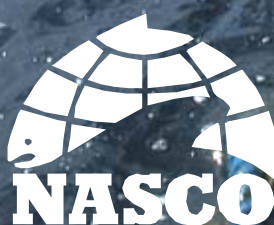


Interactions Between Aquaculture and Wild Stocks of Atlantic Salmon and Other Diadromous Fish Species: Science and Management, Challenges and Solutions

Conveners' Report

Lars Petter Hansen
Malcolm Windsor



Acknowledgements

The Symposium organizers would like to gratefully acknowledge the support of the following Organizations:

Research Council of Norway



Directorate of Fisheries (Norway)



Royal Norwegian Ministry of Fisheries and Coastal Affairs



Scottish Executive



Fisheries and Aquaculture Research Fund (Norway)



Directorate of Freshwater Fisheries and Salmonid Enhancement Fund (Iceland)



The Worshipful Company of Fishmongers (UK)



Intervet International BV (Netherlands)



Pharmaq AS (Norway)



Norwegian Farmers Union



Directorate of Nature Management (Norway)



Norwegian Institute for Nature Research



Royal Norwegian Ministry of the Environment



DEFRA (UK)



National Marine Fisheries Service (USA)



Atlantic Salmon Trust (UK)



Marine Institute (Ireland)



ScanVacc AS (Norway)



Norwegian Salmon Rivers



City of Bergen



NINA SPECIAL REPORT 34
Norwegian Institute for Nature Research (NINA)

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Hansen, L.P. & Windsor, M. 2006. Interactions between aquaculture and wild stocks of Atlantic salmon and other diadromous fish species: science and management, challenges and solutions. – NINA Special Report 34. 74 pp. Trondheim, October, 2006.

ISSN: 0804-412X

ISBN 10: 82-426-1736-8

ISBN 13: 978-82-426-1736-1

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Availability: Open. Publication type: Printed publication
Cover picture Courtesy of the Scottish Salmon Producers' Organisation, Perth, UK
Key words: Atlantic salmon, aquaculture, interactions, diadromous fish

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Preface by the Presidents of NASCO and ICES

The subject of this Symposium is of vital importance not only to those who are involved with conservation and management of wild salmon stocks, but also to those involved in salmon farming. It is also a fine example of scientists making their research relevant and responsive to the needs of policy makers. As Presidents of NASCO and ICES, we commend this report to you, and we reaffirm the commitment of our Organizations to cooperate on topics of mutual interest, like this one.

The two Conveners have done an excellent job in drawing together dozens of papers and presentations, hours of discussion and summaries by Chairmen and other participants. They have used all this information to draw conclusions that all of us should consider very carefully. It is clear that while considerable progress is being made in improving understanding of interactions between wild and cultured salmon and managing them, two significant challenges remain. These are to improve containment of farmed salmon either through physical or biological means, and to control sea lice on farms, so that damage to the wild stocks is avoided. The stakes are high. For example, if the fears about genetic impacts of escapees come true, and there is evidence that they are happening, then we run the risk of compromising very ancient and diverse stock structures. This will harm both the wild fish and the fish farming industry. We urge all those concerned to read this report, and to act appropriately. We believe that there is now a basis for improved cooperation between wild and farmed salmon interests that should give confidence that solutions can be found to the remaining challenges in managing interactions between cultured and wild salmon. These solutions are required urgently.

*Ken Whelan, President of NASCO and Michael Sissenwine,
President of ICES*

Executive Summary

Since the early 1980s, farming of Atlantic salmon has become a major industry with a production in the North Atlantic in 2005 of approximately 0.8 million tonnes, or 380 times the reported catch of wild salmon in the same area. There are concerns about the disease, parasite, genetic and ecological interactions of salmon farming on the wild salmon stocks and a regime is required that allows the industry to prosper while safeguarding the wild stocks. Interactions between wild and cultured salmon are not restricted to those arising from salmon farming. Where fish are deliberately released to the wild, a regime is also required under which the risks as well as the benefits are carefully considered.

In response to concerns about interactions between salmon aquaculture and the wild salmon stocks, a series of international meetings has been convened over the last 16 years to review scientific understanding of interactions and provide guidance on appropriate management responses. The most recent of these symposia, held in Bergen, Norway, during 18 - 21 October 2005, is reported here. It is clear that since the first symposium in 1990 scientific understanding of the interactions between cultured and wild salmon has increased considerably. The latest information presented in Bergen confirms that cultured salmon can have significant negative impacts on the wild stocks. While real progress has been made in managing these interactions, some very significant challenges remain, particularly with regard to further reducing the impacts of escapees and sea lice. A further major development since the last symposium in 1997 is that the representatives of the industry present in Bergen accepted that their industry can have damaging impacts on the wild stocks. This is very welcome because it is a prerequisite to cooperative action, which has developed considerably between wild and farmed salmon interests but which needs to continue and be enhanced if solutions are to be found to the remaining challenges.

The Conveners propose that interactions between farmed and wild salmon need to be virtually eliminated, not just reduced. There are risks not only from farmed salmon but also from inappropriate stocking practices to be addressed. While progress is being made in managing interactions, the large scale of the salmon farming industry means that solutions are urgently required. We believe that progress in addressing the sea lice problem has been made and can continue to be made by concerted action and widespread use of best practice but it is clear that difficulties remain, particularly with regard to protecting wild sea trout populations. The prospect of resistance

developing to the available lice treatments is a real concern for both wild and farmed salmon interests. Progress has also been made in reducing escapees but their numbers remain large relative to the wild stocks and they may be irreversibly damaging the stock structure and diversity of the wild Atlantic salmon. In our view, this symposium confirms that containment of farmed salmon must be made much more effective. If physical containment cannot be achieved then the use of sterile salmon may be necessary.

We believe that if no action is taken now, and if the views of the many scientists and experts at the symposium, and the two preceding symposia, are correct, we risk the loss of the diversity of local adaptations in the wild stocks of salmon in the North Atlantic. This may well have serious consequences for their fitness, productivity and ability to survive environmental change.

Lars Petter Hansen (ICES Co-Convenor) and
Malcolm Windsor (NASCO Co-Convenor)
6 October, 2006

Sammendrag

Fra tidlig på 1980 tallet til i dag har oppdrett av Atlantisk laks utviklet seg til en betydelig industri. I 2005 ble det produsert ca 0,8 mill tonn laks i Nord Atlanteren, eller ca 380 ganger så mye som rapportert fangst av villaks i det samme området. Effekter av lakseoppdrettet på villaks, som sykdommer, parasitter, genetik og økologi er bekymringsfullt, og det er behov for å utvikle en strategi for å sikre de ville laksebestandene samtidig som lakseoppdrettet fortsatt forblir en viktig næring. Interaksjonene mellom vill og kultivert laks er dessuten ikke bare begrenset til oppdrettet. En strategi hvor både risikoer og fordeler blir nøye vurdert, er påkrevet også for laks som skal settes ut i naturen for kultivering/havbeite.

Over de siste 16 årene har det blitt arrangert flere internasjonale møter hvor både vitenskapelig forståelse og rådgiving til forvaltningen om interaksjonene mellom lakseoppdrett og vill laks har vært tema. Det siste av disse symposiene som ble holdt i Bergen 18 - 21 oktober 2005 rapporteres her. Siden det første symposiet i 1990 har det vitenskapelige grunnlaget for å forstå interaksjonene mellom oppdrettet og vill laks økt betydelig. Informasjonen som ble presentert i Bergen bekreftet at oppdrettslaks kan ha negativ effekt på ville laksebestander. Selv om det har vært framgang i forvaltningen av disse, gjenstår det betydelige utfordringer, spesielt for å redusere lakselusproblemet. En viktig utvikling siden det siste symposiet i 1997 var at representantene fra industrien som var tilstede i Bergen nå aksepterte at industrien kan ha ødeleggende effekt på ville bestander. Dette er viktig fordi det er en forutsetning for samarbeid, og selv om dette nå har bedret seg betydelig må samarbeidet fortsette og bli ytterligere forbedret hvis man skal finne løsninger på utfordringene.

Vi foreslår at interaksjonene mellom oppdrettslaks og villaks må praktisk talt elimineres, ikke bare reduseres. Problemer også i forbindelse med feilaktig utsetting av laks for kultivering og havbeite må det også fokuseres på. Selv om det er framgang i å forvalte interaksjonene krever det betydelige volumet i oppdrettsvirksomheten hurtige løsninger. Vi tror at framgangen som har kommet i forvaltningen av lakselusproblemet kan videreføres i felleskap og sørge for at kunnskapen om de beste løsningene blir spredt, men det er også klart at det er store problemer som må løses, spesielt for å beskytte bestandene av sjørret. Resistensutvikling mot de forskjellige avlusingsmedikamenter er også bekymringsfull både for oppdretts- og villaksinteressene. Det er også gjort framskritt i å redusere rømmingene fra oppdrettsanlegg, men det er fremdeles svært mange

oppdrettslaks som rømmer i forhold til størrelse på bestandene av villaks. Disse rømmingene kan medføre irreversible forandringer i bestandsstruktur og diversitet av vill laks. Vi mener at dette symposiet bekreftet at tiltak for å hindre rømming må effektiviseres og forbedres. Hvis dette ikke er mulig kan sterilisering av oppdrettslaksen bli nødvendig.

Vi tror at hvis resultatene av forskningen som ble presentert på dette symposiet og de to tidligere er korrekte, og at hvis ikke betydelige tiltak blir satt inn, risikerer vi tap av lokal tilpasning og diversitet av den ville laksen i Nord Atlanteren. Dette kan ha betydelige konsekvenser for villaksens overlevelsessevne, produktivitet og evnen til å overleve forandringer i miljøet.

Lars Petter Hansen (ICES Co-Convener) og
Malcolm Windsor (NASCO Co-Convener)
6 October, 2006



INTRODUCTION



The River Imsa, Norway where life-cycle experiments with farmed and wild salmon and their crosses have contributed to understanding the interactions between wild and cultured salmon.

I. Introduction

I.1 Background

Paradoxically, at a time when there is serious concern about the status of wild Atlantic salmon stocks, the abundance of salmon in the North Atlantic Ocean has probably never been higher as a result of the rapid growth of salmon farming.

Since the early 1980s, farming of Atlantic salmon has become a major industry, with production in 2005 of approximately 785,000 tonnes in the North Atlantic, a reduction compared to 2004 (831,000 tonnes) but a 5% increase on the previous five-year mean production. Most of this production occurred in Norway (72%) and Scotland (17%). The provisional worldwide production in 2005 was approximately 1.3 million tonnes with Chile producing approximately 405,000 tonnes. The worldwide production of farmed Atlantic salmon is approximately 600 times the reported catch of salmon in the North Atlantic (ICES, 2006a). Progress is being made in managing the interactions between wild and farmed salmon, and collaboration between wild and farmed salmon interests is improving (Anon, 2006). However, the wild stocks are in a weakened state and vulnerable to a wide range of anthropogenic impacts. There are, therefore, concerns about the disease, parasite, genetic, and ecological impacts of salmon farming on wild salmon stocks (Hansen *et al.*, 1991; Hutchinson, 1997; Youngson *et al.*, 1998; Hutchinson, 2006). A regime is required that allows the industry to prosper but, at the same time, safeguards the wild stocks so as to maintain the social and economic benefits from both wild and farmed salmon. This has not been, and will not be, easy. Currently, the Atlantic salmon is to the fore but, as aquaculture develops and diversifies into other species, the wild stocks of these and other species may be affected, and the nature of interactions may be similar.

Interactions between cultured and wild salmon are not restricted to those arising from salmon farming. In response to the decline in the abundance of wild salmon stocks, cultured fish are stocked for mitigation, restoration, and rehabilitation purposes. Furthermore, although 'commercial' ranching of salmon is no longer undertaken in the North Atlantic, there is interest in ranching to support recreational fisheries in some rivers. A regime is required under which the risks as well as the benefits are carefully considered before deliberately releasing any cultured fish into the wild.

In response to concerns about interactions between salmon aquaculture and the wild salmon stocks, a series of international meetings aimed at reviewing scientific understanding of interactions and providing guidance on appropriate management responses has been convened. The first major international symposium on this subject, sponsored by the Norwegian Directorate for Nature Management and NASCO, was held in Loen, Norway, in 1990 (Hansen *et al.*, 1991). NASCO was sufficiently concerned by the gravity of the threats and their potentially irreversible nature that, in 1991, it adopted guidelines designed to minimise impacts of aquaculture on the wild stocks. These guidelines were replaced three years later by the Oslo Resolution, which in turn was replaced in 2003 by the Williamsburg Resolution (NASCO, 2006a). This Resolution was developed to ensure that the measures taken by NASCO Parties and their relevant jurisdictions to minimise the impacts of aquaculture, introductions and transfers, and transgenics were consistent with the Precautionary Approach. The development of the Williamsburg Resolution drew on information presented at a second major international symposium, convened by ICES and NASCO, held in Bath, England, in 1997, which reviewed the scientific and management aspects of interactions between salmon culture and the wild salmon stocks (Hutchinson, 1997; Youngson *et al.*, 1998).

Since the first symposium in 1990, production of farmed salmon in the North Atlantic has more than trebled. Aquaculture is certainly not the only threat to the wild salmon stocks, and NASCO is addressing a wide range of other issues relating to salmon conservation and management (e.g. the management of fisheries and habitat protection and restoration) and has recently established an International Atlantic Salmon Research Board to investigate the factors influencing the mortality of salmon at sea and the opportunities to counteract them. The Board has recently endorsed an ambitious international programme of research, the SALSEA programme, containing a comprehensive mixture of freshwater, estuarine, coastal and offshore elements, ensuring a thorough overview of factors which may affect the mortality of Atlantic salmon at sea.

NASCO and ICES believe that the progress now being made in managing the interactions between wild and cultured salmon must be maintained, enhanced, and given more urgency to ensure that all aquaculture practices are conducted in a sustainable manner that does not threaten wild stocks. They therefore agreed to hold a third

international symposium in Bergen, Norway, during 18 - 21 October 2005.

This publication forms the report of the Bergen symposium. It is intended to serve as a record for ICES and NASCO of the symposium and of the Conveners' conclusions, which have been based on all the information presented. It also represents a report to the sponsoring organizations and a record of the state of international knowledge of this subject in 2005, the challenges that remain in managing interactions between cultured and wild salmon and possible solutions to these challenges, and it provides recommendations for future research requirements. The intention is that this report will be made widely available to those involved in the culture of salmon, to managers of wild salmon stocks and to those involved in research on interactions between wild and cultured fish.

A second publication containing those scientific papers accepted following peer review has been published as a Special Symposium Volume of the ICES Journal of Marine Science that has been guest-edited by Dr Peter Hutchinson (Hutchinson, 2006).

1.2 Objectives of the Symposium

The objectives of the symposium were:

- (i) to summarise available knowledge of the interactions between aquaculture and wild salmon stocks and other diadromous fish species;
- (ii) to identify gaps in current understanding of these interactions and to develop recommendations for future research priorities;
- (iii) to review progress in managing interactions, the remaining challenges, and possible solutions; and
- (iv) to make recommendations for additional measures to ensure that aquaculture practices are sustainable and consistent with the Precautionary Approach.

The aim of the symposium was to build on the existing collaboration between wild and farmed salmon interests so as to identify the remaining challenges and possible solutions in moving toward sustainable culture of Atlantic salmon. As such, the focus was on practical approaches to managing interactions between wild and cultured salmon.

1.3 Structure of the Symposium

Ms Janne Sollie, Director General of the Directorate for Nature Management in Norway, opened the symposium which was structured into four plenary sessions and a

poster session. In total, 4 keynote papers, 35 invited and contributed papers and 13 poster papers were presented. The abstracts of these papers are contained in Annex 1.

The first of the plenary sessions was a keynote session intended to set the scene with reviews of the value of wild Atlantic salmon, developments in the sustainability of the salmon farming industry, the stock status and management of wild Atlantic salmon, and the ecology of cultured Atlantic salmon and their interactions with wild fish. Following this keynote session there were plenary sessions focusing on genetic and ecological interactions and their management, and on disease and parasite interactions and their management. The final plenary session was a synthesis session intended to highlight the remaining challenges and their possible solutions. Following summaries of the three plenary sessions (see Annexes 2 - 4) and poster session (see Annex 5) by the Co-Chairmen, six participants from different interests were asked to give their perspectives on the information presented during the symposium, i.e. their 'take-home' messages (see Annex 6). There were two representatives of non-governmental organizations, two representatives of the fish farming industry, and two representatives of administrations involved in the management of salmon farming or wild salmon. There was then a general period of discussion.

The symposium was closed by Mr Peter Gullestad, Director of the Norwegian Directorate of Fisheries and a Vice-President of ICES.

About 110 participants from 15 countries attended the symposium, including delegates with experience of research into, and management of, interactions between cultured and wild salmon in the North Atlantic Ocean, Baltic Sea and North Pacific Ocean. A list of participants is given in Annex 7.

1.4 Acknowledgements

The Conveners express their sincere thanks to the symposium Steering Group: Dr Malcolm Beveridge, Ms Mary Colligan, Professor Tom Cross, Mr Knut Hjelt, Dr Peter Hutchinson, Mr Arni Isaksson, Mr Geoff Perry, and Mr Chris Poupard. We would also like to thank Dr Peter Hutchinson for his assistance in preparing this report and Ms Margaret Nicolson and Ms Bente Halsteinsen for administrative support. The Conveners also thank the participants who provided their take-home messages during the final session: Ms Katherine Bostick, Ms Fiona Cameron, Mr Knut Hjelt, Dr Jens Christian Holm, Mr James

Ryan, and Mr Øyvind Walsø. The details of the affiliations of those mentioned here and elsewhere in this report are given in Annex 7.

Finally, ICES and NASCO acknowledge with gratitude the generous support of the following organizations: Research Council of Norway, Directorate for Nature Management (Norway), Directorate of Fisheries (Norway), Norwegian Institute for Nature Research, Royal Norwegian Ministry of Fisheries and Coastal Affairs, Royal Norwegian Ministry of the Environment, Scottish Executive, DEFRA (UK), Fisheries and Aquaculture Research Fund (Norway), Directorate of Freshwater Fisheries and Salmonid Enhancement Fund (Iceland), National Marine Fisheries Service (USA), the Worshipful Company of Fishmongers (UK), Atlantic Salmon Trust (UK), Intervet International BV (the Netherlands), Marine Institute (Ireland), Pharmaq AS (Norway), ScanVacc AS (Norway), Norwegian Farmers Union, Norwegian Salmon Rivers, and the City of Bergen.

2

OVERVIEW OF THE MEETING



Photograph courtesy of the Scottish Salmon Producers' Organisation.

2. Overview of the Meeting

2.1 Session I: Opening Addresses and Keynote Presentations

The symposium was opened by Janne Sollie, the Director General of the Directorate for Nature Management, who noted that while the topics on the symposium programme were similar to those at the Loen and Bath meetings in 1990 and 1997, respectively, the situation had changed because of the significant growth of the salmon farming industry since 1990 and the continuing decline in wild stocks. She noted that it is now recognised that salmon farming can pose serious threats to the wild stocks and that while progress has been made in managing impacts and in improving cooperation among the salmon farming industry, the authorities and various stakeholders, additional measures are required in order to move towards sustainable culture of Atlantic salmon. To highlight this she referred to two events in Norway in 2005 that had resulted in 600,000 farmed salmon escaping to the wild.

ICES and NASCO representatives then highlighted the importance of the topic of the symposium to their organizations, challenging the participants to urgently find solutions to the real problems that remain in managing interactions between cultured and wild salmon.

The first keynote presentation by Pat O'Reilly highlighted the social and economic values of wild Atlantic salmon. In addition to the very significant values associated with the fisheries and eco-tourism, the symposium was reminded that the Atlantic salmon has a high profile and the general public care about conserving the resource even if they do not use it. He noted that there are many pressures on the wild salmon stocks, which are extremely vulnerable given their present status, and that while there has been progress in minimising impacts of salmon farming, containment is not adequate given the growth in production. He indicated that the continuing escape of farmed salmon to the wild poses risks of genetic damage to the wild stocks, which would not be in the salmon farming industry's long-term interests because the diversity present in the wild stocks is the industry's seed corn. He believed that if the industry is perceived to be damaging the wild salmon stocks, consumers may reject its products.

The second keynote presentation by Helge Midttun focused on the development of the salmon farming industry since the 1960s and its importance to coastal communities around the North Atlantic and elsewhere.

Worldwide production of farmed salmon has trebled in the last ten years but he stressed that the continued success of the industry will require that it is conducted in harmony with the environment and that where conflicts arise, these are resolved through cooperation and planning. He indicated that while the industry had addressed environmental concerns with regard to effluents of nutrients and organic matter, and antibiotic usage had been dramatically reduced, the level of escapes remains too high relative to the abundance of the wild stocks, although around 98% of all farmed salmon are successfully contained. He concluded that for the salmon farming industry to continue its growth, the product must be perceived to be safe and healthy, the industry must not be associated with damage to the natural environment, and the industry should be seen to be open and transparent and willing to focus on animal welfare and environmentally sustainable practices.

In the third keynote presentation Walter Crozier reviewed the status and management of wild salmon stocks. All four European stock complexes were considered by ICES to be outside precautionary limits in 2004 and in North America 31% of monitored rivers achieved less than 50% of their conservation limits. Some stocks are critically endangered and the projections for stock rebuilding for low productivity stocks are very long-term. He referred to the wide range of pressures on wild salmon stocks, including habitat loss and degradation, pollution, predation, climate change effects, and interactions with cultured salmon. Progress is being made in reducing exploitation and in addressing other factors, but the clear message was that given the status of the wild stocks, it is essential that human activities do not exacerbate the situation.

The fourth and final keynote presentation by Bror Jonsson provided a comprehensive review of the literature concerning the ecology of cultured Atlantic salmon in nature and their interactions with wild salmon. He concluded that cultured salmon compete for food, space and breeding partners with wild salmon in nature and that their performance and reproductive success in nature are variable but can be much poorer than those of wild fish of similar size. The reduced fitness is the result of morphological, physiological, ecological and behavioural changes that occur in hatcheries. The success of cultured fish increases with the amount of time they have spent in nature. Cultured fish may, through density-dependent mechanisms, displace wild fish, increase their mortality and reduce their growth rates, with effects on associated life-history traits, biomass and production. He highlighted the

need for further research on the factors influencing the performance of hatchery fish in nature and the ecosystem effects of increasing salmon abundance in fresh and sea water.

2.2 Session 2: Genetic and Ecological Interactions and their Management

This session comprised twenty presentations. The topics addressed were modelling studies of genetic and ecological impacts; environmental impacts of salmon farming in Chile; selection programmes in aquaculture; the level and causes of escapes and incidence of escapees in the wild; behaviour of escapees; physical and biological containment of farmed salmon; genetic impacts of escapees; stocking programmes; striped bass/salmon interactions and genetic stock identification.

Modelling studies

Two presentations reported on modelling studies. Since the Bath symposium there has been significant progress in two areas related to genetic and ecological interactions. First, genetic methods to distinguish individuals and populations have been refined and genetic information on both wild and farmed salmon populations has increased. Second, studies on the spawning success and survival of farmed and wild salmon and their crosses have been completed in the Rivers Imsa (Norway) and Burrishoole (Ireland). Data on relative fitness and spawning success of wild and cultured salmon were used to model the genetic and ecological effects of farmed salmon on wild salmon under various intrusion scenarios. The model suggests that with a fixed intrusion rate of 20% escaped farmed salmon at spawning, substantial changes take place in wild salmon populations within ten salmon generations. Low intrusion scenarios (varying from 0 to 25% per year) suggest that farmed offspring are unlikely to become established in the population, while under high intrusion scenarios (varying from 0 to 75% per year), the model suggests that the wild salmon populations eventually become mixtures of hybrid and farmed descendants. The low and high intrusion scenarios were based on the incidence of escapees found in Norwegian rivers. The model also indicated that recovery is not likely under all scenarios, even after many decades with no further intrusions, and the authors concluded that further measures to reduce escapes of farmed salmon, and their spawning in the wild, are required urgently.

Population dynamic modelling using data on catches, returns, juvenile densities and escapements was used to

estimate the impacts of marine salmon farming on survival of wild salmonids using populations less exposed to farming as controls. While there are significant challenges in analysing these data (including data quality, a high degree of natural variability and missing data), impacts on the survival of wild fish related to the scale of farmed fish production in the area were identified.

Environmental impacts of salmon farming in Chile

A review of the impacts of Atlantic salmon farming on marine coastal ecosystems in Chile indicated that when this subject was last reviewed in 1996, the evidence did not suggest significant impacts. Today, the industry is considered to be consolidated but with potential for further expansion to the south into pristine coastal areas. After almost ten years of sustained growth, recent research indicates a significant loss of benthic biodiversity and localised changes in physico-chemical properties of sediments in areas with salmonid farms. The presence of farms was also found to increase the density of dinoflagellates and the abundance of omnivorous and carrion-feeding sea birds. Farmed salmon escapees are also a concern in Chile. The authors concluded that it is urgent that an ecosystem approach is implemented to assess and manage all impacts from salmonid farming in Chile.

Selection programmes in aquaculture

In a review of the history of genetic research within the aquaculture industry it was reported that the goal within the Norwegian aquaculture industry is domestication to improve production performance by reducing mortality and increasing growth rate. Both mass selection (selecting individual fish out of the entire population) and family selection (selecting particular families out of the population) are used but less than 5% of fish stocked in aquaculture originate from selection programmes. Most of the genetic improvement is based on mass selection without any pedigree information. Mass selection can only be used to improve traits recorded on breeding candidates (e.g. growth rate, shape, colour, grilse or multi-sea-winter fish) whereas family breeding is required to improve meat and carcass quality and resistance to diseases and parasites. In future, focus areas for breeding programmes will include use of selective breeding to develop strains of salmon capable of utilizing vegetable oils, to develop more robust strains with high survival and good production performance in farming and to reduce the fitness of escapees for survival in the wild.

Level and causes of escapes and incidence of escapees in the wild

Five presentations focused on the level and causes of escapes and the incidence of escapees in the wild.

