked adults. For the adult stocking portion, the Maine Technical Advisory Committee recommended stocking enough adults to fully seed the habitat available in the Dennys River and enough adults to seed 50 percent of the available habitat in the Machias River. Consistent with the river-specific stocking strategy for the DPS Rivers, the St. Croix River (non-DPS) would be stocked with individuals that had an undetermined origin or surplus to the pre-determined total for each of the DPS Rivers.

Based on the previous year's redd counts, stocking logistics were modified for 2001. In 2000 the fish were held at an intermediate freshwater acclimation site for four weeks prior to stocking; this increased handling two-fold. In 2001 the fish were stocked directly into the river at various locations; as a result the fish seemed to be in better condition and were less stressed. When moving and handling adult broodstock immediately prior to spawning, stress can be significant and may impact gamete quality and viability.

To assess in-river movement of post-release adults, 15 ultrasonic telemetry receivers were deployed throughout the Dennys River drainage (Figure 1). Prior to each stocking, individual adults stocked into the Dennys River were tagged with ultrasonic transmitters; 60 in 2000 and 43 in 2001. In the St. Croix River, 25 post-spawn adults were fitted with transmitters that could be detected in offshore arrays set by the Atlantic Salmon Federation and Fisheries and Oceans Canada. Four fish were recorded 40 km off the mouth of the Magaguadavic River between 6 and 28 days post-tagging.

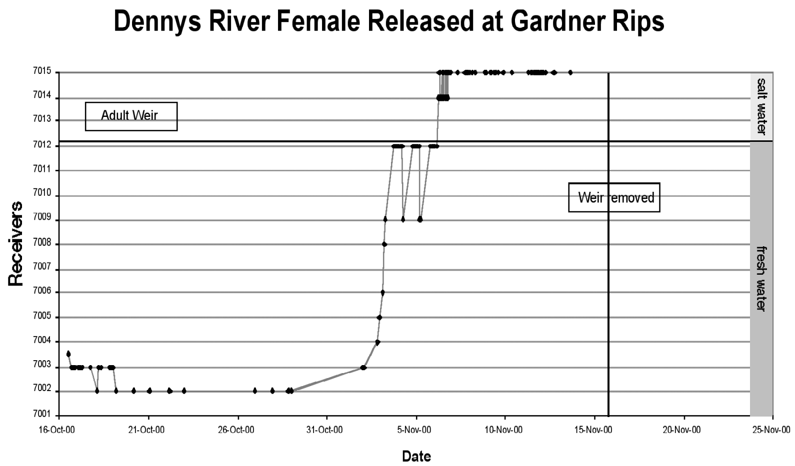

Figure 1

*Example of Telemetry Tracking Data**

** Data supplied by Tim Sheehan NOAA Fisheries*

Redd surveys were carried out in both years (2000 and 2001) by State of Maine Atlantic Salmon Commission, St. Croix International Waterway Commission and National Marine Fisheries Service personnel between early November and mid-December. A follow-up redd survey was conducted in 2002 on selected tributaries of the St. Croix River to assess spawning activity from returning adults or holdover fish. No redds were recorded. A minimum of 170 redds for 412 females released (0.4 redds/female) was recorded in the mainstream St Croix River survey in 2000 compared to 430 redds from the 305 female salmon released (1.4 redds/female) in 2001. The observed redds appeared to be well constructed and in appropriate habitat. In a small-scale study conducted in a tributary of the Dennys River (Cathance Stream), 10 salmon (6 females and 4 males) were stocked into a confined area between two weirs. Spawning activity was monitored several times a week until ice-in. The researchers observed one pair spawning and found several areas of digging and eggs deposited in other locations. The prime spawning areas within the study area were not used; the redds found were poorly constructed and difficult to recognize.

The goal of the project was primarily to assess the utility of adult stocking as a new tool in efforts to rebuild depleted Atlantic salmon stocks in several eastern Maine Rivers. The objectives of the project were to: 1) involve the industry in the restoration program, 2) evaluate the feasibility of using river-specific captive reared (freshwater and marine) adult salmon released to spawn naturally and contribute genetically and demographically to a natural spawning population, and 3) as a gene banking approach to protect against the loss of genetic material from these three populations in the event of a catastrophic event at Craig Brook National Fish Hatchery. Because this is such a novel technique, assessment and monitoring of the success of this program in producing juveniles and returning adults is vitally important.

Evaluation is not completed and included a number of different projects to assess the value of this type of approach for rebuilding and restoring Atlantic salmon populations in Maine. These projects include: telemetry to determine spawning ground movements and post-spawning distribution; evaluation of natural egg deposition and artificial fertilization rates, survival and fecundity; elastomer tagging for stock identification; assessment of smolt emigration and stage-specific juvenile survival; contribution of returning adults and size and morphology analysis for three different populations. Ongoing assessment and analysis should be completed in 2006. To date no comparison has been made between this program and spawning stock recruitment as a result of wild spawning or other stock enhancement stocking programs.

