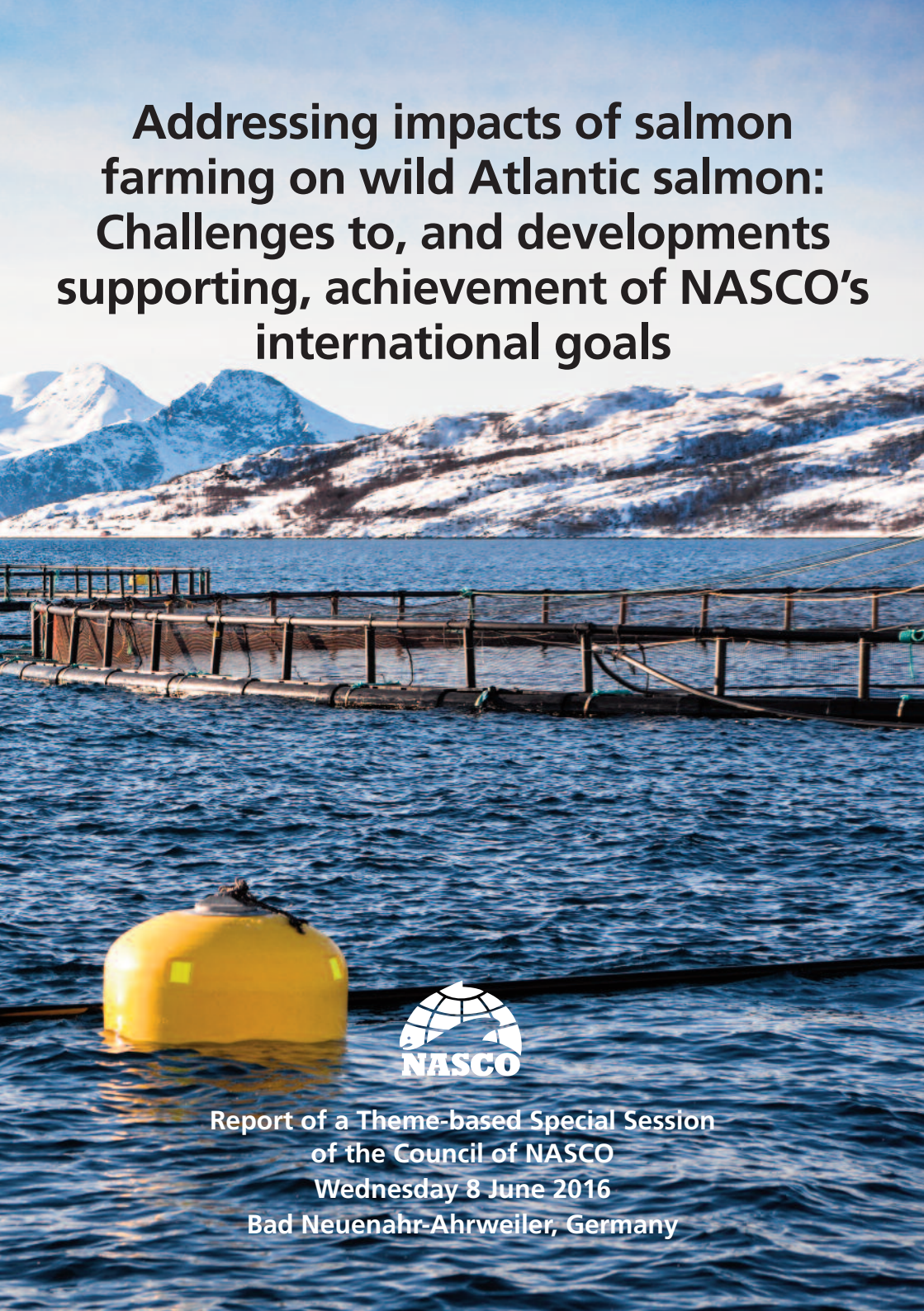
Addressing impacts of salmon farming on wild Atlantic salmon: Challenges to, and developments supporting, achievement of NASCO's international goals



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Addressing impacts of salmon farming on wild Atlantic salmon: Challenges to, and developments supporting, achievement of NASCO's international goals

Steering Committee

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Addressing impacts of salmon farming on wild Atlantic salmon: Challenges to, and developments supporting, achievement of NASCO's international goals

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Executive Summary

Under NASCO's Williamsburg Resolution (CNL(06)48), the Parties agree to co-operate in order to minimise adverse effects to the wild salmon stocks from aquaculture, introductions and transfers and transgenics. The objective of NASCO's Theme-based Special Sessions is to allow for greater exchange of information on a topic related to NASCO's agreements and guidelines and the over-arching objective for the 2016 session was to facilitate an exchange of information relating to protecting wild Atlantic salmon stocks from impacts of salmon farming and to promote sustainable salmon farming practices by: reviewing the latest scientific information on the impacts of salmon farming on the wild salmon stocks; reviewing progress and sharing best practice on approaches to implement effective sea lice management at salmon farms; reviewing progress and sharing best practice on approaches to ensure that 100% of farmed fish are retained in both freshwater and marine production facilities; and reviewing new developments that could facilitate achievement of the international goals for sea lice and containment.

It is clear that scientific understanding of the impacts of salmon farming on the wild stocks has increased considerably since the 2005 NASCO/ICES Symposium. At that time, production of farmed salmon in the North Atlantic was around 800,000 tonnes but this production has subsequently doubled. The advice provided by ICES in 2016 in response to a request from NASCO confirms that there is substantial and growing evidence that salmon aquaculture activities can affect wild Atlantic salmon, through the impacts of sea lice as well as farm escapees. The predictions made by scientists at earlier NASCO/ICES symposia about the consequences of escapes appear to have materialised despite efforts to improve containment measures.

The Steering Committee notes with great concern the confirmation by ICES of widespread introgression of farmed salmon genes into wild salmon populations in Norway, with the highest levels in salmon farming areas, and the detection of introgression in other countries. In its advice, ICES indicates that the consequences of this introgression are likely to be depression of fitness, decreased overall productivity, erosion of genetic diversity and decreased resilience. Repeated invasions of farmed salmon in a wild population may cause the fitness of the native population to seriously decline and potentially enter an 'extinction-vortex' in extreme cases. This is consistent with the stark

warning from the Conveners of the 2005 NASCO/ICES Symposium who concluded that *'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'.* The Conveners indicated that such loss of genetic diversity would not be consistent with obligations under either the NASCO Convention or the Convention on Biological Diversity which aims to conserve genetic diversity both within and among species.

The latest advice relating to sea lice is also worrying as it indicates that, for salmon stocks experiencing poor marine survival, there could be a reduction in salmon returning to the river of up to 39% as a consequence of sea lice infestations and this could adversely affect achievement of conservation requirements for affected wild salmon stocks. The warning signs that resistance to therapeutants was developing, and which had been highlighted by the Conveners of the 2005 NASCO/ICES symposium, have materialised and this is a concern for both the industry and those charged with protecting the wild stocks.

The wild stocks of Atlantic salmon are currently vulnerable because of reduced marine survival all around the North Atlantic. The Steering Committee believes that there is now sufficient evidence of significant adverse impacts from salmon farming having occurred that all Parties/jurisdictions with salmon farms must implement further, more stringent measures to protect the wild stocks from the impacts of salmon farming if they are to meet their obligations under the NASCO Convention. The Williamsburg Resolution states that where significant adverse impacts on wild salmon stocks are identified, the Parties should initiate corrective measures without delay and that these should be designed to achieve their purpose promptly.

The Steering Committee notes the statement made by the representative of ISFA to the 2016 Annual Meeting of the Council of NASCO that the industry is developing rapidly, but that advances in relation to minimising impacts of farmed salmon on the wild stocks had not been reflected in the presentations at the Theme-based Special Session. The Steering Committee notes that since 2013 the Council has retained an item on its agenda entitled 'Liaison with the Salmon Farming Industry' specifically to allow for an exchange of information on issues concerning impacts of aquaculture on wild

salmon. The Steering Committee recommends that ISFA use this opportunity to provide relevant information to the Council each year commencing in 2017.

New approaches that could assist in addressing impacts are at various stages of development and implementation but there are undoubtedly substantial challenges to be addressed if the international goals for salmon farming are to be achieved. In the Steering Committee's view, there is now an urgent need for all Parties/jurisdictions to adopt stronger measures if their international responsibilities are to be met, which it believes is not currently the case. The Steering Committee reiterates that the agreed international goals are that:

- **there is no increase in sea lice loads or lice-induced mortality of wild salmonids attributable to the farms; and**
- **100% of farmed fish are retained in all production facilities.**

An escaped farmed salmon (foreground) together with wild salmon in a river in Finnmark, Norway. Courtesy of Rune Muladal, Naturtjenester i Nord

Introduction

NASCO's objective is to contribute through consultation and co-operation to the conservation, restoration, enhancement and rational management of salmon stocks in the North Atlantic Ocean, taking into account the best scientific evidence available to it. In support of this objective, NASCO has developed a range of agreements and guidelines, particularly in relation to the management of salmon fisheries, habitat protection and restoration and aquaculture and related activities.

When NASCO was established in 1984, production of farmed salmon in the North Atlantic was around 25,000 tonnes. By 2015, this production had increased to more than 1.6 million tonnes, or about 1,300 times the reported total nominal catch of wild salmon. The growth of this major industry has raised concerns, particularly about the genetic and other impacts of escaped farmed salmon on the wild salmon stocks and about the transmission of diseases and parasites, especially sea lice, from farmed to wild salmon. While the industry has made progress, its scale and other factors mean that serious concerns remain. The impacts of salmon farming on the wild salmon stocks were first reviewed by NASCO in 1988. Subsequently, NASCO organised workshops and convened international symposia with the International Council for the Exploration of the Sea (ICES), most recently in 2005. It has also requested advice from ICES, most recently that received in 2016, to ensure that it has the best available scientific information on which to base its decisions.

In the light of this scientific information, NASCO has adopted agreements and guidelines designed to minimise the impacts of aquaculture on the wild salmon stocks. These include the *Resolution by the Parties to the Convention for the Conservation of Salmon in the North Atlantic Ocean to Minimise Impacts from Aquaculture, Introductions and Transfers, and Transgenics on the Wild Salmon Stocks* (CNL(06)48), known as the *'Williamsburg Resolution'* which was adopted in 2003 and amended in 2004 and 2006. In 2009, *Guidance on Best Management Practices to address impacts of sea lice and escaped farmed salmon on wild salmon stocks* (SLG(09)5), referred to as the BMP Guidance, was developed through the NASCO/International Salmon Farmers' Association (ISFA) Liaison Group and adopted by both organisations. This BMP Guidance has the following international goals:

- 100% of farms to have effective sea lice management such that there is no increase in sea lice loads or lice-induced mortality of wild salmonids attributable to the farms; and
- 100% farmed fish to be retained in all production facilities.

In 2013, NASCO adopted an 'Action Plan for taking forward the recommendations of the External Performance Review and the review of the 'Next Steps' for NASCO', CNL(13)38. This states that aquaculture remains a focus area for NASCO in terms of concerns over impacts on wild Atlantic salmon and that, in general, NASCO has established the goal to minimise adverse impacts to wild stocks from aquaculture activities. However, the Action Plan recognises that it is for the Parties and jurisdictions to identify and implement appropriate measures to meet this goal, with progress being tracked through Implementation Plans and Annual Progress Reports. The 2013-2018 Implementation Plan template, agreed by the Council, seeks information relating to salmon farming, including:

- the approach for determining the location of aquaculture facilities in freshwater and marine environments to minimise the risks to wild salmon stocks;
- information to demonstrate progress towards the achievement of the international goals for effective sea lice management such that there is no increase in sea lice loads or lice-induced mortality of wild stocks attributable to sea lice;
- information to demonstrate progress towards the achievement of the international goals for ensuring 100% containment.

In its reports to the Council (see CNL(14)11, CNL(15)12 and CNL(16)13), the Implementation Plan/Annual Progress Report Review Group noted that for some Parties/jurisdictions, providing quantitative data to demonstrate progress towards the international goals for sea lice and containment is challenging. The Review Group concluded that the Implementation Plans and Annual Progress Reports for all Parties/jurisdictions with salmon farming should present quantitative data in a transparent manner to demonstrate progress towards the international goals for sea lice and containment, rather than describing only the management measures in place.

The objective of NASCO's Theme-based Special Sessions is to allow for greater exchange of information on a topic related to NASCO's agreements and guidelines. Previous sessions had focused on the management of fisheries (2014) and on the impacts of hydropower

(2015). The reports of these sessions are available from the NASCO Secretariat as documents CNL(14)72 and CNL(15)56, respectively. The Council of NASCO therefore agreed that it would be appropriate that the 2016 Theme-based Special Session should focus on developments in relation to minimising the impacts of farmed salmon on wild salmon stocks. A Steering Committee was appointed (Willie Cowan (European Union), Kim Damon-Randall, Chair, (USA), Paddy Gargan (European Union), Heidi Hansen (Norway) and Paul Knight (NGOs)) to work with the Secretary in developing a Programme, Objectives and a Report of the session.

A resistance board weir used to remove escaped farmed salmon in the river Etne, Norway. Courtesy of Atle Kambestad

Objectives

The over-arching objective for the 2016 Theme-based Special Session was to facilitate an exchange of information relating to protecting wild Atlantic salmon stocks from impacts of salmon farming and to promote sustainable salmon farming practices by:

- reviewing the latest scientific information on the impacts of salmon farming on the wild salmon stocks, with particular focus on the impacts of sea lice and escaped farmed salmon;
- reviewing progress and sharing best practice on approaches, including regulatory frameworks, to implement effective sea lice management at salmon farms;
- reviewing progress and sharing best practice on approaches, including regulatory frameworks, to ensure that 100% of farmed fish are retained in both freshwater and marine production facilities; and
- reviewing new developments that could facilitate achievement of NASCO's international goals for sea lice and containment including technology development (e.g. cage design and closed containment), rearing strategies, access to a broad suite of therapeutants, biological controls, monitoring regimes, training and recapture efforts.

The Programme was divided into three sessions: 'Scientific background'; 'Progress and challenges in achieving NASCO's international goals'; and 'New developments that could affect achievement of NASCO's international goals'. The Steering Committee had requested that in the presentations by the Parties/jurisdictions during the session on 'Progress and challenges in achieving NASCO's international goals' general background information be kept to a minimum and that specific information be provided to address the objectives of the session. In particular, the Steering Committee requested that each presentation by Parties/jurisdictions:

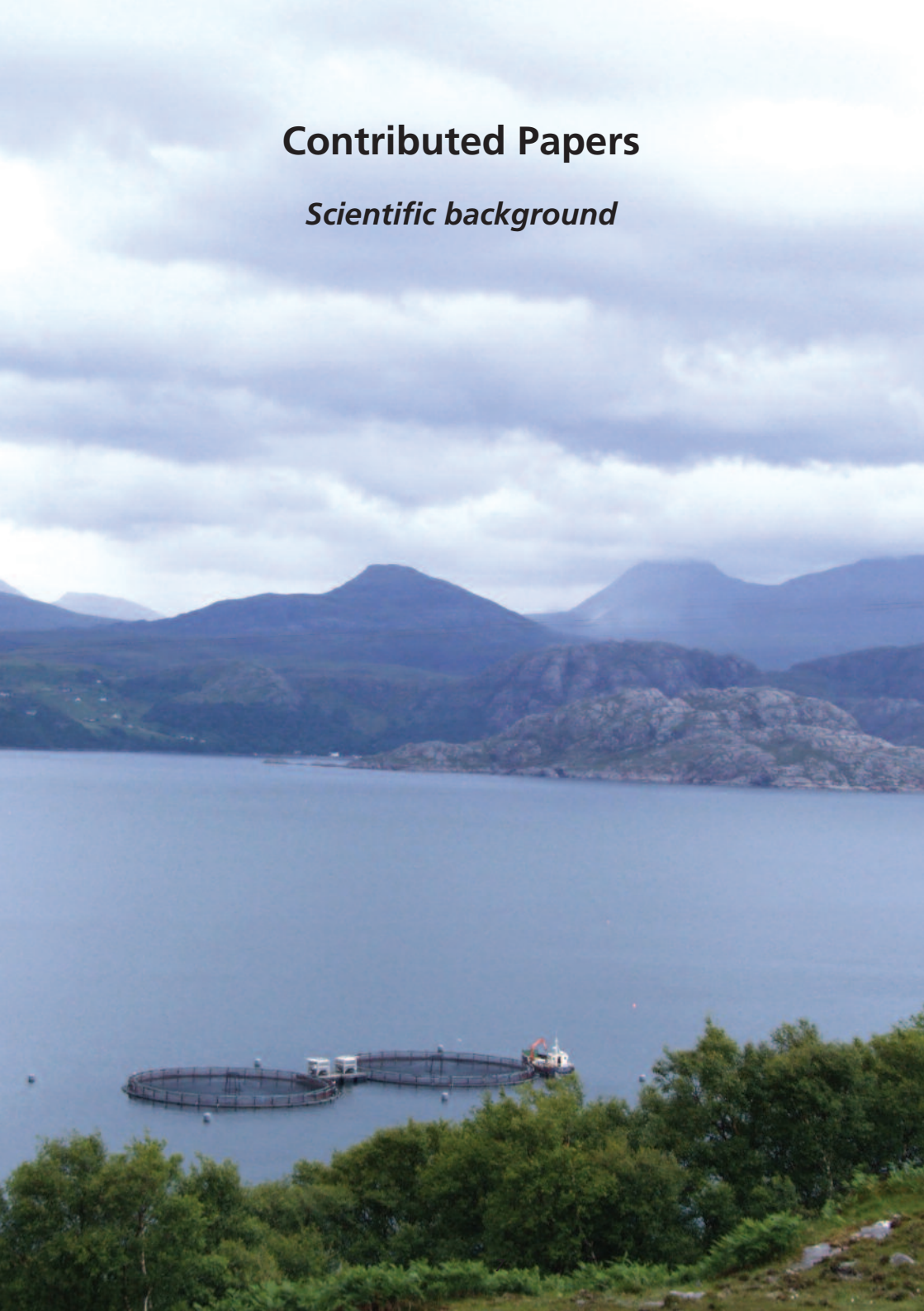
- provide quantitative information to demonstrate whether or not there has been progress towards NASCO's international goals for sea lice and escaped farmed salmon;
- identify particular challenges in achieving NASCO's international goals for sea lice and escaped farmed salmon;

- describe the approach to verifying compliance with regulations and codes of practice in relation to sea lice and escaped farmed salmon; and
- describe methods used to support innovation to develop alternative production techniques to promote sustainable salmon farming.

This report contains the papers submitted in relation to each presentation, a summary of the discussions held during the Theme-based Special Session and the conclusions drawn from the session by the Steering Committee. The papers have been subject to editorial revisions for inclusion in this report.

Contributed Papers

Scientific background



CNL(16)9

(Section 10.1.8 only)

Possible effects of salmonid aquaculture on wild Atlantic salmon populations: the effects of sea lice, genetic interactions and the impacts on wild salmon production

Advice from ICES in response to a question from NASCO posed in 2015

Paper presented by Mr Eskild Kirkegaard, International Council for the Exploration of the Sea

Advice summary

ICES advises that there is substantial and growing evidence that salmon aquaculture activities can affect wild Atlantic salmon, through the impacts of sea lice as well as farm escapees. Both factors can reduce the productivity of wild salmon populations and there is marked temporal and spatial variability in the magnitude of reported effects.

Effects of sea lice on wild Atlantic salmon

- The sea louse (*Lepeophtheirus salmonis*) is a parasite of salmonids that has widespread geographic distribution. Salmon farming has been shown to increase the abundance of lice in the marine environment and the risk of infection among wild salmon populations. There is considerable spatial and temporal variability in the extent of affected areas.
- Lice are also a serious problem for the Atlantic salmon farming industry and have been so since the 1970s.
- Laboratory studies show that 0.04-0.15 lice per gram fish weight can increase stress levels and that infections of 0.75 lice per gram fish weight can kill hatchery-reared smolts if all the lice develop into pre-adult and adult stages. This is the equivalent of 11 lice per smolt. This is also supported by field studies.
- Current marine mortality rates for salmon are often at or above 95%, the causes of which are largely unknown.
- There are differing perspectives on the impact of lice. In one perspective, the 'additional' marine mortality attributable to lice is estimated at around 1%. In another perspective of the same data, losses are expressed at between 0.6% and 39% reduction in adult returns to rivers. The most important factor causing this variability

is the level of total marine mortality. The greatest impact from lice is likely to occur on post-smolts during the early period of marine migration.