In Norway, the causes of escapes are categorised as: technical failure, towing of cages, handling errors, predators, floating objects, damage by boat propellers, and escapes during smolt production. Since 1997, the reported number of escaped farmed salmon has varied between 200,000 and 500,000 fish annually. These are minimum estimates. The industry accepts that these numbers are too high and is working towards a level of escapes that is as close to zero as practicable. Norwegian farmed salmon producers have a 'National Action Plan to Prevent Escapes' which focuses on preventative measures for all causes of escapes. Some elements of the plan apply to all installations but there are separate elements dealing with smolt/fry production, on-growing facilities, slaughterhouses and well-boats. The plan includes elements for improvement such as information and education, internal control systems, environmental management systems and stronger responses from the authorities in relation to negligence. Most of this action plan has been implemented in regulations and the Norwegian salmon farming industry has invested considerably in research and development projects aimed at reducing escapes.

While information is reported on large-scale escapes from marine facilities in most countries, the scale of smaller but more frequent 'trickle losses' (for example during handling, net changes, fish transfers, etc.) remains unquantified. Furthermore, there may be escapes from freshwater hatcheries. A study from Canada involved monitoring for escaped juvenile farmed salmon in the proximity of more than 90% of commercial hatcheries producing salmon smolts at locations next to freshwater streams in New Brunswick. Escaped juvenile farmed fish were recorded at 75% of the sites sampled, although numbers varied by site and year. The results highlight the need for implementation of an effective containment strategy for freshwater hatcheries, and the authors concluded that this should be readily achievable.

The detection of European ancestry in escaped farmed salmon was reported from two sampled rivers in New Brunswick. The use of European strains for commercial culture by the salmon farming industry has never been permitted in either Nova Scotia or New Brunswick. However, the authors concluded that their findings

highlight the need for improved containment strategies for freshwater hatcheries and for genetic screening programmes for salmon farming broodstock to minimise the likelihood of introgression of non-local genetic material into severely depressed wild salmon populations in the Bay of Fundy region.

A study in Norway examined the relationship between the frequency of farmed salmon in wild populations and fish farming activity. The data revealed a significant positive correlation between the incidence of escaped farmed salmon in rivers and the number of farmed salmon in net pens at the county level, suggesting that protection areas may reduce the impact of escapees in nearby wild salmon populations. The lack of a significant correlation between the incidence of farmed salmon relative to the reported number of escaped farmed salmon suggests that the reported statistics underestimate the number of escaped fish owing to under-reporting or non-reporting (e.g. of small-scale 'trickle losses') of some escape events. A reduction in the correlation coefficient for the relationship between the stock of farmed salmon and the incidence of escaped farmed salmon in rivers over time suggests that there may have been a reduction in the number of smolts and post-smolts escaping from farms in recent years. Fish escaping at these stages would be expected to 'home' to the area of escape.

A paper from the UK and Ireland reviewed the development and results of monitoring programmes for the incidence of escaped farmed salmon in rivers and fisheries. Escapees have occurred at varying frequencies and intervals in coastal and freshwater fisheries throughout Scotland and Ireland and in northwest Wales and England. While escapees occur at generally low frequencies in fisheries in Scotland, they have been reported at far higher frequencies in some areas in some years (22% in coastal fisheries and 19% in freshwater fisheries). Similarly, in Northern Ireland escapees occur at an average level of 4.2% and a maximum of 13.8%. However, in Ireland the frequency of escapees is low in all regions, with an average of <0.1% to 0.6%, and a maximum frequency of 2.2%. No escapees were reported in fisheries in England and Wales in 2003 or 2004 but in 2001, following an escape event in Northern Ireland, escapees comprised up to 19.4% of coastal catches and 30% of catches in freshwater fisheries. The authors assessed the effectiveness of the monitoring programmes and made recommendations for their improvement. In particular, it was noted that ideally data should be collected by scientific sampling from in-river

stocks and from fishery-independent sources and that monitoring should be primarily targeted in regions where salmon farms are situated.

The results of a pilot study to trace the farm of origin of escaped salmon using microsatellite DNA and genetic assignment tests indicated that escaped farmed salmon could be assigned with a high degree of accuracy (>90%) to farm strain, but with lower accuracy (67%) to farm of origin. The study suggests that genetic markers have potential for tracing the farm of origin of escaped farmed salmon but further work is required.

Behaviour of escapees

Three papers provided information on the behaviour of escaped farmed salmon, two of which involved tagging and release of farmed fish.

In the Bay of Fundy, Canada, acoustically tagged farmed salmon were found to disperse rapidly (within a few hours) beyond 1 km from the release site, suggesting that recapture efforts may be unsuccessful in environments subject to major tidal influence. Many of the tagged 'escapees' were assumed to have been preyed upon by seals. None of the tagged fish were detected in any of the monitored salmon rivers draining into the Bay of Fundy. However, in the past, farmed salmon are known to have entered rivers in the region following large-scale escape events.

In Norway, large farmed salmon tagged prior to release did not appear to home to their release site and their distribution appeared to be related to ocean currents. The survival and distribution of the tagged 'escapees' depended on the time of year of the escape, with salmon released in the autumn, one year prior to sexual maturation, surviving poorly, whereas those released in the winter and spring showed higher survival. It was hypothesised that salmon escaping during the autumn are transported with currents to Arctic areas and do not survive the winter, and that salmon escaping during the winter and spring move with currents and may enter homewater fisheries and spawning populations far from the site of release when they mature.

A second study from Norway indicated that escaped farmed female salmon spawned in four out of six rivers studied. The proportion of successful farmed spawners in these rivers varied from 0 - 83% among rivers and years and was positively correlated to the proportion of farmed fish in autumn catches and negatively correlated to the density of wild fish. At high densities of wild fish, farmed

salmon appeared to be excluded from spawning, probably through breeding competition.

Physical and biological containment of farmed salmon

In Norway the objective of the salmon farming industry is to reduce escapes to a level at which they pose no risk to the wild stocks. New cage designs and mooring systems were described that are intended to reduce the probability and consequences of accidents both with regard to technical failure and incorrect use and operation of equipment.

The use of sterile farmed salmon (all-female triploid fish) would prevent spawning of escaped farmed fish in the wild, eliminate farm production losses associated with early maturation and protect investments made in developing novel genotypes. The pros and cons of using sterile salmon in aquaculture were described. The mass production of all-female triploid salmon is easy to achieve at a commercial scale, and inexpensive, although there are some logistical issues concerning broodstock requirements. There is abundant evidence that this is an effective method of eliminating maturation and preventing spawning of farmed fish in the wild. However, there are several problems with regard to the performance of all-female triploid fish in aquaculture, which can include a reduced ability to withstand chronic stress and an increased incidence of deformities. Maximising the performance of triploid fish requires a clear understanding of their biology and a long-term commitment to selective breeding based on triploid production characteristics and a clearer understanding of their biology. The author concluded that until this is done, the true advantages and disadvantages of sterile salmon will not be known.

Genetic impacts of escapees

A study of temporal stability in Atlantic salmon populations in Norway indicated that significant genetic changes were observed in three of seven study rivers, probably as a result of gene flow from farmed salmon which have been reported from these rivers in large numbers. There was also some evidence of diminishing genetic differentiation among populations.

Stocking programmes

Three papers reviewed various aspects of stocking programmes. A review of the Pacific salmon hatchery programmes on Hokkaido Island, Japan, suggested that more effective use of stocking programmes would require more specific evaluation of the benefits of these programmes and comparison of the benefits to other

management approaches, such as harvest controls and habitat rehabilitation. It was concluded that adaptive learning approaches should be utilised for hatchery programmes to minimise the risks associated with them and to promote sustainable wild stocks.

A study from rivers in France and Spain indicated a loss of regional population structure in wild Atlantic salmon populations. Significant genetic differentiation between neighbouring rivers, typical in Atlantic salmon, that existed prior to stocking, was lost after only a decade of stocking with salmon of foreign origin. The authors concluded that their findings highlight the risks to the genetic diversity of wild stocks subjected to stocking with foreign-origin material.

In the period between 1995 - 1999, approximately 800,000 reared salmon from two Baltic salmon strains were released at the islands of Bornholm and Møn in the Baltic Sea. Estimates of straying of ranched Baltic salmon into rivers on the Swedish west coast, based on tag recaptures, indicated that the proportion of releases recaptured outside the Baltic was low (on average 2%). The proportion of straying salmon in rivers on the west coast of Sweden varied between years and among rivers. However, the ranching programme had been discontinued due to concern about deleterious effects on the wild populations.

Striped bass/salmon interactions

A paper from the US described the implications of the successful stock rebuilding programme for striped bass on populations of Atlantic salmon and other anadromous species. Moderate to strong negative correlations were found between estimates of the abundance of striped bass, a known predator of salmon smolts, and returns of salmon to New England rivers. Further research is required to quantify the proportion of smolt production consumed by striped bass, particularly for salmon populations listed under the Endangered Species Act.

Genetic stock identification

Genetic stock identification methods have been used to monitor changes in wild and hatchery proportions of Atlantic salmon in Finnish catches in the Baltic Sea. The proportions of seven stock groups, important to fisheries management, were assessed in catch samples taken between 2000 and 2005. For example, in the Gulf of Bothnia area, the proportion of wild fish showed an increasing trend in all areas until 2003, mainly because of the decrease in total catches caused by the relatively

greater mortality of hatchery-reared fish compared with wild fish. In 2004, the total number of wild fish caught had also increased, indicating an increase in the abundance of wild stocks. The threatened eastern Estonian and Russian wild stocks were recorded only in the western part of the Gulf of Finland, where the proportion of wild fish increased from 9% in 2003 to 19% in 2004.

2.3 Session 3: Disease and Parasite Interactions and their Management

This session comprised fifteen presentations, many of them focusing on the biology and control of sea lice and their impacts on wild stocks.

Overview of diseases in farmed and wild salmon

A review of parasitic agents affecting Atlantic salmon, from viruses and bacteria to ectoparasites, concluded that epidemics can affect both farmed and wild fish and have consequences for both: population regulation in wild fish and economic damage and welfare effects in farmed fish. Wild fish are the ultimate source of parasites and can also be reservoirs for infection which impede eradication programmes in farms, but farming can exacerbate disease problems through promoting conditions favouring epidemics, long-range transport and spill-over back into the wild. It was noted that epidemics among farmed populations do not necessarily result in epidemics among wild fish populations, highlighting the importance of good bio-security and husbandry in mitigating risk.

Sea lice biology, impacts on wild stocks, and control

A review of the biology and genetics of sea lice, focusing on research conducted since the last major review of the subject in 1999, concluded that research on sea lice has developed considerably, and genetic techniques are now being applied to increase understanding of sea lice life history and biology. Information on the developmental stages under different environmental conditions, the behaviour, distribution and dispersal of free-living stages, monitoring practices and population structure has increased, and modelling studies have been undertaken. Molecular genetics work also raises the possibility of developing a vaccine against sea lice.

An investigation into how sea lice infestations affect the physiology of wild sea trout was described. Since 1989 sea trout stocks on the west coast of Scotland have declined catastrophically, accompanied by the 'premature return' to fresh water of post-smolts typically bearing heavy sea lice infestations. Laboratory studies were conducted to assess the sea lice infestation levels that

trigger sub-lethal, chronic and acute physiological stress in sea trout. A threshold level of thirteen lice per fish was determined.

A study into the susceptibility of wild, farmed and wild-farmed hybrid Atlantic salmon to sea lice, furunculosis and Infectious Salmon Anaemia (ISA) concluded that there were no large and systematic differences in susceptibility but the topic merits further research.

A review of the impacts of sea lice on farmed and wild salmonids concluded that sea lice must presently be regarded as a potentially important population-regulating factor in many salmonid stocks. Methods to assess infestation levels on migrating post-smolts have been developed. Pest management measures introduced by the farming industry to reduce the number of sea lice larvae in salmon farming areas are probably of most benefit to salmon stocks. Reference was made to the high infestation pressure imposed by farms on wild stocks in many areas and the inverse relationship between the incidence of lice on wild sea trout and distance from fish farms.

Concerns about the impacts of sea lice from Atlantic salmon farming on wild salmonids are not restricted to the North Atlantic area. Farming of Atlantic salmon in the Broughton Archipelago area of British Columbia has given rise to concerns that sea lice from the farms may have resulted in high mortality of pink salmon. In 2002, concern had been expressed that the low return of pink salmon was the result of sea lice infestation and led to the introduction, in 2003, of a Provincial Action Plan that established a fallowed migration corridor for pink salmon and mandatory monitoring of sea lice. A study presenting information on marine mortality of pink salmon from rivers in this area indicated exceptional survival of pink salmon migrating to sea in 2003 but it was not possible to conclude whether this was due to the introduction of a Provincial Action Plan, increased freshwater flow which could lead to conditions less favourable to sea lice production, or other effects.

A study involving the treatment of Atlantic salmon smolts with emamectin benzoate (SLICE®) prior to release indicated that survival did not differ between treated and control groups released in May but there was a two-fold increase in survival in treated compared to control groups released in June. Furthermore, one-sea-winter fish returning from the treated groups were about 15% heavier than controls and the authors concluded that infestation levels changed from non-lethal to lethal during

the smolt migration period and that sub-lethal lice levels may affect growth, size at spawning and, consequently, fecundity of wild fish.

Studies of sea lice dispersal and behaviour are crucial to understanding the infestation pressure that sea lice in farms pose for wild salmonids and two presentations examined these aspects. Weekly plankton samples from Loch Shielraig in Northwest Scotland indicated an increase in larval densities during the farm production cycle, followed by a decrease as the farms harvested and were left fallow. Nauplii showed no preference for depth but significantly greater densities of copepodids were recovered at the surface than at depth. The densities of larvae varied considerably over the two-year sampling period.

A study from Norway examined the effects of both hydrography and lice abundance on infestation rate of Atlantic salmon and sea trout smolts emigrating from two contrasting fjord systems in Norway. Differences in infestation pressure between the two fjords were found and, in addition, within a system, year-to-year differences in hydrography could cause changes in sea lice dispersion that markedly altered infestation risks to wild fish. In the Altafjord, infestation levels on migrating salmon post-smolts were not high enough to cause problems, and in the Sognefjord the infestation levels declined in response to treatments by salmon farmers at the critical time in the spring. However, reductions in infestation intensity were not found for sea trout in either fjord. It was concluded that wild and farmed salmon can coexist in Norwegian fjords if appropriate lice management strategies are used.

Aquaculture impacts on disease resistance

A study from the Burrishoole system in Ireland examined the impacts of disease associated with aquaculture on the genetic variability of sea trout by examining variations at a locus critical to immune response (MHC1) and six neutral microsatellite loci before and during aquaculture activities. A decrease in genetic variability at the MHC1 locus was observed, indicating a selective response that was not mirrored by similar reductions at neutral loci. This decrease corresponded with aquaculture activities commencing in the catchment. Subsequent recovery in variability seen among later samples may reflect an increased contribution by resident brown trout to the sea trout stock.

Health management

Four presentations focused on health management

practices. A review of health management practices in Scottish salmon farms indicated that bacterial diseases are largely under control due to use of vaccines but viral diseases remain a serious concern. Management measures and access to efficient medicines have been successful in reducing sea lice levels in farm salmon but more progress is required. A key message was the threat posed by the emergence of new diseases but the potential of genetic selection to improve disease resistance, the emerging field of nutraceuticals (dietary supplements) and the continued importance of application of best practice to avoid disease problems were highlighted.

A review of trends in the use of medicines in Norwegian salmon farming concluded that there were no toxicological risks to wild fish from drugs used in the salmon farming industry. The use of inadequate lice treatments can result in heavy lice infestations and increased mortality of emigrating salmon and sea trout smolts. However, extensive sea lice treatment increases the risk of resistance developing and may represent an increased risk to wild salmonids.

A review of the use of 'cleaner' fish to control sea lice on farmed fish indicated that wrasse are widely used in Norwegian salmon farms and that techniques to culture wrasse are now developing. The study found that given the correct conditions wrasse are one of the most cost-effective and environmentally benign ways to control sea lice. Wrasse prefer to feed on pre-adult lice and particularly adult female lice. Lice eggs do not survive passage through the wrasse digestive system. The authors concluded that wrasse should, therefore, be considered as part of an integrated sea lice management strategy.

In Scotland, a Tripartite Working Group providing a forum for cooperation among regulators, farmers and wild fish interests has been established and has resulted in the sharing of information and the development and implementation of area management agreements (AMAs). AMAs provide local solutions to maximise the effectiveness of sea lice management and to control and reduce escapees. Twenty areas in three regions of Scotland were targeted and eighteen agreements were expected to be in place by the end of 2005. This approach has improved communication among the parties involved, although it is too early to draw conclusions about the benefits to wild salmonids.

Gyrodactylus salaris

The last paper in the session reported on the introduction

and spread of *Gyrodactylus salaris*. The parasite was introduced to Norway in 1975, probably through the importation of smolts from the Baltic, and has dramatically reduced stocks of salmon in 45 rivers. The parasite is known to be present in Denmark and Germany and is likely to have been introduced to other European countries with movements of live rainbow trout, although the UK and Ireland are free of the parasite. In Norway, an action plan has been developed involving surveillance, prevention of spread to other rivers, eradication and restoration. 27 of the 45 infected rivers have been successfully treated and there is growing use of acidified aluminium as a treatment method in addition to continuing use of rotenone. The dangers posed by live fish movements, particularly of rainbow trout, and the importance of international cooperation to prevent the further spread of the parasite were highlighted. For the UK and Ireland preventing the importation of the parasite is the major objective.

2.4 Session 4: Poster Session

This session comprised a total of 13 presentations focusing on studies of the abundance, distribution, behaviour and source of escapees; the biology of sea lice and genetic aspects of stocking programmes. There were also posters on aquaculture-free zones, the comparative feeding behaviour of juvenile cultured and wild salmon and the effects of domestication on the growth, behaviour and physiology of fish.

Escapees

Sampling in the River Teno (Tana River), a border river between Norway and Finland, in the period between 1987 - 2004 indicated that escapees made up a small proportion (0.08 - 0.53%) of the catch during the fishing season. However, small samples collected after the close of the fishing seasons in six years suggested higher proportions of escapees in some years, raising concerns about the genetic impacts on native salmon populations.

Research in Norway involving acoustic tagging of farmed salmon 'escapees' showed that several of the tagged fish remained in the vicinity of the escape site after several weeks, suggesting that it may be possible to recapture escapees, although these findings contrast with the results of studies in the Bay of Fundy (see section 2.2) where the fish moved rapidly away from the release site.

A second study in Norway using catch data from a gill net fishery conducted after the fishing seasons for salmon and sea trout indicated that there was a low incidence of wild

fish in the catches and, provided that the conservation status of local wild salmonid stocks is taken into account, such a fishery may reduce the number of escapees, thus lowering the risk of introgression with wild salmonid populations and removing potential sources of sea lice, and provide information on relative abundance of escapees in the sea.

A third presentation from Norway described a study, the 'TRACES' project, that is being conducted in the Hardangerfjord to examine the costs and efficiency of identifying and tracing the origin of farmed salmon. In 2003, a national Committee had been established in Norway to identify methods to trace the origin of escaped farmed salmon and had concluded that no methods were ready at that time for implementation. Two methods were, however, identified that merited further investigation: coded-wire tagging and a 'contingency approach' based on the characteristics of the fish. In the 'TRACES' project, DNA microsatellite markers, single nucleotide polymorphisms, fatty acid profiles, trace element and stable isotope composition were assessed with regard to their utility in tracing the farm of origin of escapes.

A study involving acoustic tracking of wild cod found that they occurred in the exit corridors of wild salmon smolts from critically endangered salmon rivers in the Bay of Fundy. The authors expressed concern that as field trials rearing farmed cod are now underway, escapees from cod farms might behave like the wild cod in their study, and they could prey on wild salmon smolts. The authors concluded that there is a need for careful consideration to cage design and siting so as to avoid interactions with wild cod and with wild salmon and other diadromous species.

Sea lice biology

Two posters presented information on sea lice biology. The first examined the infestation success of sea lice at different temperatures ranging from 6 - 16°C and showed that lice were infectious for a longer period of time at low temperatures. These data are important in modelling the dispersal and survival of free-living lice larvae.

The second presentation examined the role of freshwater acidification on the sensitivity of salmon smolts to sea lice. Many rivers in southern Norway can be periodically acidified to sub-lethal levels and additionally there are many fish farms in the region. This study concluded that the combined effects of moderate acidification in fresh water and moderate sea lice infestation in sea water can

have the same negative effect as higher acidification or higher lice infestation. The authors concluded that there is a need, therefore, to consider the effects of multiple stressors on smolt survival rather than using single-factor models.

Stocking programmes

A study from the rivers Ulla and Lerez in Spain examined genetic variation in the restored populations. These populations were close to extinction in the 1990s but a restoration programme involving habitat improvements, fishery regulations and a supportive breeding programme, based on native juveniles and returning adults, has been undertaken since 1995. The study indicated that modern populations are very similar genetically to those present prior to stocking, although the populations are more similar today than in the past.

The Connecticut River lost its salmon population about 200 years ago due to human activities but a salmon run has been re-established based mainly on stock from the Penobscot River. The current genetic profile of salmon in the Connecticut was shown to be very similar to that of its donor population in the Penobscot, indicating that the effective number of breeders in both rivers has been large enough to preserve genetic variability and that no genetic bottlenecks occurred during the restoration programme. The differences that were detected were considered to be adaptive responses to environmental variation.

A study from the Burrishoole River in Ireland analysed stock and recruitment data for a population receiving variable, but significant, quantities of naturally spawning, hatchery-origin fish over a thirty-five year period. The results suggest that the hatchery fish had a significant depressive impact on the recipient population of about 30% and the author concluded that removal, rather than addition, of hatchery fish may be the most effective strategy to improve productivity and resilience in wild stocks. In the last eight years, hatchery fish were effectively excluded from spawning in the wild and a significant improvement in freshwater production of smolts was observed.

Aquaculture-free zones

A presentation from Iceland reported on the rationale for the establishment of aquaculture-free zones in wild salmon-producing areas to protect valuable salmon angling fisheries. Salmon farming is not permitted in bays and fjords with the most valuable salmon rivers and in the areas where it is permitted, the experience gained will be

used to further evaluate the impacts of salmon farming in Iceland.

Behaviour of cultured and wild parr

Studies in the Louvenga River in Russia highlighted differences in feeding behaviour between wild and cultured parr. Cultured parr were less able to differentiate food items from non-food items than wild fish and were more aggressive. However, wild parr were able to optimize their feeding conditions by choosing habitats with preferred sizes of prey, higher densities of food items and current velocities that allowed them to maintain station and feed effectively.

Domestication effects

The growth, behaviour and physiology of domesticated (fast-growing), non-selected (slow-growing) and hybrid strains of coho salmon and rainbow trout under both culture and semi-natural rearing conditions were compared. Under all rearing environments growth was strongly correlated with the proportion of domestic genes. Anti-predator behaviours and hormone profiles showed similar trends. The study concluded that knowledge of the genetic changes responsible for altered growth rates in fish is crucial to increasing ability to predict the consequences of introgression between fast- and slow-growing strains of fish.

2.5 Session 5: Synthesis Session - Challenges and Solutions

This session comprised inputs from a number of sources, including a summary from each of the three plenary sessions and the poster session by the Co-Chairmen (see Annexes 2 - 5) and six participants from different interests were then asked to give their perspectives on the information presented during the symposium, i.e. their 'take-home messages' (see Annex 6). There were perspectives from two representatives of non-government organizations, two representatives of the salmon farming industry and two representatives of administrations involved in the management of salmon farming and wild salmon. There was also a wide-ranging discussion, including consideration of future research requirements.

There was general agreement in the presentations in this session that compared to the symposium in Bath in 1997, understanding of the interactions between wild and cultured salmon has increased considerably. This information had conclusively identified a serious threat to the wild salmon stocks from escapees, particularly where the wild stocks are depressed, and from sea lice. The

salmon farming industry representatives acknowledged that it could no longer be claimed that salmon farming poses no threat to the wild salmon stocks, highlighted the progress that has been made in addressing impacts and indicated that the industry would continue to address issues related to interactions with the wild stocks in the future. There was recognition that there is a need to avoid a culture of blame and for wild and farmed salmon interests to work closely together in addressing problems. Generally there has been a significant change in attitude within the salmon farming industry since the Bath symposium with regard to recognition of the impacts the industry may have on the wild stocks. In Bath, there had been a clear difference in perception between those representing the salmon farming industry and those representing wild fish interests. The former had stressed the economic benefits of the industry and questioned whether their industry had any significant effects on the wild stocks, while the latter believed that firmer actions by the industry were required to protect the wild stocks.

Two concerns dominated the session: the need to minimise escapes through improved containment strategies and for further improvements to pest management strategies to minimise the impacts of sea lice. While considerable progress has been made in relation to both issues, the continuing increase in production of farmed salmon means that measures to minimise negative impacts of salmon farming must be introduced at a faster tempo than the industry expands.

It was recognised that there was no room for complacency despite the progress that has been made, and that there is an urgent need to reduce escapes, for example through matching technology to site conditions, application of the NASCO/North Atlantic salmon farming industry Liaison Group's containment guidelines, improved cage design and maintenance, appropriate staff training with regard to operational procedures and increasing awareness of the potential impacts of escapees on wild stocks, continuing research and development into less vulnerable and more operator-friendly cage systems, improved monitoring systems to determine numbers of farmed salmon in cages, and development of improved strains of triploid, or other forms of sterile salmon, with a view to their use by the industry. For sea lice, there is a need to reduce levels on farmed salmon to as close to zero as possible through use, for example, of area management agreements involving synchronised treatments, single year classes and fallowing. In this regard it was recognised that there is a need for an adequate

suite of anti-lice medications and development of vaccines. Furthermore, additional farm sites may be needed to allow for effective fallowing.