Preliminary assessment of these data showed good initial survival for all stocks transferred to freshwater fish culture facilities, but some mortality was experienced at different marine grow-out sites. The large number of hatchery juveniles (e.g., smolts) stocked into natal rivers resulted in very few returning adults. The adults reared to maturity in marine net pens were large, robust and very fecund individuals that had a high fertility rate in the hatchery, but had very low reproductive success in the wild. Adult fish movement on the spawning grounds was random; most moved a limited distance, 2-3 km, some individuals moved both upstream and downstream. In general, fish that were placed in the upper reaches of the river moved downstream and the fish placed in the lower river moved upstream. Natural spawning in the rivers occurred later than artificial spawning in the hatchery and later than their wild conspecifics. Redds were constructed throughout the drainage; however some redds were poorly constructed and/or were not in prime spawning areas with high-quality substrate. In summary, the adult fish used in this study had highly variable behavior on the spawning grounds which may help explain their low reproductive success in the wild.

Considerations for future projects should include a closer look at rearing environments and techniques to minimize hatchery effects. As with any stocking program, additional research is needed to resolve the uncertainties involved with domestication and artificial propagation. New innovative rearing environments such as natural spawning channels developed to simulate a natural wild environment may have significant advantages. Ideally, rearing fish under natural conditions closely mimicking the receiving environment could act to enhance the behavior of post-release adults.

Overall, the experimental stocking project showed great promise for wild and farmed salmon groups working collaboratively. Careful planning well in advance of the actual fish transfer will benefit and protect the interests of all parties. The first steps for involving industry or NGO groups in these types of projects is developing clearly defined goals and objectives with up-front expectations for quality fish rearing, fish health and stocking. A great deal of trust and respect will help ensure a successful project. The demographic boost of adult spawners in these rivers provided opportunities for natural spawning to produce river-reared juveniles and adults. As with any stocking program it is not clear that a two-year trial program is long enough to adequately assess the efficacy of the program. Despite the tremendous boost in adult spawners, low numbers of naturally reared juveniles were captured and only a few naturally spawned adults have returned to these rivers in 2004 and 2005.

The authors would like to acknowledge the assistance of the Maine aquaculture industry, NOAA's National Marine Fisheries Service, US Fish and Wildlife Service, Atlantic Salmon Commission and St. Croix International Waterway Commission in conducting this project. Funding for this project was provided through in-kind contributions from each of the participating companies and agencies.

Restoration programmes – Session Chairman's Summary

Chris Poupard, Chairman of NASCO's NGO Group

The session comprised four quite different, but complimentary papers, covering the storage and practical use of genetic material in gene banks, the role of a hatchery in restoring salmon to the Tyne, and two papers on co-operative approaches to salmon restoration, one focussing on freshwater and the other on marine net pen rearing.

Ketil Skår emphasized the value of gene banks for restoration of salmon stocks, particularly for Norwegian rivers where re-stocking was required following eradication of *Gyrodactylus salaris*, and in rivers wiped out by acidification. It was important to ensure that rivers were completely disease-free prior to stocking, and he emphasized the long-term value of preventing the escapes of farmed fish.

Nigel Milner made it clear in his paper that the role of re-stocking was to kick-start a restoration programme only made possible by improvements in water quality, and this theme was picked up by many contributors in discussion. Although many members of the angling public saw re-stocking as a universal panacea, contributors were in unanimous agreement about the need to first identify and correct problems with water quality and habitat in any restoration programme.

George Lapointe described his long experience in conserving and restoring rivers in Maine. He identified a number of key criteria for the success of any restoration programme; clear objectives, clear expectations, real understanding, trust, adaptive management and adequate follow-through. His final point, the need for good communication, was a common theme for all speakers.

David Bean and Sebastian Belle described joint efforts raising smolts in state hatcheries followed by on-growing by the private sector in net pens prior to re-stocking. Sebastian highlighted the differential costs of state and private sector-reared fish, suggesting the possible economic advantages of a greater involvement by the aquaculture industry.

Two key questions emerged from the discussion period:

What is a salmon stock and how is it defined?

Several participants suggested more thought should be given to this aspect before restoration programmes were undertaken, particularly on rivers with several tributaries and a history of different run-timings. The genetic typing work currently being undertaken as part of the SALSEA project would assist.

With many stocks to save, how to decide priorities?

The large costs of long-term restoration of some stocks in the face of developing threats, like climate change, were recognised. Participants recognised the socio-economic pressures involved, but were keen to stress the importance of not writing off smaller rivers on cost grounds alone.