Effects of escapees and genetic interactions on wild Atlantic salmon

- Farmed salmon are domesticated and display substantial differences to wild salmon in a wide range of fitness-related traits.
- Very large numbers of domesticated salmon escape from fish farms each year. Escapees are observed in rivers in all regions where farming occurs, although the number of escapees varies both spatially and temporally. The numbers of escapees have approached 50% or more of the spawning population in some rivers in some years. There is limited monitoring in rivers away from fish-farming regions.
- The spawning success of escaped farmed salmon is much lower than in wild salmon. Despite this, a large number of Norwegian wild salmon populations exhibit widespread introgression of farmed salmon genomes. Introgression has also been shown in other countries.
- The introgression of farmed salmon reduces the viability of the populations in rivers, caused by maladaptive changes in life history traits.
- The presence of farmed salmon and their offspring in a river has been shown to result in a decreased overall productivity of the wild population through competition for territory and food.
- The long-term consequences of introgression across river stocks can be expected to lead to erosion of genetic diversity and therefore to decreased resilience.

Basis of the advice

Background

The farming of Atlantic salmon has expanded rapidly since the early 1980s. Production of farmed salmon in the North Atlantic is now approximately 1.5 million tonnes (over 2 million tonnes worldwide) and vastly exceeds the nominal catch of wild Atlantic salmon (FishstatJ; FAO, 2013). In 2014, it was estimated that farmed Atlantic salmon production exceeded the nominal wild catch in the North Atlantic by over 1,900 times (ICES, 2015).

Interactions between salmon farming and wild stocks have raised concerns, in particular related to disease, parasite, genetic and ecological interactions. Such issues have been subject to extensive research and dialogue as efforts have been made to balance current needs of industry with the need to safeguard wild stocks. The topic remains an area of continued intensive research interest.

This request for advice was addressed by a workshop, (Workshop to address the NASCO request for advice on possible effects of salmonid aquaculture on wild Atlantic salmon populations in the North Atlantic, WKCULEF). This enabled experts in aquaculture effects, wild Atlantic salmon, disease transmission and genetic interactions to share and discuss relevant information and recent findings. WKCULEF was convened in Copenhagen, 1-3 March 2016, and was attended by 25 representatives from five ICES Member Countries.

Methods

The WKCULEF terms of reference were addressed though a comprehensive review of recent peer-reviewed literature, presentations from participants, reviews of working documents prepared ahead of the meeting, as well as the development of documents and text for the report during the meeting. It was particularly difficult to disentangle the issue of the possible impact of salmon aquaculture on wild salmon production from the sea lice and genetic interaction questions. Information pertaining to population-level effects was incorporated into the sections dealing with these main issues.

The published literature with respect to the effects of lice and genetic interactions on wild salmon populations from salmonid aquaculture is inevitably focused on countries that have established salmon farming industries. This is a consequence of the importance of both farmed salmon production and wild stocks to national interests. However, relatively little is known about the scale of possible effects of lice and genetic changes on wild salmon in areas without salmon farms in the immediate vicinity.

The terms of reference for WKCULEF focus on interactions between salmon farming and Atlantic salmon. However, salmon farming activities can impact on other salmonid species, in particular sea trout, Arctic char and species of Pacific salmon, and selected references relating to these species have been included where considered relevant.

Elaboration on the advice

The effects of sea lice on Atlantic salmon

The sea louse (*Lepeophtheirus salmonis*) has a widespread geographic distribution, is a specific parasite of salmonids and has been a serious problem for the Atlantic salmon farming industry since the 1970s (Thorstad *et al*., 2015). Lice have a greater economic impact on the industry than any other parasite (ICES, 2010) and control of lice levels on farms is of key importance. In recent years, lice have also developed resistance to one or more of the chemicals commonly used to manage lice levels and resistant lice have been reported in all areas of Norway, except Finnmark County in northernmost Norway (Aaen *et al*., 2015; Besnier *et al*., 2014). The high density of salmon in cages has provided a high number of potential hosts and promoted the transmission and population growth of the parasite (Torrissen *et al*., 2013). As a result, salmon farming has been shown to increase the abundance of lice in the marine environment. However, knowledge of parasite infection rates and resulting effects in wild populations of fish is relatively poor.

Historically, naturally occurring lice levels on wild salmonids have typically been low – a few (0-10) adult lice per returning salmon and sea trout (Torrissen *et al*., 2013; Serra-Llinares *et al*., 2014). Elevated levels of lice on wild salmon collected from coastal areas in the vicinity of salmon farms have been regarded as evidence that mariculture is a main source of the infections and studies have demonstrated a link between fish farming activity and lice infestations on wild salmonids (Helland *et al*., 2012, 2015; Serra-Llinares *et al*., 2014). Thus, the risk of infection among wild salmon populations can be elevated in areas that support salmon mariculture, although louse management activities can reduce the prevalence and intensity of infection on wild fish (Penston and Davies, 2009; Serra-Llinares *et al*., 2014). There is considerable uncertainty about the extent of the zones of elevated risk of infection and this will be subject to both spatial and temporal variability, for example as a result of changes in local hydrological processes (Amundrud and Murray, 2009; Salama *et al*., 2013, 2015; Jones *et al*., 2015; Johnsen *et al*., 2016).

The extent to which elevated infections of lice pose a risk to the health of wild salmon populations has been the subject of extensive research. However, there are many difficulties in quantifying effects at the population level, particularly for fish stocks that are

characterised by highly variable survival linked to environmental variables, such as Atlantic salmon (Vollset *et al*., 2015; Helland *et al*., 2015). The following sections aim to summarise the current state of knowledge in relation to the impact of lice on Atlantic salmon. The literature reviewed includes some results from studies on Pacific salmon. This is considered to provide added insight, but needs interpreting with some caution since there are differences between the situation in the Pacific and the Atlantic, including in the genome of the lice themselves as well as the ecological context of the salmon. In the Pacific, salmonids are more diverse in their life-history traits, species composition and abundance; the salmon farming industry is also smaller.

Physiological effects

Several laboratory studies have presented the effect of lice on the physiology of Atlantic salmon, sea trout and Arctic charr smolts (reviewed in Finstad and Bjørn, 2011; Thorstad *et al*., 2015). Major primary (nervous, hormonal), secondary (blood parameters) and tertiary (whole body response) physiological effects (e.g. high levels of plasma cortisol and glucose, reduced osmoregulatory ability and reduced non-specific immunity) occur when the lice develop from the sessile chalimus second stage to the mobile first pre-adult stage. Reduced growth, reproduction, swimming performance and impaired immune defence have also been reported (Finstad and Bjørn, 2011). The susceptibility and response to louse infection varies among individuals, populations and species of salmonid.

It has been shown in laboratory studies that 0.04-0.15 lice per gram fish weight can increase stress levels, reduce swimming ability and affect the water and salt balance in Atlantic salmon (Finstad *et al*., 2000). In sea trout, the same authors found around 50 mobile lice are likely to give direct mortality, and 13 mobile lice, or approximately 0.35 lice per gram fish weight might cause physiological stress in sea trout (weight range 19-70 grams). Around 0.05-0.15 lice per gram fish weight were found to affect growth, condition and reproductive output in sexually maturing Arctic charr (Tveiten *et al*., 2010).

Finstad *et al*. (2000) also found that infections of 0.75 lice per gram fish weight, or approximately 11 lice per fish, can kill a recently emigrated wild salmon smolt of about 15g if all the lice develop into pre-adult and adult stages. This is consistent with field studies on infections in salmon post-smolts in the Norwegian Sea where more than 3,000 post-smolts have been examined for lice, but none

observed carrying more than 10 adult lice (Holst *et al*., 2003). Fish with up to 10 mobile lice were observed to be in poor condition with a low haematocrit level and poor growth. These authors also conducted an experimental study of naturally infected migrating salmon smolts collected during a monitoring cruise. Half of the fish were deloused as a control, and the health of the two fish groups were monitored in the laboratory. Only fish carrying 11 mobile lice or less survived. The results have been further verified in the laboratory on wild-caught Atlantic salmon post-smolts infected with lice and showing the same level of tolerance for lice infections (Karlsen *et al*., in prep.).

These results have been used to provide estimates of death rates according to lice densities on migrating salmon smolts and have been adopted in the Norwegian risk assessment for fish farming (Taranger *et al*., 2015). The categories are: 100% mortality in the group >0.3 lice per gram fish weight, 50% in the group 0.2-0.3 lice per gram fish weight, 20% in the group 0.1-0.2 lice per gram fish weight and 0% in the group <0.1 lice per gram fish weight. Wagner *et al*. (2008) discuss the wider factors that should be taken into account when estimating sea louse threshold levels detrimental to a host.

In practice, numerous biotic and abiotic stressors (e.g. pollutants) and ecological processes are likely to mediate the relationship between lice and the marine survival of Atlantic salmon. While laboratory estimates of lethal loads and physiological responses are attractive to predict impacts on wild populations, this is likely an over-simplified view because natural ecological processes such as predation and competition will probably remove infected fish before lice kill the fish directly. Early marine growth is important for smolts to enable them to reduce the risk of predation and to allow access to more diverse prey fields, and reduced growth rates will affect fish under resource-limited or parasitised conditions. Furthermore, studies with Pacific salmon (Peacock *et al*., 2014) have demonstrated that sub-lethal effects seen in laboratory trials may increase or decrease observed mortality in the field. As such, laboratory results ideally need to be connected with behavioural changes (e.g. migration behaviour; Birkeland and Jakobsen, 1997) in the fish that alter predator-prey interactions between the smolts and their predators as well as the smolts and their prey.

Evidence from monitoring programmes

Monitoring programmes have been implemented in a number of countries to assess lice levels to inform management decisions. Given the difficulties of sampling out-migrating wild salmon smolts, sea trout are commonly sampled and may in some cases be used as a proxy for potential levels on salmon (Thorstad *et al*., 2014).

In Norway, lice infection on wild salmonid populations is estimated through a national monitoring programme (Serra-Llinares *et al*., 2014; Taranger *et al*., 2015). The aim of the lice monitoring programme is to evaluate the effectiveness and consequences of zone regulations in National Salmon Fjords (areas where salmon farming is prohibited), as well as the Norwegian strategy for an environmentally sustainable growth of aquaculture.

Monitoring is carried out during the salmon smolt migration and in summer to estimate lice levels on sea trout and Arctic charr. The fish are collected using traps, fishing nets and surface trawling (Holm *et al*., 2000; Holst *et al*., 2003; Heuch *et al*., 2005; Bjørn *et al*., 2007). Sentinel cages have also been used to investigate infestation rates (Bjørn *et al*., 2011).

The results of monitoring indicate considerable variation in the risk of lice-related mortality (low <10%; moderate 10% - 30%; and high >30%) between years and sampling locations. The risk for sea trout (and also Arctic charr in the Northern regions) is higher compared with Atlantic salmon post-smolts and the results show moderate-to-high risk of lice-related mortality on sea trout in most counties with high salmon farming activity.

The estimated risk of lice-related mortality for Atlantic salmon varies between years and sites. It was low at most sites in Norway in 2010 and 2013, but moderate or high at several sites in 2011, 2012 and 2014.

In Scotland, analysis of wild sea trout monitored over five successive farm cycles found that lice burdens above critical levels were significantly higher in the second year of the production cycle (Middlemas *et al*., 2010). In Norway, preliminary analysis of data from fallowing zones indicate that lice levels in farming areas are also correlated with biomass. In years with high biomass, lice epidemics are present in some zones, but such epidemics are not seen in years with low biomass (Serra-Llinares *et al*., submitted).

As noted previously, research effort on interactions between farmed

and wild salmon is concentrated in areas where salmon farming is most prevalent. The same applies to monitoring efforts and little, if any, monitoring is undertaken in many areas more remote from salmon farming areas, representing a potential gap in our knowledge.

Population effects

Population-level impacts of lice infestation have been estimated in Atlantic salmon post-smolts from a series of long-term studies and analyses in Ireland and Norway involving the paired release of treated and control groups of smolts (Jackson *et al*., 2011a, 2011b; Jackson *et al*., 2013; Gargan *et al*., 2012; Skilbrei *et al*., 2013; Krkošek *et al*., 2013; Vollset *et al*., 2014, 2015). These studies assumed that the louse treatments were efficacious and that released smolts were exposed to lice during the period of the outmigration in which the treatment was effective. Furthermore, the studies were not designed to discriminate between lice from farm and non-farm sources. In addition, the baseline marine survival from untreated groups, which is used as a comparator for treated groups, is itself likely to be affected by louse abundance, introducing an element of circularity that leaves the interactive effects between lice and other factors on salmon survival poorly characterised.

Survival estimates have been based on a statistical analysis of differential survival to adults among release groups (Gargan *et al*., 2012; Jackson *et al*., 2011a, 2011b, 2013), including odds ratios (Jackson *et al*., 2013; Skilbrei *et al*., 2013; Krkošek *et al*., 2013, 2014; Torrissen *et al*., 2013; Vollset *et al*., 2015). An odds ratio is a measure of association between an exposure and an outcome and represents the odds that an outcome will occur given a particular exposure, compared to the odds of the outcome occurring in the absence of that exposure. Thus, in these studies, the odds ratio represented the probability of being recaptured in the treated group divided by the probability of being recaptured in the control group. All studies reported an improved return rate for treated versus control salmon, but all showed significant spatial and temporal variability.

Gargan *et al*. (2012) reported that the ratio of return rates of treated:control fish in individual trials ranged from 1:1 to 21.6:1, with a median ratio of 1.8:1. Similarly, odds ratios of 1.1:1 to 1.2:1 in favour of treated smolts were reported in Ireland and Norway, respectively (Torrissen *et al*., 2013). Krkošek *et al*. (2013) reported that treatment had a significant positive effect with an overall odds ratio

of 1.29:1 (95% CI: 1.18-1.42). A recent meta-analysis of Norwegian data (Vollset *et al*., 2015) based on 118 release groups (3,989 recaptured out of 657,624 released), reported an odds ratio of 1.18:1 (95% CI: 1.07-1.30) in favour of treated fish. Untreated returning salmon were on average older and had a lower weight than treated fish (Vollset *et al*., 2014; Skilbrei *et al*., 2013).

The survival of Atlantic salmon during their marine phase has fallen in recent decades (Chaput, 2012; ICES, 2015). This downturn in survival is evident over a broad geographical area and is associated with large-scale oceanographic changes (Beaugrand and Reid, 2003; Friedland *et al*., 2000, 2005, 2009, 2014). For monitored stocks around the North Atlantic, current estimates of marine survival are at historically low levels, with typically fewer than 5% of out-migrating smolts returning to their home rivers for the majority of wild stocks and with even lower levels for hatchery-origin fish (ICES, 2015).

The scientific literature provides differing perspectives of the mortality attributable to lice (Jackson *et al*., 2013; Krkošek *et al*., 2013). In one view (Jackson *et al*., 2013), the emphasis is placed on the absolute difference in marine mortality between fish treated with parasiticides and those that are not. In this instance, viewed against marine mortality rates at or above 95% for fish in the wild, the mortality attributable to lice has been estimated at around 1% (i.e. mortality in treated groups is 95% compared to 96% in untreated groups). This 'additional' mortality between groups is interpreted as a small number compared to the 95% mortality from the treatment groups.

The other perspective of this same example is in terms of the percent loss of recruitment, or abundance of returning adult salmon, due to exposure to sea lice. In this perspective, the same example corresponds to a 20% loss in adult salmon abundance due to sea lice; for every five fish that return as adults in the treated groups (95% mortality), four fish return as adults in the untreated group (96% mortality). In other words, one in five fish is lost to sea lice effects. These perspectives are solely differences in interpretation of the same data. Where impacts of lice have been estimated as losses of returns to rivers, these indicate marked variability, ranging from 0.6% to 39% (Gargan *et al*., 2012; Krkošek *et al*., 2013; Skilbrei *et al*., 2013). These results suggest that a small incremental increase in marine mortality due to lice (or any other factor) can result in losses of Atlantic salmon that are relevant for fisheries and conservation management and which may influence the achievement of conservation requirements

for affected stocks (Gargan *et al*., 2012). Vollset *et al*. (2015) concluded that much of the heterogeneity among trials could be explained by the release location, time period and baseline (i.e. marine) survival. Total marine survival was reported to be the most important predictor variable. When marine survival was low (few recaptures from the control group), the effect of treatment was relatively high (odds ratio of 1.7:1). However, when marine survival was high, the effect of treatment was undetectable (odds ratio of ~1:1). One explanation for this finding is that the detrimental effect of lice is exacerbated when the fish are subject to other stressors, and the findings of other studies support this hypothesis (Finstad *et al*., 2007; Connors *et al*., 2012; Jackson *et al*., 2013; Godwin *et al*., 2015). Potential interactive effects of multiple factors are likely to be important for explaining the result from meta-analysis where the effect of sea lice on salmon survival depends on the baseline survival of untreated fish (Vollset *et al*., 2015). In conclusion, the authors cautioned that though their study supported the hypothesis that lice contribute to the mortality of salmon, the effect was not consistently present and strongly modulated by other risk factors, suggesting that population-level effects of lice on wild salmon stocks cannot be estimated independently of the other factors that affect marine survival.

Escapees, genetic interactions and effects on wild Atlantic salmon

Numbers of escapees and observations in rivers

Although aquaculture technology and fish farm safety has significantly increased over the past decade or more, each year large numbers of Atlantic salmon still escape from aquaculture installations into the wild. Although many of these are reported (e.g.http://www.fiskeridir.no/Akvakultur/Statistikk akvakultur/Roemmingsstatistikk), in many circumstances, escapes go unnoticed. In Norway, the true numbers escaping from farms have been estimated to be 2-5 times higher than the official statistics (Skilbrei *et al*., 2015). The numbers of farmed escapees are also reported in Scotland (http://aquaculture.scotland.gov.uk/data/fish_escapes.aspx) and in eastern Canada and the United States (NASCO, 2015), but the degree of under-reporting in these regions has not been estimated.

Farmed salmon may escape from both the freshwater (Clifford *et al*., 1998a; Carr and Whoriskey, 2006; Uglem *et al*., 2013) and the marine stages of production (Clifford *et al*., 1998b; Webb *et al*., 1991; Carr *et al*., 1997a). Most known escapes occur from sea cages (Jensen *et al*.,

2010). However, due to differences in rearing practices between countries and regions, the magnitude of freshwater escapes may differ. In some countries, such as Scotland, it is likely to be higher than, for example, in Norway. In Scotland, in the order of 20 million smolts are produced annually from freshwater pens (Franklin *et al*., 2012). In Norway, most smolts are produced in land-based tanks from which escape is less likely. Although the probability of surviving to adulthood and maturing vary between the different life-history stages at which the salmon escape, the great majority of salmon that escape from farms disappear, never to be seen again (Skilbrei, 2010a, 2010b; Hansen, 2006; Whoriskey *et al*., 2006). Nevertheless, some escapees enter rivers where native salmon populations exist and other fish escape direct to river systems. While not all escapees are sexually mature (Carr *et al*., 1997b; Madhun *et al*., 2015), some may attempt to spawn with wild salmon (this can include both precocious parr and adults). Escaped farmed salmon have been observed in rivers in all regions where Atlantic salmon farming occurs: Norway (Gausen and Moen, 1991; Fiske *et al*., 2006), United Kingdom (Youngson *et al*., 1997; Webb *et al*., 1991; Green *et al*., 2012), eastern Canada and the United States (Morris *et al*., 2008; Carr *et al*., 1997a) and Chile (Sepulveda *et al*., 2013). Furthermore, farmed salmon can migrate great distances post-escape (Hansen and Jacobsen, 2003; Jensen *et al*., 2013), and have been observed in rivers at a considerable distance from the main concentrations of salmon farming, for example in Iceland (Gudjonsson, 1991). Still, the incidence of farmed escaped salmon in rivers has been correlated with the volume of farming in Norway (Fiske *et al*., 2006) and in Scotland where there are differences between the east and west coasts (Green *et al*., 2012). Relatively little is known about possible levels of spawning by escapees in river systems away from centres of aquaculture production. Numbers of escapees in such areas are typically assumed to be low (ICES, 2015), but can be subject to temporal variation (e.g. higher in rivers at spawning time than evidenced from in-season catches).

The incidence of farmed escaped salmon has been investigated in a number of rivers in Norway (Fiske *et al*., 2006). A new national monitoring programme for farmed escaped salmon was established in Norway in 2014 based upon data from angling catches, dedicated autumn angling and diving surveys. The results for 30 of the 140 rivers surveyed exceeded a frequency of 10% escapees (see http://www.imr.no/publikasjoner/andre_publikasjoner/romt_oppdrettslaks_i_vassdrag/nb-no). These studies demonstrate that the number of escapees

within rivers varies in time and space (Gausen and Moen, 1991; Fiske *et al*., 2006).