It was recognised that there is a need to further enhance the dialogue, cooperation and trust that is developing between wild and farmed salmon interests and that local and regional cooperation, in addition to regulation, will be required in future. A solution in which the wild stocks are protected and the industry can develop in a sustainable manner; a 'win-win' scenario, will require that the evidence of impacts is accepted and that cooperative and pragmatic ways of addressing them are urgently found. The view was expressed that the remaining challenges can only be addressed, and a 'win-win' solution found, if all interests pull in the same direction rather than continuing the 'tug-of-war' approach that has prevailed in the past. The worst possible outcome would be that at a subsequent ICES/NASCO symposium there are more presentations on mounting evidence of problems rather than reports on the solutions that have been implemented

3

CONCLUSIONS BY THE CONVENERS



*The trap on the Srahrevagh River, a tributary of the Burrishoole River, used in experiments designed to increase understanding of wild and cultured salmon interactions.
Photograph courtesy of the Marine Institute, Ireland.*

3. Conclusions by the Conveners

3.1 Introduction

It is clear that since the first symposium in Loen in 1990, scientific understanding of the interactions between cultured and wild salmon has increased considerably and the science confirms that cultured salmon can have significant negative impacts on the wild stocks. Real progress has been made in managing interactions but some significant challenges remain, particularly with regard to further reducing the impacts of escapees and sea lice. These two topics dominated the symposium presentations, the discussions and the 'take-home messages' and are, in part, related to the large scale of the industry. A further positive development since the last symposium relates to the extent of cooperation between wild and farmed salmon interests and it is clear that this process needs to be further enhanced in future. Furthermore, the industry now acknowledges that its activities can have damaging impacts on the wild stocks and we believe that this acceptance provides a basis for making real progress in finding cooperative solutions to the remaining challenges.

In developing our conclusions, we have considered the keynote speeches, the scientific and other information presented at the symposium, the summaries made by the Chairmen, the 'take-home messages' and the discussion sessions. We have also taken into account the findings from the recent Trondheim Workshop (Anon, 2006) and other relevant information.

We have had to evaluate a great deal of material and to make judgements about it and about how much weight to give it in coming to conclusions. We want to make it clear that to do this inevitably involves a great deal of personal judgement. The reader will be aware that this is the case in coming to many professional or other judgements. Just as two different juries might well have come to different verdicts after hearing evidence from the same trial, two different conveners might have come to somewhat different conclusions from this symposium. However, we are comforted that in coming to our conclusions, there was a degree of unanimity at this meeting that was not present at the two earlier symposia, which helps us greatly. We want to reassure the readers of this report that we have tried hard to be objective.

We also need to make it clear that although NASCO and ICES co-convened, and other organizations sponsored, and supported, the Bergen symposium, the views expressed

here are entirely those of the two Conveners.

We have come to a number of conclusions. It should be noted, however, that while the title of the symposium referred to interactions between wild and cultured salmon and other diadromous fish species, the vast majority of papers concerned interactions between wild and farmed Atlantic salmon and our conclusions therefore relate principally to these interactions and their management.

3.2 The Salmon Farming Industry

A major change, and a most welcome one, since the last ICES/NASCO symposium in Bath in 1997, is that the salmon farming industry, certainly those representatives present in Bergen, now fully accept that their industry can have damaging impacts on the wild stocks. We very much welcome this because it is a prerequisite to cooperative action. We realize that, for various reasons, this has not been easy for them to accept, but this acceptance can have major dividends for cooperation to mutual benefit in the future. In Bath and before, there had been a climate of blame, public accusation and counter-accusation. Today, we feel that the climate has greatly improved, as was demonstrated at the symposium.

As concrete evidence, we look not only at statements made by representatives of the industry at the Bergen symposium, but at the newly energized NASCO/North Atlantic salmon farming industry Liaison Group which, for the first time, held a joint meeting earlier in 2005, the Trondheim Workshop, which not only discussed and debated some controversial issues (such as use of sterile fish in aquaculture) but sought new ways to cooperate (Anon, 2006). The goodwill and frankness that characterized both that meeting and the Bergen symposium should encourage us all to build on the cooperation that is developing.

It will be evident from this report that we, the Conveners, believe that it is vital that actions be taken to protect and conserve the integrity of the wild stocks. But we would argue that it is clearly very much in the interests of our colleagues in industry, too. It protects their 'seed corn', their future, it protects them from bad publicity and in today's climate we expect that that aspect is vital for their future marketing, sales and economic success.

Both Conveners have been involved in these issues of interactions between farmed and wild salmon for many years but, for the first time, we feel encouraged by a new atmosphere of cooperation, frankness and the will to succeed. We hope that this will characterize the

consideration of our conclusions from the Bergen symposium. We do not underestimate the difficulties of implementing some of our conclusions, but we must emphasize the potentially severe damage to the wild stocks, and consequently the costs to society, of not doing so.

3.3 Disease and Parasite Interactions and their Management

There has been considerable progress in addressing disease and parasite problems in aquaculture through, for example, improved husbandry and use of vaccines. There has also been progress in developing management strategies to reduce the levels of sea lice on farms and thereby reduce transmission to the wild. While sea trout appear to be particularly badly affected there is evidence of impacts on wild salmon stocks as well. In some situations wild salmonid populations have suffered stock collapses that have been linked to sea lice infestations. Such stock collapses have implications for the diversity of the wild stocks (see section 3.4). It is clear that actions such as coordinated lice treatments, use of single generations and fallowing through area management initiatives are having benefits in protecting the wild stocks and that the cooperation between wild and farmed salmon interests on these initiatives is a positive development. However, there may still be problems for wild stocks from sea lice, perhaps more so during the second year of the farm production cycle. These management strategies may be voluntary but in some situations they may need to be incorporated in regulations. Successful area management depends on commitment from all partners, open dialogue, transparency and input from all interested parties.

Significant challenges remain in addressing sea lice issues, not least the need for the industry to be allocated additional sites to facilitate on-growing of single generations, and the limited number of treatments approved for sea lice control. While effective treatments are available, not all are licensed for use in aquaculture in all countries and we urge the regulatory authorities to make these available as quickly as possible where environmentally acceptable. Development of resistance to the available treatments in the future would have serious implications for both wild and farmed salmon interests. Development of a vaccine against sea lice would be a major step forward. Alternative approaches, such as the use of wrasse in the cages to clean salmon of sea lice, might offer benefits.

The eradication of the parasite *G. salaris* from infected rivers and prevention of its further spread are essential. In Norway, the parasite was spread by stocking following its introduction from the Baltic. Risk analysis suggests that movements of live fish, particularly rainbow trout, are the most likely source of spread among other countries. This is a difficult area since it raises issues associated with international trade agreements but it is essential that appropriate safeguards are in place to control such movements in a manner that does not jeopardize the wild stocks. It is also important that the two chemical treatments presently in use in Norway to eradicate the parasite, rotenone and acidified aluminium sulphate, are available for use in future. NASCO's North-East Atlantic Commission has developed recommendations in relation to *G. salaris* (NASCO, 2004; 2006b) and we believe that it is important that these recommendations are implemented urgently.

3.4 Genetic and Ecological Interactions and their Management

Although there has been progress in reducing the proportion of farmed fish that escape to the wild, the growth in production by the industry means that the number of fish escaping is still large relative to the wild stocks. There is no doubt that a proportion of escapees enter rivers and interbreed with the wild stocks. In some cases, they make up very high percentages of spawning stocks and genetic changes in some wild populations have been detected. To put it bluntly, this means that in the last 30 years a large-scale, uncontrolled genetic experiment, which we believe poses the risk of irreversible changes to the wild stocks, has been undertaken. It is still continuing. In doing so, in the North Atlantic we are running the risk of changing local adaptations that have taken centuries or more to develop by allowing fertile farmed salmon, which have been selected for traits valuable to aquaculture, to interbreed with the wild stocks that have evolved their own characteristics over millennia.

Since the symposium we are aware of recent advice from ICES to NASCO regarding the genetic impacts of farmed Atlantic salmon on the wild populations (ICES, 2006b). In this advice ICES indicates that very large numbers of farmed salmon escape annually relative to wild salmon abundance; a substantial body of useful quantitative data on genetic impacts of farmed salmon on wild stocks has been collected; gene flow from farmed to wild salmon will reduce the natural inter-population heterogeneity found in the wild Atlantic salmon, therefore reducing the adaptive

potential of the species; and experimental studies confirm that escaped farmed salmon can have major negative impacts on wild salmon populations.

In Bergen, information was presented confirming that genetic changes have been observed in some wild populations exposed to escapees but not in others, suggesting that the impacts are influenced by the numbers of farmed fish intruding, their reproductive success (which may be related to the time they have spent in the wild) and the abundance of the wild fish population in the river. The results of a model that simulated a 20% fixed annual intrusion rate of farmed escapees suggest that within ten salmon generations there will be substantial changes in the wild population. These changes may be irreversible. In some Norwegian rivers the proportion of escapees already greatly exceeds 20%. Low intrusion scenarios suggest that farmed offspring are unlikely to become established in a population whereas high intrusion scenarios suggest that the populations eventually become mixtures of hybrid and farmed descendants. Recovery of wild populations is not likely under all circumstances even after many decades without further intrusions. These findings are extremely worrying to us.

We recognize that these models may be over-simplified and merit further development. Nevertheless, the implications of permanently and irreversibly altering a North Atlantic salmon stock structure that has probably persisted for millennia, with consequences for the viability and productivity of these stocks, can hardly be overstated.

The new information both from the symposium and from ICES can only lead to the conclusion that urgent action is required to eliminate these interactions. The huge disparity in numbers of wild and farmed fish means that if the problem is to be dealt with effectively, either physical containment would have to improve so much as to be effectively 100%, or biological containment (use of sterile fish) in aquaculture would have to be implemented.

We are well aware of the costs and difficulties associated with both of these options but what are the costs of destroying the genetic integrity of the wild stocks? Could the salmon farming industry itself suffer catastrophically at some future time if the genetic diversity of the species was lost? Would consumers be willing to pay more for farmed salmon that were reared in a manner that safeguarded the wild stocks (as with dolphin-friendly tuna)? We urge that this issue be addressed with a new urgency. There is no time to lose and it should not be an insuperable problem to keep 100% of farmed fish in cages

or to introduce triploid fish. The technology for the latter is well established though the husbandry will need to be improved. But even if the decision was taken today to use triploid salmon, it would take about ten years before they could be available on a commercial scale and considerably longer if selection for improved performance is to be achieved. We urge that the technology and the husbandry of sterile fish be further assessed so that it might be introduced later. It seems to be the one approach that can deliver 100% containment. In the interim, however, improved physical containment measures should be implemented in both marine and fresh waters, such as greatly improved cage design, screening, etc., and elimination of 'trickle losses' (for example during handling, net changes, fish transfers, etc.), and consideration should be given to establishing more protection areas for wild fish. The NASCO/North Atlantic salmon farming industry Liaison Group's containment guidelines should, therefore, be seen as a minimum standard for physical containment that need to be implemented widely and reviewed as to their continuing appropriateness given the latest information.

It is not just intrusions from accidental escapes of farmed fish that pose a risk. There are risks, we believe, from deliberate stocking of salmon rivers. It is certainly not the case that stocking is always beneficial; it can do harm. The goals and rationale for such stocking need to be very carefully evaluated before such action proceeds, and we urge those involved to follow the stocking guidelines developed by NASCO (NASCO, 2006a).

The conclusions about genetic change above are, we believe, the most important ones emerging from the symposium. There are also some subsidiary issues:

- storms were identified as a major source of escapes in 'catastrophic' losses and since most climate-change scenarios involve stormier weather than at present, we do not see present containment arrangements as adequate;
- when fish escape they may disperse very quickly from the site of release, moving with the currents, and their fate is probably very variable. Thus we believe that in many situations there will be difficulties in recapturing escapees immediately, and such efforts would require contingency plans to be in place detailing the gear to be used and other arrangements. Other approaches might involve recapture efforts targeting escapees which may enter rivers later than wild fish;

- monitoring programmes for escapees should ideally be based on scientific sampling programmes independent of the fisheries for wild salmon and targeted on areas in proximity to the fish farming activity;
- the number of escapees is significantly under-reported, not necessarily as a result of deliberate intent but, for example, because of 'trickle losses'. There is a need for improved reporting procedures and methods for assessing the number of fish in cages. It is important that systems are in place that provide early warning of escapes and that information is provided by farmers on the number of fish escaping, the date and time of escape, the life stage and size of the escapees, their health status, and, if available, information on their genotype.

3.5 Research Recommendations

There has been significant progress in our understanding of interactions and their management since the last symposium in 1997. However, there is a need for further research and development if the interactions between wild and farmed fish are to be managed successfully, and we have listed the main topic areas here:

- development of improved cage technology to ensure containment of farmed fish;
- development of methods to monitor the stock of farmed salmon in cages and to detect escape events at an early stage;
- improvements to the performance of sterile (all-female triploid) fish for use in aquaculture and development of alternative methods to produce sterile fish;
- development of domesticated strains of farmed fish with low survival in nature;
- development of methods to identify farmed salmon in nature and trace them back to strain or farm of origin;
- improvements to understanding of the performance (migration, dispersal and survival) and life history strategies of farmed salmon escaping at different sites, times and life stages;
- development of models to predict the fate of escaped farmed salmon;
- further development of methods to control sea lice in fish farms and to minimise resistance to therapeutants;
- further development of models to predict dispersal and survival of sea lice larvae in nature;

- introduction of improved, standardised scientific monitoring of farmed salmon in wild salmon populations;
- development of improved approaches to recapturing escaped farmed salmon;
- further development and refinement of models to predict genetic and ecological impacts of farmed salmon on wild fish; and
- assessment of the socio-economic effects of escaped farmed salmon.

However, under the Precautionary Approach the absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures.

3.6 Final Thoughts

When, nine years later, we read the conclusions from the Bath symposium we find that they are still mostly valid but with an added urgency. The interactions between farmed and wild salmon can be damaging and need to be eliminated, not just reduced. There are risks not only from farmed fish but from inappropriate stocking practices, which also need to be addressed.

NASCO, all of its Parties and relevant jurisdictions have adopted the Precautionary Approach and two central planks of this approach are that: the absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures; and that priority should be given to conserving the productive capacity of the resource where the likely impact of resource use is uncertain. We consider that the matter of escapees and sea lice must be seen as urgent because of the risks of irreversible changes in the wild stocks.

We believe that progress in addressing the sea lice problem is being made. Progress can continue to be made by concerted action and widespread use of best practice, but it is clear that challenges remain if the wild stocks are to be protected, particularly with regard to sea trout populations. The prospect of resistance developing to the treatments available is also a real concern for both wild and farmed salmon interests. Much more progress in improving containment is, however, urgently needed because continuing escapes of fertile farmed salmon are putting at risk the very stock structure and diversity of the wild North Atlantic salmon. Farmed salmon must be much more effectively contained. It is odd, to say the

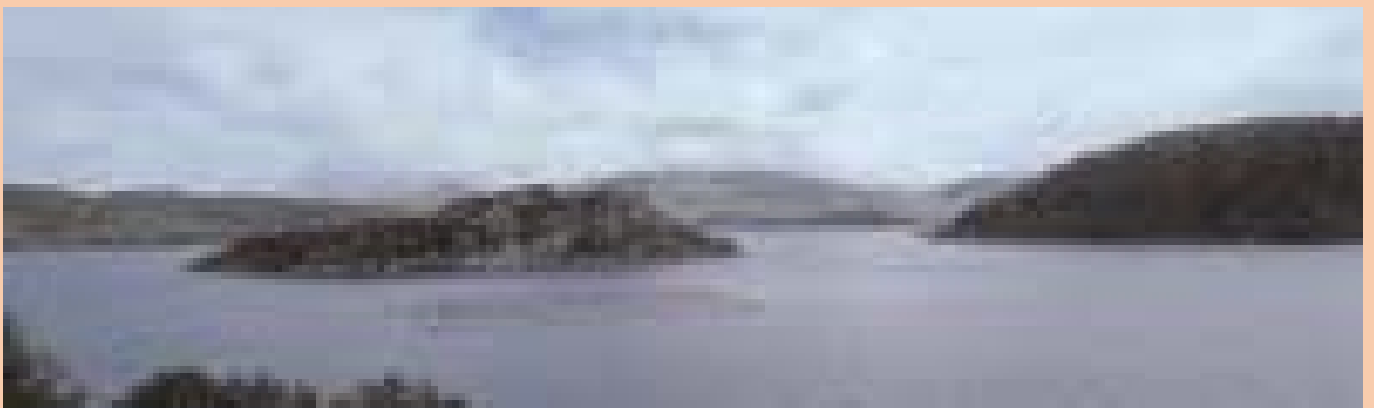
least, that the escape into the marine environment of huge numbers of farmed fish (millions in some years) is accepted as 'normal'.

Farming of salmon is a very competitive sector internationally. Nevertheless, we can only repeat what was reported from Bath in 1997, that we believe that new approaches and attitudes to escapees are required and that they should apply to all areas of the North Atlantic so that, internationally, salmon farming operates on an even-handed basis. There will always be the response that one major producer, Chile, will not need such stringent practices because it has no wild stocks to conserve and that this will put other producers at a competitive advantage. That may be so but it is illogical, in our view, to allow damage to North Atlantic stocks because a competitor operates without this concern. We might as well argue that we will not clean up our air pollution by requiring our car industries to have catalytic converters, because it is not required in other parts of the world.

Quite apart from NASCO's obligation to protect wild stocks, there are requirements under the Convention on Biological Diversity to conserve genetic diversity both within and among species. If no action is taken now, and if the views of the many scientists and experts at this symposium, and the two preceding symposia, are correct, we risk the loss of the diversity of local adaptations in the wild stocks of salmon in the North Atlantic. This may well have serious consequences for their fitness, productivity and their ability to survive environmental change.

4

REFERENCES



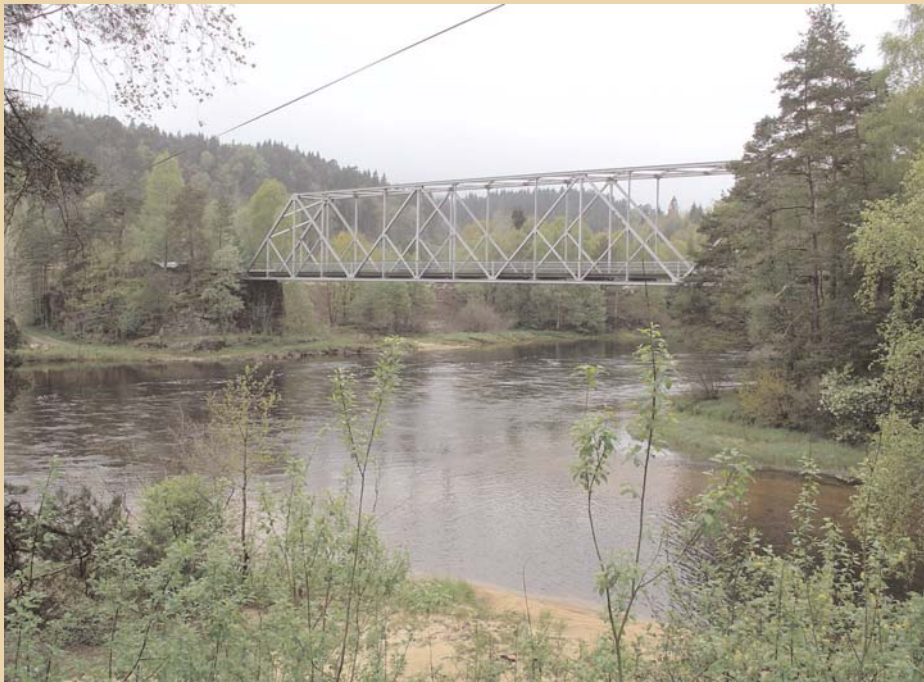
Photograph courtesy of the Scottish Salmon Producers' Organisation.

4. References

- Anon. 2006. Wild and Farmed Salmon - Working Together: Report of a one-day workshop organised by the NASCO/North Atlantic salmon farming industry Liaison Group. North Atlantic Salmon Conservation Organization (NASCO), Edinburgh, Scotland, UK. 86pp.
- Hansen, L. P., Håstein, T., Naevdal, G., Saunders, R. L., and Thorpe, J. E. (Eds). 1991. Interactions between cultured and wild Atlantic salmon. Proceedings of a symposium hosted by the Directorate for Nature Management and Norwegian Institute for Nature Research, held in the Hotel Alexandria, Loen, Norway, 23 - 26 April 1990. *Aquaculture*, 98: 1-324.
- Hutchinson, P. (Ed). 1997. Interactions between salmon culture and wild stocks of Atlantic salmon: the scientific and management issues. *ICES Journal of Marine Science*, 54: 963-1225.
- Hutchinson, P. (Ed). 2006. Interactions between aquaculture and wild stocks of Atlantic salmon and other diadromous fish species: science and management, challenges and solutions. *ICES Journal of Marine Science*, 63: 1159-1371.
- ICES. 2006a. Report of the Working Group on North Atlantic Salmon (WGNAS), 4 -13 April 2006, ICES Headquarters. *ICES CM 2006/ACFM:23*. 254pp.
- ICES. 2006b. Scientific Advice from ICES - Assessing Genetic Effects. Supplementary report to the North Atlantic Salmon Conservation Organization (NASCO), Edinburgh, Scotland, UK. Council document CNL(06)41. 6 pp.
- NASCO. 2004. 'Road Map' for Taking Forward the Recommendations from the Workshop on *Gyrodactylus salaris* in the Commission Area. North Atlantic Salmon Conservation Organization (NASCO), Edinburgh, Scotland, UK. North-East Atlantic Commission document NEA(04)13. 8 pp.
- NASCO. 2006a. Resolution by the Parties to the Convention for the Conservation of Salmon in the North Atlantic Ocean to Minimize Impacts from Aquaculture, Introductions and Transfers, and Transgenics on the Wild Salmon Stocks, the Williamsburg Resolution (Adopted at the Twentieth Annual Meeting of NASCO in June 2003 and amended at the Twenty-First Annual Meeting of NASCO in June 2004, and at the Twenty-Third Annual Meeting of NASCO in June 2006). North Atlantic Salmon Conservation Organization (NASCO), Edinburgh, Scotland, UK. Council document CNL(06)48. 44 pp.
- NASCO. 2006b. Report of the Working Group on *Gyrodactylus salaris* in the North-East Atlantic Commission Area. North Atlantic Salmon Conservation Organization (NASCO), Edinburgh, Scotland, UK. North-East Atlantic Commission document NEA(06)3. 48 pp.
- Youngson, A. F., Hansen, L. P. and Windsor, M. L. 1998. Interactions between salmon culture and wild stocks of Atlantic salmon: the scientific and management issues. Report by the Conveners of a symposium organised by ICES and NASCO, held at Bath, England, UK during 18 - 22 April 1997. Norwegian Institute for Nature Research (NINA), Trondheim, Norway. ISBN 82-426-0884-9.

ANNEX I

Abstracts



The acidified River Mandal, Norway where a stock rebuilding programme involving liming and stocking is being undertaken.

Annex I: Abstracts

Note: These abstracts are those submitted prior to the symposium.

Keynote Presentations

Wild Atlantic salmon - so valuable, so vulnerable

Pat O'Reilly

After briefly surveying the environmental, social and economic benefits of healthy wild salmon stocks to communities in countries bordering the North Atlantic, in this keynote address the author also highlights the Atlantic salmon's iconic significance worldwide. There follows a brief review of past and present pressures on salmon stocks not only via direct exploitation but also via damage to their environment and measures already taken or underway to reduce impacts via the air, land and fresh water. Finally, the presenter focuses on the marine environment and proposes aspects which, with international cooperation and partnership working, need to be urgently addressed in order to forge a sustainable future for the salmon farming industry and to conserve for future generations healthy, abundant wild salmon stocks.

A global review of the salmon farming industry and developments with regard to sustainability

Helge Midttun

Farming of Atlantic salmon is a young industry. It started in Norway in the 1960s and has since spread to various corners of the world. In 2004, production of Atlantic salmon made up close to 80% of the global production of salmonids, which was around 1.5 million tonnes. The largest salmon-producing countries today are Norway, Chile, Scotland and Canada. In the Northern hemisphere, Norway is the biggest producer of Atlantic salmon, and the salmon industry has become an important means of income for many communities along the long coastline. Norway has clean waters and environmental conditions that are well suited for building a viable and sustainable aquaculture industry. Like any other industrialised food production system, salmon farming impacts the environment, and the salmon producers must accept that they will be subject to rigorous evaluation of the environmental impact of their activities. Fortunately, through focus and dedication from all stakeholders in the

industry, and in close collaboration with the authorities, many of the environmental problems associated with the salmon industry have been substantially reduced as the industry has matured. Improvements have become noticeable in areas such as fish health, feed resources management, net pen technology, etc. Through continued efforts on R&D and technology development the industry is expected to advance even further in the future. The salmon industry has evolved rapidly, and in order to continue to grow is dependent on a clean environment. Going forward, maintaining high environmental standards and securing a fully traceable and sustainable chain of production will be a prerequisite for maintaining consumer trust in salmon.

An overview of the status and management of wild Atlantic salmon (*Salmo salar* L.)

Walter W Crozier

Atlantic salmon occur naturally in over 2,000 rivers from around latitude 43°N to latitude 70°N along the coasts bordering the North Atlantic Ocean. Catch trends reflect variously the evolution of fishery types, the abundance of salmon and also the impact of management measures. Since the adoption in 1983 of the Convention for the Conservation of Salmon in the North Atlantic Ocean, the distant-water fisheries at West Greenland and Faroes have been regulated by the North Atlantic Salmon Conservation Organization through internationally negotiated quotas. In the 1980s, reducing stock abundance began to seriously impact catches and, more recently, catches have declined further as a result of management measures introduced to conserve stocks. The latter have included various compensatory non-fishing schemes in the distant-water fisheries, progressive moratoria, buyouts and closures of commercial homewater salmon fisheries in some countries, together with restrictions on rod fisheries in many rivers. Wild salmon have increasingly come under a wide range of pressures, including habitat loss and degradation, pollution, predation, climate change effects and possible interactions between wild and reared salmon and, as an overall result, stock status has declined in many parts of the natural range. The most recent assessment by the International Council for the Exploration of the Sea shows that the North American and European stock complexes are outside precautionary limits. Management advice has evolved in response to the requirements of the Precautionary Approach, with conservation limit reference points having been defined and catch advice increasingly

being framed in terms of probability of achieving pre-agreed management objectives. With many salmon stocks around the North Atlantic presently outside precautionary limits, and in some cases threatened or endangered, managers are beginning to place emphasis on seeking catch advice in terms of rebuilding objectives for particular stocks or groups of stocks.