Finally, the Chairman highlighted the need for trust between all parties identified earlier by George Lapointe. Where trust had been established, such as in the development of Area Management Agreements in Scotland, good results followed. He hoped that the dialogue established at this seminar would result in increased co-operation between the aquaculture industry and wild fish interests.

Summing-up and close of Workshop

Ken Whelan, President of NASCO

Ladies and gentlemen, my name is Ken Whelan, and I am the President of NASCO. I would like to try to sum up what has been a very valuable Workshop which has facilitated a very useful dialogue. It is clear from the information presented that area management initiatives have generated valuable hydrographic and environmental data and have stimulated more proactive management of freshwater habitats. Through the use of single bay management, single generation sites and synchronised fallowing, real progress is being made in relation to minimising impacts of diseases and parasites, which are key issues for wild fish interests. We must recognise that there are a number of challenges that remain, including the problem of allocating additional sites to the industry to facilitate rearing of single generations and fallowing, and the limited number of available medicines, particularly for the treatment of sea lice. Successful area management initiatives depend on real commitment from all partners, frequent and open communication and greater involvement of other interested parties. In some situations there may be a need to absorb appropriate area management strategies into regulatory protocols rather than relying solely on voluntary agreements. I am personally very encouraged by the notable successes in managing disease and parasite interactions. However, containment of farm salmon remains a concern for wild fish interests. The development of third-party audited containment management systems may represent a significant step forward.

Escapes of farmed salmon remain large relative to wild salmon abundance despite progress made by the industry in improving containment. In these circumstances, the use of all-female triploid salmon by the farming industry could eliminate the potential for genetic interaction with the wild stocks. We have heard today that techniques for production of all-female triploid salmon exist, and trials suggest that these fish return in greatly reduced numbers to fresh water, reducing the opportunities for interactions with wild fish. We must also recognise that, from the industry's perspective, they perform poorly in sea cages and appear to be less able to tolerate environmental stressors. There would, therefore, be higher costs to the industry associated with the use of sterile salmon, as there are with all measures to ensure containment, and these would have to be considered in relation to the costs to the wild stocks from genetic impacts of escaped farmed salmon. Personally I believe that such impacts on the wild stocks may also affect the long-term sustainability of the industry. Society may be willing to pay a higher price for farmed all-female triploid salmon if these fish could be presented as a way to protect the wild stocks. On the other hand, there may be consumer resistance to the technique if it was seen as genetic manipulation. I would like to suggest that these issues be given very careful consideration by the Liaison Group. There was a clear message to us all that triploids need to be considered as a novel species and that future trials should be undertaken based on selecting the best-performing stocks in order to see if the performance problems could be eliminated. However, we would need to determine how high a priority should be afforded to such research, and consideration might also be given to alternative methods of producing sterile salmon, such as methods involving chemical interference.

The information presented during the session on restoration demonstrated to me that wild fish restoration programmes can benefit from fish farmers' expertise but we must recognise that there is no quick fix and rebuilding requires patience and commitment, as with the implementation of successful area management initiatives. In many situations, habitat protection and restoration, rather than stocking, will be the most appropriate approach to restoration, but stocking can be useful in some situations in 'kick-starting' rebuilding efforts. It is apparent from the presentations today that restoration is a complex and involved process and that hatchery programmes may either be of limited value (for example in the River Tyne) or essential in conserving stocks (for example the Norwegian living gene banks). In the event that our efforts to restore stocks fail, consideration may need to be given to maintaining salmon stocks until conditions become more favourable. The Workshop also highlighted the fact that difficult decisions will need to be made concerning how to prioritise stocks for restoration and whether to continue restoration efforts in the long term if the stocks fail to respond or to rely on a gene bank. In Norway the system of designating national salmon rivers and fjords aimed to afford additional protection to the largest stocks while in the US, under the Endangered Species Act, efforts to conserve all designated stocks are a legal requirement. We are all aware that when wild populations fall to low numbers they are very vulnerable to the impact of fish farm escapees, highlighting the need for improved containment, either physical or biological. Finally, I would note the importance of involving all interested parties in salmon restoration initiatives, e.g. Watershed Councils in the US, and of educational outreach programmes.

So in closing this Workshop, I would like to highlight that today we have heard about some very positive examples of wild and farmed salmon interests working together. I believe that further development of this working relationship in the future should lead to mutual benefits and attainment of the shared goals of healthy wild salmon stocks and a sustainable salmon farming industry. The Workshop findings will be presented to the Liaison Group for its consideration and decision as to the next steps. Finally, I would like to thank all contributors for what has been a very interesting day with high-quality presentations and lively discussion periods, and I wish you all a safe journey home.

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