Farmed salmon escapees may attempt to spawn with wild salmon or among themselves. Observations of farmed salmon spawning with wild fish have been reported in rivers in Scotland (Webb *et al*., 1991, 1993; Butler *et al*., 2005), Norway (Lura and Saegrov, 1991; Saegrov *et al*., 1997) and Canada (Carr *et al*., 1997a). However, experiments demonstrate that the spawning success of farmed salmon is significantly reduced (Fleming *et al*., 1996; Fleming *et al*., 2000; Weir *et al*., 2004), perhaps just 1% - 3% and <30% of the success of wild males and females, respectively (Fleming *et al*., 1996). However, the relative spawning success is likely to also vary with the life-stage at which the fish escaped (Fleming *et al*., 1997; Weir *et al*., 2005). Therefore, if a river has, for example, 10% farmed escapees observed on the spawning grounds, the genetic contribution to the next generation is likely to be significantly lower than 10%. One explanation for the wide range of estimates of the relatively low spawning success of escapees is that they originate from aquaculture stocks that have been changed the most by domestication. If so, these inter-breeding events likely have more serious consequences than inter-breeding events of a similar magnitude involving less domesticated stocks. This would mean that simply focusing on the rate of inter-breeding will not necessarily provide a full picture of the genetic consequences of escapees (Baskett and Waples, 2013).

The life-stage of the escapees affects potential impact. Escapes of smolts are believed to assume a normal migration pattern, few immature adults return to rivers, maturing fish have a higher tendancy to return to nearby rivers (Skilbrei *et al*., 2015). This is also affected by the time of year relative to migration patterns in the wild. Thus smolts that escape when natural migration is occurring in the spring have a greater tendancy to return than those escaping at other times of the year (Skilbrei *et al*., 2015).

The rate at which escapes occur may also have implications for the possible impact. Hindar *et al*. (2006) concluded that large pulses of escapes are more damaging than small amounts of gradual 'leakage'. However, Baskett *et al*. (2013) reached the opposite conclusion; that constant, small-scale leakage created greater fitness losses to the wild population. The different conclusions can be largely explained by different time frames of reference: Hindar *et al*. (2006) focused on short-term effects, while Baskett *et al*. (2013) evaluated mean effects over long periods of time. However, this topic merits more detailed

study. Baskett *et al*. also did not explicitly consider overlapping generations, and so more work is needed in order to evaluate results as a function of escapes across generations in Atlantic salmon. This is important to resolve, as it is convenient to ignore low-level leakage because it is very difficult to eliminate or even monitor, but some results, at least, suggest it can have extremely important effects on wild populations.

Identification of escapees

Farmed salmon escapees are typically identified using external morphological characteristics, including growth patterns on fish scales (Fiske *et al*., 2006; Lund and Hansen, 1991). In Norway, genetic methods to identify farmed escaped salmon back to their farm(s) of origin have been developed and are routinely implemented in cases of unreported escapes (Glover *et al*., 2008; Glover, 2010). By the start of 2016, the method has been used in ~20 cases of unreported escape and has resulted in initiation of legal investigations successfully resulting in fines for companies found in breach of regulations (Glover, 2010). Since 2003, all aquaculture salmon in Maine must be marked before placement into marine net pens, so that in the event of an escape the fish can be traced to the farm of origin (NMFS, 2005). Maine's marking programme utilises a genetic pedigree-based approach to identify fish. In other countries, no formal active identification programmes are in place. There are on-going efforts to develop other genetic and non-genetic tagging methods to permit the routine identification of escapees back to their farms of origin.

Intraspecific hybridisation and introgression

Only few published studies have addressed genetic changes in wild populations following the invasion of escaped farmed Atlantic salmon. This may be due to the fact that such studies are often challenging. For example, they often require representative samples of the wild populations ideally before and after invasion, and access to representative farmed samples, as well as an informative set of molecular genetic markers (Besnier *et al*., 2011; Karlsson *et al*., 2011).

The first studies of introgression were conducted in Ireland (Clifford *et al*., 1998b, 1998a) and Northern Ireland (Crozier, 1993; Crozier, 2000), demonstrating introgression of farmed salmon in rivers as a response to escapes from local farms. These escapees originated from both cage escapes in salt water, as well as escapes from freshwater smolt rearing facilities located within rivers. The first studies in Norway demonstrated temporal genetic changes in three out of seven

populations located on the west and middle parts of the country, and concluded that introgression of farmed salmon was the primary driver (Skaala *et al*., 2006). A more recent spatio-temporal investigation of 21 populations across Norway revealed significant temporal genetic changes in several rivers caused by introgression of farmed salmon, and importantly, observed an overall reduction in inter-population genetic diversity (Glover *et al*., 2012). The latter observation is consistent with predictions of population homogenisation as a result of farmed salmon breeding with wild fish (Mork, 1991). Importantly, all rivers that displayed temporal genetic changes due to spawning of farmed escapees displayed an increase in genetic variation, revealed as the total number of alleles observed in the population. This is consistent with introgression from fish of a non-local source. The final published study in Norway used recently developed diagnostic genetic markers for identification of farmed and wild salmon (Karlsson *et al*., 2011) to estimate cumulative introgression of farmed salmon escapees in 20 wild populations (Glover *et al*., 2013). In this study, cumulative introgression over 2-3 decades ranged from 0% to 47% between rivers. Differences in introgression levels between populations were positively linked with the observed proportions of escapees in the rivers, but it was also suggested that the density of the wild population, and therefore level of competition on the spawning grounds and during juvenile stages, also influenced introgression (Glover *et al*., 2013). A recent study conducted in the Magaguadavic River in eastern Canada has also demonstrated introgression of farmed escapees with the native population (Bourret *et al*., 2011).

The most recent and extensive investigations of introgression of farmed salmon were recently published as a report in Norwegian by researchers from NINA and IMR (http://www.nina.no/english/News/News-article/ArticleId/3984). A total of 125 Norwegian salmon populations were classified using a combination of the estimate of wild genome P(wild) (Karlsson *et al*., 2014) and the introgression estimates from the study by Glover *et al*. (2013). The latter authors established four categories of introgression: green = no genetic changes observed; yellow = weak genetic changes indicated – i.e. less than 4% farmed salmon introgression; orange = moderate genetic changes documented – i.e. 4% - 10% farmed salmon introgression; red = large genetic changes demonstrated – i.e. >10% farmed salmon introgression. Based upon these analyses, 44, 41, 9 and 31 of the populations studied fell into categories green to red, respectively. There are no similar estimates in other countries.

Domestication and divergence from wild salmon

From the very start of the Atlantic salmon aquaculture industry in the early 1970s, breeding programmes to select salmon for higher performance in culture were initiated (Gjedrem *et al*., 1991; Ferguson *et al*., 2007; Gjoen and Bentsen, 1997). The largest and most significant of these programmes globally have been those initiated in Norway, based upon material originating from >40 Norwegian rivers (Gjedrem *et al*., 1991). Other programmes in Norway were also established from wild salmon, and in other countries salmon breeding programmes have also been established. Farmed salmon originating from the three main breeding companies in Norway: Marine Harvest – Mowi strain, Aqua Gen AS and SalmoBreed AS, dominate global production although this varies from country to country. For example, in eastern Canada only the St John River domesticated strain (Friars *et al*., 1995) is permitted for use in commercial aquaculture, and in Scotland some locally based strains, e.g. Landcatch (Powell *et al*., 2008) are also being used.

Initially, salmon breeding programmes concentrated on increasing growth, but then expanded to include other traits that are also of commercial importance, such as flesh characteristics, age-at-maturation and disease resistance (Gjedrem, 2000, 2010). Currently, breeding programmes have advanced to 12+ generations, and genome-assisted selection is being utilised in several of the breeding programmes. Quantitative Trait Loci (QTL)-selected sub-strains are now commercially available, displaying characteristics such as reduced sensitivity to specific diseases (Moen *et al*., 2009) and increased growth. It is likely that full utilisation of genomic selection will increase the number of traits that can be accurately targeted by selection for rapid gains in breeding. For example, the recently identified strong influence of the vgll3 locus on age-at-maturation in salmon (Ayllon *et al*., 2015; Barson *et al*., 2015) could represent an effective target to inhibit grilsing (i.e. early maturation) in aquaculture.

As a result of: (1) directional selection for commercially important traits; (2) inadvertent domestication selection (the widespread genetic changes associated with adaptation to the human-controlled environment and its associated reduction in natural selection pressure); (3) non-local origin; and (4) random genetic changes (drift), farmed salmon display a range of genetic differences to wild salmon (Ferguson *et al*., 2007). Examples of these differences include growth rate under controlled conditions (Glover *et al*., 2006; Glover *et al*.,

2009; Solberg *et al*., 2013a, 2013b; Thodesen *et al*., 1999), gene transcription patterns (Bicskei *et al*., 2014; Roberge *et al*., 2006, 2008), stress tolerance (Solberg *et al*., 2013a) and behavioural traits including predator avoidance and dominance (Einum and Fleming, 1997). In addition, farmed salmon strains typically display lower levels of allelic variation when compared to wild salmon strains (Norris *et al*., 1999; Skaala *et al*., 2004), although not all classes of genetic marker reveal the same trends (Karlsson *et al*., 2010). Looking at the level of genetic variation coding for phenotypic traits such as growth, some data are emerging that suggest a possibly reduced variation in farmed strains (Solberg *et al*., 2013a; Reed *et al*., 2015). The latter observation is expected given the fact that farmed fish have been selected for this trait since the early 1970s.

Fitness studies

Thus far, only three published studies have addressed survival of farmed, hybrid and wild salmon in the natural environment. Such studies are exceptionally demanding on logistics, and require unusually long and costly experimental periods.

The first study was conducted in the river Burrishoole in Ireland, and involved planting eggs of farmed, hybrid and wild parentage into a natural river system (McGinnity *et al*., 1997). These fish were identified using DNA profiling and followed through a two-generation experiment. The authors concluded that the survival from fertilisation to adult return (life-time success) of farmed fish was just 2% of wild fish (McGinnity *et al*., 2003). The relative life-time success increased along a gradient towards the offspring of F1 hybrid survivors spawning together with wild salmon (i.e. back crosses) that displayed life-time success of 89% compared to pure offspring of wild salmon. The authors concluded that repeated invasions of farmed salmon in a wild population may cause the fitness of the native population to seriously decline, and potentially enter an "extinction-vortex" in extreme cases.

In Norway, a slightly different but complimentary investigation was conducted in the River Imsa (Fleming *et al*., 2000). Here, the authors permitted migrating adult salmon of farmed and wild native origin entry to the River Imsa, once they had been sampled in the upstream trap. They thereafter spawned naturally and their offspring were monitored until adulthood. This study reported a lifetime fitness of farmed salmon (i.e. escaped adult to adult) of 16% compared with wild salmon (Fleming *et al*., 2000). Important additional data from

this study was the fact that productivity of the wild salmon from the river decreased, following the permitted invasion of farmed salmon, both with respect to the total smolt production and when smolt production from native females was considered alone (Fleming *et al*., 2000). This is because the offspring of the farmed and hybrid salmon competed with wild salmon for both territory and resources, and the dynamics of this may vary across life-history stages (Sundt-Hansen *et al*., 2015).

The most recently published study to address the relative fitness of farmed and wild Atlantic salmon in a natural environment was conducted in the River Guddal in Norway (Skaala *et al*., 2012). Here, these authors used a similar design to the Irish study, releasing large numbers of farmed, hybrid and wild salmon eggs into a river that had no native Atlantic salmon population and following their survival. The study included planting out eggs across three cohorts, and permitted for the first time comparisons of family as well as group-fitness (farmed, hybrid and wild) in freshwater. As there were no local wild fish, salmon from the Norwegian gene-bank were used as a wild-fish proxy. While these authors reported reduced genetic fitness of farmed salmon offspring compared to the non-local wild salmon, egg size was closely related to family survival in the river. Therefore, some farmed salmon families with large eggs displayed relatively high survival rates in freshwater (higher than some wild families). When these studies were controlled for egg size, farmed salmon offspring displayed significantly lower survival in freshwater compared to the wild salmon. To illustrate this, in 15 of 17 pair-wise comparisons of maternal half-sib groups, families sired with wild males performed better than families sired with farmed fish. The study also revealed that farmed and wild salmon overlapped in diet in the river, an observation also reported from an earlier small-scale release study (Einum and Fleming, 1997) and from the full-generation study in the river Imsa (Fleming *et al*., 2000).

Studies examining the underlying details, mechanisms and genomics of the observed survival differences between farmed and wild salmon in natural habitats have also been published (Besnier *et al*., 2015; Reed *et al*., 2015), although the exact mechanisms still remain elusive. For example, attempts at quantifying predation in the wild (Skaala *et al*., 2014) and predation susceptibility in semi-natural contests (Solberg *et al*., 2015) have not revealed greater predation of farmed salmon offspring than wild salmon offspring, despite earlier studies

suggesting reduced predation awareness caused by domestication (Einum and Fleming, 1997).

Collectively, the results of the whole-river studies outlined above are supported by the widespread literature demonstrating the reduced fitness of hatchery reared salmonids, including those fish used in stocking programmes (Araki *et al*., 2007, 2009; Christie *et al*., 2014).

Short-term (few generation) consequences of introgression for wild salmon populations

In natural habitats such as rivers, territory and food resources are typically limited, and survival is often controlled by density-dependent factors, and habitats have carrying capacities (Jonsson *et al*., 1998; Bacon *et al*., 2015). Studies have demonstrated that the offspring of farmed salmon compete with wild salmon for resources such as food and space (Skaala *et al*., 2012; Fleming *et al*., 2000). Therefore, when farmed salmon manage to spawn, and their offspring constitute a component of a given river's juvenile population, the production of juveniles with a pure wild background will be depressed though competition for these resources. In addition, data from controlled studies have indicated that the total productivity of smolts in the river following introgression of farmed salmon can decrease (Fleming *et al*., 2000; McGinnity *et al*., 1997).

As discussed in the section above, farmed salmon display a range of genetic differences to wild populations, which includes various life-history and behavioural traits. In whole-river experiments with farmed and wild salmon (McGinnity *et al*., 1997, 2003; Fleming *et al*., 2000; Fraser *et al*., 2010a; Skaala *et al*., 2012) differences in freshwater growth and body shape, timing of smolt migration, age of smoltification, incidence of male parr maturation, sea-age at maturity and growth in the marine environment have been observed, with some variation across farmed-wild comparisons (Fraser *et al*., 2010b). Therefore, where farmed salmon have introgressed in natural populations, it is likely that recipient populations will display changes in life-history traits in the direction of the farmed strains. Given that life-history traits are likely to be associated with fitness in the wild and local adaptation (Garcia de Leaniz *et al*., 2007; Taylor, 1991; Fraser *et al*., 2011; Barson *et al*., 2015), these changes in life-history characteristics are likely to be associated with a loss of fitness (which will also contribute to an overall reduction in productivity). These changes will be difficult to detect against the background of natural variability in stock abundance and require long-term studies to

quantify accurately. At present, there is a lack of empirical data demonstrating such changes in affected wild populations.

The short-term consequences for wild populations is expected to be dependent on the magnitude and frequency of inter-breeding events. For example, in rivers where density of wild spawners is low, spawning success of escapees should increase compared with locations where density of wild spawners is high. Similarly, low density of wild juveniles with reduced ability to compete should give farm offspring better survival opportunities than they will have in locations with a high density of wild juveniles. Thus, when populations are under stress and the density of individuals goes down, impact from escapees is expected to increase. These expectations are supported both by modelling (Hutchings, 1991; Hindar *et al*., 2006; Castellani *et al*., 2015) and by studies on observed introgression rates in salmon (Glover *et al*., 2012; Heino *et al*., 2015; Glover *et al*., 2013), and also by studies on brown trout supplemented by non-local hatchery fish (Hansen and Mensberg, 2009).

Atlantic salmon river stocks are characterised by widespread structuring into genetically distinct and differentiated populations (Ståhl, 1987; Verspoor *et al*., 2005). This is conditioned by the evolutionary relationships among populations (Dillane *et al*., 2008; Dionne *et al*., 2008; Perrier *et al*., 2011) and adaptive responses to historical and contemporary environmental differences (Taylor, 1991; Garcia de Leaniz *et al*., 2007). A spatio-temporal genetic study of 21 populations in Norway revealed an overall reduction in inter-population diversity caused by inter-breeding of farmed escaped salmon (Glover *et al*., 2012). It is likely that further introgression of farmed salmon will continue to erode this diversity.

Long-term (more than a few generations) consequences of introgression for wild salmon populations

The conservation of genetic variation within and among populations (as outlined in the UN Convention on Biological Diversity, 1992) is important for the resilience of local stocks to human or natural disturbances (Ryman, 1991; Schindler *et al*., 2010), and in the long term, reduced genetic variability will affect the species' ability to cope with a changing environment (Lande and Shannon, 1996; McGinnity *et al*., 2009). Therefore, gene flow into wild populations caused by successful spawning of farmed escapees potentially represents a powerful evolutionary force. It erodes genetic variation among these populations (Glover *et al*., 2012), and in the long run, may also erode

the genetic variation within populations under certain situations (Tufto and Hindar, 2003) as the recipient wild populations become more similar to the less variable farmed populations.

Although evolutionary theory and modelling permits us to outline general trajectories, it remains difficult to predict and demonstrate the evolutionary fate of specific wild populations receiving farmed immigrants. The severity and nature of the effect depends on a number of factors. These include:

- the magnitude of the differences between wild and farmed populations (both historical and adaptive differences);
- the mechanisms underlying genetic differences between wild and farmed salmon;
- the frequency of intrusions of farmed fish; and
- the numbers of intruding farmed fish relative to wild spawning population sizes (Hutchings and Fraser, 2008).

Furthermore, wild populations that are already under evolutionary pressure from other challenges such as diseases, lice infection, overharvest, habitat destruction and poor water quality, etc., are more likely to be sensitive to the potential negative effects of genetic introgression and loss of fitness. Therefore, genetic introgression has to be seen in the context of other challenges.

There have been a number of attempts to model the persistence of wild salmon populations inter-breeding with farmed conspecifics. Early modelling work by Hutchings (1991) predicted that the extinction risk of native genomes is largest when inter-breeding occurs and when farmed fish occur frequently and at high densities. The risk is largest in small, wild populations, which is related to both demographic and genetic effects. Hindar *et al*. (2006) refined this work by using life-stage specific fitness and narrowing the modelling to scenarios based on experimental data. They found that under high intrusion scenarios the recovery of the wild population is not likely under all circumstances, even when inter-breeding has not occurred for many decades. Baskett *et al*. (2013) used a model with coupled demographic and genetic dynamics to evaluate how genetic consequences of aquaculture escapes depend on how divergent the captive and wild populations are. They found negative genetic consequences increased with divergence of the captive population, unless strong selection removes escapees before they reproduce. Recent modelling work by Castellani *et al*. (2015) has focused on using

individual-based eco-genetic models, which are parameterised taking processes such as growth, mortality and maturation as well environmental and genotypic variation into account. This should allow improved power for predicting the outcome of genetic and ecological interactions between wild and farmed salmon. Further field studies would be required to verify (or otherwise) these models.

Taken collectively, existing understanding makes it clear that the long-term consequences of introgression across river stocks can be expected to lead to reduced productivity and decreased resilience to future changes (i.e. less fish and more fragile stocks).

Knowledge gaps

This advice provides a review of the current evidence based on the latest available information in the peer-reviewed literature. While these recent findings have advanced our understanding of the interactions between salmonid aquaculture and wild salmon, substantial uncertainties remain and further investigations are recommended.

Knowledge gaps in relation to impacts of lice include:

- Natural mortality. In order to put mortality from lice into context, there is a need to better understand the causes underlying the current approximate 95% natural mortality of wild salmon and their interactions.
- Transfer of lice. In order to understand better the variation in infestation rates in wild salmon, there is a need to further explore the temporal and spatial variability in the mechanisms underlying the transfer of lice from farmed fish to wild salmonids.
- Long-term effects. There have been few studies of long-term effects of lice on wild salmon populations.
- Distance effects. Little is known on impacts in areas further away from salmon farming concentrations (applies also to escapees).

Knowledge gaps in relation to impacts of farm escapees include:

- Scale of introgression. Monitoring should continue in order to characterise changes in introgression through time. In addition, further characterisation of aquaculture strains would better inform management decisions.
- Factors affecting introgression. There is uncertainty around the environmental and biological factors that influence levels of

farmed salmon introgression.

- Consequences of introgression and escapees. There is limited knowledge of the ecological consequences of introgression and escapees. This particularly includes effects on the productivity of fish populations in rivers.
- Effects of escapes on the genetic structure of wild Atlantic salmon populations. There is a need for a better understanding of the underlying genetic differences between farmed and wild salmon and how these affect fitness.
- Timing and pace of escapes. There is conflicting evidence surrounding the long-term differences in impact between escapes resulting from major events and gradual leakage.

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Advances in understanding the impacts of sea lice on wild Atlantic salmon

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Introduction

Sea lice (*Lepeophtheirus salmonis*) have a widespread geographical distribution, are an important parasite of salmonids and have been a serious problem for the fish farming industry since the 1970s (Finstad *et al.*, 2011; Thorstad *et al*., 2015). The high density of salmon in cages has provided a high number of potential hosts and promoted the transmission and population growth of the parasite (Torrissen *et al*., 2013). As a result, salmon farming has been shown to increase the abundance of lice in the marine environment. However, knowledge of parasite infestation rates and the resulting effects in wild populations of fish are not yet fully understood.