Cultured Atlantic salmon in nature: review of ecology and interactions with wild fish

Bror Jonsson and Nina Jonsson

Hatchery-raised Atlantic salmon released in nature compete with wild fish for food, space and breeding partners. Their competitive ability differs from that of wild fish owing to morphological, physiological, ecological and behavioural changes which occur in hatcheries. The change is partly phenotypic, partly genetic. The faster growth rate of hatchery juveniles influences age and size at smolting and maturity, reproductive output and longevity. Fast-growing parr tend to smolt younger, produce more but smaller eggs, and attain maturity and die younger. Juvenile learning influences a number of behavioural traits, and differences in early experience appear to affect feeding and spawning success, migratory behaviour and homing ability. The genetic change is chiefly due to natural selection in hatcheries with differential mortality among genotypes, and brood stock selection based on production traits such as large adult body mass and fast growth rate. Due to higher aggression, experimental evidence has revealed that hatchery parr often dominate wild parr; but hatchery parr can be subordinate if smaller, when they co-occur in fast-flowing water and when wild smolts have prior residence. During spawning, the fitness of wild salmon is higher than that of hatchery-reared conspecifics. Hatchery males do poorly in intra-sexual competition, courting and spawning, and hatchery females have higher egg retention, construct fewer nests, and are less efficient in covering of the eggs in the bottom substratum. In rivers, early survival of hatchery offspring is reduced compared with their wild counterparts. Experimentally, it has been found that the life-time reproductive success of farmed fish is only 1/6 of that of similar-sized wild salmon. As a result of ecological interactions, hatchery fish may partly displace, increase the mortality and decrease the growth rate, adult size, reproductive output, biomass and production of wild conspecifics through density-dependent mechanisms.

Genetic and Ecological Interactions and Their Management

Genetic and ecological interactions between wild and cultured diadromous fish

Kjetil Hindar, Ian A Fleming, Phillip McGinnity and Ola Diserud

Cultured salmonids are released in large numbers, either intentionally or accidentally, and make up significant proportions of salmonid populations in fresh and salt water. This causes considerable concern, because interactions between cultured fish and wild fish can reduce the fitness and productivity of wild populations. The interactions must be understood both within the species' range and outside it, as salmon aquaculture is a worldwide enterprise. This paper reviews genetic and ecological interactions between wild and cultured diadromous fish, focusing on the effects of farm Atlantic salmon (*Salmo salar*) on wild salmon. Farm salmon have been under artificial selection for growth and other economically important traits for 30 years, and are genetically different from their origin at the molecular and quantitative genetic level. Escaped farm salmon spawn in the wild with limited success. Their offspring outgrow those of wild origin, but appear to suffer higher mortality. Crosses between farm and wild salmon show intermediate performance. Whole-river experiments in Ireland and Norway show that the lifetime success of farm salmon was reduced relative to wild salmon. The overall productivity also appeared depressed. Based on these findings, we make model predictions about the future of wild salmonid populations.

Interactions between salmon farming and marine coastal ecosystems in the south-east Pacific

Alejandro H Buschmann, Verónica A Riquelme, María C Hernández-González, Daniel Varela, Jaime Jiménez, Luis A Henríquez, Pedro A Vergara, Ricardo Guíñez and Luis Filún

Salmon aquaculture exportation in Chile reached 311,000 tons in 2004, making it the second-largest producer of farmed salmon in the world behind Norway. Because of this, the industry is now considered as consolidated but with further potential expansion. In order to keep on growing, the salmon industry must expand its activities further south and thus reach pristine areas with little human activity so far, resulting in increasing calls for conservation actions. Nevertheless, the environmental effects of salmon cultivation in southern Chile remain

largely unknown. The impact of this industry before 1996 has been reviewed, but evidence at that time did not suggest significant effects. However, after almost 10 years of intensive growth, current evidence suggests that some effects on the sea bed in licensed aquaculture areas are associated with significant loss of benthic biodiversity in addition to changes in the physico-chemical properties of local sediments. Another main aspect is related to the induction of harmful algal blooms (HABs) through the input of nitrogen into the water from fish culture facilities. A field study carried out using the beyond BACI sampling methodology described by Underwood (1994) suggests that the presence of salmon pens significantly increases the density of dinoflagellates, in pulses however. Salmon escapees are another public concern, with data suggesting that they prey on native species, although the life expectancy of farmed salmon in the wild appears to be rather low. Marine birds are also affected by the installation of salmon farms, where the particular abundance of omnivorous, diving and carrion-feeding birds increases from three to five times in areas with salmon aquaculture installations compared to control areas without them. Chile urgently requires an ecosystem approach in order to fully understand all the effects of aquaculture activities on its southern coastal ecosystems.

Past, present and future of genetic improvement in salmon farming

Odd Magne Rødseth and Arne Storset

Historically, fish culture can be traced back to 475 B.C. in China. In Europe, management of common carp was common in monasteries during the Middle Ages. The introduction into Europe of American salmonids, rainbow trout and brook trout, opened the 'modern' era of fish farming. A fourth period came with the development of dry pellet feeds in the 1960s. The fifth period started with the development of the farming of Atlantic salmon in sea cages in the 1970s. This marked the starting point of large-scale farming of Atlantic salmon which rapidly spread to Scotland, Ireland, the Faroe Islands, North America and Chile, the latter being the fastest-growing player in the market. The sole effect of domestication of wild fish improves production performance in several respects. Although data are scarce, decrease of mortality and increase in growth rate due to domestication are well demonstrated for species like common carp, rainbow trout and Atlantic salmon. To increase the production performance considerably, the stocks must be improved by means of selective breeding. Selection is the process

that determines which fish become parents. There are different modes of selection, the most important of which being: (i) selecting individual fish out of the entire population (mass selection), (ii) selecting particular families out of the population (family selection). The number of parents selected (selection intensity) must attempt to balance the rate of genetic improvement needed with maintenance of suitable genetic variation. To improve a population, only the fish with the best genes should be selected as parents. A breeding value is a quantitative calculation of the value of a fish as a genetic parent, and is a measure of the potential performance of its offspring. Therefore the 'best' fish are those with the best breeding values. The definition of 'best' depends on the economic importance of traits and their underlying genetics. Currently, less than 5% of the fish material stocked for aquaculture originates from selection programmes. Most of the genetic improvement in fish is based on mass selection without any pedigree information (97% of aquaculture). Advances in selection methodologies developed for livestock animals have been transferred to fish for application in family breeding programmes (Atlantic salmon, rainbow trout, tilapia, Arctic char, shrimp). A family selection programme for Atlantic salmon was initiated by AKVAFORSK in the early 1970s. The base populations consisted of wild salmon caught in some 40 Norwegian salmon rivers. This is the most long-lasting and comprehensive breeding programme in fish and has, since the mid-1980s, been run by Aqua Gen AS. The present salmon generation is the result of the eighth selection. Mass selection can only be used to improve traits that are recorded on the breeding candidates while they are still alive (e.g. growth, shape, colour, low percentage of grilse), and it is not efficient to improve discrete and lowly heritable traits such as survival rate. To improve carcass and meat quality traits family breeding must be employed - the same with resistance to specific pathogens and parasites. In Aqua Gen's breeding programme resistance against one bacterial and two viral diseases are included. Research and requirements from the fish farming industry and customers will most probably bring forth new breeding technologies and focus areas in future fish breeding: *Molecular methods*: DNA fingerprinting is already in use in parentage assignment in family breeding programmes. Marker-assisted selection and genomic selection are novel technologies that in the future will supplement traditional breeding based on quantitative genetics and make the selection more precise and cost-efficient. Transgenic technology seems to be efficient to improve growth in wild fish, but seems to be less efficient

in domesticated populations. The development of transgenic fish is in progress in many countries in Asia and Latin America. In Europe and Canada, production of transgenic Atlantic salmon is discouraged (The Williamsburg Resolution, NASCO June 2003). *Ability to consume vegetal ingredients and improvement of feed conversion and feed utilization:* Atlantic salmon and many other fish species are carnivorous. Fish proteins can be replaced by other sources, but they are highly dependent on fish oils. Selective breeding to obtain a fish that can utilize vegetal oils to a greater degree and be more feed-efficient will make aquaculture more sustainable with regard to marine feed resources. *Maintain animal integrity and functional traits and animal welfare:* Effects of selection must always be monitored as part of a selection programme in order to detect any production disorders that may arise. Selective breeding to bring forth a more robust fish with high survival and good production performance under aquaculture conditions will be increasingly important in future breeding programmes. *Preservation of wild stocks:* Fish can escape and breed with their wild conspecifics. Use of sterile triploid fish is advocated as a tool to decrease genetic interaction between domesticated and wild populations. Reluctance in the industry due to negative impacts on production performance, and public perception of triploid fish as representing unethical production, are factors that will hamper use of triploid fish in Atlantic salmon farming. Further genetic selection and domestication will probably reduce the reproductive fitness of escapees in competition with wild conspecifics, thus reducing the impact of genetic interaction between domesticated and wild populations.

The causes and scale of escapes from salmon farming

Aina Valland

In Norway, the Directorate of Fisheries has collected and presented statistics on the scale and causes of escapes from salmon farming for more than the last 12 years. Through regulations the fish farmers are required to report all escape incidents and their causes to the authorities. The statistics are based on these reports and reports to the insurance companies. The figures presented are based on these statistics. Escapees from salmon farming have varied from 200,000 to nearly 500,000 each year in the last 12 years. The industry fully accepts that these numbers are too high, and the aim is to achieve a level of escapes that is as close to zero as

practicable. Most Norwegian farmers do achieve zero escapees within their own company, thus only 2-3 per thousand farmed salmon escape. There are various causes of escapes. The Directorate of Fisheries divides these causes into the following categories: technical deficiencies, towing, handling, running over by boat, boat propellers, predators, floating objects and technical deficiencies in smolt production. Working towards the aim of achieving a level of escapes that is as close to zero as practicable, the Norwegian salmon farming producers have a 'National Action Plan to prevent escapees'. The plan is in active use and is continually revised, and it focuses on preventive measures regarding all causes of escape.

The escape of juvenile salmon from hatcheries into freshwater streams in New Brunswick

Jonathan W Carr and Fred G Whoriskey

The escape of juvenile Atlantic salmon from freshwater hatcheries may be a major route for interactions between wild and farmed fish; however, the scale of this problem has not been substantially examined. We monitored temporal abundance of escaped hatchery salmon at fixed sites: over several years, and surveyed more than 90% of the salmonid hatcheries in New Brunswick in 2004. Escaped fish were recorded at 61% of the hatcheries situated near freshwater streams. Numbers varied per site; however, escaped fish were found every year at the fixed sites. In some rivers, juvenile escapees outnumbered wild salmon. A sample of escaped farmed salmon was genetically screened for the presence of European alleles. The use of European salmon strains has been prohibited on the east coast of Canada and United States for several years. For the first time in eastern Canada, varying levels of European ancestry were detected in escaped farmed salmon. These results highlight the need for the implementation of a containment strategy for freshwater hatcheries and a genetic screening programme of farmed salmon to reduce escapes and to stop the introgression of European genes into severely depressed wild Atlantic salmon populations in the Bay of Fundy region.

Sonic tracking of experimentally released farmed Atlantic salmon in the Cobscook Bay region, Maine

Fred G Whoriskey, Paul Brooking and Gino Doucette

Farmed Atlantic salmon (*Salmo salar*) (N = 273) were surgically implanted with sonic tags (pingers), and

experimentally 'escaped' from their cage site during winter 2003 and spring 2004. Experimental releases occurred during either the day or night, on rising and falling tides. Cobscook Bay has a large tide range and fast tidal currents. Moored receivers were positioned to follow the movements of these fish in the Bay and surrounding inshore areas, up to the point that they dispersed from the coastal zone to open water in the Bay of Fundy. Additional receivers and counting facilities placed in 40 rivers draining to the Bay of Fundy let us determine whether surviving escapees strayed into them, especially during spawning season. In both seasons, escapees generally dispersed rapidly away from their cage sites. Heavy seal predation apparently rapidly killed many escapees in spring, but not winter. Course tracks of the fish indicate a combination of active swimming and drift with prevailing tidal currents. None of the escapees were detected entering rivers in the region where they could interact with spawning of endangered wild populations of Atlantic salmon.

Migration and survival of farmed Atlantic salmon (*Salmo salar* L.) released from two Norwegian fish farms

Lars P Hansen

Salmon escape from fish farms, and high numbers of escaped farmed salmon have been reported from Norwegian fisheries and spawning populations, as well as in oceanic areas north of the Faroe Islands. Many salmon escape from fish farms in the autumn and winter, and it is therefore of interest to study the migratory pattern and survival to sexual maturity of farmed fish escaping at this time of the year. The purpose of the present study was to assess migration and survival of large farmed salmon escaping from fish farms at different times in the autumn and winter. Farmed salmon were individually tagged with external tags and released from two fish farms, one in south Norway and the other in north Norway. Salmon released in the autumn one year before attaining sexual maturity appeared to survive poorly to sexual maturation, whereas salmon escaping later in winter showed higher survival. The escaped salmon tended to move with the current, and did not appear to have a homing instinct. Based on results from the tagging experiments, direction and speed of ocean currents, and from available information of the abundance of fish farm escapees in salmon fisheries and stocks in several countries in northeast Europe, two alternative hypotheses are proposed: (1): Salmon that escape early in the autumn the

year before they become sexually mature are transported with the currents to arctic areas and subsequently do not survive the winter. (2): Large salmon escaping from fish farms in Ireland, Scotland, the Faroe Islands and Norway in the winter and spring move with the current and may enter homewater fisheries and spawning populations far away from the site of escape, the following summer and autumn, when they become sexually mature.

The incidence of escaped farmed salmon in relation to the extent of fish farming activity

Peder Fiske, Roar A Lund and Lars Petter Hansen

In Norway, there have been restrictions on salmon farming in several fjords to reduce the potential negative impact from farming on important stocks of wild Atlantic salmon. This practice is now being revised, and has resulted in the establishment of 'National salmon rivers and fjords' with similar restrictions on salmon farming. There is limited knowledge on the incidence of escaped farmed salmon in fisheries and brood stocks related to the extent of fish farming in nearby areas. Such knowledge will be of significant importance when assessing if measures such as 'National salmon fjords' are likely to reduce the number of farmed salmon in nearby rivers. A pilot study published in 1994 concluded that fish farm escapees occur in fisheries and brood stocks more as a result of a number of small escapement episodes rather than by large single escapements. This was demonstrated by a positive correlation between the proportion of escaped farmed salmon in marine salmon fisheries and brood stocks in relation to the density of rearing units and the number of smolts released into sea pens in the different geographical regions considered. This work was based on results from the two first years (1989 and 1990) of the nationwide surveillance programme of the salmon stocks in Norway. The present study has the same scope, but is based on data from 16 years of surveillance (1989-2004). Norway is divided into different regions, and we analyse the incidence of escaped farmed salmon in the fisheries in relation to the intensity of salmon farming in the different regions. Our results suggest a positive correlation between the intensity of salmon farming, and the incidence of escaped farmed salmon in the rivers in the nearby area.

The development and results of programmes to monitor the incidence of farm-origin Atlantic salmon (*Salmo salar* L.) in rivers and fisheries of the British Isles

Alan Walker, Malcolm C M Beveridge, Walter Crozier, Niall O'Maoileidigh and Nigel Milner

An inevitable consequence of the development of the Atlantic salmon (*Salmo salar* L.) mariculture industry in UK and Irish coastal waters over the last three decades has been the loss of farm-origin fish to the wild, their occurrence in inshore waters and rivers, and their exploitation by commercial and recreational fisheries. Since 1984, the International Council for the Exploration of the Sea (ICES) has reported the results of national and other programmes to quantify the occurrence of escaped farmed salmon in international waters, homewater fisheries and in river stocks, and more recently has examined methodologies to improve knowledge on the distribution and movements of escapees. In this paper we report on the development of programmes to quantify the spatial and temporal distribution of escaped farmed Atlantic salmon in the UK and Ireland, and assess the implications of the presence of these fish for the ongoing assessment and management of wild stocks.

Using genetic markers to trace escaped salmon to farm of origin

Vidar Wennevik, Øystein Skaala and Kevin A Glover

In Norway, and other salmon-producing countries, large numbers of fish escapees are reported each year. Whilst official statistics are based upon events that are reported to the authorities, the real number of fish escaping from sea-cages is probably much higher; however. There is a need for a monitoring tool that can trace salmon back to farm of origin, especially in cases where large numbers of escapees have been observed without an escapement having been reported. Here, we report the results of a pilot study investigating the possibility of tracing salmon to farm of origin using microsatellite DNA and genetic assignment tests. Seven samples from different smolt producers, and of different strains, were collected from four different fish farms located in the Hardangerfjord on the west coast of Norway. Based upon 11 microsatellites, average assignment of individual salmon to farm of origin was 67%, while assignment between strains was over 90%. This study demonstrates that the use of genetic markers for tracing escaped salmon to farm of origin may be feasible and should be investigated further.

Density-dependent spawning success and contribution from farmed female Atlantic salmon to wild populations

Harald Lura

Spawning success of female Atlantic salmon (*Salmo salar*) was studied in six Norwegian rivers during 2-4 years. Successful reproduction of farmed salmon was found in 4 rivers. Proportions of successful farmed spawners varied between 0 and 83 % among rivers and years. The proportion of successful farmed spawners was positively correlated to proportions of farmed fish in autumn catches and negatively correlated to density of wild fish ($r^2=0.79$). This multiple correlation showed that more than 30-40 % of autumn catches must be farmed fish when densities of wild fish are high, before any contribution to local populations can be expected. At low density of wild spawners farmed fish perform well. On average, wild females produced larger eggs than farmed females. Due to variation in egg weight in wild fish among rivers, this difference was only significant in two rivers. There were no differences between groups in fertilization and survival rate. In one river, farmed fish spawned earlier than wild fish. Salmon domesticated for several generations thus contribute to local populations, but are excluded at high densities of wild fish, likely due to breeding competition. The contribution from escaped farmed salmon in 59 Norwegian rivers during the latest decade is estimated to 5.2 %, but there was high variation among rivers.

Estimating impacts of salmon farming on salmonid survival in the wild: a meta-analytic approach using population dynamics data

Jennifer Ford and Ransom Myers

Time series describing marine survival or abundance of salmonids exist in many areas for relatively long periods (30+ years). In this study, we apply population dynamic modelling to these existing datasets to estimate impacts of sea cage salmon farming on survival of wild salmonids, using populations less exposed to salmon farming as controls. Hypothesized impacts include increased incidence of disease, competition, and genetic changes in wild populations. Cumulatively, these impacts may be expressed in wild populations as a reduction in mean survival, much like the impact of fisheries. Data types being used include catches, returns to rivers, juvenile densities, and escapements, from around the North

Atlantic and Canada's Pacific Coast. While significant challenges to analysis of this data include a high degree of natural variation, missing data, and variation in data quality, this approach allows for direct estimation of impacts on natural populations.

Temporal genetic stability in Atlantic salmon populations

Øystein Skaala, Vidar Wennevik and Kevin A Glover

Every year, farmed salmon escape from sea cages and hatcheries in high numbers. Selection programmes and domestication have changed their genetic composition to perform better in the cultured environment, and possibly worse in natural environments. Therefore, immigration of high numbers of escaped farmed salmon in natural salmon stocks may potentially alter the genetic traits and cause fitness changes in wild salmon. To investigate the temporal stability in a number of wild Norwegian salmon stocks, genetic profiles were produced from historical scale samples and more recently collected scale material. Salmon from Rivers Namsen, Etne, Opo, Vosso, Granvin, Eio and Håelva were genotyped at the following microsatellite loci: Ssa13.37, Ssa28, SsOSL85, Ssa197, Ssa20.19, SsaF43, Ssa202, Ssa85, Ssa171, SsOSL417 and SsOSL438. In Rivers Namsen and Etne no changes were observed in DNA profiles between historical and new samples. In River Vosso genetic stability was observed between historical baseline and spawners up to 1997, while a significant change was observed in later year classes. This change corresponds in time to year classes spawned after high immigration of farmed salmon. A significant change in genetic profiles over time was also observed in River Opo. A reduction in Fst values over time was observed, indicating reduced level of population differentiation.

Pros and cons of using sterile salmon in aquaculture

Tillmann Benfey

Sterile populations are useful for the prevention of spawning of escaped farmed fish in the wild, the elimination of farm production losses associated with early maturation and/or the protection of investments made in developing novel genotypes. Given the generally reduced performance of sterile fish in aquaculture to date, the true need for sterile populations should be assessed on a case-by-case basis prior to their large-scale use for commercial production. This paper briefly summarizes the options available for rendering fish reproductively sterile, and then

focuses on the pros and cons of using all-female triploid populations of Atlantic salmon for aquaculture. The mass production of all-female triploid populations is easy and inexpensive to achieve, although there are some logistical constraints with respect to broodstock requirements. Maximizing the performance of triploid fish requires a clear understanding of their unique biology as well as a long-term commitment to selective breeding based on triploid production characteristics. As yet, neither of these issues has been adequately addressed through commercial culture; until this is done, the true advantages (and disadvantages) of sterile salmon cannot be known.

Development in cage technology designed to minimize escapes from salmon farms

Arne Fredheim

Escape of fish from fish farms is one of the major environmental impacts caused by modern fish farming. Reduction of the number of escapees has been a major objective for the Norwegian fish farming industry in recent years. The long-term aim is to reduce the extent of escapes to a level where they do not pose a threat to the wild salmon. The focus on reducing escapes has resulted in the development of technical requirements for floating fish farms. Improvement to operations and handling of equipment and fish to prevent accidents has also been considered important. New fish farms have to be certified according to technical requirements and to prove they have the necessary strength to withstand environmental conditions at the particular location. Included in the requirements are user manuals developed by the equipment manufacturers for mounting, handling, operating and maintaining of all equipment. To further minimize escapes from fish farms, cage design needs to focus both on reducing probability and consequences of accidents both with regard to technical failure and incidents and to reduce the possibility and consequence of incorrect use and operation of equipment. Based on such aspects, new net cage designs and improved mooring systems have been developed.

Conflicts between diadromous fish restoration programmes (e.g. shad, striped bass) and conservation of populations of Atlantic salmon

Douglas Grout

Anadromous populations of striped bass (*Morone saxatilis*) are found along the Atlantic coast of North America from Maine to North Carolina. Recruitment overfishing

combined with water quality problems led to a substantial decline in resource abundance during the 1970s and 1980s. Cooperative interstate fishery management of striped bass began in 1981 when an interstate fishery management plan was developed by an organization of Atlantic coastal states, the Atlantic States Marine Fisheries Commission (ASMFC). Effective fishery management under the ASMFC, combined with several key pieces of federal legislation that strengthened ASMFC management and provided funding for important research and monitoring, contributed to a 10-fold increase in abundance of the striped bass stocks by the late 1990s. The dramatic increase in striped bass abundance has resulted in increased predation on the populations of a variety of species including American shad, river herring, and menhaden. Predation of striped bass on Atlantic salmon smolts in North America has been documented but no quantification of striped bass impacts on stocks of Atlantic salmon has been conducted to date.

A review of the Pacific salmon hatchery programmes on Hokkaido Island, Japan

Kentaro Morita, Toshihiko Saito, Yasuyuki Miyakoshi, Masa-aki Fukuwaka, Toru Nagasawa and Masahide Kaeriyama

Hatchery programmes involving the mass release of artificially propagated fishes have been implemented worldwide to supplement wild populations and to increase harvests. The island of Hokkaido in Japan is one of the most active regions for Pacific salmon hatchery programmes, with ca. 1.2 billion juveniles released annually along a coastline of ca. 3000 km. In the last quarter of the 20th century, coastal catches of chum and pink salmon increased dramatically, whereas those of masu salmon did not. In addition to the development of hatchery technologies, several possible hypotheses may explain these catch trends, including climate change, closing of high-seas fisheries, rehabilitation of water quality, habitat loss caused by damming and channeling, and increased pressure from recreational fisheries. Even when these other confounding factors have been accounted for, it is still difficult to evaluate whether all hatchery programmes have actually resulted in net population increases. To use hatchery programmes more effectively, we need to evaluate river- and species-specific net benefits from hatchery programmes, and compare hatchery programmes with other management tools, such as fishery controls and habitat rehabilitation. Rather than resisting change, future hatchery programmes should incorporate active adaptive learning approaches to minimize the risks

associated with artificial propagation, and to promote sustainable salmon stocks.

Loss of regional population structure following stock enhancement in Atlantic salmon

Fernando Ayllon, Jose L Martinez and Eva Garcia-Vazquez

Many wild Atlantic salmon populations were enhanced with domesticated stocks in the past century. To evaluate the degree and the direction of the genetic changes produced in wild south European populations by domesticated stocks, variation at microsatellite loci was examined in historical and present scale collections of seven Spanish and French populations. Significant genetic differentiation between neighboring rivers, typical of Atlantic salmon, existed before stock enhancement but was lost in only a decade of stocking. Introgression of domesticated genomes into local gene pools was detected in the studied populations. These results show that losing genetic diversity is a real threat for wild populations subjected to enhancement practices.

Estimates of straying salmon *Salmo salar* into rivers on the Swedish Kattegat west coast from coastal releases in the Baltic Sea

Stig Pedersen, Gorm Rasmussen, Einar E Nielsen, Lars Karlsson and Per Nyberg

During the years 1995-99 reared salmon from two Baltic strains were released at the islands Bornholm and Møn in the Baltic Sea. A total of (a) 600,000 reared salmon were released from net pens (using the 'delayed release' technique, keeping the salmon in net-pens for approx. three months after smoltification) and (b) 208,000 reared salmon were released directly from the hatchery. Of these, 15,958 were tagged with Carlin tags. In the year 2000, 65,300 coded wire tagged salmon were released as delayed release salmon close to Bornholm. Recaptures from the Carlin tagged releases varied between 2.8 and 26.4% (average 13.1%). Recaptures in the Baltic Sea dominated (average 98%), while a minor part of the salmon were recaptured outside the Baltic Sea, either in the sea (1%) or in fresh water (1%). Straying rates from these releases into six rivers on the Swedish west coast were estimated using information from various sources (captures in traps, information from the sports- and brood stock fisheries, genetic analysis). The proportion of straying salmon was estimated to vary from 1.5 - 2% in River Åtran to between 10 and 40% in the River Nissan, with large variation between years. Due to the possible

deleterious effect on the local wild salmon populations, releases were discontinued.