Several studies have demonstrated a link between fish farming activity and sea lice infestations on wild salmonids (Middlemas *et al*., 2010, 2013; Serra-Llinares *et al*., 2014, 2016; Helland *et al*., 2015). Thus, the risk of infestation among wild salmon populations can be elevated in areas that support salmon mariculture, although louse management activities can reduce the prevalence and intensity of infection on wild fish (Penston and Davies, 2009; Serra-Llinares *et al*., 2014).

The extent to which elevated infestations of sea lice pose a risk to the health of wild salmon populations has been the subject of extensive research. However, there are many difficulties in quantifying effects at the population level, particularly for fish stocks that are characterised by highly variable survival linked to environmental variables, such as Atlantic salmon (Vollset *et al*., 2015).

Sea lice - physiological effects on salmonids

Several studies on the effect of sea lice have been performed on smolts of Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*) and Arctic charr (*Salvelinus aplinus*) (reviewed in Finstad and Bjørn, 2011; Thorstad *et al*., 2015). Primary (nervous, hormonal), secondary (blood parameters) and tertiary (whole body response) physiological effects

occur in the host when the lice develop from the sessile chalimus 2 stage to the mobile first pre-adult stage. These include high levels of plasma cortisol and glucose, reduced osmoregulatory ability and reduced non-specific immunity. Furthermore, sub-lethal tertiary effects, (e.g. reduced growth, reduced reproduction, reduced swimming performance and impaired immune defence) have also been reported (see Finstad and Bjørn, 2011 for references).

Laboratory studies have shown that 0.04-0.15 lice per gram fish weight can increase stress levels, reduce swimming ability and create disturbances in water and salt balance in Atlantic salmon. In sea trout, around 50 mobile lice are likely to give direct mortality and 13 mobile lice, or approximately 0.35 lice per gram fish weight, might cause physiological stress in sea trout (weight range of 19-70g). Moreover, around 0.05-0.15 lice per gram fish weight were found to affect growth, condition and reproductive output in sexually maturing Arctic charr (Tveiten *et al*., 2010).

Laboratory studies have also indicated that infections of 0.75 lice per gram fish weight, or approximately 11 sea lice per fish, can kill a recently emigrated wild salmon smolt of about 15g if all the sea lice develop into pre-adult and adult stages (Finstad *et al*., 2000). Studies of naturally infested wild salmon post-smolts indicate that only those with less than 10 lice survived the infestation. This is consistent with field studies on sea lice infestations in salmon post-smolts in the Norwegian Sea, where more than 3,000 post-smolts have been examined for lice but none were observed carrying more than 10 adult lice. Fish with up to 10 mobile lice were observed to be in poor condition with a low haematocrit level and poor growth (Holst *et al*., 2003). The results have been further verified in the laboratory on wild caught Atlantic salmon post-smolts infested with sea lice and showing the same level of tolerance for sea lice infestations (Karlsen *et al*., in prep.).

These results have been used as a management tool in Norway to provide estimates of death rates according to lice densities on migrating salmon smolts and have been adopted in the Norwegian risk assessment for fish farming (Taranger *et al*., 2015; Svåsand *et al*., 2016).

Sea lice monitoring programmes

In Norway, lice infestation on wild salmonid populations is estimated through a national monitoring programme (Serra-Llinares *et al*., 2014, 2016; Taranger *et al*., 2015; Svåsand *et al*., 2016; Nilsen *et al*., 2016).

The aim of the sea lice monitoring programme is to evaluate the effectiveness and consequences of zone regulations in National Salmon Fjords (areas where salmon farming is prohibited) and of the Norwegian strategy for an environmentally sustainable growth of aquaculture.

Given the difficulties of sampling out-migrating wild salmon smolts, sea trout are commonly sampled and in most cases used as a proxy for potential lice levels on salmon (Thorstad *et al*., 2014). Monitoring is carried out during the salmon smolt migration (period 1) and in summer (period 2) to estimate lice levels on sea trout and Arctic charr. The fish are collected using traps, fishing nets and surface trawling and sentinel cages are used to hold smolts to investigate infestation rates (Bjørn *et al*., 2011; Taranger *et al*., 2015; Svåsand *et al*., 2016). The results indicate considerable variation between years and sampling locations in the risk of lice-related mortality (Nilsen *et al*., 2016; Svåsand *et al*., 2016).

Sea lice - population effects

Several long-term studies and analyses looking at population level impacts of sea lice infestation in Atlantic salmon post-smolts have been performed in Ireland and Norway. These studies have involved the paired release of treated and control groups of smolts (Gargan *et al*., 2012; Jackson *et al*., 2013; Skilbrei *et al*., 2013; Krkošek *et al*., 2013; Vollset *et al*., 2014, 2015). These studies assumed that the sea lice treatments were efficacious and that released smolts were exposed to sea lice during the period of the out-migration in which the treatment was effective.

Survival estimates have been based on a statistical analysis of differential survival to adults among release groups (Gargan *et al*., 2012; Jackson *et al*., 2013) including odds ratios (Jackson *et al*., 2013; Skilbrei *et al*., 2013; Krkošek *et al*., 2013; Torrissen *et al*., 2013; Vollset *et al*., 2015). All studies reported an overall improved return rate for treated versus control salmon, but all showed significant spatial and temporal variability in the magnitude of the treatment effect.

Gargan *et al*. (2012) reported that the ratio of return rates of treated:control fish in individual trials ranged from 1:1 to 21.6:1, with a median ratio of 1.8:1. Similarly, odds ratios of 1.1:1 to 1.2:1 in favour of treated smolts were reported in Ireland and Norway, respectively (Torrissen *et al*., 2013). Krkošek *et al*. (2013) reported that treatment had a significant positive effect with an overall odds ratio of 1.29:1 (95% CI: 1.18-1.42). A recent meta-analysis of

Norwegian data (Vollset *et al*., 2015) based on 118 release groups (3,989 recaptured out of 657,624 released) reported an overall odds ratio of 1.18:1 (95% CI: 1.07-1.30) in favour of treated fish. Further analysis showed that the age of returning salmon was on average higher and the weight lower in untreated fish compared with treated fish (Skilbrei *et al*., 2013; Vollset *et al*., 2014).

The survival of Atlantic salmon during their marine phase has fallen in recent decades (Chaput, 2012; ICES, 2015). This downturn in survival is evident over a broad geographical area and is associated with large-scale oceanographic changes (Beaugrand and Reid, 2003; Friedland *et al*., 2014). For monitored stocks around the North Atlantic, current estimates of marine survival are at historically low levels with typically fewer than 5% of out-migrating smolts returning to their home rivers for the majority of wild stocks, with lower levels for hatchery-origin fish (ICES 2015). Viewed against marine mortality rates at or above 95%, the 'additional' mortality attributable to sea lice has been estimated at around 1% (Jackson *et al*., 2013).

However, the impacts of sea lice have also been estimated as losses of returning adult fish to rivers. Such estimates indicate marked variability, ranging from 0.6% to 39% in individual trials (Gargan *et al*., 2012; Krkošek *et al*., 2013; Skilbrei *et al*., 2013). These results suggest that sea lice induced mortality has an impact on Atlantic salmon returns which may influence the achievement of conservation requirements for affected stocks (Gargan *et al*., 2012).

Vollset *et al*. (2015) concluded that much of the heterogeneity among trials could be explained by the release location, time period and baseline (i.e. marine) survival. Baseline survival was reported to be the most important predictor variable. When this was low (few recaptures from the control group), the effect of treatment was relatively high (odds ratio of 1.7:1). However, when baseline survival was high, the effect of treatment was undetectable (odds ratio of ~1:1). Vollset *et al*. (2015) concluded that their study supported the hypothesis that sea lice contribute to the mortality of salmon.

Summary

Sea lice have a widespread geographical distribution, are an important parasite of salmonids and have been a serious problem for the Atlantic salmon farming industry since the 1970s.

Salmon farming has been shown to increase the abundance of lice in the marine environment and the risk of infestation among wild

salmonid populations.

Laboratory studies have demonstrated that infestations of 0.75 lice per gram fish weight, or approximately 11 sea lice per fish, can kill a recently emigrated wild salmon smolt of about 15g if all the sea lice develop into pre-adult and adult stages.

A number of studies in Norway and Ireland have estimated the relative marine survival of smolts treated to provide lice resistance versus control groups and reported an overall improved return rate for treated salmon. There is significant spatial and temporal variability in the magnitude of the treatment effect. When baseline survival (i.e. survival of control group) was low, the effect of treatment was high. In contrast, when baseline survival was high, the effect of treatment was undetectable. These results suggest that sea lice induced mortality has an impact on Atlantic salmon returns, which may influence the achievement of conservation requirements for affected stocks.

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Advances in understanding the impacts of escaped farmed salmon on the genetic integrity of wild Atlantic salmon

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Introduction

Escaped farmed Atlantic salmon have been recognised as a threat to wild salmon populations since the late 1980s when high proportions of escaped farmed salmon were found in several rivers (Gausen and Moen, 1991; Hindar *et al*., 1991). International symposia on the potential genetic, ecological and epidemiological impacts of escaped farmed salmon, organised by NASCO, ICES and/or national authorities, have been held in 1991 (Loen, Norway; published in Hansen *et al*., 1991), 1997 (Bath, UK; published in Hutchinson, 1997) and in 2005 (Bergen, Norway; published in a Conveners' Report by Hansen and Windsor, 2006 and in a special issue of the ICES Journal of Marine Science by Hutchinson, 2006).

In 2016, a group of experts on interactions between aquaculture and wild salmonids met at the ICES Headquarters to summarise the state of knowledge as a response to questions posed by NASCO (ICES, 2016). The general findings of that group will not be the focus of this paper which presents information on advances in the understanding of the genetic impacts of escaped farmed salmon since 2007 in the following fields: (i) genetic introgression of farmed to wild Atlantic salmon; (ii) salmon biology; (iii) consequences of introgression; (iv) mechanisms of interactions; and (v) broodstock control.

Genetic introgression

Studies of gene flow from farmed to wild salmon face difficulties because the two groups belong to the same species, and the domestication process is still in its infancy (12th generation of breeding since the 1970s). Early demonstrations of gene flow were, therefore, opportunistic and were most easily carried out where farmed salmon of Norwegian origin met local wild populations e.g. in Ireland and the UK.

Modern molecular genetics now employ thousands to hundreds of thousands of Single Nucleotide Polymorhisms (SNPs), and the genome sequence of Atlantic salmon was recently published in *Nature* (Lien *et al*., 2016). This development was used by Karlsson *et al*. (2011) to search for a set of SNPs that could distinguish between farmed and wild Atlantic salmon on a generic basis. These authors used a 7k SNP-chip to compare historical samples of wild salmon from 13 Norwegian rivers with samples of farmed salmon from the three major breeding companies, each of them represented by four year classes. A set of c. 60 SNPs was found to be collectively diagnostic for the farmed and historical wild salmon on a generic basis, even though there are genetic differences among the breeding lines of farmed salmon, as well as among wild salmon populations.

This set of SNPs (or a slight modification of it) was used to study levels of genetic introgression in 20 Norwegian Atlantic salmon populations where a historical sample of the population could be compared with a modern sample (Glover *et al*., 2013). In the cases where a genetic change was found, these authors checked whether the change was best explained by introgression of farmed salmon or by genetic exchange with neighbouring wild populations. They found levels of genetic introgression from farmed to wild salmon ranging from 0 to 47%.

At the same time, Karlsson *et al*. (2014) developed an alternative approach for analysis that was not dependent on a historical sample for assessing genetic introgression in a modern sample. First, they calculated a genetic centre point for wild and farmed salmon, respectively, to which any individual could be compared with respect to probability of belonging (e.g. probability of being wild, or proportion of wild genome; *P(Wild)*. Then, by analysing a large set of historical wild salmon and salmon from the dominating breeding nuclei, they defined an expected distribution of P(Wild) estimates for pure wild salmon individuals and for pure farmed salmon individuals. Because analyses were conducted at the individual level, the obtained probability distribution includes all evolutionary processes that act on the genetic composition of the individual, including genetic drift and gene flow between wild populations (Karlsson *et al*., 2014).

This approach enables quantification of farm genetic introgression from a contemporary sample without having historical samples from the particular population involved, as every individual can be compared to the probability distribution of wild salmon. Local historical samples will increase the precision as long as they constitute

a good representation of the spawning population before any impact of escaped farm salmon. Simulations demonstrated that the method gives a precise estimate of P(Wild) at the population level (Karlsson *et al*., 2014), although not necessarily for individual fish.

Analyses of Norwegian population samples, using this method, are now available from more than 20,000 individual Atlantic salmon hatched in the wild from more than 100 rivers representing three quarters of the total number of Atlantic salmon spawning in Norwegian rivers (Karlsson *et al*., 2016a). In this study, the range of population estimates of farmed to wild introgression varied from 0 to more than 40%, and statistically significant introgression was found in one half of the populations studied.

Upon request from Norwegian authorities, the studies by Karlsson *et al*. (2016a) and Glover *et al*. (2013) were recently combined by researchers from NINA and from the Institute of Marine Research (IMR) to classify 125 populations with respect to their genetic integrity (Anon., 2016). The researchers established four categories of introgression: green = no genetic changes observed; yellow = weak genetic changes indicated but less than 4% farmed salmon introgression; orange = moderate genetic changes documented 4% - 10% farmed salmon introgression; red = large genetic changes demonstrated >10% farmed salmon introgression. Based upon these analyses, 44, 41, 9 and 31 of the populations studied fell into categories green-yellow-orange-red, respectively. In Figure 1, these 125 populations are shown on a map of Norway.

The study shows that only one third of Norwegian Atlantic salmon populations are without signs of genetic introgression in these samples which, for the large majority of rivers, are based on samples of adult Atlantic salmon that have spent their entire life in the wild. The highest genetic introgression is found in the fish farming regions along the west coast of Norway, and there is a highly significant correlation between genetic introgression and the long-term average proportion of escaped farmed salmon in the rivers (Karlsson *et al*., 2016a).

Salmon biology

Knowledge about the biology of Atlantic salmon has recently been summarised in the books by Jonsson and Jonsson (2011) and Aas *et al*. (2011) and in the ICES Journal of Marine Science issue from the Salmon at Sea symposium in 2012 (Chaput, 2012). One finding is a much wider oceanic distribution area of Atlantic salmon than

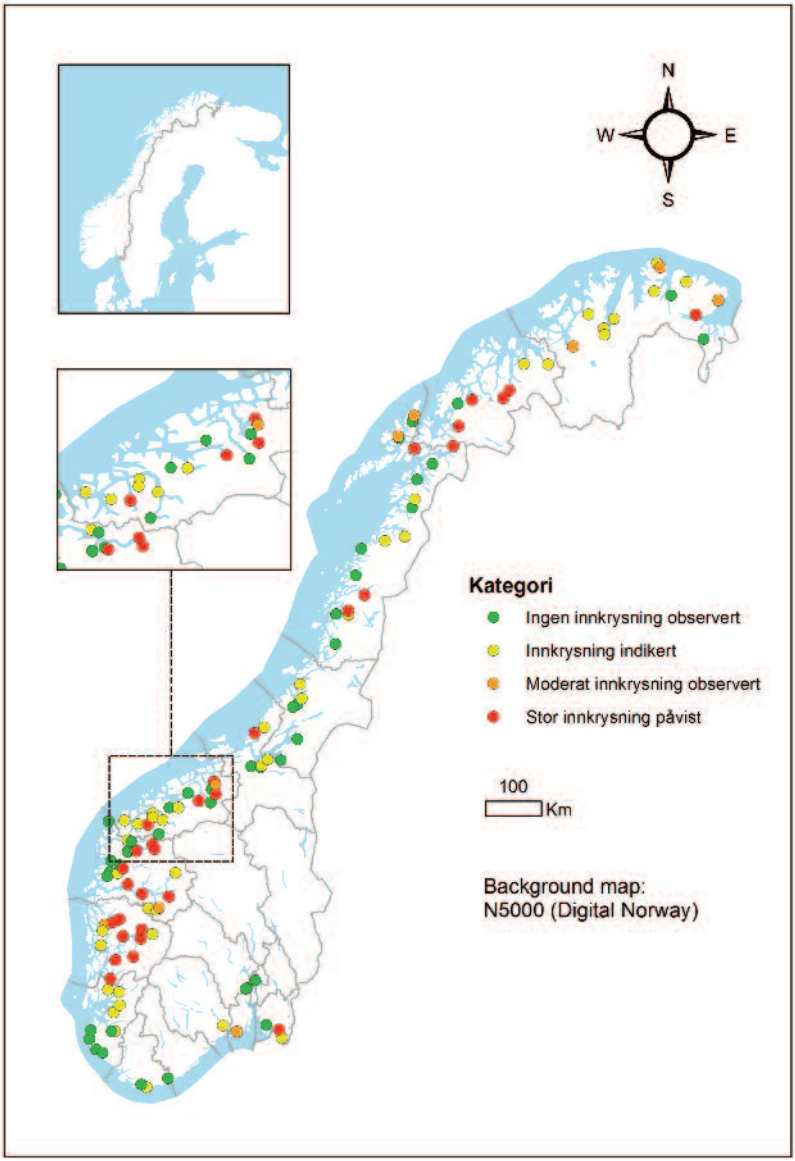

Figure 1: *Categorisation of 125 salmon populations in Norway with respect to farmed to wild salmon genetic introgression. The categories used are green = no introgression observed, yellow = introgression indicated, orange = moderate introgression demonstrated, red = high introgression demonstrated (from Anon., 2016; Glover et al., 2013; and Karlsson et al., 2016a)*

previously mapped, especially to the north and northeast (beyond the archipelago of Svalbard and far into the Barents Sea). Incidentally, escaped farmed salmon are found alongside wild salmon near the coast of Spitsbergen at 80°N (Jensen *et al*., 2013).

The 7k SNP-chip has been used to describe the large-scale population genetic structure of Atlantic salmon (Bourret *et al*., 2013), confirming earlier studies showing distinct groups in Europe and North America (Ståhl, 1987) and also showing a clear distinction of wild salmon between the eastern Atlantic Ocean, the Barents-White Sea and the Baltic Sea (Bourret *et al*., 2013). As a consequence of this, the genetic contrast between farmed Atlantic salmon and historical wild salmon populations along the European coast must be established separately for Atlantic Ocean populations and Barents-White Sea populations (Karlsson *et al*., 2016a). Interestingly, both of these phylogeographic groups were represented among the wild source populations that gave rise to farmed Atlantic salmon, but only Atlantic Ocean populations were represented by generation three in the Norwegian breeding programme (Gjøen and Bentsen, 1997).

More than 220,000 SNPs studied in 1,500 salmon from 57 rivers in Fennoscandia were used recently to unravel the genetic basis for sea-age (and thereby body size) at maturity in Atlantic salmon (Barson *et al*., 2015). The study indicated that 39% of the genetic variation in sea-age at maturity could be ascribed to a single gene. Moreover, the study demonstrated a new mechanism for maintenance of genetic variation in a major-effect gene, as a fish with both the early- and the late-maturing allele became large if it was a female and remained small if it was a male (Barson *et al*., 2015). This finding is a leap forward in our knowledge about the ecological genetics of Atlantic salmon and may have implications for management of both wild and farmed salmon. In a parallel study finding the same major gene effect, Ayllon *et al*. (2015) proposed that targeted selection in farmed strains could be used to reduce the incidence of early maturation in aquaculture.

In April 2016, the complete DNA sequence of the Atlantic salmon genome was published (Lien *et al*., 2016). This, and the above studies, demonstrates that salmon biology is entering the genomic era, and that we can expect major leaps of knowledge of both wild and farmed Atlantic salmon biology in the future.

Consequences of introgression

Whole-river controlled experiments in Ireland (Burrishoole river

system) and Norway (River Imsa) led McGinnity *et al*. (1997; 2003) and Fleming *et al*. (2000) to conclude that intrusion of escaped farmed salmon into natural rivers could lead to lowered fitness and productivity, with repeated escapes causing cumulative fitness depression and potentially an extinction vortex in vulnerable populations (McGinnity *et al*., 2003). This conclusion was based on the results from following mixed populations from natural spawning or experimental crosses through one or two generations, and characterising the growth rate, survival, life history and reproductive capacity relative to the native population.

Similar studies have now been performed in a second Norwegian stream, the River Guddalselva; (Skaala *et al*., 2012) where a family-based analysis provided qualitative support for the early studies in the Burrishoole and the Imsa, although with some quantitative differences. Skaala *et al*. (2012) also found an effect of density on the relative performance of farmed offspring (which was reduced with higher density) and an effect of egg size (with larger eggs leading to higher offspring performance).

In Canada, experiments across two generations with one farmed and two wild populations (Fraser *et al*., 2010a; 2010b) suggested that farmed-to-wild population crosses could differ substantially and under some conditions be sufficiently mismatched to prevailing environmental conditions that they would have reduced survival in the wild. They concluded that repeated farmed-wild inter-breeding could adversely affect wild populations, reaffirming conclusions from previous experimental studies.