Changes in wild and hatchery proportions of annual Atlantic salmon (*Salmo salar*) catches in the Baltic Sea

Marja-Liisa Koljonen

DNA level information, an 8-loci microsatellite baseline database of 32 Atlantic salmon (*Salmo salar* L.) stocks, has been used together with a Bayesian estimation method to estimate stock and stock group proportions of Finnish catches in the Baltic Sea area. The proportions of seven stock groups important in terms of fisheries management were assessed in catch samples taken in four years (2000, 2002, 2003 and 2004). In the Gulf of Bothnia area the proportion of wild fish showed a rising trend until 2003 in all areas, but was mainly the result of decreasing total catches, which was due to relatively higher mortality of hatchery fish than of wild fish. In 2004 the total numbers of caught wild fish had also increased, indicating an increase in the abundance of the wild stocks. In catches from the Åland Sea, the proportion of wild fish increased from 44% to 70% in 2000-2004, corresponding to catch numbers from 4,628 to 7,329 individual fish. In the Gulf of Finland, the largest contribution was made by local hatchery fish, the Neva salmon, which are released by Estonia, Finland and Russia. In the western part of the Gulf of Finland, fish originating from the Baltic Main Basin made a substantial contribution. The threatened, eastern Estonian and Russian wild stocks were recorded only in the western part of the Gulf of Finland, with a proportion from 9% in 2003 to 19% in 2004.

Disease and Parasite Interactions and Their Management

Parasite interactions between wild and farmed fish

Ron Stagg, Rob Raynard and Sandy Murray

This paper will consider both micro- and macro-parasite induced disease of fish. Micro-parasites such as bacteria or viruses are microscopic, they have life cycles that are of very short duration into relation to the life expectancy of the host (hours versus years) and they tend to elicit a strong immune response in the host. Macro-parasites tend to be larger and to have life spans which are similar in magnitude to the life expectancy of the host and they only have weak interactions with the host immune system.

Epidemics of micro-parasitic organisms are associated with the dynamics between susceptible, infected and recovered (immune) hosts and are therefore associated with the number of infected hosts. In contrast macro-parasitic epidemics are associated with both the number of infected hosts and the intensity of infection. In both cases successful invasion of the host by the parasite and the spread or evolution of an epidemic is indicated when the basic reproductive number (R_0) is greater than one. This occurs when a host infected with a micro-parasite gives rise to more than one secondary infection or a macro-parasite produces more than one offspring surviving to reproductive age in the course of its life. Parasite epidemics can affect both farmed and wild fish and have consequences for both: population regulation in wild, economic damage and welfare effects in farmed fish as a result of losses, decreased growth or trade limitations. Wild fish are the ultimate source of parasites and can also be a reservoir of infection which impedes eradication programmes in farms. However, the farming of fish can exacerbate disease problems through the promotion of conditions leading to epidemics (such as enhanced transmission and evolution), long-range transport (through trade and introductions) and spill-over of parasites back into the wild. Normally there is a balance between the ability of the host to resist invasion and the ability of the parasite to reproduce successfully. Maintaining fish in culture can alter this balance such that epidemics are more likely. The rearing of fish under aquaculture conditions, with good husbandry and management, should not necessarily cause reduced resistance to parasites because of stress in the host. Much more important will be the impact of culture conditions on the transmission of infection, particularly the contact rate between susceptible and infected hosts and the duration of infection. Although originating in wild populations the emergence of parasitic infections is an inevitable consequence of farming fish and this is illustrated by an examination of some of the more important diseases that have emerged in Scottish aquaculture in the past 20-30 years. However, examination of some of these case histories also indicates that epidemics in farmed fish do not necessarily result in epidemics in wild populations and that management measures such as good bio-security and husbandry can be effective risk mitigation measures.

Sea lice biology and genetics

Karin Boxaspen

Studies of sea lice biology, including both the species

Lepeophtheirus salmonis and *Caligus elongatus*, have been conducted from various perspectives over the last two decades. Pike and Wadsworth last reviewed parts of this topic in 1999, but new research and the application of genetic methods to certain aspects of the problem necessitates an updated review. The focus of this research has been in areas such as life-history biology, study of developmental stages under different and varying conditions (temperature and salinity), behaviour, distribution of sea lice and dispersal of free-living stages, monitoring practices, population structure and modelling. The results of this research have been used to refine management strategies and risk analysis concerning sea lice infections in wild and farmed populations of anadromous fish. Studies implementing methods based on molecular biology have been used to describe population structure, possible differences in genetic characterization of geographically separate populations and population markers. Susceptibility to sea lice and the potential for selective breeding have also been addressed. To try and understand the parasite/host relationships at a molecular level, work has been started to characterise proteins and the main aim of the work is to explore the possibility of developing a vaccine against sea lice.

Impacts of salmon lice on wild salmonids

Bengt Finstad, Pål A Bjørn, Jens Christian Holst, Peter Andreas Heuch, Roar Kristoffersen, Chris Todd, Neil Hazon, Paddy Gargan, Oliver Tully and Scott McKinley

Research carried out over the past 15 years has indicated that salmon lice must presently be regarded as a potentially important population-regulating factor in many salmonid stocks. Their actual detrimental impact, in terms of absolute reductions in the sizes of the total wild salmon run, is, however, uncertain due to a lack of systematic investigations. Methods to assess salmon lice infestation of seaward-migrating post-smolts in the early stages of their marine phase have now been successfully developed. As a precautionary measure, the salmon farming industry has introduced various strategies to reduce the numbers of salmon lice larvae in many aquaculture areas, and hence the potential horizontal and vertical transmission to wild fish. The effects of these reductions are probably mostly beneficial to the wild salmon stocks. This presentation summarizes current knowledge on interactions between lice on farmed and wild salmonids, including theoretical and empirical studies of lice production and infestation dynamics, routes of transmission and monitoring data from Norway, Ireland and Scotland.

Temporal changes in genetic variability in wild sea trout (*Salmo trutta* L.) from two Irish rivers affected by Atlantic salmon aquaculture

James Coughlan, Elvira de Eyto, Eileen Dillane, Ola Diserud, Philip McGinnity, Brian O'Farrell, Killian O'Farrell, Rene Stet and Thomas Cross

Several studies have documented the harmful genetic effects of intra-specific hybridisation of reared and wild Atlantic salmon (*Salmo salar* L.). However, the effects of salmon aquaculture on wild congeners are less well understood. Since the late 1980s, severe sea trout declines have occurred in many Irish rivers, thought to be caused by sea lice infestations associated with fish farming. The effects of other introduced diseases are also likely to affect wild salmonids. Here, we analyse how the introductions of diseases associated with intensive salmon farming and ranching have had an impact on the genetic variability of cohabiting sea trout. We compared variation at a locus critical to immune response (MHCI) with variation at six neutral microsatellite loci. Sea trout samples (archived scales) were investigated from two rivers (the Burrishoole and Erriff) both with a history of aquaculture. A substantial decline in allelic richness and gene diversity at an MHCI marker, that was observed in both rivers since aquaculture started (which may be an indication of a selective response in the two populations), was not reflected by similar reductions at neutral loci in the Burrishoole system. In the case of the Erriff, both the MHCI and the neutral markers showed evidence of a reduction in genetic variability. Subsequent recovery of variability at MHCI seen among the later Burrishoole samples was not apparent in the Erriff trout. The differences in the observed temporal patterns of genetic variability between the two rivers may reflect the relative proportions of sea trout to freshwater-resident fish in these systems.

Stress and osmoregulatory dysfunction in laboratory-controlled sea lice infestation of sea trout

Alan Wells, Christal Grierson, Iain Russon, Sjoerd Wendelaar Bonga, Paal Bjorn, Bengt Finstad, Chris Todd and Neil Hazon

Since 1989, sea trout stocks on the west coasts of Scotland and Ireland have declined catastrophically, accompanied by widespread observations of 'premature return' of post-smolts to fresh water, within a few weeks of their first migration to sea. These fish typically bore

heavy infestations of largely juvenile stages of sea lice. We undertook laboratory-based infestation of wild sea trout smolts with *Lepeophtheirus salmonis*, in order to determine the threshold levels of sea lice which induce sub-lethal physiological stress and osmoregulatory dysfunction. In a parallel series of experiments for sea-lice infested post-smolt sea trout, we also examined the physiological consequences of premature return to fresh water. The osmoregulatory ability and status of these fish was assessed by a variety of physiological, biochemical and histological techniques including branchial, intestinal and renal Na⁺K⁺-ATPase activity, plasma ion composition, and drinking rate. Stress was assessed by determination of plasma levels of cortisol, MSH, glucose and lactate and liver glycogen levels. In addition, the integrity of skin and gill tissue was assessed by SEM, TEM and confocal laser scanning microscopy. This suite of analytical techniques has allowed us to estimate the sea lice infestation levels that trigger sub-lethal, chronic and acute physiological stress in sea trout.

Survival and growth of sea-ranched Atlantic salmon treated against salmon lice prior to release

Ove T Skilbrei and Vidar Wennevik

Smolts were treated with SLICE® (orally administered emamectin benzoate) prior to releases in the River Dale, western Norway, to study the potential effects of salmon lice during the early stay in the sea. A total of 10,470 treated and control fish of 10 family groups were adipose fin-clipped, micro-tagged, and released in the Dale River on three different dates in 2002: May 11, May 25 and June 7, in accordance with the timing of the natural smolt run. Grilse returns in 2003 did not differ between the treated and control group smolts released in May 2002, but the grilse returns from the treated smolts released on 7 June 2002 were almost twice those derived from the untreated control group. The weights of the grilse generally declined from the first to the third release date, and the treated fish were approximately 15 % heavier than the controls. The higher return rate of smolts treated and released on June 7 was also observed for the 2-sea-winter salmon in 2004. We conclude that the infestation level of salmon lice changed from non-lethal to lethal levels during the period of the smolt migration, and that non-lethal infestation levels may considerably affect Atlantic salmon by reducing growth rate and spawning size.

Exceptional production of pink salmon in 2003/2004 indicates that farmed salmon and wild Pacific salmon can coexist successfully in a marine ecosystem on the Pacific coast of Canada

Richard J Beamish, Simon Jones, Chrys-Ellen Neville, Ruston Sweeting, Grace Kareman, Sonja Saksida and Elysha Gordon

Juvenile pink salmon that entered the marine waters in a marine ecosystem along the eastern margin of Queen Charlotte Strait in 2003 and returned as adults in 2004 had very high marine survival. The early seaward migration and mid-summer rearing in 2003 was in an area containing 16 active Atlantic salmon farms. Two species of sea lice were commonly found on farmed salmon and wild salmon. The exceptional marine survival of pink salmon indicates that pink salmon populations and farmed salmon coexisted successfully in 2003.

Susceptibility to the sea louse (*Lepeophtheirus salmonis*), Infectious Salmon Anemia and Furunculosis among salmon of wild, farmed and hybrid parentage

Kevin A Glover

Genetic differences between Atlantic salmon of wild and farmed backgrounds have been observed for a variety of biological, behavioural and life-history traits. Notably, several authors have demonstrated that salmon of farmed parentage display reduced survival in natural ecosystems compared to the offspring of wild parentage. Despite these key differences however, at present, potential differences in susceptibility to disease have been little explored. Susceptibility to disease represents an important aspect of fitness under both domestic and natural environments. It is also conceivable that genetic differences in susceptibility to disease may exist between salmon of farmed and wild parentage due to the different selection regimes they are exposed to in their respective environments. Here, we summarise the results of four studies where salmon of wild, farmed and hybrid backgrounds have been compared in their susceptibility to the sea louse (*Lepeophtheirus salmonis*), Infectious Salmon Anemia and Furunculosis. Together, results from these studies indicate that large and systematic differences in susceptibility to disease are unlikely to exist among salmon of farmed and wild parentage. It is recommended, however, that this topic deserves further investigation.

Salmon lice infection of running Atlantic salmon in two Norwegian fjords: effects of hydrography and lice abundance

Peter Andreas Heuch, Jens Christian Holst, Lars Asplin, Bengt Finstad, Pål A Bjørn and Audun Stien

Research carried out during the 1990s identified salmon lice as a potentially serious population-regulating factor in Norwegian salmonid stocks. Various management measures were imposed, amongst them a veterinarian act in 1997 regulating the numbers and stages of salmon lice allowed per individual fish in farms. Through a comparative study between two major salmon fjords, Altafjord and Sognefjord, we focused on interactions between salmon lice and wild and farmed salmonids. In Altafjord the results indicate that salmon lice were never a problem for migrating post-smolts of salmon, while in the Sognefjord the conditions have gone from negative before 2002 to good during 2002-2004. This coincides with the fish farming industry's efforts to reduce the salmon lice production in the farms in the critical spring period. Hydrographic-biologic modelling of data from Sogn from a three-year period showed that environmental factors do not explain the reduced infection of the running salmon smolts. For sea trout the situation seems less positive. A clear reduction of salmon lice infection intensity on sea trout was not recorded in either the Altafjord or in the Sognefjord. It is concluded that wild and farmed salmon can coexist in Norwegian fjords if the total amount of salmon lice larvae in the fjord is adapted to the local hydrographic conditions and the population characteristics of the wild salmonids. To ensure precautionary salmon lice management in Norwegian fjords there is a need for more knowledge on environmental and biological parameters, in particular where there are plans for increasing the output of farmed fish.

Two-year sea lice larvae plankton survey

Michael J Penston, Ian M Davies and Alain F Zuur

An extensive plankton survey was carried out in the Loch Torridon system, on the west coast of Scotland, to investigate sea louse infective pressure. The survey consisted of plankton tows collected weekly at a number of sites within the sea loch over a 2-year period, between 2002 and 2004. In total, 884 samples were collected and 8,382 lice larvae were recovered, of which 58% were nauplii and 42% were copepodids. The species of the nauplii were not determined, but copepodids were retained for identification. From the 416 samples

containing preserved copepodids, a random selection of 102 samples were examined for the presence of *Lepeophtheirus salmonis* and *Caligus elongatus*. The vast majority of the copepodids retained were *L. salmonis*, and only a few were *C. elongatus*. During the survey, salmon fish farms in the Loch Torridon system completed a production cycle. Generalised Additive Models (GAMs) were used to describe the distribution of lice larvae. The models suggested an increase in larvae densities during the farm production cycle, followed by a decrease as the farms harvested and were left fallow. Significantly greater densities of copepodids were recovered at the surface than at 2.5 and 5 metre depths. Nauplii showed no preference for any of the depths sampled. Densities of sea lice larvae were found to vary considerably, ranging from 0 to 243 larvae m⁻³. This high variability in the data was also indicated in the GAM models.

The current state of health management in aquaculture - progress to date and future challenges

Graeme Dear and Edward Branson

Fish health management has developed from being a 'new concept/minor species/green-fingered/let's try it and see' aspect of aquaculture to one which increasingly utilises the most advanced scientific technology to provide solutions to health challenges. The current status of fish health and options available to the farmer to control pathogens are described in the context of a rapidly evolving industry. The inter-relationship between the key parameters of legislation, economics, environment, host, consumer concerns and veterinary medicines are examined in the context of reducing antibiotic use and increasing pressure to control parasitic and viral diseases such as sea lice, IPNV and pancreas disease. While vaccine availability and husbandry methods have advanced to the point where they have reduced, but not eliminated, the need for antibiotics, the future challenges revolve around the importance of a greater understanding of the needs of aquaculture healthcare. In an environment which is increasingly demanding from regulatory, environmental, retailer, consumer and wider stakeholder interests - it is important not to forget the main purpose of the subject, i.e. fish health and welfare. These challenges will be discussed and key areas identified for veterinary care and future research and development to assist in the management of fish health.

Trends in the usage of drugs in Norwegian aquaculture

Kari Grave and Tor Einar Horsberg

All use of drugs in farmed aquatic organisms in Norway is prescription-based. Such drugs have to be dispensed through pharmacies or authorized feed mills and this has facilitated the establishment of a comprehensive surveillance programme on drug usage in fish farming in Norway. The main aim of this surveillance system is to carry out risk-based drug residue control, but the data obtained are also used to make public valid drug usage data in aquaculture. Such statistics might be used to assess the environmental consequences of drug use in fish farming regionally or nationally, i.e. impact on wild salmon. The present paper will focus on impact of use of the major drug groups (antibacterial drugs and drugs against salmon lice infestations) in Norwegian fish farming, and basically discuss consequences for wild salmon. It is concluded that use of drugs in fish farming is unlikely to cause any toxicological harm to wild salmon. In Norway, drug use in aquaculture is considered unlikely to be a food safety problem as regard wild salmon, e.g. causing drug residues. However, in countries/regions with intensive farming and extensive use of drugs, food safety risks might be considered. Regarding use of drugs against salmon lice infestations, it is concluded that suboptimal treatment against salmon lice infestations is likely to result in heavy salmon lice infections and consequently increased mortality in smolt approaching the sea. Likewise, extensive treatment increases the risk for resistance development which may result in a poor effect of the drug within the farm and consequently an increased risk for wild salmonids.

The Scottish Tripartite Working Group Approach: Building consensus and making progress to protect wild fish interests alongside salmon farming

Phil Gilmour

The objective of the Scottish Tripartite Working Group (TWG) approach is to bring together, under a voluntary initiative, the salmon farming industry, the wild fish sector and Government to facilitate discussion and co-operation. Consensus between the three parties is being, and will continue to be, improved through the sharing of information and development and implementation of area management agreements (AMAs). AMAs provide local solutions to maximise the effectiveness of sea lice

management and control and bring additional benefits which minimise fish disease risks. Another issue covered in AMAs is the minimisation of escapes of farmed fish which can have the potential to interbreed with genetically unique wild salmon stocks. Reaching agreement on containment and contingency planning to minimise escapes of farmed fish and facilitate efforts to recapture them is also covered within the AMA process. Three regions of Scotland (Argyle and Lochaber, north-west Scotland and the Western Isles) were targeted because of the presence of both salmon farms and wild fish interests. Twenty areas were originally identified as suitable for the development of AMAs. It is hoped that eighteen AMAs will have been signed before the end of this year. This will represent good progress over the second stage of the TWG process, covering the period 2003-2005. The costs of staff resources and projects over this timescale comes to almost £1 million.

Use of wrasse in the control of sea lice on farmed salmon

Per Gunnar Kvenseseth, Johan Solgaard and Kristin Ottesen

Concerns over the negative effect of sea lice on farmed and natural stocks of salmonids, and the environmental concerns over chemicals used to control sea lice in the salmon farming industry, have resulted in the search for alternative treatments. One successful alternative involves the use of cleaner fish, where one species of fish (the cleaner) feeds on parasites from another fish (the host). Widely used as cleaner fish within the Norwegian salmon farming industry are several species of wrasse (family Labridae). All wrasse used to date have been caught by traps in the wild. New research is now developing methods for the culture of wrasse. Given the right conditions wrasse is one of the most effective, cost-efficient and environmentally benign ways of controlling sea lice on farmed salmon. Cleaner fish, used correctly, will keep the level of sea lice at a continuous low level on farmed salmon. Stomach content analysis has shown up to 272 pre-adult/adult lice in one ballan wrasse. Over 40% of ballan wrasse examined were found to have consumed sea lice. Wrasse will also control sea lice reproduction as they prefer grazing on pre-adults and particularly adult female lice. Sea lice eggs do not survive or hatch after passing through the gut of a cleaner fish. Updated information on results and protocols are given on www.leppefisk.no.

Control and treatment of *Gyrodactylus salaris*

Jarle Steinkjer and Edmund Peeler

Gyrodactylus salaris is a freshwater, monogenean ecto-parasite of Atlantic salmon. Infection of its original host, Atlantic salmon in the Baltic watershed, is generally inapparent. It is only on Atlantic stocks of Atlantic salmon (*Salmo salar*) that the parasite multiplies unchecked causing a high level of mortality in juveniles and, consequently, dramatic reductions in wild populations. In 1975 the parasite was introduced into Norway, probably through the importation of Atlantic salmon smolts from the Baltic region, and has dramatically reduced stocks of Atlantic salmon in 45 rivers. It is known to be present in Denmark and Germany and is likely to have been introduced into other European countries with the importation of live rainbow trout (only the UK and Eire have demonstrated freedom from the parasite). *G. salaris* can infect rainbow trout (*Oncorhynchus mykiss*) permanently, and cause infection of up to 50 days in several other species. In this paper the action plan implemented by the Norwegian authorities to combat the parasite will be reviewed. The plan includes surveillance to ensure early detection, prevention of the spread of the parasite to uninfected rivers, and measures to eradicate the parasite through chemical treatment and barriers to migration. Chemical treatment has been implemented in a total of 27 out of 45 infected watercourses in Norway. For countries such as the UK and Eire that are free of the parasite, and have significant stocks of potentially susceptible Atlantic salmon, preventing the introduction of the parasite is the major objective of any control programme. However, contingency plans to minimise the impact of the parasite, if introduced, are also critical. Restriction of live fish movements is central to the control of the spread of *G. salaris* between catchments. The potential importance of other routes (e.g. fishing gear) will be considered in the light of the survival characteristics of the parasite off the host. Differences in the control of *G. salaris* in Norway and the UK will be discussed.

Poster Presentations

Sonic tracking of wild cod, *Gadus morhua*, in an inshore region where cod aquaculture is developing

Paul Brooking, Gino Doucette and Fred Whoriskey

East Coast North American finfish farmers are beginning to diversify into the culture of fishes other than Atlantic

salmon. Sea cage trials have begun with Atlantic cod (*Gadus morhua*). We fitted inshore wild cod with sonic tags during the summer of 2004, to provide data on the habitats they used, their temporal residency, and their coastal movements. This information can help determine the potential for interaction among wild and escaped farmed cod, and escaped cod and other species. Wild cod remained within a restricted corridor in the inshore zone. They generally concentrated in deep holes (~ 100 m) but undertook local movements, possibly related to feeding. There was a gradual movement offshore detected as winter advanced, with fish of reproductive size moving away first, possibly to offshore spawning areas. One fish was still present in February 2005. Cod, known Atlantic salmon smolt predators, resided in the principal migration corridor for smolts from severely depressed wild Atlantic salmon populations. If escapes of farmed cod occur, and they occupy the same habitats as their wild counterparts, it could increase predation upon salmon smolts. Siting and engineering of cod farms should be done to minimize the probability of escapes.

Genetic variation after and before the Atlantic salmon supportive breeding programme in the rivers Ulla and Lérez (Galicia, Spain)

Maria Saura, Pablo Caballero, Armando Caballero and Paloma Morán

Management of wild Atlantic salmon (*Salmo salar* L.) populations based on stocking procedures has been widespread over the European range of this species during the second half of the past century. In southern European rivers, stock transfers from northern European countries have been justified by a severe decline in native populations. However, the efficiency of this type of management to increase effective population size has been very poor; mainly because the stocks employed for supplementation presented genetic characteristics different from those of native populations. Since 1995, all salmon released in the rivers Ulla and Lérez (north-west Spain) are descendants of naturally returning adults and of wild parr reared until the spawner stage wholly in fresh water (holobiotic rearing), artificially mated in Carballedo hatchery. The success of this supportive breeding programme has been monitored using physical markers, and the results seem to be satisfactory. To investigate the genetic variability ten years after the beginning of the programme and to test the genetic differences between the present-day populations and those before the

restoration programme, genetic variation at five microsatellite loci was analysed in a collection of old scales (1950-1965) and samples from modern returning adults (1998-2004), including individuals born in the river and in the hatchery. Heterozygosity values and average number of alleles are very similar in modern and old populations. Populations inhabiting the rivers Ulla and Lérez are more similar nowadays than they were in the past. Although the present Ulla and Lérez populations were initially restored using a stock mix from other Galician rivers (including the River Ulla), there are genetic differences between both populations, suggesting some degree of local adaptation and low straying rates.

Distribution and biological characteristics of escaped farmed salmon in a major subarctic salmon river (River Teno, Finland/Norway)

Eero Niemelä, Jaakko Erkinaro, Jukka-Pekka Vähä, Craig R Primmer, Sturla Brørs, Esa Hassinen and Majja Länsman

Escaped salmon from Norwegian fish farms in the Arctic Ocean show a wide spatial dispersion in the large subarctic river Teno, northernmost Scandinavia, supporting perhaps the largest wild Atlantic salmon stock complex in the world. Farmed salmon were caught throughout the >250km-long main stem and major tributaries during the fishing season (June-August) in 1987-2004 when the proportion of escapees in catch varied between 0.08 and 0.53%. However, the number of escapees increased towards the end of the fishing season. The proportion of wild 1-5SW salmon caught in August represented 15-25% of the total catch, whereas the corresponding proportion for the escaped salmon was as high as 69%. Experimental sampling after the season (September-October) has revealed high proportions of escapees, up to 50%. Weight of the escaped salmon varied between 2 and 10 kg. Up to 88% of the escaped salmon caught in August showed significant gonad development, and there are also direct observations of escapees on spawning grounds during the breeding season. This reflects high potential for successful reproduction of escaped salmon. Scale analysis indicated that 4.5% of the escaped salmon were repeat spawners. Highly significant genetic differentiation was observed between wild and escaped farmed salmon captured in the river.

Towards sustainable salmon aquaculture - zoning of the Icelandic coastline

Sigurdur Gudjonsson

Over 100 Icelandic rivers foster natural salmon populations that are considered as important parts of Icelandic nature. Sport fishery of Atlantic salmon is very important for Iceland with annual turnover of approximately 125 million euros. Large fishing companies show interest in salmon cage rearing. Cage rearing of salmon was tried in Iceland in the 1980s and 1990s but was not successful, as conditions are harsh around Iceland. Salmon has been farmed in land-based units since the 1980s. Interested salmon farmers claim that cage rearing around Iceland can be successful today because of better salmon strains, better cages and better knowledge. They have also argued that salmon farming can be important in Iceland, creating jobs and improving the economy in rural areas. River owners fear that only a few farmed salmon in their river can harm the image of their pristine river and salmon. Furthermore, river owners and environmentalists fear that salmon cage rearing will threaten the valuable wild stocks, as salmon escapees from the cages will migrate to the rivers, cause genetic mixing and breakdown of the local adaptation of the stocks, as well as spreading parasites and diseases. They fear that eventually it will leave the rivers without salmon, ruining their income. Discussion and debate of these different views has been going on in Iceland. Positive and negative sides of salmon farming in other countries were evaluated. The Icelandic parliament, Althingi, passed new legislation on fish farming enabling the government to manage fish farming better. Salmon farming is not allowed in the bays and fjords with the most valuable salmon rivers. This was considered as a step towards sustainable salmon farming and as a compromise between these opposing views. Salmon farming is only allowed in certain areas and the experience gained there will be used for further evaluation and development of salmon farming in Iceland.

Use of catch statistics to monitor the abundance of escaped farmed salmon and rainbow trout in the sea in a region of western Norway

Ove T Skilbrei and Vidar Wennevik

Catch statistics and scale samples have been collected from a gill net fishery targeted for escaped farmed salmonids (1 October - 28 February) for the years 2001 - 2004 in Hordaland County, western Norway. An attempt

has been made to classify the fish into different groups, or escapement events, by using catch per unit effort (catch per net per day) and size distribution of the catch from different geographical sub-regions. In addition, the genotypes of some sub-samples are compared. It is concluded that most of the escaped farmed fish were of local origin and that catch per unit effort may be a useful tool for monitoring escape incidents and the relative abundance of escaped farmed fish. There were clear indications of a decline in the stock of escaped rainbow trout during the fishery.

The feeding behaviour features of cultured and wild salmon in Kola Peninsula rivers

Alexander V Orlov, Yuri V Gerasimov and Oleg M Lapshin

In order to investigate the behaviour and distribution of young salmon and adaptation of cultured fish to the natural environment, an underwater survey was conducted on the Shugor and Luvenga rivers. Behaviour was examined, current speed measured and drift samples collected. The food and feeding habits of 34 wild and 44 cultured smolts released from the Kandalaksha fish nursery were also studied. The young fish moved freely over the area in all directions, 5 to 10 m away, stopping every 1 to 2 m. They became somewhat aggressive only when, on very rare occasions, they moved within 0.3 m of each other. From about the same distance the parr would flee from the approaching observer. The young fish mostly fed in the bottom 15 cm of the water column, with current speeds of 0.2 to 0.35 m/s, making 5 to 10 cm feeding lunges every 20 seconds. When cultured fish moved from these areas into areas with higher current speeds (average speeds of 0.5 m/s) and lower drift density (2.55 species/m³) they did not show a tendency to return to slower-moving water, unlike wild fish. The smolts fed on bottom invertebrates carried with the current, and insects which had fallen onto the surface of the water. The cultured fish had a significantly larger share of the former in their diet (40% and 25% respectively). Few of the fish examined had empty stomachs so it may be assumed that both the wild and cultured smolts were feeding actively. However, on the basis of the average food quantity per stomach it may be assumed that the wild smolts were feeding more actively than the cultured ones. Invertebrate content in the above rivers is 3% of the total quantity of formed particles, the remaining 97% being exuvium of aquatic and terrestrial insects, algae and various plant remains. Non-feed remains were found in 13% of wild and 25% of cultured salmon, i.e. the cultured

smolts are less capable of differentiating food in the water, making more false food lunges (from 20 to 30%) than wild fish. The cultured fish were more aggressive, in terms of the frequency of brawls, with individual fish reacting to each other from larger distance. Wild smolts would flee to escape from the closing observer, while the cultured fish would allow the observer to come closer. The cultured and wild fish have generally similar diet and feeding behaviour. Certain differences, however, were observed in the saturation ratio and distance of response to feed, to each other and to the diver.

Physiological and behavioural effects of introgression of salmonid fast-growing domestic genotypes into non-selected genetic backgrounds

Wendy Tymchuk and Robert H Devlin

Domestication in fish often involves direct selection for improved growth rates as well as other correlated traits, and can therefore have a significant impact on life history. Many fitness-related traits, such as growth, competitive ability and anti-predator behaviour, have been found to have a genetic component. Due to an altered selection regime, the cultured fish may not be as adapted to the natural environment as wild fish. This research summarizes the growth, behaviour and physiology of fast-growing (domesticated aquaculture), slow-growing (non-selected), and hybrid (F1, F2 backcross, and F3 backcross) strains of coho salmon (*Oncorhynchus kisutch*) and rainbow trout (*O. mykiss*). Growth of the strains was compared under both culture and semi-natural rearing conditions. Under all environments, there was a strong correlation between growth and the proportion of domestic genes within the genotype. Comparisons of anti-predator behaviour and hormone profiles illustrated similar trends. Assessment of the expression of fitness-related phenotypes in the hybrid strains can provide information on the genetic changes that have evolved during the domestication process. Knowledge of the genetic changes responsible for altered growth rates in fish is crucial information needed to increase our ability to predict the consequences of introgression between fast- and slow-growing strains of fish.

Genetic history of a restoration river, the Connecticut River

Fernando Ayllon, Stephen Gephard, Francis Juanes and Eva Garcia-Vazquez

The Connecticut River lost its Atlantic salmon population

due to human activity 200 years ago. Foreign hatchery-reared stocks were employed to restore the population. An annual run of salmon has been successfully re-established, although that population is not yet self-sustaining. We have examined variation at microsatellite loci in historical and modern scale collections to evaluate the degree and the direction of the genetics changes occurred in the introduced stocks. The current genetic pattern of the Connecticut River restoration population was very similar to that of its Penobscot River donor population. We found no difference in heterozygosity, mean number of alleles per locus, number of migrants, or FST values, all suggesting that no gene drift or founder effects have occurred. Differences between the donor and the derivative populations for both sea-run age and allele frequencies at the isozyme locus *MEP-2** are likely adaptive responses to environmental variation.

Interactions between acidification in fresh water and sea lice sensitivity as an underlying factor causing delayed responses

Frode Kroglund, Bengt Finstad, Sigurd O Stefansson, Torstein Kristensen, Bjørn O Rosseland, Hans C Teien and Brit Salbu

Severe acidification is acknowledged as the cause for the extinction of numerous Atlantic salmon (*Salmo salar* L.) populations in Southern Norway. Acidification mobilizes aluminium (Al) from the soil, resulting in elevated Al concentrations in the freshwater ecosystem. In fresh water, cationic (labile or inorganic) forms of Al (Al³⁺) accumulate onto fish gills, where gill-Al concentrations exceeding 250 µg Al/g gill dry weight are associated with increasing mortality due to respiratory and ionoregulatory dysfunction. At lower concentrations, fish health can still be affected (measured as reduced growth), although blood ion levels can remain within a range that is normal for pre-smolts. However, at these concentrations, Al may still interact with gill Na⁺-K⁺-ATPase and inhibit enzyme activity. Reduced Na⁺-K⁺-ATPase activity is associated with poor seawater performance. An exposure to Al has no observable effect on the timing of, or the behaviour during, downstream migration, but a gill-Al concentration of 20 to 50 µg Al/g gill dry weight is sufficient to reduce adult return rates by 20 to 50 % relative to the untreated controls. Acidification had a delayed effect, where the response is reduced post-smolt to adult survival. Following entry into seawater, Na⁺-K⁺-ATPase activity is restored to normal levels over the first few weeks. During this recovery phase, the post-smolt is more vulnerable to predation due to the poor hypo-

osmoregulatory capacity affecting anti-predatory behavioural traits like avoidance. Fish that survive this initial phase appear to adapt fully to sea water, as growth and the age of adult returns were not very different from the controls. Pre-smolts, first exposed to sublethal levels of Al in slightly acid water (pH 5.8; 5-15 µg Al/l) for a period of days (episode) to weeks (long-time), then to a post-exposure treatment to sea lice (*Lepeophtheirus salmonis* Krøyer) copepodids, indicate additional and hitherto unpublished delayed effects that also have population responses. Infestation of the post-smolt with copepodids had no adverse effect on hypo-osmoregulatory capacity before the sea lice reached adult stages. After 42 days, the acid-exposed fish infected with sea lice suffered elevated mortality in an Al-dose-dependent manner relative to the same untreated groups. The sub-lethally Al-exposed smolt appears to be more sensitive to disease and parasite attacks suggesting a reduced tolerance to additional stressors. Many of the salmon-bearing rivers on the South-western coast of Norway can be periodically acidified to sublethal levels for period lasting from days to weeks prior to and during the smolt run. This is also a region heavily populated with fish farms. The combined effects of moderate acidification (in fresh water) and moderate sea lice infestation (in sea water) can have the same devastating effects as higher acidification levels or higher sea lice densities. Year to year variations in acidification pressure and salmon lice densities can in combination obscure, but also explain, some of the year to year variation in post-smolt survival and hence the variation in Atlantic salmon year-class strength in Norwegian rivers located along the south-western coast. Rivers on the South coast are mainly affected by acid rain, while more northern rivers are not affected by acidification. As many salmon populations encounter multiple stressors, caution should be used towards using single pressure explanatory models.

Infection success of salmon lice (*Lepeophtheirus salmonis*) related to temperature

Karin Boxaspen

The development rate for salmon lice larvae is highly temperature-dependent. Hence, the time from hatching of nauplii to an infectious copepodid will vary with the natural cycles in the sea and the copepodid's life span is prolonged at lower temperatures. This has implications for dispersal of larvae in the environment and the subsequent decision of what is the sensible regional size

of salmon farming areas. The infection success of salmon lice as a function of copepodid age have been studied in controlled systems from 6°C to 14°C. Newly hatched salmon lice were collected every day from a hatching system and placed in holding units. Copepodid groups of specific and different age were used to infect salmon in a temperature-controlled system and the successful moult to chalimus recorded. The salmon lice were, as expected, infectious for a longer time at the lower temperatures. The maximum staying time from hatching to last settlement observed for one individual was found to be 30 days (at 6°C).

Measuring the impact on the natural production of Atlantic salmon (*Salmo salar*, L.) of native origin hatchery fish spawning in the wild

Philip McGinnity

There has been a dramatic and persistent decline in Atlantic salmon numbers throughout most of the species' geographical range. This decline in wild stocks has led to widespread releases of artificially spawned and reared Atlantic salmon in an attempt to supplement natural production. 'Common garden' experiments undertaken under natural river conditions, show that genetic differences among wild and hatchery populations, result in significant performance differences that led to a reduction of productivity, particularly in environments where density-dependent mortality factors are important regulators of survival. However, no studies have shown, either in real time or retrospectively, losses in natural production in non-experimental wild populations of Atlantic salmon as a result of the deliberate release of hatchery fish. Spawner-recruit relationships provide a valuable conceptual framework for predicting and may, in those few instances where they exist, provide a practical opportunity of measuring the effects of genetic alterations or genetic differences between populations on the productivity and abundance of Atlantic salmon. Here, I present an analysis of stock and recruitment data for a population receiving variable, but significant quantities of naturally spawning hatchery fish over a 35-year period, as an indirect measure of changes in the productivity of a natural population. It is significant that the hatchery population was founded from the wild population investigated and thus might be thought to represent the most genetically suitable material for stock enhancement. An analysis of the residuals from the stock and recruitment relationship suggests that a significant proportion of the variation

around the relationship can be explained by the proportion of naturally spawning hatchery fish and that these incursions have had a significant depressive impact on the recipient population of approximately 30%. Removal, rather than addition, of hatchery fish, therefore, may be the most effective strategy to improve productivity and resilience in natural populations. Hatchery fish have effectively been excluded from spawning in the wild in this river for the last eight years; a significant improvement in the freshwater production of salmon smolts has followed.

Movements of cultured salmon in a Norwegian fjord system

Ove Skilbrei, Jens Christian Holst, Marianne Holm and Ole Torrissen

A study has been initiated in 2005 in a Norwegian fjord system to study the behaviour and movements of escaped Atlantic salmon. Adult salmon (2-4 kg) from a commercial fish farm are tagged with coded acoustic transmitters with depth sensors and released at different dates. A total of 24 data-logging receivers record the movements and swimming depths of the simulated escapees at various locations in the Hardangerfjord. Some examples from the first recordings are shown. They show that several individuals are still in the vicinity of, or are passing by, the fish farm several weeks after release. Although the released salmon move close to the surface for most of the time, diving is also observed. It was a clear tendency that salmon dived to 20 to 50 metre depth immediately after release. Repeated deep diving down to more than 200 metre depth was also observed.

Tracing escaped farmed salmon by means of naturally occurring DNA markers, fatty acid profiles, trace elements and stable isotopes - TRACES

Øystein Skaala, Bengt Finstad, Vidar Wennevik, Kevin Glover and Bjørn Barlaup

In 2003, the Norwegian Ministry of Fisheries and Coastal Affairs took the initiative to set up a national committee to explore available methods that could be used for tagging of farmed fish, in order to trace the origin of escaped farmed salmon. The committee, with representatives from the aquaculture industry, the research community and the management authorities, found that there were no methods ready for implementation. It was concluded that two different methods of identifying escaped salmon should be

investigated further: snout tagging (coded wire tags) and a stand-by, contingency approach, based on naturally occurring characteristics of the fish. Based on these recommendations, a project group led by Dr. Øystein Skaala, Institute of Marine Research, with specialists in genetics, chemistry and population biology, has been put together. A steering group, jointly led by the Fisheries Directorate and the Directorate for Nature Management, was also put together. A project has been designed to test out the precision of methods that potentially can be used for tracing escaped salmon back to sea pen of origin. The focus is put on naturally occurring characteristics of the fish, and a stand-by contingency approach. Samples of salmon from all fish farms in the Hardangerfjord basin, and escaped farmed salmon, will be collected. DNA profiles, lipid acid profiles, trace element composition and stable isotope composition will be established, and the usefulness of the various methods in tracing the sea pen of origin of escaped salmon will be investigated.

ANNEX 2

Keynote Presentations - Session Chairmen's Summary



Photograph courtesy of the Scottish Salmon Producers' Organisation.

Annex 2: Keynote Presentations - Session Chairmen's Summary

Lars Petter Hansen and Malcolm Windsor

Janne Sollie, the Director General of the Directorate for Nature Management, opened the symposium and reminded us that while the topics on our programme this week were similar to those at the previous symposia held in 1990 and 1997, the situation has changed. She referred to the significant growth of the industry since 1990 and to the continuing decline in wild stocks despite major reductions in fishing effort and a wide variety of measures to address habitat issues in fresh water. She noted that our understanding of interactions between cultured and wild salmon has increased markedly since 1990 and that it is now recognised that salmon farming can pose a serious threat to the wild stocks. However, she noted that progress is being made - there is now improved cooperation between the salmon farming industry, the authorities and various stakeholders. Furthermore, new management measures designed to minimise impacts have been introduced, not least NASCO's Oslo/Williamsburg Resolution. She noted, however, that we cannot afford to be complacent and to highlight the importance of our work she referred to two very significant escapes of farmed salmon in Norway this year, which amounted to about 600,000 fish. She concluded that additional measures are still required and she stressed the need for solutions to the challenges that remain, in order to move closer towards sustainable culture of Atlantic salmon.

We were then reminded of the importance of the topic of this symposium to both NASCO and ICES. The representative of ICES, Dr Niall Ó Maoiléidigh, told us that the subject of the symposium was highly relevant to the ICES work programme and the President of NASCO, Dr Ken Whelan, challenged us to urgently find solutions to the real problems that remain in managing interactions between cultured and wild salmon.

We then had four excellent keynote presentations, which set the scene for the week.

Pat O'Reilly highlighted, most eloquently, the social and economic values of the wild Atlantic salmon. In addition to the very significant values associated with the fisheries and eco-tourism, he reminded us that the general public care about the wild Atlantic salmon, an indicator of environmental well-being, and are prepared to pay very substantially to conserve it. He described, in military terms, the vulnerability of the resource - assault from the

air, land battles, attacks on freshwater habitat - and referred to the progress being made on many fronts to address these problems through cooperation among the interested parties. While many problems can be tackled at a national or local level, he stressed the need for international cooperation in addressing the problem of salmon survival at sea. With regard to salmon farming, he stressed the need for further progress on implementing NASCO's Williamsburg Resolution to minimise impacts of aquaculture, and the need to apply a Precautionary Approach. He noted that progress is being made, but containment is not adequate, given present levels of farmed production. This, he believed, was not in the industry's long-term interests, not least because the genetic diversity present in the wild stocks is their future seed-corn. However, he believed that enhanced cooperation between wild and farmed salmon interests can address the remaining challenges. He cautioned that while sound science can inform political decision-making, the real power lies with the general public. The message was clear: if the salmon farming industry was perceived to be damaging the wild stocks, consumers may reject its products. He concluded with a powerful rallying call to us all: Mother Nature has thrown down the gauntlet; we must not wait until she has thrown in the towel.

Our second keynote speaker was Helge Midttun, who referred to the development of the salmon farming industry since the 1960s, an important source of income for coastal and other communities around the North Atlantic and elsewhere. Worldwide production in the last decade has trebled, reaching 1.2 million tonnes in 2004, and he considered that the continued success of the industry will require that it is conducted in harmony with the environment, and that where conflicts arise, the way forward is through cooperation and planning. He referred to the fact that the world's fish stocks are fully exploited so aquaculture has a vital role to play in meeting future demand for seafood. He suggested that effluents of nutrients and organic matter from salmon farming no longer represent a major environmental problem, and antibiotic usage has been dramatically reduced. He accepted that while almost 98% of all farmed salmon are contained in cages, the level of escapes is still too high relative to the abundance of wild stocks. He stressed that for the salmon farming industry to continue its growth, the product must be perceived to be safe and healthy, it must not be associated with any form of deterioration of the natural environment and the industry should be seen to be open and transparent, and willing to focus on animal welfare and environmentally sustainable practices.

Walter Crozier picked up on Pat O'Reilly's theme of the vulnerability of wild salmon stocks, presenting information developed by ICES which confirmed the depressed state of salmon stocks around the North Atlantic. All four European stock complexes are considered by ICES to be outside precautionary limits, and in North America 31% of monitored rivers are achieving less than 50% of their conservation limits. Some stocks are critically endangered. Much has been achieved with regard to reducing exploitation, particularly in the distant-water fisheries, but many factors are influencing the stocks. He stated that while over-exploitation is not always part of the problem, exploitation control is often part of the solution to rebuilding stocks. However, the modelled projections for stock rebuilding for low productivity stocks are very long-term. The message is clear; given the status of these stocks we must ensure that human activities do not exacerbate the situation.

Then Bror Jonsson presented an extremely comprehensive review of the literature concerning the ecology of cultured Atlantic salmon in nature and their interactions with wild fish. He concluded that hatchery salmon compete for food, space and breeding partners with wild salmon in nature, and that their performance and reproductive success, though variable, can be much poorer than that of wild fish. The reduced fitness is due to a variety of changes, including morphological and physiological changes which occur in the hatchery, some of which are short-term, others long-term. Hatchery fish in nature may partly displace, increase the mortality and reduce the growth rate of wild fish, with effects on associated life-history traits, biomass and production through density-dependent mechanisms. He highlighted the need for further research on the factors influencing performance of hatchery fish in nature and the ecosystem effects of increasing salmon abundance in fresh and sea water:

James Ryan then reported to us on the Trondheim Workshop, 'Wild and Farmed Salmon - Working Together', which had examined three themes: area management initiatives; the pros and cons of using sterile salmon in farming and restoration initiatives. He referred to possible future initiatives that might be explored through the NASCO/salmon farming industry Liaison Group in the light of the Workshop findings, including possible development of guidelines on area management initiatives and on restoration programmes, and he suggested that the use of sterile salmon be given further careful consideration by that Group.

Following the presentations we had an interesting discussion which focussed on aspects such as straying rates and their implications for natural recolonisation of rivers; approaches to stocking; the impacts of sea lice, a major problem for the industry and for the wild stocks; and the possible consequences of climate change on interactions between wild and cultured salmon, including those arising from increased frequency and severity of storms.

In summary then, a number of themes emerged from this valuable keynote session:

- Wild salmon stocks have enormous user and existence values. The general public cares about this most charismatic of fish species. Similarly, the salmon farming industry is an important source of income for coastal communities, whose success depends on its activities being conducted in harmony with the environment. The challenge is to find ways in which wild and farmed salmon can co-exist.
- Since the first symposium in 1990, our scientific understanding of interactions has increased considerably. It is even more clear that cultured salmon can have significant impacts on the wild stocks. While there is a need for additional research, under a Precautionary Approach this must not be used to delay further management action to minimise interactions.
- Despite the major sacrifices that have been made in reducing exploitation of wild salmon, and the progress made in protecting and restoring salmon habitat, and in introducing measures to minimise impacts of aquaculture, the abundance of wild stocks remains low, and in some cases critically low, for reasons we don't fully understand. We must, therefore, ensure that our activities do not exacerbate the situation.
- If the salmon farming industry is to continue its growth it must be seen to be environmentally sustainable. Safeguarding the wild stocks is likely to be in the long-term interests of the industry. If it is perceived to have damaged the wild stocks there could well be a consumer backlash.
- While we have made real progress with regard to understanding and managing impacts of aquaculture so as to protect the wild stocks, and the industry has made significant progress, some big challenges remain, particularly with regard to further reducing escapes and in managing sea lice. It is clear that further

progress can be made through a cooperative approach but we believe it has to have a greater sense of urgency.

- Climate change raises considerable uncertainty both about the prospects of rebuilding the wild stocks and the further development of the industry.
- There is not much time if we are to safeguard the future genetic diversity and abundance of the wild stocks. At the same time the demand for farmed fish continues to grow. So the task for the symposium is to urgently highlight the major challenges and identify possible solutions to these.

ANNEX 3

Genetic and Ecological Interactions and their Management - Session Chairmen's Summary



Photograph courtesy of the Scottish Salmon Producers' Organisation.

Annex 3: Genetic and Ecological Interactions and their Management - Session Chairmen's Summary

Mary Colligan and Tom Cross

Introduction

The session entitled 'Genetic and Ecological Interactions and their Management' contained a wide variety of presentations on observed interactions between aquaculture and wild stocks of Atlantic salmon and other diadromous fish species. Significant progress has been made since the 1997 symposium in Bath, England, at which time there was some evidence, but much speculation, about how wild and aquaculture stocks would interact in the natural environment. Since the Bath symposium there has been more experience with, and study of, interactions between wild and aquaculture salmon. As these interactions have become more prevalent, so has experience in methods for managing these interactions. Presentations at the Bergen symposium provided evidence of management experiences, highlighting both successes and failures.

The Presentations

The first paper was presented by Kjetil Hindar and entitled 'Genetic and ecological interactions between wild and cultured diadromous fish.' New research since the Bath symposium was highlighted, particularly experiments in Norway and Ireland. The presentation identified a number of modelled effects farm fish escapees can have on wild fish. In some cases the population eventually becomes composed entirely of hybrids as the effects are cumulative over generations.

Experiences with aquaculture in Chile were presented by Alejandro Buschmann in a paper entitled 'Interactions between salmon farming and marine coastal ecosystems in the south-east Pacific.' The full environmental effects of aquaculture in Chile are not known. However, the diversity in the benthic environment has been documented to have been reduced in the vicinity of aquaculture cages. The abundance of predators was also observed to be higher in areas with aquaculture installations. It was strongly recommended that the effects on native fish needed to be studied.

A presentation on the history of genetic research within

the aquaculture industry was presented by Arne Storset, entitled 'Past, present, and future of genetic improvement in salmon farming.' Individual and family selection methods were reviewed. Molecular methods of selection were identified as likely to increase in importance in the future. It was emphasized that the goal within the Norwegian aquaculture industry was domestication.

Aina Valland's presentation, 'The causes and scale of escapes from salmon farming,' identified the following causes: technical failure, predators, floating objects and boat propellers. The relative contribution of each of these causes was found to vary significantly from year to year. The importance of internal control systems and education and training to ensure staff competence were emphasized.

'The escape of juvenile salmon from hatcheries into freshwater streams in New Brunswick,' presented by Jonathan Carr, illustrated that escapes from freshwater hatcheries can be a significant cause for concern. Escaped fish were recorded at the majority of hatcheries located near freshwater streams. A call was made for implementation of containment strategies for freshwater hatcheries.

Information on the behavior of escaped salmon was presented by Fred Whoriskey in a paper entitled 'Sonic tracking of experimentally released farmed Atlantic salmon in the Cobscook Bay region, Maine.' Escapes were simulated in the winter and spring. Escapees were found to disperse rapidly beyond 1 km from the location of their release. Many of the escapees were eliminated quickly in the spring, possibly attributable to predation by seals.

Additional information on the behavior of escaped farmed salmon was presented by Lars Petter Hansen in the presentation 'Migration and survival of farmed Atlantic salmon released from two Norwegian fish farms.' The escaped fish did not appear to home to their release site. The survival and distribution of escapees depended on the time of year of the escape and the release site. Much of the distribution could be explained by currents.

Peder Fiske's presentation, 'The incidence of escaped farmed salmon in relation to the extent of fish farming activity,' found a positive correlation between the intensity of fish farming and the incidence of escapes. This study suggests that the number of salmon in net pens is a better indicator of farm escapees in rivers than the number of reported escapees.

Alan Walker described the development of programmes to quantify the spatial and temporal distribution of

escaped farmed Atlantic salmon in the UK and Ireland in the presentation, 'The development and results of programmes to monitor the incidence of farm-origin Atlantic salmon in rivers and fisheries of the British Isles.' The presentation assessed the implications of the presence of escaped fish for the ongoing assessment and management of wild stocks. Farmed fish can inflate catch-based spawning escapement and may increase the risk to wild stocks. He suggested that one needs to look locally at the stock specifics in order to determine what levels of escapees are significant.

'Using genetic markers to trace escaped salmon to farm of origin,' presented by Vidar Wennevik, reviewed the results of a pilot study investigating the possibility of tracing salmon to farm of origin using microsatellite DNA and genetic assignment tests. Although genetic methods for tagging are difficult, the point was made that the alternative of physical tagging can be very costly. Escaped farmed salmon were able to be assigned with a high degree of certainty to strain, which may be somewhat indicative of farm of origin. It was suggested that further work should be undertaken to determine if precision can be increased to provide enough information to assign an escapee to its farm of origin.

Harald Lura's presentation, 'Density-dependent spawning success and contribution from farmed female Atlantic salmon to wild populations,' presented results from a study on six rivers in Norway. The proportion of successful farmed spawners was found to be positively correlated to the proportions of farmed fish in autumn catches and negatively correlated to the density of wild fish. Salmon domesticated for several generations contributed to local populations, but were excluded at high densities of wild fish, likely due to breeding competition.

'Estimating impacts of salmon farming on salmonid survival in the wild: a meta-analytic approach using population dynamics data,' was presented by Jennifer Ford. This theoretical model was used to estimate the impacts of sea cage salmon farming on survival of wild salmonids using populations less exposed as controls. This theoretical model identified potential impacts of up to a 1% reduction in the productivity of wild fish for each tonne of farmed fish production, in the areas studied.