The number of controlled experiments is limited and they are extremely time- and manpower-demanding. The advance in characterising individual fish by their P(Wild) provides another way of testing whether introgression of farmed to wild salmon has an effect on the ecology and life history of wild salmon. Preliminary analyses by Geir Bolstad (NINA) and co-workers, of non-introgressed and introgressed adult wild salmon from more than 50 populations suggest that ecological and life-history changes are widespread in Atlantic salmon populations.

Mechanisms of interactions

Artificial selection for increased growth rate in farmed Atlantic salmon doubled the capacity for growth over the first five generations of the breeding programme (Thodesen *et al*., 1999). Experiments with families of farmed salmon, wild salmon and their

crosses now show that growth rate in a hatchery is a 'perfect marker' in that all families of farmed salmon grew faster than all families of farmed-x-wild salmon which grew faster than all families of wild salmon (Solberg *et al*., 2013).

In the wild, however, a higher growth capacity may be a mixed blessing, as energy-rich food is not easily available throughout the year and the search for food may render the fish vulnerable to predators. The earliest free-living life-stage may be one where increased growth capacity may be particularly advantageous because in late spring/early summer growth conditions may be at their best. Experiments with offspring of wild and farmed salmon in stream channels at Ims, Norway, showed a higher realised growth in farmed than in wild juveniles, and that the presence of farmed juveniles reduced the survival of wild juveniles in confined enclosures (Sundt-Hansen *et al*., 2015). This may be one mechanism explaining how farmed juveniles could have reduced survival compared with wild juveniles (Fleming *et al*., 2000; McGinnity *et al*., 2003), and still reduce the survival of wild juveniles in whole-river experiments.

Broodstock control

The ability to distinguish farmed offspring from wild offspring by molecular genetic methods is now being actively used in Norwegian management. Stock enhancement of wild Atlantic salmon has a long history, and is actively used as a compensation for reduced smolt productions caused by hydropower regulation. Moreover, populations in danger of extinction are being propagated in live gene banks until the man-made factor that threatens these populations is controlled. In either case, it would be unfortunate if propagation of wild fish was actually propagating fish of farmed heritage.

Norwegian management authorities have, therefore, requested that all wild broodstock are checked with respect to their genetic origin (i.e. after fish that are escaped farmed salmon have been excluded by scale reading). In autumn 2014 and 2015, all broodstock were tested genetically with the set of SNPs that distinguish between farmed and wild salmon (Karlsson *et al*., 2011), and with the analytical method of Karlsson *et al*. (2014). A fixed P(Wild) was set to exclude all pure farmed salmon and only a small percentage of pure wild salmon. In 2014 and 2015, 14% and 18%, respectively, of all broodstock were excluded as parents for stock enhancement and gene banking because of their likely farmed heritage (Karlsson *et al*., 2016b).

Sterile salmon in fish farming has been advocated as one way to reduce genetic interactions. Sterility on a large scale can be easily induced by triploidy and triploid families of farmed salmon are commercially available today. Triploid salmon may however develop secondary sexual characteristics. Experiments have now been conducted with triploid (sterile) males (Fjelldal *et al*., 2014). Qualitative observations demonstrated that triploid male Atlantic salmon displayed the full range of spawning behaviors of wild males, and stimulated the wild female to spawn in the absence of wild males. The authors maintain, however, that quantitative data are needed before suggesting triploidy as a mitigative action.

Spontaneous triploid salmon are found at low frequencies in farmed salmon. A comparison of large numbers of farmed salmon in aquaculture, with escaped farmed salmon in the wild, suggests that only a fraction of triploid farmed fish may enter rivers (Glover *et al*., 2016). This is an interesting observation, because in addition to the reduction of genetic interactions, it may indicate that the transfer of disease agents from farmed to wild fish may be reduced with a reduction in farmed fish seeking fresh water.

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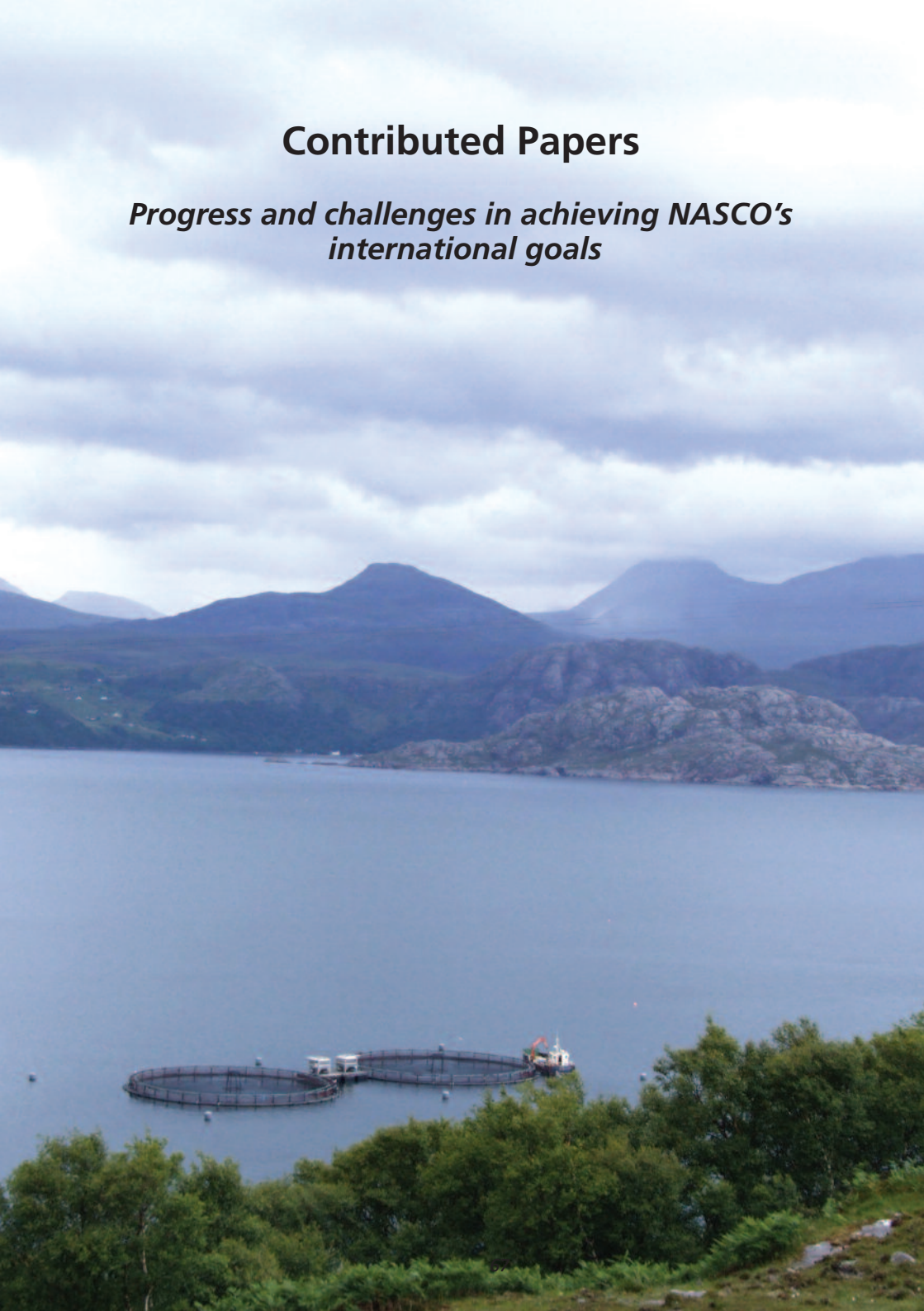
Contributed Papers

Progress and challenges in achieving NASCO's international goals



CNL(16)41

Measures introduced in Norway to meet NASCO goals of reducing impacts from sea lice and escapees on wild salmon

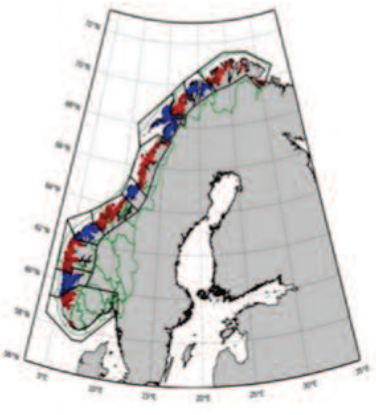
Paper presented by Mr Yngve Torgersen, Ministry of Trade, Industry and Fisheries

In order for Norway to maintain its position as a world-leading producer and exporter of farmed Atlantic salmon, the production must be socially, economically and environmentally sustainable. It is the policy of the Norwegian Government to enable growth and competitiveness of the salmon farming industry, within a framework of environmental sustainability. This paper provides a short outline of the main measures currently being taken to minimise the impact of sea lice and escapees from salmon farming on wild salmonids in Norway.

White Paper presented to the Storting on growth in the aquaculture industry

In March 2015, the Norwegian Government presented a White Paper to the Storting (the Norwegian Parliament) on growth in the Norwegian salmon farming industry. To lay the foundation for further growth, a new system intended to keep the industry's environmental footprint within acceptable limits was proposed. This White Paper was debated in Parliament on 15 June 2015 and its main elements were endorsed by the Parliament which decided that environmental impact (footprint) should be the most important determining factor in future growth in the salmon farming industry.

The Parliament also decided to divide the Norwegian coast into production areas and the Institute for Marine Research (IMR) has prepared a proposal to do so using different models and analyses on



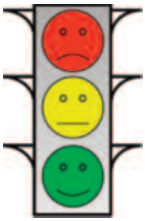
how particles (organic matter or pathogens) spread along the coast using data from the siting of fish farms and coastal currents. Furthermore, the Parliament has decided to use sea lice impacts on wild populations as the indicator when determining whether or not a production area is suitable for growth in production of farmed salmon.

It is essential that the selected indicators of changes in the environmental footprint correlate with the biomass within a given production area. Consequently, not all indicators are suitable.

Issue	Can an indicator be designed, i.e. impact measured in the environment?	Is there a good correlation between biomass and the size of the indicator?	Is there a good correlation between source and where impact is measured?
Escapes	Yes (prevalence at breeding grounds and genetic drift in wild populations)	No	No
Pollution/Effluent	Yes (level of dissolved nutrients and organic material)	Yes	Yes
Diseases/parasites	Yes (mortalities in wild stocks)	Yes	Yes
Feed resources	No	Yes	No

Table 1: *Assessment of possible indicators*

It was concluded that, in the short and medium term, sea lice are the only appropriate indicator which can be used in this system for capacity adjustment at the licensing level within defined production areas. The selection of indicators will, if necessary, be adjusted if the environmental challenges posed by the industry change; this will allow for inclusion of other indicators of environmental impacts in the system over time or the removal of those currently in use.



A traffic light system is used. If the indicator in a production area is green, capacity could be increased by 6 percent; yellow signifies that capacity should remain unchanged; and red signifies that capacity should be reduced. Capacity changes will be considered every second year on the basis of the results from the indicator system.

Sea lice

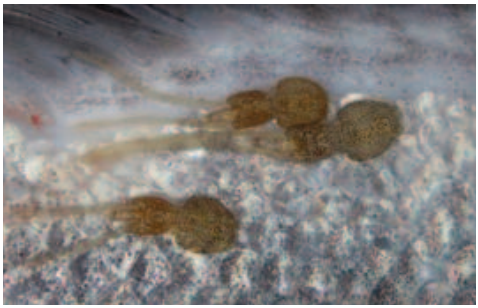
Monitoring

The impact on wild salmonids of sea lice from farmed fish has, until now, been determined through field studies on wild salmonids. This is both time consuming and expensive. The main monitoring will now shift to a model-based system using data on sea lice (copepodites)

No / Low influence	Moderate influence	High influence
It is likely that <10% of the wild salmonids will die due to sea lice infestations	It is likely that 10% - 30% of the wild salmonids will die due to sea lice infestations	It is likely that >30% of the wild salmonids will die due to sea lice infestations

***Table 2**: Action limits regarding sea lice impact on wild salmonids*

emission from all sea-based facilities in a production area and relate this to the risk of unacceptable impacts on wild salmonids. Norwegian research institutions will test the model this season. Surveillance on wild salmon will be used to verify the results. The model will be continuously adjusted as new knowledge is acquired.



Regulations

The introduction of the new system does not imply any significant changes with regard to the sea lice regulations applicable to the individual site. The regulations in Norway require the farmers to co-ordinate their sea lice control and have operational plans to control sea lice as agreed to by the Norwegian Food Safety Authorities (NFSA). The maximum limit, set at 0.5 adult female lice per fish (using a standardised counting method), is intended to ensure a proactive approach to sea lice control. There is compulsory weekly reporting of sea lice counts to the NFSA, together with information on sea temperature, treatments (including the drug used and the quantity), results from sensitivity tests and the number of cleaner fish deployed in cages.

Norwegian fish farmers are required to take co-ordinated de-licing measures every spring at low treatment thresholds (0.1 motile/adult female lice) to protect Atlantic salmon smolts migrating to sea. Monitoring shows that the campaigns have been successful. However, there are still reports of high levels of sea lice on sea trout (*Salmo trutta trutta*) in certain areas.

The NFSA may order co-ordinated de-licing operations, fallowing and, if necessary, slaughtering. In addition, the NFSA can establish designated areas with stricter regulations than the general regulatory framework. During 2015, the NFSA took action against a number of fish farms which were exceeding the sea lice limit in a more or less systematic manner and required slaughter and/or reduction for the next production cycle of site-MAB (maximum allowed biomass).

The Norwegian Veterinary Institute is responsible for the national monitoring programme of sensitivity of drugs against sea lice. In Norway, reduced sensitivity and resistance to pharmaceutical products used in sea lice control is widespread along the coast. This shows the importance of using measures other than pharmaceuticals. An action plan regarding reduced sensitivity and resistance to pharmaceuticals is under development.

Genetic impact

Escapees

Even though it was concluded that genetic impact is not a suitable indicator in the new system for capacity adjustment at the licensing level, the Norwegian authorities currently place great emphasis on reducing challenges following escapes of farmed salmon. 'Prevention is better than cure', hence the government emphasises the need to prevent escapees. Examples of the approach used include technical requirements for aquaculture installations (the Norwegian Standards for sea-based aquaculture facilities (NS 9415) and land-based facilities (NS 9416)) and the strengthening of the inspection services of the Directorate of Fisheries.

For several years, the Directorate of Fisheries has had a special focus on escapes of small numbers of smolts from salmon farming facilities, including use of the correct mesh size in the nets

according to the size of the fish stocked into them. It is now considered that the number of escapes reported by the operators is closer to the real number than was the case in previous years. In 2016, the Directorate of Fisheries will pay special attention to escapes from smolt production sites on land, as they have found that there is a problem regarding the escape of smaller fish from such farms.

Reported escape incidents											
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016*
Salmon	32	23	20	34	38	17	9	19	38	33	3
Trout/Rainbow trout	6	3	2	1	4	4	2	2	5	3	1
Cod	11	9	17	23	11	3	2	2	1	0	0

*Note: *To-date in year*

Table 3: *The reported number of escape incidents countrywide as of 29 February 2016*

Year	Number of escaped salmon	Number of escaped rainbow trout	Number of escaped cod
2004	553 000	10 000	20 000
2005	717 000	8 000	213 000
2006	921 000	15 000	290 000
2007	298 000	315 000	85 000
2008	111 000	7 000	304 000
2009	225 000	133 000	222 000
2010	291 000	6 000	166 000
2011	365 000	4 000	7 000
2012	38 000	133 000	57 000
2013	198 000	200	55 000
2014	303 200	2 700	14 000
2015	160 000	84 000	0
2016*	1 000	53 000	0

*Note: *To-date in year*

Table 4: *The reported number of escaped fish countrywide as of 29 February 2016*

The funding of the monitoring of escaped fish in rivers has been increased since 2014, improving the scale and quality of the programme which currently covers approximately 165 rivers. In 2015, 128 rivers were assessed to have a moderate prevalence of escaped fish (<10%) while 17 rivers were assessed to have a high prevalence of escaped fish. There are regional differences in the prevalence of escaped fish in rivers, but generally, the prevalence of escaped fish in the years 2006 to 2015 has been gradually declining.

The polluter-pays principle

With regard to escapes from aquaculture, the Norwegian Government has implemented the principle of 'the polluter-pays' through binding agreements with the industry together with legislative measures. In 2015, an arrangement for removal of escapees was implemented based on indicators of an acceptable threshold of farmed salmon in the rivers during the spawning season for wild salmon.

Indicator	Not required to plan mitigation measures	Planning of mitigation actions should be considered	Required to plan mitigation actions
Yearly percent	<4% escaped fish in catches from a river	4-10% escaped fish in catches from a river	>10% escaped fish in catches from a river

Table 5: *Indicators and action limits for prevalence of farmed fish in rivers*

In accordance with legislation, the aquaculture industry was given the responsibility for financing mitigation measures in rivers with a high prevalence of escaped farmed fish. The industry should also cover the cost of recapturing escapees in the sea when the source of the fish is unknown. The approach adopts the principle of 'one for all - all for one', and encourages the industry to develop good methods of traceability. The goal is that all farmed fish are traceable and that only the owner of the fish ('the polluter') should pay. The use of sterile fish is also rewarded.

Sterile fish

The use of sterile fish in fish farming can contribute to reducing genetic and ecological impacts from escaped farmed fish. Research on sterile farmed salmon is on-going to evaluate animal welfare

considerations and performance in relation to various environmental factors. Consequently, triploid fish are currently being reared under research licences. In addition, several commercial salmon farmers have started using triploid fish in accordance with 'green' salmon farm licenses (see below).

Technology development

Technological solutions, that may solve the industry's major environmental challenges, are continually being tested and developed and the government has implemented several measures to facilitate the technology development and implementation.

'Green licenses'

In 2013, the Norwegian Government allocated 45 new licenses for salmon and rainbow trout with the objective of stimulating the industry to develop and implement technology that was more environmentally friendly than existing practices with regards to sea lice and escapees.

Licenses for technology development project

The Norwegian Government has now decided to allocate special licenses for technology development projects which can contribute to solving one or more of the environmental or area challenges facing the industry. These projects have to involve considerable innovation and investments. Currently, only one company has been given such licenses. However, a significant number of applications are in the process of being assessed. Technological developments include equipment for use in off-shore locations.

Land-based salmon farming

In order to facilitate growth in the salmon farming industry, the Norwegian Parliament has decided not to limit the number of licenses for land-based salmon farming. Furthermore, these licenses will be granted without payment of the normal licence fee.

CNL(16)47

Supporting sustainable aquaculture growth alongside a thriving recreational fisheries sector: Reducing the impacts from sea lice and escapes on wild fish in Scotland in parallel with NASCO's international goals

Paper presented by Mr Alastair Mitchell, Marine Scotland

Introduction

The Scottish Government is fully supportive of the sustainable growth of aquaculture alongside a thriving recreational fisheries sector. Scottish Government supports the aquaculture industry to achieve its sustainable growth targets of 210,000 tonnes (whole wet) finfish and 13,000 tonnes shellfish by 2020, with due regard to the environment. If these targets are met the Scottish aquaculture industry will be estimated to have an annual turnover of well in excess of £2billion and support over 10,000 jobs in some of Scotland's most fragile rural communities. The European Union has committed to pursuing significant growth of the aquaculture sector under the Blue Growth Agenda. Scotland has the most developed salmon farming industry in the European Union accounting for 94% of the total farmed salmon production in the European Union. Farmed salmon is Scotland's No. 1 food export.

Marine Scotland's mission is to manage Scotland's seas for prosperity and environmental sustainability and to develop aquaculture in line with the European Union's Blue Growth Agenda and Scotland's National Marine Plan (NMP).

The NMP (http://www.gov.scot/Resource/0046/00465865.pdf) sets out Scotland's national strategy to ensure sustainable economic growth of marine industries, while taking into account environmental protection. The NMP sets out policies with economic, social and

marine ecosystem objectives and outlines protection for marine and special protected areas and the continuing presumption against finfish aquaculture development on the North and East coasts of Scotland in order to help safeguard migratory fish species. The Scottish Government recognises the need to mitigate the impacts of salmon farming on wild fish, including salmon and trout, which are iconic and economically important species in Scotland, and supports NASCO's goals of minimising any potential impacts of aquaculture on wild Atlantic salmon. It is the aim of both the Scottish Government and the Scottish aquaculture industry to reduce interactions of aquaculture with wild fish by lessening incidences of escape and managing sea lice to the lowest achievable level.

Containment

The Scottish fish farming industry has made significant improvements in containment in recent years (Figure 1) and the Scottish Government continues to promote best practice. Escapes reported in 2015 were the lowest on record since statutory reporting was introduced in 2002. All authorised fish farm businesses are inspected under the Aquaculture and Fisheries (Scotland) Act 2007 for satisfactory measures to contain fish and prevent escapes. Escapes, suspected escapes and circumstances which give rise to a significant risk of escape must be reported to Scottish Ministers.