Øystein Skaala's presentation, 'Temporal genetic stability in Atlantic salmon populations,' indicated that wild salmon populations in rivers with high numbers of farmed escapees became genetically more similar to each other

over time. While no genetic changes were observed in some rivers, changes were observed in rivers which have a higher proportion of farmed fish escapees. This work was conducted using independent assignment methodology.

The 'Pros and cons of using sterile salmon in aquaculture' were presented by Tillmann Benfey, who emphasized the importance of assessing the need for sterile populations and the full potential benefits and negative effects. A strain that performs very well as a diploid may or may not be a good performer as a triploid, so development of a triploid production strain requires an intentional breeding programme. Research on methods of sterility were encouraged as well as full investigation of all of the potential consequences, including effects on stress resistance and the immune system.

Arne Fredheim reviewed existing and potential new cage designs in his presentation, 'Development in cage technology designed to minimize escapes from salmon farms.' The development in Norway of technical requirements for floating fish farms were reviewed as well as the certification requirements for new farms. A potential new cage design was presented that focuses on reducing the probability and consequence of accidents both with regard to technical failure and incidents, and to reducing the possibility and consequences of incorrect use and operation of equipment.

'Conflicts between diadromous fish restoration programmes (e.g. shad, striped bass) and conservation of populations of Atlantic salmon' was presented by Douglas Grout. Information was presented on the efforts that resulted in successful recovery of anadromous populations of striped bass along the Atlantic coast of North America. The dramatic increase in striped bass abundance has resulted in increased predation of a variety of species including American shad, river herring, and menhaden.

Kentaro Morita's presentation, 'A review of the Pacific salmon hatchery programmes on Hokkaido Island, Japan,' illustrated the large-scale release of salmon to support commercial harvests. It was suggested that to use hatchery programmes more effectively we need to evaluate river- and species-specific net benefits from hatchery programmes, and compare hatchery programmes with other management tools, such as fishery controls and habitat rehabilitation. Adaptive learning approaches should be utilized for hatchery programmes to minimize the risk associated with artificial propagation and to promote sustainable salmon stocks.

'Loss of regional population structure following stock enhancements in Atlantic salmon' was presented by Paloma Moran. Significant genetic differentiation was found between neighboring rivers in Spain but was lost in only a decade of stocking. Introgression of domesticated genomes into local gene pools was detected, showing that losing genetic diversity is a real threat for wild populations subjected to enhancement activities.

Gorm Rasmussen's presentation, 'Estimates of straying salmon into rivers on the Swedish Kattegat west coast from coastal releases in the Baltic Sea,' reviewed releases of salmon from 1995-1999 from two Baltic strains. Some fish were reared and then released from netpens while others were released directly from the hatchery. The programme was discontinued due to possible deleterious effects on the local wild salmon populations from strays.

'Changes in wild and hatchery proportions of annual Atlantic salmon catches in the Baltic Sea' was presented by Marja-Liisa Koljonen. DNA level information from an eight-loci microsatellite baseline database of 32 Atlantic salmon stocks was used with a Bayesian estimate method to assess the stock and stock group proportions of Finnish catches in the Baltic Sea area. The proportion of wild salmon showed a rising trend until 2003 in all study areas as a result of higher mortality of hatchery fish than of wild fish.

Synthesis

As illustrated by the above brief summaries, this session included a great deal of information. An attempt was made to identify the key information across all the presentations and to capture the key issues and points made during the discussion period. This is summarized below.

Escapees

The information presented indicated that escaped farmed fish dispersed quickly from the immediate vicinity of cages (>1 km) and tended to move with dominant currents. The fate and survival of escapees is highly variable and is affected by a number of factors, including location of escape, season of escape, age and maturity of the escapees and the presence of predators. Heavy seal predation appeared to be experienced by fish escaping in the spring in North America compared to those that escaped in the winter. Fish that escape at an early stage from marine cages appear to attempt to return to the site of their release.

Interactions

Compared to the Bath symposium in 1997, there appears to be a decline in the number of escapees and improvements in reporting. A positive correlation has been observed between intensity of fish farming and incidence of escapees. The number of salmon in net pens is a better predictor of farm escapees in rivers/fisheries than the reported number of escapees. This could indicate problems with reporting or perhaps indicate that 'trickle losses', not observable to the fish farmer, are a greater source of escapees than previously thought. Escapes from freshwater facilities are not well documented and it is not known if this is an isolated or widespread problem. Risks are posed by hatchery programmes designed for intentional stocking as well as unintentional escapes from commercial culture operations. Goals of hatchery programmes need to be well thought out - they need to match the solution to the problem and evaluate effectiveness. All of the potential implications of intentional releases need to be well thought out (*Gyrodactylus salaris* implications of Baltic salmon strays into the Atlantic).

Genetic Interactions

Modelling evidence was presented that wild populations can eventually become composed of hybrids due to aquaculture escapees. Genetic research by the aquaculture industry has resulted in a significant increase in growth of aquaculture fish (growth has been doubled in eight generations in Norway). Emerging molecular methods provide opportunities for DNA fingerprinting and marker-assisted selection which would make selection more precise and cost-effective. It was stated that the genetic approach in Norway now is to merge the four genetic lines and questions were raised as to what implications this could have for using genetics to identify farm source. The fact that genetic change has been observed in some rivers over time and not others is influenced by the numbers of farmed spawners and density of wild fish. This finding illustrates the importance of looking at stock specifics to determine the level of escapees that would be significant. It was demonstrated that significant genetic differentiation can be reduced quickly due to stocking of non-native strains.

Ecological Interactions

Observed environmental effects from aquaculture facilities include algal blooms and a significant loss of benthic biodiversity and diversity of other fish. Predation on

native species was also found to increase as a result of escapees preying on native species and an increase in marine birds near farms. The use of a theoretical model comparing populations exposed to salmon farming to those not exposed identified a reduction in productive capacity of up to 1% per tonne of production in the areas studied. An increase in predation on salmon as a result of a successful restoration programme for another anadromous species emphasized the importance of thinking of the entire ecosystem.

Management of Interactions

Increased reporting of escapees was identified as a positive development. Reporting of all escapees and causes is required in Norway and other countries. Interactions between vessels and cages were identified as a significant cause of escapees and the simple solution of requiring radar reflectors and updating navigational charts was identified. The National Action Plan in Norway is designed to prevent escapees (staff competence, information and education, environmental management systems). In addition, new certification requirements in Norway require capability assessments to ensure that the equipment at a farm is matched to the site conditions. Solutions to freshwater escapement may be inexpensive and relatively easy (redundant screening).

One of the tools that has been identified for management is better information on when, where, and how escapes occur. Mandatory reporting is one source of such information. If farmed fish were marked in a way to indicate farm of origin this could prove useful in being able to trace escapees back to a farm to learn more about the cause of that escape. Using genetic markers, escaped farmed salmon may be assigned with a high degree of certainty to strain (which may be somewhat indicative of farm of origin). Both biological and physical methods of containment were reviewed and discussed. In considering triploidy, it was emphasized that it is important to be explicit about the purpose of sterility. Further research into cage design was encouraged and it was suggested that cage design should focus on reducing the probability and consequences of accidents as well as minimizing potential for incorrect use. Another management tool presented was the decision to move to native strains for intentional enhancement programmes.

Recommendations for Future Research

Although much has been learned since the Bath symposium, many more questions remain unanswered.

The following research needs were identified during the discussion:

- Environmental effects of farming of salmon in Chile;
- Information on spawning success of escapees;
- NASCO and ICES have suggested a joint experiment to track escapees;
- Need further genetic work to determine if precision can be increased to provide enough information to assign an escapee to farm of origin;
- Pros and cons of triploids warrants further investigation and discussion - effects on immunity, stress response;
- Development of a high-performing triploid strain requires a deliberate selective process.

Recommendations and Challenges for Management

The fact that the causes of escapees are diverse and highly variable on an annual basis (technical difficulties, boat propellers, predators, floating objects) means that there must be multiple management actions targeting these various sources. The question was raised as to whether management should change seasonally and/or depending on age of fish in recognition of the anticipated differences in survival of the escapees. Storms were identified as major source of escapees and the question was raised as to whether climate change would increase storm events and lead to more escapees. The aquaculture industry appears to be moving toward larger and larger cages which pose significant management challenges as the loss of one of these cages could release more fish than an entire site using older, smaller cages. Also, sites are moving further away from salmon rivers and to more exposed areas which may also increase their vulnerability to storms. Managers were cautioned to consider the effects of farmed fish on catch advice as they can inflate catch-based spawning escapement (which may increase risk to wild fish). There was a strong emphasis on the application of an ecosystem approach to fully understand all of the effects of aquaculture.

ANNEX 4

Disease and Parasite Interactions and their Management - Session Chairmen's Summary



*The River Drammen, Norway where stocking is being used to mitigate losses caused by the parasite *Gyrodactylus salaris*.*

Annex 4: Disease and Parasite Interactions and their Management - Session Chairmen's Summary

Malcolm Beveridge and Chris Poupard

Fifteen papers on the two broad themes of science and management of disease and parasite interactions were presented, none of them considering species other than Atlantic salmon and sea trout.

Ron Stagg opened the session with a broad-ranging presentation that dealt with micro- and macro-parasites, in essence covering the entire gamut of Atlantic salmon disease agents, from viruses and bacteria to ectoparasites. The paper examined some of the more important diseases that have appeared in salmon farms in Scotland since the inception of the industry and in so doing concluded that while originating in wild populations, the emergence of parasitic infestations among farmed fish, sometimes with increasing associated virulence, is an inevitable consequence of farming. Much of the presentation focused on epidemics, exploring the insights being gained through the use of new types of mathematical modelling tools. The paper pointed out the key differences between micro- and macro-parasite epidemics. It concluded that epidemics among farmed populations do not necessarily result in epidemics among wild fish populations, stressing the importance of good bio-security and husbandry in mitigating risk.

Sea lice, and *Lepeophtheirus salmonis* rather than *Caligus elongatus*, were mentioned in Ron Stagg's presentation and indeed dominated much of the rest of the day's presentations and discussions. Karin Boxaspen reviewed what we know about the biology and genetics of the parasite, focusing on recent research on life history, especially the impacts of temperature and salinity on developmental rates, on behaviour and dispersion. She reviewed new information on natural distribution and advances in the application of genetic techniques to understand parasite population structure and genetic diversity. The new discoveries are being applied to refine pest management strategies and to assess risks to wild fish populations. Molecular genetics work raises the possibility of a vaccine being developed against the parasite.

A series of presentations explored the theme of wild-farmed fish pathogen interactions. Neil Hazon reported

on how sea lice infestation affected the physiology of wild sea trout. In a series of laboratory trials, the threshold levels of infestation at which physiological stress and osmoregulatory problems occur were determined. A threshold level of infestation at which mortality among sea trout smolts was likely to occur was determined to be 13 lice per fish. The susceptibility of wild, farmed and wild-farmed hybrid Atlantic salmon to sea lice and to Infectious Salmon Anaemia (ISA) and furunculosis was explored by Kevin Glover. No differences among fish treatment groups were found for furunculosis or ISA, and the differences apparent in exposure to sea lice disappeared when differences in body size among treatment groups were taken into account. In conclusion, while domestication to date does not seem to have led to any systematic divergence in disease resistance from wild salmon, future selection programmes may.

The paper presented by Bengt Finstad summarized present knowledge of interactions between lice on farmed and wild salmonids, drawing on much monitoring data from Scotland, Ireland and Norway. Key points from the presentation included the high infection pressure imposed by farms on wild stocks in many areas and the inverse relationships between incidence of lice on wild sea trout and distance from fish farms.

In determining the infection pressures that sea lice on farmed fish pose for wild salmonids it is important to understand sea lice dispersal and the behaviour of wild salmonids that makes them susceptible to infestation. Two papers provided us with insights. Michael Penston presented two years of plankton survey data from Loch Shiel in Northwest Scotland. Higher nauplii densities were found at sample sites close to farms while copepodid levels were highest at sites away from farms. Dispersal of copepodids was shown to be largely explained by wind-driven currents; by contrast, nauplii were found throughout the top 5 m. Generalised Additive Models were used to analyse the pattern of planktonic lice abundance, which showed an increase from stocking of farmed fish throughout the production cycle, followed by a marked decrease when fallowing began again.

Peter Andreas Heuch looked at the effects of both hydrography and infection pressure on infection rate of Atlantic salmon and sea trout smolts emigrating from the two contrasting fjord systems. These studies illustrated not only differences between areas in terms of infection pressure, but also that within a system year-to-year

differences in hydrography could cause changes in sea lice dispersion that radically altered risks to wild fish. Differences between emerging dispersion models in Norway and Scotland were briefly discussed.

Ron Stagg had posed the question of whether anyone had determined the impacts of sea lice on wild fish populations. Bengt Finstad attributed this to the lack of systematic investigation, a deficiency currently being addressed through the collaborative research project with industry, recently initiated in the Hardangerfjord system.

Tom Cross also appeared to have anticipated the question of impacts of sea lice on wild fish populations but explored qualitative changes at the genotype and phenotype level rather than numerical changes. They examined impacts of diseases associated with farming on genetic variability of sea trout from two systems, the Erriff and the Burrishoole. Archived scale samples were examined and variations at both a locus critical to immune response (MHC I) and six neutral microsatellite loci were measured. Two contrasting situations were found: in the Erriff, decreases in genetic variability were found in both MHC I and the neutral markers. By contrast, later samples from the Burrishoole showed a recovery in MHC I variability. Evidence was presented to show differences between the two systems in the relative proportions of sea trout to freshwater-resident fish, with proportionally much higher numbers of freshwater-resident trout in the Burrishoole.

Chrys-Ellen Neville presented a paper on the effects of fish farm lice on wild pink salmon. Large numbers of pink salmon smolts emigrate through the Queen Charlotte Strait, an area of intense Atlantic salmon farming activity. Data from a recent year class was presented, showing that adult pink salmon returned in unusually high numbers the following year but it was not possible to conclude whether this was due to the Provincial Action Plan which introduced a fallowed migration corridor, or increased freshwater flow, which could lead to conditions less favourable to sea lice production, or other factors.

Another session theme was sea lice control. Current health management practices on Scottish salmon farms were discussed by Graeme Dear. Bacterial problems were shown to be largely under control due to vaccines, resulting in major reductions in the use of antibacterial compounds. Viral diseases remained a serious concern, recent ISA outbreaks having largely been controlled only through rigorous culling. Management measures, in combination with access to good medicines, have been

critical in reducing sea lice levels on farms, although more effort is required by some sectors of the industry. A key message was the threat posed by the emergence of new disease challenges, but also flagged up were the potential of genetic selection to improve disease resistance, the emerging field of nutraceuticals, and the continued importance of application of best practice to avoid disease.

Trends in the use of medicines in the Norwegian salmon farming industry were presented by Kari Grave. This presentation focused on the question of whether the current use of antimicrobials and anti-sea lice medicines in particular posed any threat to wild fish. While it was concluded that there were no toxicological risks, sub-optimal treatments against sea lice promoted heavy lice infestations and increased infection pressure on emigrating Atlantic salmon smolts. At the opposite extreme, over-reliance on certain key medicines increased the risk of development of resistance with consequent welfare concerns and increased risks to wild fish. Ove Skilbrei assessed whether treatment of ranched Atlantic salmon against sea lice with orally administered emamectin benzoate prior to release affected survival. Survival did not differ between treatment and control groups released in May, but there was a two-fold increase in survival in treated compared with untreated fish released in June. Moreover, treated fish were almost one third heavier. It was also concluded that sub-lethal lice levels may affect growth and, therefore, size at spawning and fecundity of wild fish.

The use of cleaner wrasse to control sea lice on farmed fish was reviewed by Per Gunnar Kvenseth. The presentation informed the audience of the efficacy and cost-effectiveness of using wrasse to control sea lice in commercial farm situations and the recent advances in breeding of ballan wrasse in particular. He concluded that wrasse should be considered as part of an integrated sea lice management strategy.

Data sharing, trust and cooperation among regulators, farmers and wild fish interests are the foundations essential to any effective management control strategy. The achievements of the Scottish Tripartite Working Group approach to this were reviewed by Phil Gilmour. Organisational aspects at national, regional and local levels were explained. Success was judged in terms of the degree of consensus that had been achieved, the number of Area Management Groups that had been formed and Area Management Agreements that had been signed.

While it had proved difficult to draw conclusions about the beneficial effects on wild fish populations, it was agreed that the approach had transformed communications among parties, provided value for money and represented the way forward for the future.

Finally, there was a single paper on *Gyrodactylus salaris*, presented by Jarle Steinkjer. The introduction and spread of the disease to 45 salmon rivers in Norway was documented. The key features of the Norwegian action plan were presented: surveillance, prevention, eradication and restoration. To date, 27 of the 45 infected rivers had been successfully treated, with plans to treat a further four in the next year. The growing use of acidified aluminium as a treatment method, which unlike rotenone kills only the parasite and not the fish, was discussed. The dangers posed by fish movements, especially of rainbow trout, and the importance of international cooperation to stop the further spread of the parasite were highlighted. Despite being the sole paper considering the problem, it stimulated much debate.

Synthesis

The introductory overview provided some context in which disease and parasite interactions might be viewed and provided warnings and some comfort as to what might be expected with regard to the emergence of new diseases in aquaculture and the implications for both farmed and wild fish. This and the presentation on *Gyrodactylus salaris* aside, the session on disease and parasite interactions and their management proved to be very much concerned with sea lice and Atlantic salmon.

It was apparent that much more is now known about all aspects of sea lice biology than at the Bath symposium in 1997. The focus at the present meeting on the more problematic *Lepeophtheirus salmonis* at the expense, perhaps, of finding out more about *Caligus elongatus*, reflects the situation in the scientific research community: a quick scan of the literature shows there to have been something like six times more publications on *L. salmonis* than *C. elongatus* in the past eight years. It is clear that we now have a much better understanding of fecundity and its regulation, hatching and larval development, the role of temperature in determining infection success, mortality at various life stages, dispersal and the role of behaviour. All of this has led to better tools for identification of sea lice and is enabling the development of increasingly effective integrated pest management strategies and still holds out the hope of an effective vaccine being developed.

Monitoring data from various countries were reviewed, demonstrating once again that infection pressure posed by fish farms remains an important issue in many areas. It is now clear that lice abundance tends to change in a fairly predictable manner during the farm production cycle and that this knowledge can be used to help manage lice numbers. By virtue of their behaviour sea trout are highly susceptible to sea lice infestation, susceptibility decreasing with distance from farms. New studies in Norway, however, clearly show that infestation levels on emigrating Atlantic salmon smolts are highly site-dependent and that risk of infestation also varies from year to year with tidal conditions, wind strengths, etc. Since the Bath symposium there have been a number of important, EC-funded international projects that have provided much information about the effects of sea lice on fish physiology and osmoregulation in particular. For both Atlantic salmon and sea trout, lice burden is now recognised as a strong predictor of mortality; for sea trout smolts, for example, the number 13 has more than just superstitious connotations. That we may not yet fully understand risk, however, is evident from the Canadian study, which showed that the links between infection pressure, lice burdens and mortality rates among migratory pink salmon to be perhaps less than straightforward. On-going projects in Scotland and Norway are likely to bear fruit in terms of our abilities to assess effects of sea lice on wild fish at the population level. While it might have been suspected that prolonged, elevated mortality rates on sea trout might affect selection for migratory behaviour, the work at Burrishoole in Ireland clearly demonstrates this.

Sea lice management has evolved considerably in the past eight years thanks to increased knowledge and to greatly improved management. The effectiveness of the Scottish Area Management Agreement regime in terms of data sharing to improve lice control clearly provides much encouragement. Nevertheless, concerns were also clearly expressed about the heavy reliance on a handful of key medicines and, from some quarters, about the increasing size of farms from a disease management point of view as well as in terms of escapes. Perhaps wrasse, still popular in Norway but abandoned elsewhere for various reasons, should be reconsidered as an important option in any Integrated Pest Management regime. Finally, while there are signs of improvement, sea lice remain a major challenge to all interested in sea trout and Atlantic salmon.

ANNEX 5

Poster Session - Session Chairmen's Summary



Photograph courtesy of the Scottish Salmon Producers' Organisation.

Annex 5: Poster Session - Session Chairmen's Summary

Arni Isaksson and Peter Hutchinson

The poster session comprised a total of 13 presentations from 8 countries. The subjects covered in ten of the posters can be roughly grouped into three main topic areas: (1) studies on the abundance, distribution, behaviour and source of escapees (5 papers); (2) genetic aspects of stocking programmes (3 papers); and (3) sea lice biology (2 papers). There were also papers on aquaculture-free zones, the feeding behaviour of cultured and wild salmon smolts and on the effects of domestication.

Escapees

A study in the River Teno, also called Tana, a border river between Norway and Finland, presented the results of sampling for escapees during and after the fishing season. The results indicated that escapees were widely distributed in this river but made up a small proportion of the catch during the fishing season. However, in some small samples taken, after the season they accounted for up to 47% of the fish sampled. As there is highly significant genetic differentiation between wild and escaped farmed salmon and the escapees have high potential for successful reproduction, there is concern about the impacts on the native salmon populations

In a study from Norway, catch data from gill nets set by local fishermen to target escaped farmed salmonids were used to estimate abundance of escapees and to classify the fish into different escapement events on the basis of catch-per-unit effort. It concluded that most of the escapees were of local origin. The study indicated that it was possible to reduce the abundance of rainbow trout escapees by fishing during a 2 - 4 week period and the paper concluded that an autumn fishery may be a useful management tool, by identifying escape events, including unreported ones, and stimulating escapee recapture efforts.

A second study from Norway involving acoustic tagging of farmed salmon 'escapees' showed that several of the tagged individuals were still in the vicinity of the escape site after several weeks, suggesting that it may be possible to recapture escapees. The results from this study are somewhat different to experience in the Bay of Fundy, Canada, where most experimental 'escapees' seemed to move away from the site of release quickly.

The Norwegian Parliament has decided that approaches

to tagging farmed salmon should be considered. Of the many potential methods, two approaches were considered to have potential - coded wire tags and an approach to identify to farm of origin on the basis of naturally-occurring characteristics of the fish. A study has been initiated in the Hardangerfjord, the 'TRACES' project, to examine the costs and time efficiency of identifying and tracing sea pen origin of escapees by means of DNA microsatellite markers, single nucleotide polymorphisms, fatty acid profiles, trace elements and stable isotopes. The project will continue in 2006 subject to funding being secured.

Perhaps somewhat surprisingly for a symposium on diadromous fish, there was a poster on acoustic tracking of cod in the Bay of Fundy. There have been suggestions that diversification of aquaculture from salmon into other species of fish may offer benefits in minimising impacts on wild salmon stocks. This paper, however, reported that tracked wild cod, known predators of salmon, were found in the exit corridors of wild smolts. The concern is that escapees from cod farming, if they behave like the tracked wild cod in this study and concentrate in smolt migration corridors, could prey on wild salmon smolts.

Genetic aspects of stocking programmes

While the focus of much of this symposium has been on salmon farming, the second group of posters was predominantly concerned with the genetic aspects of stocking programmes. In southern European rivers, salmon were often stocked from northern European countries in response to declining native populations. Since 1995, the stocking programmes in the rivers Ulla and Lérez in Spain have only released descendants of naturally returning adults and of wild parr. The success of this programme is being monitored using physical markers and appears satisfactory. A study was conducted using historical scale samples to investigate genetic variation before and after the stocking. This study showed that modern populations are very similar genetically to those present prior to stocking, and there are still genetic differences between the two rivers, suggesting local adaptation and low straying rates.

Historical scale samples were also used to evaluate the degree and direction of the genetic changes which have occurred in the stocks introduced to the Connecticut River in the USA as a part of a major restoration programme. The current genetic profile of the Connecticut River stock is very similar to that of its donor population in the Penobscot River, although there have

been some differences for both sea run age and allele frequencies. The effective number of breeders in both rivers was large enough to preserve genetic variability.

The third study analysed stock and recruitment data from the Burrishoole system in Ireland, which has received variable but significant quantities of naturally spawning ranched hatchery fish founded from the wild populations over a 35-year period. The results suggest that these hatchery fish had a significant depressive impact on the recipient population and that removal rather than addition of these hatchery fish may be the most effective strategy to enhance wild stocks. Indeed, this approach is being followed and there has been a significant improvement in freshwater production of salmon smolts. However, the authors believe that common garden experiments are needed to better understand the mechanisms involved.

Sea lice

The third group of posters looked at sea lice issues and there were two presentations. The first examined infestation success of sea lice at different temperatures ranging from 6 - 14°C and found that lice were infectious for a longer period of time at low temperatures, up to 30 days for one individual at 6°C. These data are important for modelling the dispersal and survival of free-living lice larvae.

The second paper examined the role of freshwater acidification on sensitivity of smolts to sea lice and concluded that the combined effects of acidification and moderate sea lice infestation can have the same negative effect as higher acidification or higher sea lice densities. The concern here is that where multiple stressors occur, focusing only on the impacts of a single stressor may considerably underestimate the significance of the problem.

Aquaculture-free zones

One approach to protect wild salmon stocks from escapees, and possibly other adverse impacts from aquaculture, is the establishment of aquaculture-free zones. A poster from Iceland described the establishment of such zones in all wild-salmon-producing areas as a precautionary measure. This was deemed necessary to protect the valuable salmon angling fisheries in Iceland.

Behaviour of wild and cultured parr

A study conducted in Russia compared the feeding behaviour of stocked and wild salmon smolts by diving observations in the wild. While the cultured and wild

smolts had generally similar diets and feeding behaviours, there were some differences. For example, cultured salmon were less able to differentiate food items from non-food items than wild fish and were more aggressive.

Domestication effects

A comparison was made of the growth, behaviour and physiology of fast-growing (domesticated), slow-growing (non-selected), and hybrid strains of coho salmon and rainbow trout. Under all rearing environments, there was a strong correlation between growth and the proportion of domestic genes within the genotype. Comparisons of anti-predator behaviour and hormone profiles illustrated similar trends. The authors concluded that knowledge of the genetic changes responsible for altered growth rates in fish is crucial information needed to increase our ability to predict the consequences of introgression between fast- and slow-growing strains of fish.

ANNEX 6

Take-Home Messages



The City of Bergen.

Annex 6: Take-Home Messages

I. Katherine Bostick

- Many thanks to NASCO and ICES for organizing this symposium. A wealth of information has been presented here.
- I come to this meeting with a background relating to the global environmental and social impacts of aquaculture and of the global salmon farming industry in particular. Due to my relatively limited knowledge of wild Atlantic salmon, I have a different perspective than many of the individuals at this symposium.
- I am struck by a common theme of variability in and among the findings presented here, and how results are often situation-specific. The behavior of escapes varies from region to region - how quickly they move away from the farms, or not. Survival and spawning of escaped or released Atlantics can depend on time of year and age. A disease epidemic on a farm can become an epidemic in the wild, but that depends on a number of variables.
- Given this variability, there is a common temptation to continue to do more research. But we cannot get lost in this. Symposia such as this one allow us the opportunity to take a step back and look at the big picture, identify trends, and consider how to apply lessons learned from one specific location or experiment to another.
- From my experience, the extent to which the salmon aquaculture industry acknowledges impacts and attempts to reduce them is highly variable as well - among countries, companies, and down to specific farms.
- One presenter mentioned that the industry does not need to wait until there is statistically significant evidence of harm being done in order for them to take action. The example of Norwegian industry and sea lice was given. What I have seen here relating to restoration and restocking efforts and the challenges that they present make it clear to me that the industry need not wait, but also that we cannot afford to have them wait, or it will be too late.
- On a more specific note, the issue of escapes has been a large one at this symposium. There needs to be clear penalties for companies when escapes occur. Yes, there are real costs to producers when fish escape. However, there must be a cost on top of the

cost of fish lost. I've heard mention of the deliberate release of non-performers from farms - when an age-group is changed to a larger meshed cage, the slowest-growing fish can escape, and the farm does not then have to continue to put in feed for these non-performers. If this happens, it is completely unacceptable. There needs to be enforcement and penalties. Tagging, genetic or physical, was discussed here as a possible means to determine the farm of origin of escapees.

- Sea lice has been another area of focus at this symposium. Presentations here have shown that sea lice have a clear negative impact on wild salmon (mortality and decreased growth), and that in Norway, management of farms can reduce this impact. We have seen that in Canada, the same species of lice are found on farmed Atlantics and wild Pacifics. In Chile, another species of sea louse is found on farmed fish. While we heard evidence that pink salmon runs are healthy, I strongly urge governments and industry in these countries not to overlook the lessons learned from the Norwegian situation and to follow a precautionary principle approach.
- A number of the presentations here have been authored by international groups - and scientists continuing to collaborate in this way is one excellent method for sharing knowledge across borders, and hopefully, allowing us all to learn from each other. I encourage researchers to continue to reach across borders in this way.

It is clear that there is much work to be done in the future to address the issues that have come up over the past few days. We look forward to working with NASCO, ICES, and the individuals present here to work towards solutions. I believe that there are roles for governments, industry, NGOs, and other stakeholders to work with scientists to help ensure that wild and farmed salmon can co-exist.

2. Fiona Cameron

During this symposium, I have heard an impressive amount of evidence reinforcing the threat to wild fish represented by escapes from salmon farms - particularly in situations where wild stocks are severely depleted - and by sea lice infestation, which seriously affects the marine survival of wild salmonids. I believe that we now have conclusive evidence of these threats. There has been much emphasis on the need to adopt the precautionary

principle.

I heard some spokespeople for the salmon farming sector accept that these problems exist, that the industry is working hard to fix them, and that we need consensus and co-operation to meet the challenges, particularly as tonnage of farmed salmon increases and we see ongoing development of resistance to sea lice medicines.

But I also heard some hints - as one does in other fora - that there are still some people within the industry who appear to be in denial about the seriousness of these impacts on wild fish.

At the NASCO workshop in Trondheim this August, Nell Halse referred to the fish farming industry's 'justifiable paranoia'. I believe there are people on the wild fish and environmental side who are also guilty of 'justifiable paranoia'. We need to get rid of the culture of blame and look together at the multiple impacts on wild stocks, to identify what we can tackle.

A strong message I take away from this symposium is that we'd better address this sooner rather than later because, as Pat O'Reilly reminded us, many stocks of wild salmon don't have the luxury of time on their side.

We heard that we need to recognise what we can work to change - and I believe that applies to the wild fish sector too. Where there are multiple effects, it's necessary to work co-operatively on the ones we have the power to address.

It's clear that regulation has a role to play, in both sea lice management and minimisation of escapes. It's a counsel of perfection that this should be backed up by local and regional co-operation. I sense that there's a lot of interest in this, and perhaps a message for NASCO to take away is that it could facilitate some 'cherry-picking' sessions to arrive at some sort of guidelines for area management, based on what works and what doesn't?

I have learned - both in the presentations and in coffee-break conversations with other delegates - that in order to be effective, area management needs to get better at engaging communities as well as a wide range of stakeholders. It has to be inclusive, transparent, with a built-in way of measuring success - I'd probably add that it has to be accountable. Both 'sides' have to communicate - particularly in view of what we've heard about the scenario of emergent resistance to sea lice medicines, and the importance of spotting early signs of fish disease.

The challenge is: how do we report successes which may

not be easily measurable, to boost public confidence and stakeholder buy-in?

From what I've heard here, it seems to me that the most crucial requirement is good - top-notch - communication. I believe that we have to go beyond that, because 'communication' can be one-way, particularly government communication. We need more constructive dialogue and cooperation, and trust.

Malcolm mentioned at the start that he's convinced we can have 'win-win'. I'm leaving this gathering still with a sense of optimism that we can achieve that - but only if we can do away with confrontation, which is seldom constructive. We need to stop the tug-of-war and put all hands to the rope to pull in the same direction to meet the challenges.

I don't think we need any more evidence to prove that there are problems; we need to take that as a given and move on to find cooperative and pragmatic ways of addressing these problems. We need to see the wild fish side and the industry playing on the same team and seeking out the common ground.

The worst outcome would be another NASCO meeting in several years' time where we still hear mounting evidence of problems. The next one needs to be a record of the solutions that are being explored!

3. Knut A. Hjelt

During the last three days we have had a number of presentations focusing mainly on the possible interaction between aquaculture and wild stocks of Atlantic salmon. The symposium has shown us that today we have much more science-based information about possible interactions between aquaculture and wild fish than before.

The industry is still young, but over the years it has evolved tremendously, and will continue to evolve in the future. As we have heard, the industry has put a lot of effort into preventing possible negative interactions with the wild stocks. The focus has been on health, technical improvements, codes of best practice, site selection and good training and management. The production of Atlantic salmon is mainly based in areas where the wild Atlantic salmon is most abundant, which in itself is a challenge. But populations of Atlantic salmon are facing a variety of possible threats, and attention must be paid to all kinds of negative interactions, not only the topics considered during this symposium.

All kinds of food production, including aquaculture, will have some impact on the environment. The challenge is to minimize such impacts in a way that ensures that wild and farmed salmon can co-exist, and more widely for all salmon production around the world to ensure that the level of interaction with the environment is acceptable.

Having been here for three days, listening to the presentations and discussions, my opinion is that the main challenge for the industry is to minimize the number of escapees. This will most probably also have positive influences on other areas of concern.

The industry has achieved quite a lot in this area, but there is room for improvement. I will therefore briefly comment on three areas which need to be addressed.

Land-based facilities

It should be possible to eliminate almost entirely escapees and leakage from hatcheries and fry and smolt production sites. There is probably not very much science in this, but rather it involves refinement of technology, risk assessment and focus on risk awareness.

Sea-based facilities

There is a tendency towards larger units in more exposed areas when it comes to on-growing sites. The industry has taken a wide range of measures to reduce the risk of accidents, but even if the number of escape incidents is declining, the size and effect of each incident could be larger. One requirement is to be very focused on minimizing the probability of escapes occurring, and technology, moorings, nets, site selection and equipment are key words in this context. Further R&D on escape prevention, and also giving increasing focus to possible ways to minimize damage when accidents occur, is important. The industry is looking for practical and cost-effective solutions. Attention should also be paid to other possible solutions to cost-effective production and operation.

Trickle losses

An important challenge is to minimize the so called 'trickle losses;' i.e. the leakages of fish that are not being detected. R&D, surveillance, risk assessment and awareness will be of importance in solving the problem. The problem should be addressed at all life-stages, with special focus on what happens around times were fish are being moved, handled or put to sea.

The industry has escapees as one of their main focuses. We are cooperative and transparent; we do see the

problems and are working continuously towards improvements. This happens through voluntarily action and through fulfilment of regulations. Obligatory actions are probably needed in some cases. Together with the key words, cooperation, regulation, third party inspections and reactions, R&D and cost-effective solutions will be of importance. Aquaculture will in the future, as today, be an important part of international food production. As such, the salmon farming industry relies on being regarded as responsible and with a high degree of credibility. This is the case today, and it must also be so in the future. Addressing the challenge of minimizing escapees will be a part of this.

4. Jens Christian Holm

First of all - Conveners and members of the Steering Committee - congratulations to you - this has been an interesting symposium dealing with some very serious questions.

For me - representing the regulation side of aquaculture in Norway - a lot of the messages from this symposium (both questions and results) relate to *the increasing size of our salmon industry*. Industrialising a biological process very often means increasing the size scale.

Size matters. The number of salmon in one large farm can be higher than the total number of wild Atlantic salmon present in the sea originating from all Norway's salmon-producing rivers. The maximum biomass allowed in Norway's 864 licences for commercial on-growing of Atlantic salmon, trout and rainbow trout, is approximately 690,000 metric tonnes.

Net pen size, farm size and the number of farmed fish in most regions have increased in our aquaculture industry in recent years.

Larger netpens can result in larger numbers of escapees if the pen is destroyed. A larger group of farmed salmon is hard to manage if the technology and operational procedures used are not adjusted. Medical treatment is not easy in super-large units; obtaining therapeutic dosage for all individuals by oral administration will be almost impossible and resistance may be the result.

Larger farms holding higher numbers of fish in a small area will generally increase the risk of disease. And if a serious disease outbreak occurs, the number of mortalities can be so high that neither the fishfarmer nor society have an adequate infrastructure to tackle it. And sometimes a whole fish farm might collapse in extreme rough weather or if a ship collides with it.

We have to deal more with the matter of size in future regulations. Research, industry and public authorities have to continue the good work together at arenas like this symposium - so that we can avoid being outmanoeuvred by the law of large numbers.

I would like to acknowledge the excellent work carried out in the Hardangerfjord area. The outstanding results with regard to salmon lice will hopefully be matched with regard to the escapement problem. The secret: focused research, communication and coordination.

We must all work hard to minimise the negative aspects of fish farming with a faster tempo than the growth rate of the salmon farming industry. The risk of escape per salmon in captivity should be reduced more than the increase in numbers reared in captivity, in order to reduce the number of escapees. The reduction in the number of gravid salmon lice per fish in a farm should exceed the increase in the number of hosts in captivity so that the infestation pressure on wild Atlantic salmon nearby is reduced. We must start to discuss such principles if we are going to share the common resources - the Atlantic salmon and the areas it lives in - in a sustainable way.

5. James Ryan

Pat O'Reilly reminded us that the salmon has been evolving for 100 million years. Salmon farmers are keenly aware of the inestimable value of the salmon resource and they are just as intrigued by the sight of a wild salmon in nature as the most avid angler. Many times on my salmon farm I have seen all work stop so that we could watch wild salmon running up the bay towards the estuary. And no, they were not escapees!

I attended the Bath symposium in 1997 and I believe we have come a long way since then. At Bath a lot less was known about the facts of interactions and this left too much room for speculation. I think most people left that symposium more confused than when they arrived. Whereas in Bergen this week, we have been presented with the results of a lot of good research into the real effects of salmon aquaculture on wild salmon and into the mitigation of those effects. Salmon farmers can no longer claim that aquaculture poses no threat to wild salmon but can also point to a lot of scientific work which demonstrates that good management of farms ensures that the two sectors can live together in harmony.

In Bergen I have received both good news and bad news. First the bad news.

Escapees can breed with wild stocks and cause reduced

genetic diversity and reduced fitness for survival. This means that farms must do more to ensure that escapes do not occur. It also appears from research presented that the use of triploid farm stocks will likely not be the magic bullet many people had hoped for. We were told that trials with triploid stocks indicate that these fish are more difficult to rear than diploids and should really be treated like a new species. It was suggested that triploids would need many generations of selective breeding before they could equal diploids in their suitability for husbandry. It is a particular concern of the industry that no salmon farming country should be commercially disadvantaged vis-à-vis the rest of the world by being compelled to use inferior triploid stocks.

On the question of lice we have to accept that in certain situations salmon farms can magnify the lice risk for wild salmon. In these cases farmers will need to modify their management practices.

And now for the good news.

Improving Farm Management

There is a global trend of improving management practices on farms so that threats to wild stocks are being reduced. Peder Fiske informed us that there are statistical indications of better containment on Norwegian farms and Aina Valland presented figures which demonstrated that 'routine' escapes in Norway are significantly reduced, though there remains a problem with catastrophes such as a whole farm being wiped out in a storm and shipping colliding with cages. She indicated that new strategies are being adopted to help eliminate these one-off events. We were told that escapee numbers in indicator rivers in New Brunswick had fallen by 90% over the last 10 years and that in Ireland and Scotland escapees constituted less than 2% and less than 5%, respectively, of coastal salmon stocks.

In situations where it had been shown that farms were increasing the lice risk for wild salmon it was demonstrated, with examples from both Norway and Scotland, that farm management practices such as area fallowing and synchronised treatments could eliminate the farm portion of that risk. In this regard the Area Management approach used in Scotland is paying dividends and could be a model for other countries to follow. It is important, however, that this kind of strategy is supported by good science and that indicators for measuring performance are included. There should also be a spirit of equal partners and equal accountability. The

maintenance of mutual trust would be assisted by focusing not just on farm practices but also on habitat management issues.

Causes for Optimism

Other encouraging items included:

- Øystein Skaala reported on a study of genetic impacts in 7 rivers subject to long-term escapee pressure. His conclusion was that there were indications of genetic stability in the stocks of 4 of these.
- Harald Lura presented findings which indicated minimal genetic impact if escapees were maintained below 10% of river stocks. This suggests that we don't have to achieve an escape level of absolute zero - which, in any case, is probably impossible.
- Fred Whoriskey studied the fate of escapees in New Brunswick and Maine through the fascinating use of electronic markers on live fish and found evidence of massive mortality during the first few days of freedom, particularly from seal predation.
- Peter Heuch compared two Norwegian fjords in terms of farm contributions to lice loads on wild salmon smolts. In one there was no perceptible impact and in the other there was a significant problem. He concluded that dissimilar hydrographies in the two fjords accounted for the difference. This supports the findings of other authors who have reported that the level of contribution by a farm to lice numbers on local wild salmonids is determined by both the size of the lice population on the farm and the hydrography of the area - thus, farms in more open locations or near the mouths of bays/fjords will be unlikely to have a significant impact.
- Using cautious language, Ron Stagg postulated that disease epidemics in farms will not necessarily result in epidemics in wild populations and that the risk can be reduced by good management.

Thus, for me there is more good news than bad but there is no room for complacency and a lot of work remains to be done. Arising from my participation in this symposium I would like to suggest the basic elements of a way forward.

The Way Forward - Escapes

- We need to get escapes down to as close to zero as possible. To do this we need to continue implementing the NASCO Liaison Group's Guidelines

for Containment - improving the design of fish cages, matching appropriate technologies to site conditions, carrying out proper maintenance programmes and ensuring safe operational procedures. We need to ensure all farming staff are trained in the essentials of escape prevention and they should all be educated in the potential impacts of escapes. I am sure that if the people on the ground were made aware of what we have heard here this week it would act as an incentive to greater effort in escape prevention.

- The Norwegian industry is promoting the idea of a national escapes commission to investigate and report on the causes of escapes as they occur. I would suggest that we should consider a similar strategy internationally, say within the Liaison Group.
- R&D has a role to play as well, such as developing less vulnerable and more operator-friendly cage systems - Arne Fredheim's novel net design is a good example of this kind of approach. A particular hobby horse of my own is that the marine cage farming industry really needs the technologists to develop sonar-based methods of constantly monitoring the stock in a fish cage. As well as simplifying farm management this would alert the farmer to an escape event as soon as it begins.
- There has been a lot of debate here this week about the reduced fitness of farm stock and hybrids for survival in the wild. Perhaps we should encourage the breeders to actually select for traits which would make them totally unfit to survive or breed in the wild.

The Way Forward - Lice

In areas where there is a likelihood of impacts on wild salmonids, farms must keep lice levels as close to zero as reasonably possible. Achieving this requires:

- An area management approach which results in synchronised treatments and regular fallowing.
- The availability of an adequate suite of anti-lice medications and hopefully, in the near future, vaccines. In this regard the procedures for the licensing of new products needs to be a lot more streamlined.
- The availability of spare farm sites so that fallowing can be facilitated.
- Further work to be carried out on the use of wrasse in cages to remove lice from salmon. Ten years ago I was involved in trials with wrasse which were far from

encouraging. But Per Gunnar Kvenseth is quite convincing and it would certainly be an ideal solution.

The Way Forward - General Principles

I think we've come a long way since Bath and both our understanding of the interactions and our management of them have improved significantly. But we have a lot more work to do together and we need to further encourage cooperation between scientists, the farming industry, governments and the wild sector. We must regularly remind ourselves that there is a lot more that joins us than separates us - we are, in the end, all working with the same species. Being aware of this will inspire us to constantly seek win-win solutions.

6. Øyvind Walsø

First of all I would like to support what has already been said during this symposium that in recent years we have seen positive developments with regard to some of the factors in aquaculture that cause negative impacts on wild salmon stocks. We have also taken a huge step forward in developing a common understanding of the implications of escapes of farmed fish for the wild salmon stocks and in recognising that it is necessary for the industry to increase its efforts to prevent escapees. At the same time it is clear that there is still some way to go before we can say that all the issues we have been discussing for more than 15 years now can be said to have been addressed.

The continuing escape of farmed salmon is regarded as the most serious problem when we consider the negative impacts from aquaculture on the wild stocks of Atlantic salmon. This has been a key topic at the previous meetings, held in Loen, Norway in 1990, and in Bath, England in 1997. It has also been an important topic at this symposium. It seems that both the fish farming industry and the wild salmon interests now share common ground when it comes to the importance of minimising escapees.

In spite of the effort that has been invested in improving containment in net pens we see that the number of fish escaping has been fairly stable in recent years. While the proportion of farmed fish that escape may be declining, that improvement has until now been counteracted by the increase in the scale of the production of farmed salmon. As I said, the number of escapees remains too high and when it comes to their impact on wild salmon populations it is the number of escapees that is important. The numbers remain far too high.

Much has been said about physical containment measures - less about the possibilities of biological containment, for example through the use of sterile salmon. The possible use of triploid fish was discussed at the previous meetings as well as this week in Bergen. The issue was also discussed at the NASCO/North Atlantic salmon farming industry Liaison Group Workshop held in Trondheim in August this year. I feel that the answers concerning how well triploid salmon can perform in aquaculture are somewhat confusing. The answer you get can vary from triploid salmon can perform as well as diploids to their performance is so poor that the industry will not accept them. There was also a suggestion that more effort should be invested in research into alternative methods for sterilizing fish. To my mind this is a good idea that deserves further consideration in the future.

When it comes to sea-lice, it seems that the effort that has been put into addressing this problem has paid off. We now know much more about how this problem can be addressed and how it should be followed up both regarding future research and the management of farms. Yesterday we heard a number of excellent presentations on this topic and from my point of view the results from this research were the most positive news from this symposium.

And it also shows that if there is a challenge to be addressed and if the wild fish interests and farming interests really share common ground and work together the probability for success is high and certainly much higher than if we were not working together.

So that, ladies and gentlemen, ends my personal summing up from this symposium. Presumably the next meeting, in seven years' time, will be as interesting as this meeting has been. Thank you very much!

ANNEX 7

List of Participants



Releasing smolts in the River Mandal, Norway as part of a stock rebuilding programme.

Annex 7: List of Participants

Lord Alexander Antrim	Worshipful Company of Fishmongers, England, UK
Mr Vidar Baaroy	Directorate of Fisheries, Norway
Mr David Bean	National Marine Fisheries Service, USA
Dr Tillmann J. Benfey	University of New Brunswick, Canada
Dr Malcolm Beveridge	Fisheries Research Services, Scotland, UK
Mr Raoul Bierach	Directorate for Nature Management, Norway
Ms Katherine Bostick	WWF-US, USA
Dr Karin Boxaspen	Institute of Marine Research, Norway
Mr Edward Branson	Skretting, Wales, UK
Mr Paul Brooking	Atlantic Salmon Federation, Canada
Mr Sturla Brørs	Office of the Finnmark County Governor, Norway
Mr Alejandro Buschmann	Universidad de Los Lagos, Chile
Mr Pablo Caballero	Government of Galicia, Spain
Ms Fiona Cameron	Sea Trout Group, Scotland, UK
Mr Jonathan Carr	Atlantic Salmon Federation, Canada
Ms Mary Colligan	NOAA Fisheries, USA
Ms Helen Cooper	Aquaculture Licence Appeals Board, Ireland
Mr Richard Cowan	DEFRA, England, UK
Prof Tom Cross	Environmental Research Institute, Ireland
Dr Walter Crozier	Department of Agriculture and Rural Development for Northern Ireland, Northern Ireland, UK
Dr Graeme Dear	Marine Harvest Scotland, Scotland, UK
Mr David Dunkley	Scottish Executive Environment and Rural Affairs Department, Scotland, UK
Mr Arne Eggereide	Directorate for Nature Management, Norway
Mr Lal Faherty	The Western Regional Fisheries Board, Ireland
Mr Espen Farstad	Norwegian Association of Hunters and Anglers, Norway
Ms Merete Farstad	Fylkesmannen I Sogn Og Fjordane, Norway
Dr Bengt Finstad	Norwegian Institute for Nature Research, Norway
Dr Peder Fiske	Norwegian Institute for Nature Research, Norway
Mr Øyvind Fjeldseth	Norwegian Association of Hunters and Anglers, Norway
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Dr Gregory Forde	Western Regional Fisheries Board, Ireland
Dr Torbjørn Forseth	Norwegian Institute for Nature Research, Norway
Dr Arne Fredheim	Sintef Fisheries and Aquaculture, Norway
Dr Patricia Gallagher	Simon Fraser University, Canada
Dr Paddy Gargan	Central Fisheries Board, Ireland
Mr Dagfinn Gausen	Directorate for Nature Management, Norway
Mr Phil Gilmour	Scottish Executive Environment and Rural Affairs Department, Scotland, UK
Dr Kevin Glover	Institute of Marine Research, Norway
Dr Kari Grave	Norwegian School of Veterinary Science, Norway
Mr Douglas E Grout	New Hampshire Fish and Game Department, USA

Dr Sigurdur Gudjonsson	Institute of Freshwater Fisheries, Iceland
Dr Lars Petter Hansen	Norwegian Institute for Nature Research, Norway
Dr Neil Hazon	University of St Andrews, Scotland, UK
Ms Gunn Helen Henne	County Governor of Sogn og Fjordane, Norway
Dr Peter Andreas Heuch	National Veterinary Institute, Norway
Dr Kjetil Hindar	Norwegian Institute for Nature Research, Norway
Mr Ross Hinks	Council of the Conne River Micmacs, Canada
Mr Knut Hjelt	FHL Aquaculture, Norway
Dr Jens Christian Holm	Directorate of Fisheries, Norway
Ms Marianne Holm	Institute of Marine Research, Norway
Dr Peter Hutchinson	Assistant Secretary, NASCO
Mr Arni Isaksson	Directorate of Freshwater Fisheries, Iceland
Mr Tore Jakobsen	European Commission, Belgium
Mr Stig Johansson	Directorate for Nature Management, Norway
Dr Bror Jonsson	Norwegian Institute for Nature Research, Norway
Mr Knut Jørstad	Institute of Marine Research, Norway
Mr Atle Kambestad	Fylkesmannen Hordaland, Norway
Dr Lars Karlsson	Swedish Board of Fisheries, Sweden
Dr Marja-Liisa Koljonen	Finnish Game and Fisheries Research Institute, Finland
Mr Knut Kristoffersen	Fylkesmannen I Tromso, Norway
Mr Frode Krøglund	NIVA, Norway
Mr Håkon Kryvi	Fylkesmannen Hordaland, Norway
Mr Per Gunnar Kvenseth	Norsk Sjømatcenter, Norway
Dr Oleg Lapshin	Federal Research Institute of Fisheries and Oceanography (VNIRO), Russia
Dr Harald Lura	Ambio AS, Norway
Mr Patrick Martin	Fondation Saumon, France
Dr Philip McGinnity	Marine Institute, Ireland
Mr Joseph McGonigle	Aqua Bounty Farms, USA
Mr Helge Midttun	Fjord Seafood ASA, Norway
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Miss Margaret Nicolson	PA to the Secretary, NASCO
Dr Niall Ó Maoiléidigh	Marine Institute, Ireland
Mr Pat O'Reilly	Dreamstreams, Wales, UK
Mr Sumarlidi Oskarsson	Directorate of Freshwater Fisheries, Iceland
Dr Sylvain Paradis	Department of Fisheries and Oceans, Canada
Ms Susan Parker	Dreamstreams, Wales, UK
Mr Daniel Pendrey	Fisheries Research Services, Scotland, UK
Mr Michael Penston	Fisheries Research Services, Scotland, UK
Mr Geoffrey Perry	Department of Fisheries and Oceans, Canada
Mr Chris Poupard	European Anglers Alliance, England, UK

Dr Sergei Prusov	PINRO, Russia
Mr Gorm Rasmussen	Danish Fisheries Research Institute, Denmark
Mr James Ryan	International Salmon Farmers' Association, Ireland
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Ms Aina Valland	FHL Aquaculture, Norway
Dr Alan Walker	CEFAS, Fisheries and Aquaculture Science, England, UK
Mr Øyvind Walsø	Directorate for Nature Management, Norway
Mr John Webb	Atlantic Salmon Trust, Scotland, UK
Mr Vidar Wennevik	Institute of Marine Research, Norway
Dr Ken Whelan	President of NASCO, Marine Institute, Ireland
Dr Fred Whoriskey	Atlantic Salmon Federation, Canada
Dr Malcolm Windsor	Secretary, NASCO
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NINA SPECIAL REPORT 34

ISSN: 0804-412X

ISBN 10: 82-426-1736-8

ISBN 13: 978-82-426-1736-1

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