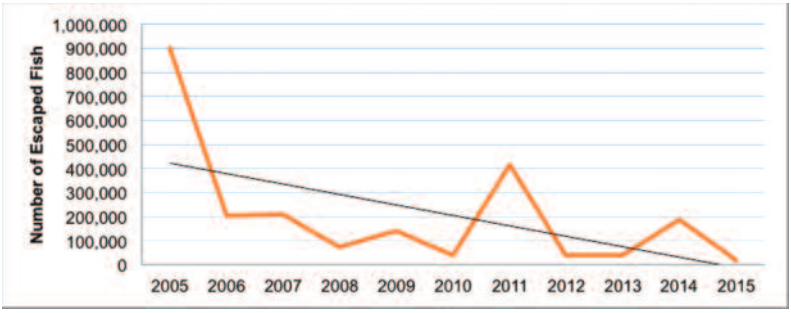


Figure 1: *Timeline of Scottish fish farm escapes (2005-2015)*

The Aquaculture and Fisheries (Scotland) Act 2013 enables Scottish Ministers to make regulations requiring the Scottish finfish farming industry to adopt a Technical Standard for fish farm equipment and ensure a suitably trained workforce. In June 2015, the Scottish Government published a Technical Standard for Scottish Finfish Aquaculture (http://www.gov.scot/Publications/2015/06/5747). Fish farms will have until 2020 to comply with the new standards.

Alongside statutory training, this new Standard will ensure all finfish farms in Scotland have site specific appropriate equipment and operational procedures to help prevent escapes in the future. Many farms are already well on the way to meeting that standard.

Sea Lice

Current Regime

Scotland has a legislative and regulatory framework in place which provides the right balance between growing aquaculture and protecting the environment. All new and modified fish farm developments are assessed by the relevant Local Authorities to determine whether planning permission should be granted. Advice is sought from statutory consultees including District Salmon Fishery Boards. Farms are licensed and controlled by the Scottish Environmental Protection Agency to ensure environmental impacts are assessed and managed and all farms are required to comply with stringent Environmental Impact Asssessment legislation.

In Scotland, Fish Health Inspectors are appointed by Scottish Ministers to enforce fish health legislation. Fish farm businesses are authorised and subject to inspection for containment measures, disease control and sea lice management. Sea lice are regulated by several key pieces of legislation:

- the Aquaculture and Fisheries (Scotland) Act 2007: allows assessment of sea lice levels on site and requires that satisfactory measures are in place for the prevention, control and reduction of sea lice;
- the Aquaculture and Fisheries (Scotland) Act 2013: any such person carrying out fish farming must be party to a farm management agreement or maintain a farm management statement; and
- the Fish Farming Businesses (Record Keeping) (Scotland) Order 2008: records in relation to staff sea lice training, sea lice records, medicinal records and sea lice responsibility on farm.

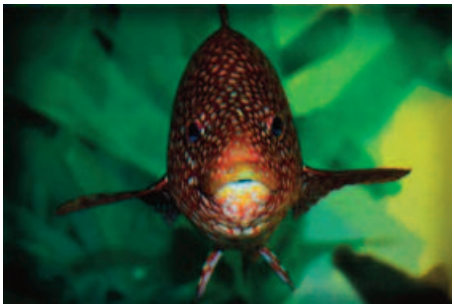
Alongside legislative requirements, the Code of Good Practice for Scottish Finfish Aquaculture (CoGP) provides a standard against which farms are measured through independent auditing. The CoGP includes the National Treatment Strategy for Sea Lice and Integrated Sea Lice Management (ISLM) which is based upon current scientific knowledge and practices, and is presently being

reviewed by industry.

Fish Health Inspectors conduct a risk-based surveillance schedule of all registered fish farms. In addition to the surveillance schedule, the Fish Health Inspectorate operate a risk ranked enhanced sea lice inspection regime, based on several indicator factors and previous sea lice performance and fully investigates sea lice control practices on site for compliance both with legislation and the CoGP recommendations.

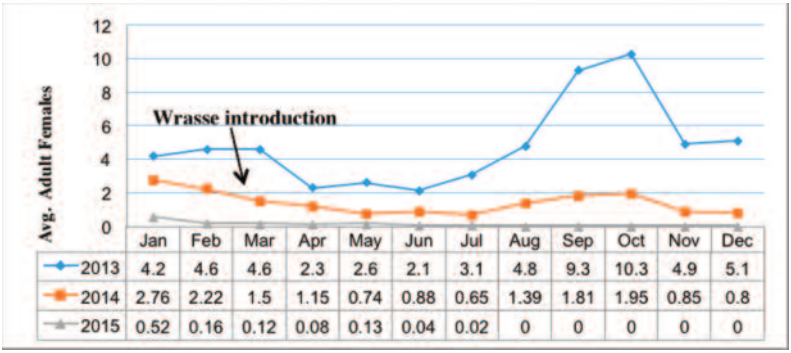
The Scottish Salmon Producers' Organisation produces quarterly reports on fish health management, providing information for 30 regions across Scotland broadly mirroring those of the salmon and sea trout fisheries. Fish health reports include information on farm management areas, stocking, fallowing, strategic sea lice treatments and average sea lice counts (published online: http://scottishsalmon.co.uk/category/industry-information/sspo-publications/).

Recent improvements to on-farm sea lice management and investment in cleaner fish



The use of cleaner fish to control sea lice as an environmentally friendly biological control is recognised as one of the key tools to control sea lice on Scottish fish farms. In 2014, the Scottish Government match-funded £22million to establish the Scottish Aquaculture Innovation Centre with improved sea lice control as a key priority. The Scottish Government is supporting the development of cleaner fish hatchery technology in order to produce cleaner fish on a commercial scale. In 2015, 250,000 wrasse and 800,000 lumpfish were produced and deployed from hatcheries in Scotland. The Scottish Government will continue to monitor and support the development of this important production sector.

In several areas, the use of cleaner fish has been shown to significantly reduce sea lice levels on site. In some cases this has resulted in zero or close to zero lice treatments alongside zero medicinal lice treatments (Figure 2).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	4.2	4.6	4.6	2.3	2.6	2.1	3.1	4.8	9.3	10.3	4.9	5.1
2014	2.76	2.22	1.5	1.15	0.74	0.88	0.65	1.39	1.81	1.95	0.85	0.8
2015	0.52	0.16	0.12	0.08	0.13	0.04	0.02	0	0	0	0	0

Figure 2: *Wester Ross Salmon sea lice levels (Leps) pre- and post-Wrasse introduction*

The Scottish industry is sharing information relating to cleaner fish use and best practice. It is also sharing knowledge on other innovative sea lice control methods such as the use of freshwater treatments, thermolicers, brush systems and the possible use of closed containment in the early production stages.

Government and Industry Commitment to Improved Management

The Aquaculture and Fisheries (Scotland) Act 2007 (AFSA) requires that satisfactory measures are in place for the prevention, control and reduction of sea lice. The Scottish Government committed to review the interpretation of 'satisfactory measures' under AFSA 2007 and, in co-operation with the industry, has created a new sea lice management policy. This will work alongside the recommended treatment criteria in the CoGP with farms now being required to report to Marine Scotland's Fish Health Inspectorate when set sea lice levels are reached.

All farms are now required to produce a site specific escalation action plan, to be triggered at levels above 3.0 adult female lice per fish. This reporting system will allow increased monitoring during any escalation in sea lice numbers and intervention where it is demonstated that satisfactory measures to control sea lice are not in place. Exceeding a level of 8.0 average female adult lice per fish will result in enforcement action, including the potential to require reduction in biomass.

The Scottish Government has worked co-operatively with the aquaculture industry to agree this new policy and the industry in turn is also revising their own integrated sea lice management strategy. This will lead to future updates to the industry CoGP.

Research and Future Interaction Management Improvements

In 2014, the Scottish Government published its Aquaculture Science and Research Strategy as an output from the Ministerial Group for Sustainable Aquaculture and is providing the best science in order to address the issue of sea lice management in Scotland (http://www.gov.scot/Resource/0045/00456584.pdf). This includes sea lice dispersal modelling of the Loch Linnhe system, one of the largest management areas in Scotland, and the recent publication of the Scottish Shelf Model (SSM).

In light of the SSM and dispersal modelling, the Scottish Government together with the industry has committed to review the boundaries of Farm Management Areas to ensure that they are optimal for sea lice management. Latest science is also informing new planning advice being issued by Marine Scotland, including measures to protect Special Areas of Conservation and Marine Protected Areas as recognised by Scotland's National Marine Plan, providing additional safeguards for wild salmonids.

Marine Scotland has embarked on a long-term programme of strategic research to investigate potential risks to wild salmon from sea lice in the Scottish coastal environment. It will complement and extend an existing project currently being undertaken through the Scottish Aquaculture Research Forum, looking at the scale of sea lice impacts on numbers of wild salmon returning to spawn. The objectives of the programme are to inform on interactions and impacts of sea lice of aquaculture origin on wild salmon populations and to develop principles and tools which can help to improve management of sea lice on farms and reduce levels in the environment.

Future Vision for the Scottish Aquaculture Industry

Aquaculture is an increasingly important industry for Scotland, helping to sustain economic growth in some of our most fragile rural, coastal and island communities, contributing towards local and international food security challenges and is a leading example for Scottish food and drink industries.

A challenge exists in growth capacity in in-shore environments where it is important to share resources responsibly and allow growth of all marine sectors, whilst safeguarding the natural environment. In the shorter term, it is expected that expansion of the aquaculture industry will occur in higher energy, more exposed sites. Coupled with

improved sea lice management, the added capacity of commercial cleaner fish production, new cage technologies and innovative production methods, the industry will aim to achieve its 2020 sustainable production targets under improved management in a shared space, beginning to design out current sustainability challenges.

In the longer term, the Scottish Government will engage with the aquaculture sector to enable expansion of the aquaculture industry further off-shore into the open sea using innovative engineering and design. Salmon producing nations will continue to share knowledge to allow industry development. Expansion into off-shore waters should reduce interactions with migratory fish, and help to mitigate against some of the current fish health issues, including sea lice management.

The Scottish Government will continue to support the sustainable growth of the Scottish aquaculture industry alongside a thriving recreational fisheries sector and continue to promote futher reduction of fish farm escapes and better management of sea lice.

CNL(16)44

Aquaculture management in Canada: Advancing NASCO's international goals

Paper presented by Mr Éric Gilbert, Fisheries and Oceans Canada

Overview of Canada's salmonid aquaculture in the North American Commission area

As a Party to NASCO and a member of the North American Commission, Canada supports NASCO's international goals to minimize impacts of aquaculture on wild Atlantic salmon, as expressed in the Williamsburg Resolution. Canada recognizes that interactions between farmed and wild Atlantic salmon must be avoided where possible and minimized and mitigated if they do occur.

We also recognize that aquaculture is an important food production system and a significant contributor to stable economic prosperity in many rural and coastal communities and to an increasing number of Indigenous peoples.

Canada's regulatory regime, at both the federal and provincial levels, can respond best to environmental risks presented by aquaculture activities when these risks are characterized using the best available scientific information and peer-reviewed science advice. Management's decision-making processes are informed by scientific advice so that levels of risk are clearly established and precautionary approaches that protect aquatic ecosystems and the species that depend on them are adopted.

In Atlantic Canada, provincial and federal governments share management responsibilities in a well-integrated system. Fisheries and Oceans Canada (DFO) is the federal lead in ensuring that aquaculture is managed sustainably across the country under the *Fisheries Act*, including where the provincial government has a lead leasing or licensing role. DFO has a regulatory role in protecting the environment and supporting the sector's economic prosperity. Provinces in Atlantic Canada issue aquaculture leases and licences. They use their own regulations and conditions of licence for day-to-day management including, for example, reporting of escapes, fish health monitoring, setting standards for containment structures, collecting information and maintaining records. Industry also has responsibilities through various Codes of Practice.

Although Atlantic salmon and rainbow trout are grown in the marine environment in Canada's part of the Commission area, natural biophysical and environmental conditions in the majority of the Atlantic region are not favourable to marine salmon aquaculture (Figure 1). These areas are, therefore, *de facto* exclusionary zones in as much as no aquaculture can or will be carried out along these coasts.

Figure 1: *The grey-shaded areas represent natural Atlantic salmon aquaculture exclusion zones, dictated by biophysical characteristics of the coastal environments*

Salmon farming is concentrated in the southwest portion of New Brunswick, on the south coast of the island of Newfoundland and

along the Atlantic coast and outer Bay of Fundy of Nova Scotia (Figure 2). In 2014 (the last year for which data are available), 30,000 tonnes of salmonids with a farm-gate value of $209.8 million were produced in these three provinces.

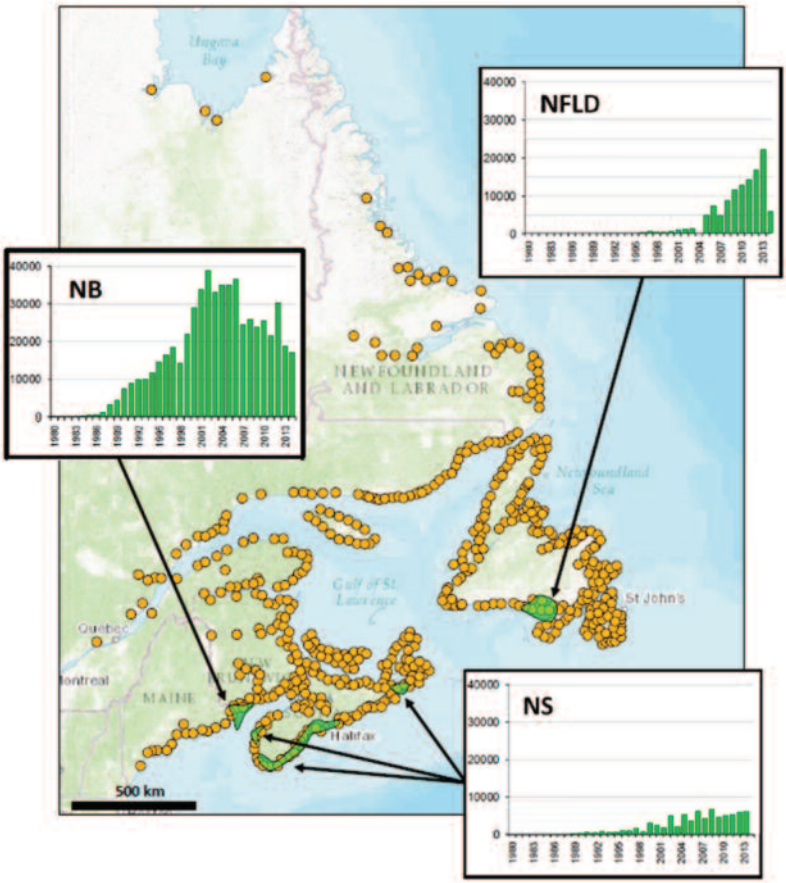


Figure 2: *Distribution of Atlantic salmon rivers in eastern Canada indicated by orange circles. Atlantic salmon aquaculture sites are indicated with green shading. Salmonid aquaculture production (in tonnes) by year from the salmon producing areas in New Brunswick, Nova Scotia, and Newfoundland from 1980 to 2014 is shown by the insets*

Conservation and protection of wild species and the aquatic ecosystem are the first and most important responsibilities of DFO. The federal government and the provinces use responsible and science-based processes for developing policy and making decisions related to siting, management of sea lice, aquatic animal health, genetic and ecological interactions and containment to establish and

maintain the conditions that allow for sustainable aquaculture development, while protecting ecosystems and wild species, including wild Atlantic salmon.

Approach to siting in Atlantic Canada

Siting is one of the most important mitigation measures that governments can use to minimize aquaculture impacts. Many of the potential impacts of aquaculture can be mitigated by applying good siting criteria (e.g. minimizing exposure to wind, avoiding proximity to commercial fishing grounds or currently populated wild salmon rivers, etc.) that are based on the biological and physical processes that characterize potential sites.

Because there are significant concerns with some populations of wild Atlantic salmon in the region, all proposed new sites and applications for expansion are assessed for their potential to result in interactions between wild and cultured salmon. DFO also estimates a site's risk to fish habitat. Where there are significant conservation concerns regarding the status of wild Atlantic salmon stocks, the protections of the *Species at Risk Act* are applied. The Introductions and Transfers Committees oversee and recommend approvals for movement and stocking of fish using assessment criteria based on fish health, genetics and habitat considerations of the receiving marine and freshwater environments. Eggs are certified as disease-free and smolts are healthy when transferred to the marine environment.

DFO's *Fisheries Act and the Aquaculture Activities Regulations* (AAR) are daily operational tools used to manage the direct impact of sites on the marine environment. Under the AAR, licence applicants must provide comprehensive information to DFO related to the predicted contour of the footprint of the biochemical oxygen-demanding matter that will be deposited during farming operations, together with information on the fish and fish habitat on the seabed and in the water column of the proposed farm site. After all risks have been evaluated, siting advice is provided to provinces which then make the licensing decisions.

Management of sea lice in Atlantic Canada

It is generally accepted that the vast majority of wild Atlantic salmon mortalities occur at sea. The ICES Report of the workshop on possible effects of salmonid aquaculture on wild Atlantic salmon populations in the North Atlantic (March 2016) concluded that the downturn in

survival of Atlantic salmon during their marine phase 'is evident over a broad geographical area and is associated with large-scale oceanographic changes.' This phenomenon has been observed in Atlantic Canada where declines in returns of wild salmon have occurred throughout the entire region, even where there is no, and has never been any, marine salmon aquaculture. However, declines have been more severe in the southern regions of eastern Canada.

As noted in the ICES advice, population-level effects of sea lice on wild salmon stocks cannot be estimated independently of the other factors that affect marine survival. At the same time, there is growing evidence that effective sea lice management contributes to more efficient aquaculture production and reduces the risks of negative interactions with wild Atlantic salmon. Effective sea lice management integrates farm-based systematic monitoring of sea lice abundance on fish with approaches for reducing the sea lice burden. All provinces in Atlantic Canada where salmon are farmed in the marine environment have regulations and/or conditions of licence in place to monitor sea lice and the use of therapeutants.

In Canada, any product used to treat sea lice must be registered with Health Canada under the Food and Drugs Act (for in-feed control products) or the Pest Control Products Act (for bath treatment control products). An environmental risk assessment is conducted before any pesticide product is authorized for sale and on-label use. Once authorized, federal and provincial governments add further requirements governing how products can be deposited.

Nationally under the *Aquaculture Activities Regulations*, licence holders are required to notify DFO regarding their intent to deposit pesticides and to report annually on their use of drug and pest control products. Information on deposits of substances collected through the *Aquaculture Activities Regulations* will be publicly reported, with the first report becoming available in early 2017.

In addition, DFO uses its scientific and research capabilities to study sea lice and their possible impacts on both farmed and wild salmon (see www.dfo-mpo.gc.ca/aquaculture/sci-res/species-especes/sea-lice-poux-eng.htm). Some research activities are conducted within the Department while others are conducted in collaboration with scientists and researchers from universities or governments across Canada, industry and international partners. Numerous studies have been conducted in the Atlantic and Pacific to look at effects of sea lice on wild salmon, including:

- modelling in support of sea lice management, genomics studies of host-parasite interaction, and other issues;
- measuring and modelling the transport, dispersal and dilution of therapeutants;
- estimating the potential for effects on non-target organisms;
- measuring the degree of therapeutant mixing within treatment containers and the implications to therapeutant efficacy; and
- developing and/or evaluating innovative alternative control measures that could replace the use of chemicals.

Sea lice are ubiquitous in the marine environment. Sea lice abundance in the wild rises in the spring in association with warming water temperatures and decreases in winter as annual temperatures reach their minima. The greatest risks of adverse effects from sea lice are on the smaller and early marine migration phase of juvenile Atlantic salmon. Wild Atlantic salmon smolts migrating out from rivers between mid-April and early June would likely encounter the initial build-up of sea lice as they become physiologically more active in the warming sea temperatures in late spring (i.e. >5oC). This situation is even more challenging for the smolts that remain close to shore where they are also susceptible to a variety of other stressors.

On salmon farms where sea lice abundances are amplified, the aquaculture industry undertakes mitigation strategies as part of management programs to keep sea lice abundance low during the warmer months (late April - October). Based on advice from veterinarians, operators may also employ the strategic use of chemotherapeutants as necessary. In choosing which therapeutants to use, veterinarians base their decisions on a range of biological and environmental factors and product characteristics.

Adult salmon returning to rivers to spawn in the spring (and in the fall in some regions) are unlikely to be significantly affected by sea lice as lice cannot survive in freshwater environments. Additionally, these larger mature salmon are less impacted by sea lice infestations although mortalities can still occur.

Figure 3 shows that smolt out-migrations and returns of adults to rivers in Canada's Atlantic region occur at times when sea lice abundance is at its hypothesized natural peak in the wild but at its lowest levels on farms because of treatment.

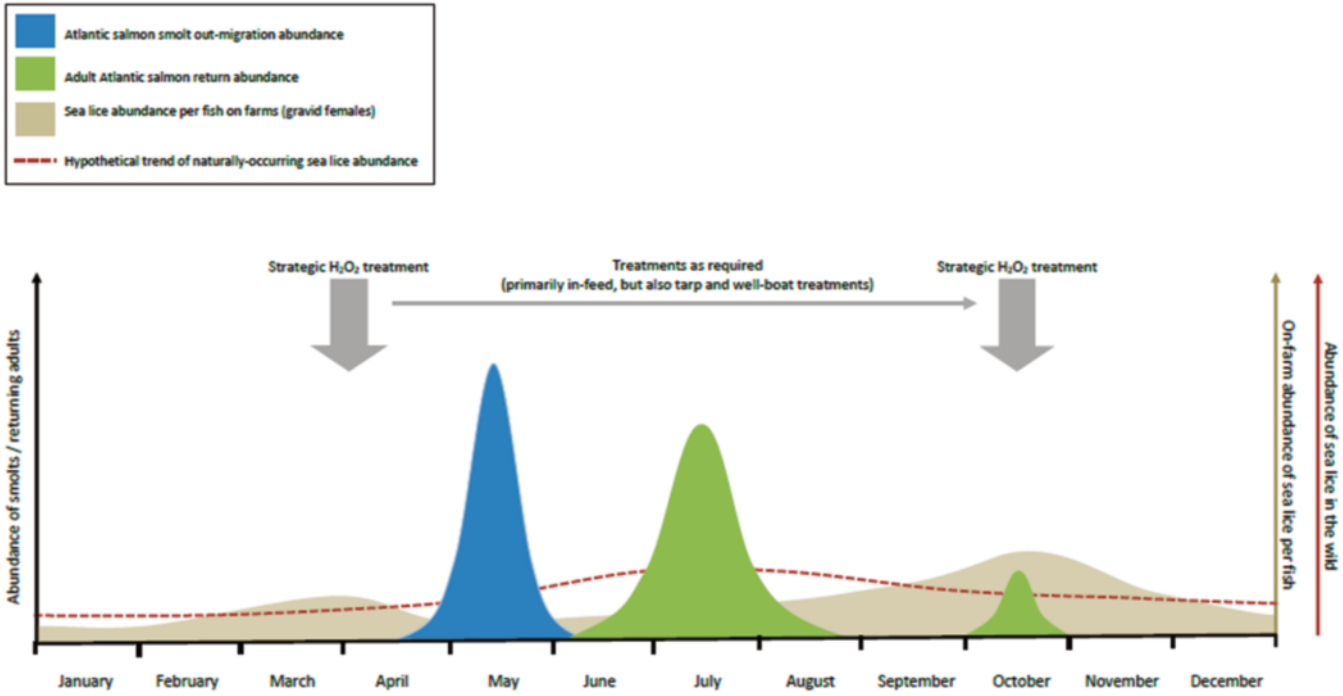


Figure 3: *Generalized abundance trends for Atlantic salmon smolt out-migration and adult returns in Atlantic Canada, gravid female sea lice per fish on Atlantic salmon farms and a hypothesized trend for naturally occurring sea lice abundance per wild fish*

The need to develop treatments for pests and pathogens that are effective but have minimal environmental impacts is a challenge for all salmon-farming jurisdictions. In the past, Canadian companies had access to only one in-feed drug to control sea lice. Over the past eight years, emergency registrations of pesticides made additional treatments available, although these have also posed risks. Due to the decreasing efficacy and environmental impact of both drug and pesticide treatments, companies and governments have continued to invest in research to explore a variety of methods for the control of sea lice on farmed fish, including new and experimental approaches such as warm-water showers, vaccines, or the use of cleaner fish.

Recently, full registration of hydrogen peroxide has provided another, more benign option for treatment of sea lice. In Atlantic Canada in 2013, Salmosan® and Paramove® were used to treat sea lice events but 99% of the volume of treatment product used was Paramove®, the active ingredient of which is hydrogen peroxide.

Canada will continue to manage potential aquaculture impacts from sea lice on wild Atlantic salmon populations through rigorous and scientifically-informed regulations, applied at both the federal and provincial levels. To support this objective, on-going, systematic monitoring of wild juvenile salmonids should be evaluated in order to assess the efficacy of sea lice management strategies, while taking into consideration the conditions imposed by the at-risk status of Atlantic salmon in some provinces and sub-regions.

Managing escapes through effective containment

Canada agrees with the NASCO objective, expressed in the Williamsburg Resolution, of minimizing escapes of farmed salmon 'to a level that is as close as practicable to zero.' Indeed, it is always the objective of regulators and farmers to ensure that 100% of farmed salmon are retained on all production sites as escapes represent a significant economic loss to fish farmers.

Effective containment techniques and prompt reporting of breaches are essential to reducing and eliminating competition for food and potential genetic interactions between wild and farmed Atlantic salmon. Consequently, every effort in the areas of technology, science and regulatory enforcement is being employed to ensure that containment structures are strong and breaches are reduced to the lowest level possible, even though the impact of genetic introgression of farmed fish on wild population fitness is currently unknown.

Containment practices are managed by provincial authorities in Atlantic Canada by means of regulations, conditions of licence, and adherence to codes of containment. All provinces require cage structures to be designed, installed and maintained to limit the risk of a breach. DFO has undertaken analyses and provided scientifically peer-reviewed advice on the technological, oceanographic and training considerations that are critical to the design of net pen containment structures to optimize structural integrity and therefore minimize the likelihood of breaches.

If and when breaches do occur, companies must implement pre-developed and approved response protocols and report to provincial authorities within a prescribed period of time. Industry has additional responsibilities established through Codes of Containment. In New Brunswick and Nova Scotia adoption of the Code is voluntary; in Newfoundland it is incorporated by reference into conditions of licence. In the event of an escape, DFO must be notified so that recapture licences can be issued, should recapture be a viable option.

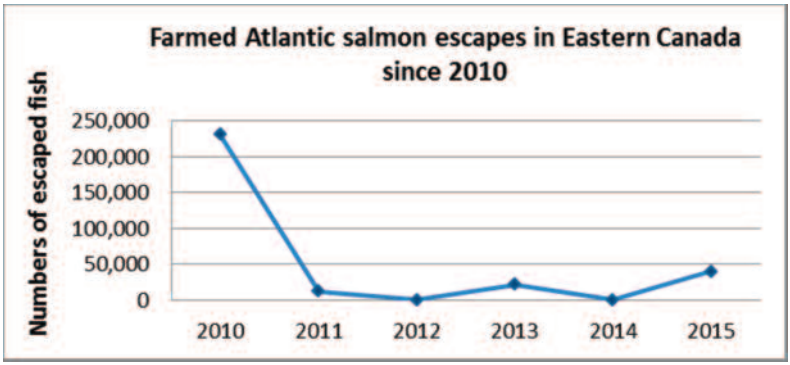


***Figure 4**: Reported numbers of farmed Atlantic salmon escapes in Atlantic Canada reported to NASCO through the North American Commission, 2010 -2015*

Data on salmonid escapes are reported to NASCO annually through the North American Commission (Figure 4). Accounting for inventory in marine cages remains a difficult task. Large breaches are readily identified and reported but trickle losses from marine production are difficult to estimate. Moreover, recapture programs for escaped salmon in the marine environment are not generally effective.

All provinces and stakeholders have worked, and continue to work, to reduce escapes. New Brunswick has revised its Governance Framework for Containment and is working on changes to its

Aquaculture Act and General Regulations. The Government of Nova Scotia's new Aquaculture Management Regulations require finfish licence holders to include a containment management strategy in their Farm Management Plans. This strategy must be audited annually by a third party and immediately following any reported breach. Marine cage site designs must also be approved by a qualified engineer before deployment. The Newfoundland and Labrador Code of Containment, reviewed annually, continues to be implemented as a condition of the aquaculture licence. Discussions continue on developing a Pan-Atlantic approach to containment.

The Government of Canada is neutral on the technological approach for environmental challenges; it sets performance and outcome standards through policy and regulations and leaves it to industry and innovators to find and implement optimal technological advances. DFO has made significant scientific and financial contributions to a number of different types of containment projects, including the development of closed-containment technology. However, based on all the information available, particularly data coming from a DFO-funded closed-containment facility in British Columbia, this technology is not yet ready for commercial application.

The Williamsburg Resolution encourages the use of reproductively sterile salmonids provided the risk of adverse effects on wild salmon stocks is minimal. The use of triploids presents the opportunity to significantly decrease the risk of successful inter-breeding between wild and farmed Atlantic salmon. Furthermore, improvements in technology have resulted in considerable success in achieving high levels of triploid induction. Moreover, the production of all-female triploids offers the further advantage of minimizing potential ecological interactions from escapees, such as competition for reproductive resources.

Conclusion

Canada is committed to working collaboratively with all salmon-producing countries to share best practices. Every year since 2008, Canada, Norway and Scotland have met to discuss aquaculture management practices based on science advice that supports regulatory decision-making, particularly with respect to salmonids. In 2012, Chile joined this group and, in 2015, the four countries signed a Joint Statement on Aquaculture. The Joint Statement supports further collaboration and sends an important signal that the four governments are working together to raise the bar for sustainable

aquaculture management in each country.

DFO is committed to on-going engagement with provinces, territories, Indigenous nations and all stakeholders. Furthermore, DFO is committed to transparency in public reporting and accountability in the management of the sector. We are aided in these respects by the efforts of industry whose members have taken additional steps to become certified to rigorous and credible third-party standards that include the four pillars identified by the FAO as necessary for responsible aquaculture: food safety, animal welfare, environment and social responsibility. All salmon production entering the market from companies in the Atlantic region is certified according to these criteria. Most companies also produce annual sustainability reports documenting their management practices and progress towards identified objectives.

The current Canadian management approach has provided federal and provincial regulatory authorities with a framework through which to identify the impacts of aquaculture on the conservation of Atlantic salmon, their habitat, dependent ecosystems and environmental sustainability. However, there remains an on-going and crucial need for improved knowledge to enable the implementation of stronger and better-integrated monitoring programs for sea lice and genetic interactions. In particular, we need to be able to discriminate aquaculture impacts from those of other human and ecological impacts as they affect wild salmon populations. This knowledge could be used to inform the assessment of environmental risks, the choice of effective indicators to monitor impacts and the establishment of acceptable tolerance levels.

To that end, DFO and provinces will continue to work on:

- minimizing interactions between farmed and wild species;
- implementing and enforcing regulatory regimes to maintain the overall risk from aquaculture at a minimal and acceptable level;
- encouraging best management practices, making use of all new scientific knowledge and innovative solutions;
- studying, modelling and assessing the risks and impacts of pathogen and sea lice transmission between wild and farmed salmon, the fate and effects of sea lice pesticides on non-target organisms and alternate tools for the management of diseases and sea lice;

- conducting studies on the fate, influencing factors and genetic and ecological impacts of escapement; and
- developing genetic tools to identify the genetic profile of Atlantic salmon (i.e. wild stocks, escapes and wild-escape hybrids).

Collectively, these will contribute towards Canada's management of a sustainable aquaculture sector, while meeting various international obligations to conserve and protect wild Atlantic salmon and minimize impacts on them from all sources.

CNL(16)51

Progress and challenges in achieving NASCO's international goals in the Faroe Islands

Paper presented by Mr Roar Heini Olsen, Faroese Food and Veterinary Authority

The rocky archipelago of the Faroe Islands is located at 62°N and 7°W with major feeding grounds for Atlantic Salmon *Salmo salar* L. to the north and yet there is no historical record of its rivers supporting any natural wild salmon population. This is presumably due to the rivers having small catchment areas, shallow and unstable water levels and at times temperatures close to or above lethal limits for salmon.

From 1947, Atlantic salmon fry originating from Icelandic rivers have been released into several Faroese rivers and, since 1950, anglers have been able to catch salmon. In 1963, a hatchery was built, whereafter fertilised salmon eggs have been imported and approximately 30,000 locally hatched fry released into local rivers annually or biennially. During the 1980s, salmon roe from Norway was also introduced to the stock in the Faroes and fish ladders have been built to facilitate the inland migration of salmon.

Commercial fishing for Atlantic salmon in the waters around Faroe Islands commenced in 1968 and the catch was approximately 40 tonnes or less annually until 1978, when catches increased to approximately 500-600 tonnes peaking at more than 1,000 tonnes in 1981. Since the establishment of NASCO in 1984, the fishery for Atlantic salmon in the Faroese Fisheries Zone has been managed in accordance with regulatory measures/decisions agreed within NASCO. Since 1991, the Faroe Islands have refrained from conducting a commercial salmon fishery within its fisheries zone in order to contribute to the conservation and re-building of salmon stocks in the North Atlantic.

Faroese coastal waters offer excellent conditions for farming Atlantic salmon, providing stable temperatures from approximately 5-12°C and high currents which ensure good sea water exchange, oxygenation and removal of faeces and feed waste. Perhaps not surprisingly, farming of salmon accounts for up to 40%, or more in some years, of Faroese export earnings, the bulk of the remaining exports being wild caught fish.

Overview of the Faroese aquaculture industry

Historical records indicate interest in and possible attempts to introduce aquaculture to the Faroe Islands as early as 1886-87, the outcome of which is unknown. The first documented aquaculture activities were in the early 1950s with farming of rainbow trout, *Oncorhynchus mykiss*, in on-shore ponds by pioneers Elith Godtfred (1915-58) and Menning Geyti (1912-88).

In the mid and late 1960s a report by Andrias Reinert, a government official at the Fishery Research Institute, led to new interest in aquaculture and trial rearing of rainbow trout in sea cages by fisher and skipper, Just í Túni (1919-95), who co-founded the Aquaculture Research Station of the Faroes, Fiskaaling, in 1970. This research station is now publicly owned.

By 1971, Norwegians had shown that the Atlantic salmon was better adapted to aquaculture production and in 1973 Just í Túni hatched the first batch of Atlantic salmon eggs in the Faroe Islands and stocked smolts to sea in 1975. At the same time, Atlantic salmon breeding material was obtained from the new Norwegian breeding programme, which later formed the basis of a Faroese programme under the Aquaculture Research Station, initially with 120 and later 400 families.

Aquaculture did not, however, emerge as an industry in the Faroe Islands until 1980, initially with 6 companies but, following high prices in the mid 1980s, expanding to 50 companies and later more than 70 with facilities at sea and 20 smolt stations on land. By this time, aquaculture was seen as a component of local development with local villagers, fishermen and farmers being eligible for leases and goverment funding (Hovgaard, 2015), although most were unable to take advantage of these incentives in the longer term.

During the 1980s and 1990s, rapid expansions in the industry were followed by equally rapid collapses in the wake of major outbreaks of parasites and diseases such as Infectious Pancreas Necrosis (IPN), Hitra Disease, Furunculosis, Costiasis and later Bacterial Kidney Disease (BKD). There were also simultaneous problems with algae and, from around 1984, salmon lice (*Lepeophtheirus salmonis* L.). Price fluctuations and a general long-term decline in prices also took their toll and resulted in a gradual reduction in the number of companies operating at sea to approximately 20.

From 1985, imports of live salmonids and their gametes were banned and, to some extent, this may have slowed the introduction of exotic diseases. Since the ban was lifted in the early 2000s, the local market proved too small and unstable to support a Faroese breeding programme, which was abandoned in favour of imported fertilised roe from the Icelandic and Norwegian breeding programmes. Today, Fiskaaling maintains a female stock and receives semen from SalmoBreed in Norway, providing a proportion of the roe for the Faroese aquaculture industry. Fiskaaling also offers research-related services to the aquaculture industry e.g. monitoring for sea lice and establishing profiles of sea currents and wave time-series to support advice on location and dimensions of fish farms as well as other aspects relevant to decision-making.

Following an outbreak of Infectious Salmon Anaemia (ISA) in the early 2000s, Faroese aquaculture legislation was strengthened to meet international recommendations and standards including mandatory all in/all out production, fallowing and disease prevention management such as provisions on maximum biomass/m^3. In the wake of a near total collapse of the industry, exacerbated by simultaneous low prices, only 4 companies remained, the largest of which currently owns half of the leases and accounts for 70-80% of salmon exports.

Slaughtered weight (tonnes) of Atlantic salmon, *Salmo salar*, and Rainbow trout, *Oncorhynchus mykiss*, from 1997 - 2015										
Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Total	17947	16858	35149	28660	40545	46896	52269	38191	19593	15662
Salmon	16651	15724	32187	27477	37731	36861	43071	33608	15549	10728
R.Trout	1296	1134	2963	1184	2813	10034	9198	4583	4044	4934
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Total	25173	38272	48622	39012	49588	62783	63338	70893	66090	
Salmon	18290	31565	42134	37221	49588	62783	63266	70893	66090	
R.Trout	6883	6707	6488	1791	-	-	72	-	-	
Source: Hagstova Føroya (Statistical Bureau of Faroe Islands) www.Hagstova.fo										

Table 1: *Weight in tonnes of harvested Atlantic salmon and Rainbow trout from 1997 to 2015*

The production in tonnes does not, however, seem to correlate well with changes in number of smolts put to sea, the number of fish at sea or the stocking density for the following reasons (courtesy of Avrik/Rúni Dam):

- the live weight per salmon at harvest was approximately 5 kg in the late 1990s and 6.6 kg in 2015;

- annual mortality at sea, including escapees, was 12% - 28% in the late 1990s and 5% - 12% from 2007 to 2015;
- from 2000 to 2002 approximately 20 million smolts were put to sea annually but the number is curently approximately 15 million annually;
- the average weight of smolts put to sea was approximately 50g in the late 1990s and approximately 170g in 2015;
- the average production time in sea cages to a weight of 6kg was 19 months in 2008 and 16 months in 2015;
- the average number of days from stocking to harvest at each production site declined from 714 in 2008 to 612 in 2015; and
- the average stocking density was up to and above 25kg/m^3 in late 1990s and is currently 7-9kg/m^3.

It appears that strict compulsory management regimes, improved theoretical knowledge and benefits from there being fewer companies involved have transformed the aquaculture industry and enabled producers to take advantage of the excellent conditions that exist for farming of salmon in the Faroe Islands. In most financially significant aspects such as feed conversion ratio, mortality, production cost, quality, price and profitability, the Faroese aquaculture industry now appears to be in the lead to the extent that in 2015, Faroese cultured salmon sold for a premium of about €1/kg compared to Norwegian farmed salmon (Kontali Analyse, 2016). In spite of all the progress, 'earthly trees are not known to grow into the heavens....'.

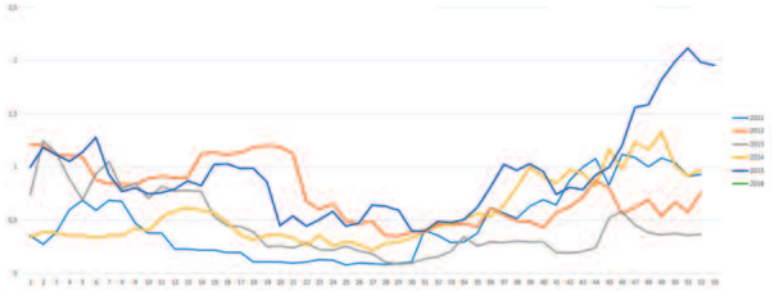
Salmon lice

As in other countries, Faroese aquaculture is struggling to address infestations of salmon lice, the cost of which is approximately €0.5/kg including prevention, treatment and losses. Sea lice, of course, pose threats to both wild and farmed salmon by stressing the fish and rendering them susceptible to pathogens. In general, sea lice are the most serious veterinary challenge facing Faroese aquaculture because of the following factors:

- increasing immunity/resistance to treatment;
- relatively few therapeutic options;
- effective treatment doses near toxic/lethal levels to salmon;
- recurrent treatment and treatment at high dosage affect the welfare and resilience of salmon;

- the early life-stages of lice spread throughout the islands within a fortnight (the total size of the Faroe Islands is such that they would comfortably fit within a single fjord system of neighbouring countries); and
- the same species/strain of lice occurs throughout the islands leading to lasting immunity.

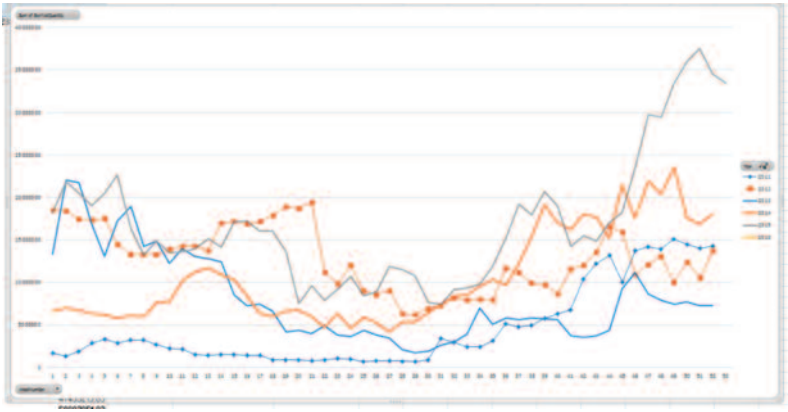
Average no. of lice per fish



Week no.

Figure 1: *The average number of lice/fish each week for the period 2011 to 2015*

Total number of lice



Week no.

Figure 2: *The total calculated number of lice each week for the period 2011 to 2015*

As may be observed, the number of lice/fish tends to decrease in the spring and summer and to increase in the fall. The unusually high increase in late 2015 is mainly due to ineffective treatments at a single producer, exacerbated by a lack of capacity for immediate

slaughter of the infested fish. In spring 2016, the average number of lice per fish was within the level found in the spring during 2011 to 2014.

Year	Breaches	Countings
2009	0	2
2010	4	80
2011	16	183
2012	32	357
2013	23*	555
2014	45*	469
2015	63	470
2016	4	15

*Note: *In 2013 and 2014, treatments were co-ordinated, at first appearing to lower infestation, but also to lead to increased immunity/resistance towards therapeutics*

***Table 2:** Counts of sea lice and number of breaches annually from 2009 to present*

As may be observed, there were 63 instances of farms breaching the threshold in 2015.

The main elements of the current provisions relating to sea lice are as follows:

- all farms must have a veterinary consultant (internal or external) and an effective management plan for the impediment of lice infestation;
- at each farm and in each unit, counting by an external independent party of sexually mature females, both motile and sessile lice of the species *Lepeophtheirus salmonis* and *Caligus elongatus*, is mandatory at fortnightly intervals from 1 May - 31 December and monthly from 1 January - 30 April. The requirement that counts be made by an independent party provides reliable information which can be used both as a basis for veterinary decision making within the companies and by the Chief Veterinary Officer (CVO);
- the data are to be available to the CVO no later than the day after the counts are made. In practice, these data are entered into a database available to/shared by the CVO; and

- the sea lice threshold used to trigger control measures is currently 2 adult female lice or 10 developing mobile lice per fish.

If the threshold is reached or exceeded, the following actions are to be taken:

- immediate mandatory notification of the CVO;
- immediate mandatory treatment in all fish units in the farm to be concluded within a fortnight and, if the CVO so demands, in all farms and units in the same fjord and/or nearby fjords;
- mandatory evaluation and new counting immediately after each treatment;
- mandatory scrutiny of the cause of ineffective treatment (each farm must have an internal or external veterinary consultant); and
- mandatory reporting to the CVO of ineffective treatment, suspicion of immunity/resistance or other inconsistency with anticipated results.

The CVO may demand additional or more frequent counting and counting of other species of lice and co-ordinated fallowing of nearby fjords if considered necessary to impede lice infestations. Exceptions or postponement of such treatment may be allowed by the CVO:

- if the breach is diminutive and other effective action is likely to lower the infestation;
- if co-ordinated treatment with other farms is imminent; or
- in case of imminent slaughter.

In the case of ineffective treatment, other agents/treatments are to be used. In the event that these also prove ineffective, the CVO can order other action to be taken including imminent slaughter or destruction. In the case of elevated infestations, disproportionately frequent or incomplete/defective treatments, the CVO may freeze or decrease the number of smolts put to sea in the following production cycle.

In addition to mandatory requirements, the following actions were taken by the CVO in 2015:

- demanding imminent slaughter in 5 cases;
- reducing the permitted number of smolts put to sea in early 2016 by 30% in one case;

- reducing the permitted number of smolts put to sea by 10% in 2 cases (1 in 2015, 1 in early 2016);
- denial of 2 applications to increase the number of smolts put to sea (1 in 2015, 1 in 2016); and
- exemption from treatment due to slaughter in one case.

Due to the increasing number of breaches and taking account the fact that research, former and new treatment regimes, empiric results and regulatory instuments have proven to be beneficial, a new proposal for firmer legislative action has been prepared (and subsequently put into force). It includes the following:

- lowering of the treatment threshold to 1.5 sexually mature female lice per salmon;
- allowing treatment on a cage by cage basis at this threshold (or voluntarily at lower thresholds); and
- making the threshold absolute with breaches automatically leading to immediate mandatory slaughter and restrictions on future stocking.

In addition to owners realising and following their own best interest, limitations on the number of smolts to be put to sea in the following production cycle may be seen as being among the most efficient tools to secure adherence to regulatory requirements.

Voluntary co-ordinated treatments were jointly undertaken by the aquaculture industry in 2013/14 leading to a preliminary decline in the number of sea lice. However, this also resulted in immunity/resistance to the drugs used, likely contributing to the recent increase in resistance. Thus, new approaches are needed both in the legislation and available treatments.

Accordingly, research and development is on-going, much of it by the Aquaculture Research Station of the Faroes, Fiskaaling, which has *inter alia* developed methods for mapping the spatial distribution of sea lice in its pelagic state (Nauplii and Copepodites) and for *in situ* estimation of naupli production at farm sites. This field effort is combined with mapping of lice distribution using hydrodynamic models.

Aquaculture companies also develop and test new approaches. Recently, lumpfish, *Cyclopterus lumpus* L., have been stocked in cages to combat lice and this approach is increasing in use. Although control is not 100% effective, the use of lumpfish may help limit

infestations. Breeding of better adapted lumpfish for use in aquaculture and with a higher appetite for salmon lice is under consideration.

As elsewhere, other approches to lice control have also been introduced, or are under consideration, including laser cannon, counter-current sea lice removers, freshwater treatment, post-treatment sea lice collectors and, not least, increasing size of smolts stocked so as to further reduce the production cycle at sea.

Escapes

Related to NASCO's sphere of concern are occasional events of escapes of farmed salmon. Given the financial implications of escapes, the prevention of such incidents is undeniably in the best interest of aquaculture farms.

Reporting of escapes to the CVO is mandatory, and farmers are obliged to have a contingency plan in case of escape incidents and to attempt to recapture escapees. Escape incidents mostly occur as a consequence of stormy weather or during handling of nets in relation to delousing and transport to slaughter etc. In such cases, prevention of further escapes, mending of nets and other actions logically become a priority.

With regard to the accuracy of reporting of escapes, it should be noted that in order to obtain insurance settlements for escape incidents, the Food and Veterinary Authority must be notified. Escape incidents are often quantified through reduced feed intake following incidents. Since mortalities are also reported on a daily basis, both to alert the Veterinary Authorities of possible disease problems and for the companies to manage feeding optimally, escapes can also be indirectly verified through calculation of loss of fish at slaughter. Relatively reliable estimates of escapees are, therefore, available with some delay or can be calculated. From 2011 to 2014, the following incidents were reported:

2011: 2 incidents, no information on number/quantity given. Average weight of fish 1.9kg. The incidents are reported to have occurred during delousing treatments and when moving fish into a new net pen.

2012: 4 incidents, with 2,741 fish escaping in two incidents but no numbers were reported for the 2 other incidents. The average weight of escapees was 4.8kg. The incidents are reported to have occurred when moving fish to slaughter, sorting of fish into two net pens and

as a result of storms.

2013: 4 incidents, estimated at 25,000 fish averaging 2.8kg. The incidents are reported to have occurred due to storms during the winter and when moving fish into a new net pen.

2014: 2 incidents estimated at 40,000 fish averaging 4.8kg. The incidents are reported to have occurred during storms and when moving fish into a net pen prior to slaughter. These numbers must be interpreted with some caution since in most cases they are based on decreased food intake in net pens. More accurate numbers may be obtained when the net pens are slaughtered.

The Faroes are small, there are few fjords and these are mostly relatively short, hence production units are increasingly placed in exposed sites, necessitating the strengthening and adaptation of the equipment to endure higher currents and waves. Furthermore, harsh weather conditions, including at less exposed sites, lead to fairly frequent renewal of the equipment. As a result, the latest technological innovations and improvements are implemented, often with improved protection against events which may result in escapes.

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CNL(16)50

Progress and challenges in achieving NASCO's international goals in Ireland

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Paper presented by Dr Cathal Gallagher, Inland Fisheries Ireland

Background

NASCO has adopted agreements and guidelines designed to minimise impacts on the wild salmon stocks. These include the *Resolution by the Parties to the Convention for the Conservation of Salmon in the North Atlantic Ocean to Minimise Impacts from Aquaculture, Introductions and Transfers, and Transgenics on the Wild Salmon Stocks* ('the Williamsburg Resolution', CNL(06)48), adopted in 2003 and *Guidance on Best Management Practices to address impacts of sea lice and escaped farmed salmon on wild salmon stocks*, SLG(09)5, adopted in 2009. The international goals under this guidance are:

- 100% of farms to have effective sea lice management such that there is no increase in sea lice loads or lice-induced mortality of wild salmonids attributable to the farms; and
- 100% farmed fish to be retained in all production facilities.

In 2015, the production of farmed salmon in Ireland was estimated to be 13,116 tonnes (Millane *et al*., 2016). There are twenty active salmon farms in operation in the country, primarily focused on the production of one-sea-winter stock, with 60% of production located along the south-west and north-west of Ireland in in-shore and estuarine waters. Salmon farming accounts for 64% of total aquaculture production in Ireland and is valued at €95million per annum to the Irish economy, with the export component of this valued in the region of €50million per annum (Anon., 2016).

Aquaculture licensing in Ireland primarily falls under the *Fisheries (Amendment) Act 1997.* The Department of Agriculture, Food and the Marine (DAFM) is the sole regulatory authority for aquaculture in the country and the licensing process is administered through the Aquaculture and Foreshore Management Division. The Minister for Agriculture, Food and the Marine has ultimate responsibility to decide on applications made to the Division and statutory consultees have the right to make submissions on any licence applications made.

Strict licensing conditions are set out for the operation of salmon aquaculture facilities. Relevant conditions include:

- that operations are conducted in compliance with international guidelines on containment (as developed by the North Atlantic Salmon Farming Industry and NASCO Liaison Group);
- that equipment (e.g. containment cages) must be fit for purpose and in good working order;
- there is a fallowing requirement before any re-stocking takes place;
- DAFM must be notified within 24 hours of any disease or any abnormal loss or mortalities that occur; and
- DAFM, Inland Fisheries Ireland (IFI) and the Marine Institute (MI) must be notified within 24 hours of any escapes that occur and licensees must keep a record of the numbers of fish that have escaped.

Progress towards goals and verifying compliance for containment: monitoring of escapes in Ireland

In the period 1980 to 2006, salmon catches have been routinely examined to detect the presence of escaped salmon primarily in the commercial drift net catch in the summer season as well as from fish dealers' premises and to a lesser extent recreational landings. Since 2007, with the cessation of the drift net fisheries, scanning for farmed salmon escapees has mainly been conducted on catches taken in estuaries and river systems, notably through trapping facilities located in the lower reaches of river systems used for run counts and broodstock collections.

In addition, the National Coded Wire Tagging and Tag Recovery Programme has facilitated the scanning of large numbers of salmon returning to Irish freshwaters from the marine environment (Millane *et al*., 2016). To ensure that salmon farms have adequate containment facilities in place to minimise the risk of escape, DAFM engineers periodically undertake on-site inspections of installations such as sea cages for structural compliance and correct positioning as specified in their licence.

The identification of escaped salmon is primarily based on morphological variation of external features such as fin, operculum (gill cover), nose morphology or scale analysis which may distinguish between farmed and wild salmon.

The rate of farmed salmon escapees detected in the wild through monitoring has consistently been reported as under 0.5% of the total specimens examined (Millane *et al*., 2016). However, it is important to note that monitoring has been largely restricted to the fishing season with little such monitoring occurring outside this period, particularly over the winter.

In Ireland, official statistics indicate that approximately 415,000 salmon were reported to have escaped from salmon farms in coastal waters in the period 1996-2004. Since 2009, six escape events have been reported. The largest numbers of reports of fish escaping has been in conjunction with storm damage events (35,000 in 2009; 83,000 in 2010; 230,000 in 2014). With regard to the reported escape in 2014, a report on the event is being finalised by DAFM which has advised that 'it is not possible, at this time, to exclude the possibility that fish escaped nor is it possible to quantify the potential number of mortalities versus escapees'.

Other relatively more moderate escape events have primarily been in association with damaged nets (e.g. in one case as a result of a service boat inadvertently breaching a containment net in a sea cage). Such incidences have resulted in the escape of 1,000 and 25,000 in 2010 and 3,500 fish in 2016.

Progress towards goals: National Sea Lice Monitoring Programme

The National Sea Lice Monitoring Programme aims to provide an objective measurement of sea lice (*Lepeophtheirus salmonis* Krøyer and *Caligus elongatus* Nordmann) infestations and inform management approaches to mitigate for these. There are five components of this strategy as follows:

- separation of generations;
- annual fallowing of site;
- early harvest of two-sea-winter fish;
- targeted treatment regimes, including synchronous treatment in bays with more than one installation; and
- agreed husbandry practices.

Separation of generations and annual fallowing aim to prevent the vertical transmission of infestations from one generation to the next, thus retarding the development of lice infestations.

The early harvest of two sea-winter salmon aims to remove a potential reservoir of sea lice infestation. Agreed husbandry practices and targeted treatments aim to enhance the efficacy of treatment regimes. In addition, targeted treatments in the autumn to winter period are intended to reduce sea lice burdens on over-wintering fish to minimise infestation in the following period.

All licensees must adhere to Monitoring Protocols on Sea Lice Monitoring and Control as a licence condition and establish an Integrated Pest Management (IPM) Plan. The latter must contain:

- a fish stocking and lice management plan in consultation with any other farms in a bay;
- a sea lice sampling and monitoring plan during the periods of high infestation;
- measures to minimise use of medicinal/chemical treatments;
- types of treatment used and their administration to ensure effective clearance of lice; and
- product rotation to minimise the risk of resistance developing in lice populations to the active ingredients.

Verifying compliance: Inspection regime for sea lice

All salmon farms are obliged to monitor for sea lice on an on-going basis and to take remedial action where necessary (*Monitoring Protocol No. 3 for Offshore Finfish Farms - Sea Lice Monitoring and Control 2000*). The Marine Institute (an agency under DAFM) manages the inspection regime with monitoring undertaken 14 times per year. This is conducted twice per month during March, April and May to coincide with the 'critical period' of infestation risk for wild salmon smolts as they migrate from Irish river systems out to sea. Throughout the rest of the year, sea lice monitoring is conducted on a monthly basis with the exception of a single monitoring in the December/January period.

During the critical period in spring, Treatment Trigger Levels (TTLs), i.e. where remedial action must be taken to reduce lice levels, are set close to zero (0.3 to 0.5 egg-bearing females per fish) but may also be informed by the numbers of mobile lice per fish. During other periods of the year, TTLs are set at 2.0 egg-bearing lice per fish. Lower TTL thresholds can also be specified for individual licences where it is considered that there is a heightened risk of infestation on wild salmon.

Verifying compliance: Results of lice monitoring in 2015 and long-term trends

In 2015, 212 inspections were conducted by the Marine Institute in the 20 active coastal/estuarine salmon farms in operation in Ireland. Overall, the results indicated that 86% of inspections were below TTLs. This was broken down into 97% compliance for smolts and 78% for one-sea-winter fish. The highest non-compliance (36% - 39%) with TTLs occurred in salmon farms located in the west of Ireland (O'Donohoe *et al*., 2016).

Since TTLs were set in 2000, mean TTLs for ovigerous (egg-bearing) females in the critical period in May have exceeded the threshold for remedial actions in all years except for the year 2001, the period 2011-2013 and the year 2015 (O'Donohoe *et al*., 2016).

Identify particular challenges in achieving NASCO's international goals for sea lice

The following issues have been identified as particular challenges in achieving NASCO's international goals for sea lice:

- farm sites located too close to salmonid rivers;
- mixed year-class production (smolt and grower fish reared in close proximity);
- rearing two-sea-winter fish with difficulty of controlling lice;
- lack of sea lice control due to protracted harvesting;
- lack of synchronised sea lice treatments between sites;
- incomplete separation of generations and insufficient fallowing; and
- fallowing not aligned with wild smolt runs.

Methods to support innovation to develop alternative production techniques to promote sustainable farming

The following methods are proposed to support innovation to develop alternative production techniques to promote sustainable salmon farming:

- use of single generation sites, often in separate bays;
- fallowing before re-stocking (4-6 weeks);
- whole-bay spring fallowing;

- harvesting carried out remote from the grower sites;
- annual synchronous 'winter' lice treatment for all adjacent sites;
- when there is a persistent problem with sea lice control, an incremental series of actions occurs - the 'Management Cell Approach (MCA)'; and
- part of MCA may be compulsory harvesting in March at farms where lice are not controlled. This is not carried out consistently.

Acknowledgements

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CNL(16)43

Progress and challenges in achieving NASCO's international goals for aquaculture in the United States

Paper presented by Mr Rory Saunders, NOAA National Marine Fisheries Service

Background

The United States has strong laws, regulations and policies governing *inter alia* the conservation and management of fisheries resources and their habitat, the protection of the environment and the protection of endangered species. Recovering Atlantic salmon stocks of U.S. origin (that only persist in the state of Maine) is a very high priority for the United States. These populations are critically endangered and are listed under the U.S. Endangered Species Act. Such listing ensures they have the highest legal protection the United States can offer. Eastern Maine is home to many of these salmon populations as well as all the commercial aquaculture facilities that raise Atlantic salmon (Figure 1).

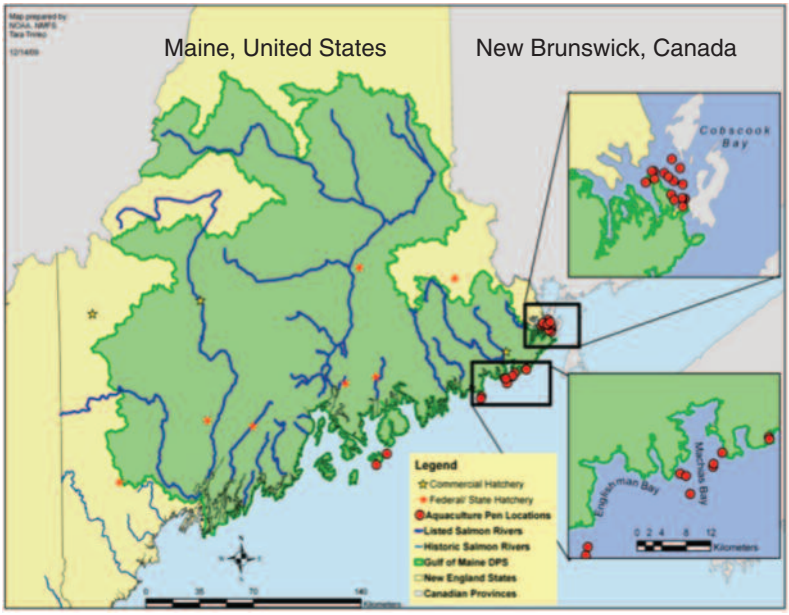


Figure 1: *Location of salmon aquaculture facilities in relation to the freshwater range of endangered Atlantic salmon populations (Gulf of Maine Distinct Population Segment or 'DPS') in the United States*

Given the strict requirements of U.S. environmental laws, the proximity of marine net pens to Atlantic salmon rivers and the precarious state of the salmon populations, the United States takes a careful and considered approach to managing salmon aquaculture operations, an approach that advances the achievement of NASCO's international goals for aquaculture.

Since 2002, the Maine salmon farming industry has significantly changed due to both state and federal regulatory requirements, bay management areas, fish health protocols and change of lease ownerships. In 2003, the implementation of a suite of rigorous management measures began in earnest in collaboration with private industry, the Maine Aquaculture Association and multiple federal and state agencies. The suite of measures implemented pursuant to this process substantially reduced the environmental effect of aquaculture and the risk to endangered salmon populations in Maine and New Brunswick and progress in reducing salmon aquaculture impacts in the United States will be described. This paper focuses on traditional practices involving grow-out from the smolt stage in net pens located in the marine environment but land-based, closed-containment facilities are not considered given the current low production levels in these facilities.

Quantitative information to demonstrate whether or not there has been progress towards NASCO's international goals for sea lice and escaped farmed salmon

Since 2003, the United States has had excellent containment in place with only two potential escape events. Using a number of reporting mechanisms, the United States provides as much information to NASCO as possible on its progress in meeting NASCO's international goals for sea lice and escaped farmed salmon. NASCO's required Annual Progress Reports are perhaps the most important reporting mechanism. In the U.S Annual Report to NASCO, three of the four actions described in the aquaculture section directly or indirectly address the potential effects of sea lice or escaped farmed salmon. Available information on salmonid disease incidences, breaches of containment of salmonids from net cages, salmonid introductions from outside the North American Commission (NAC) Area and summaries of any activities related to transgenic salmon is also provided. These important communication tools, often referred to as 'NAC Reports', are available on the NASCO website (http://www.nasco.int/reports_annual.html). Another important metric tracked on an annual basis is the number of escaped farmed

salmon captured in salmon rivers in the United States. Since the implementation of the suite of management measures from 2003, the number of suspected aquaculture escapees captured in salmon rivers in the United States has declined substantially and has become a very rare event (Figure 2).

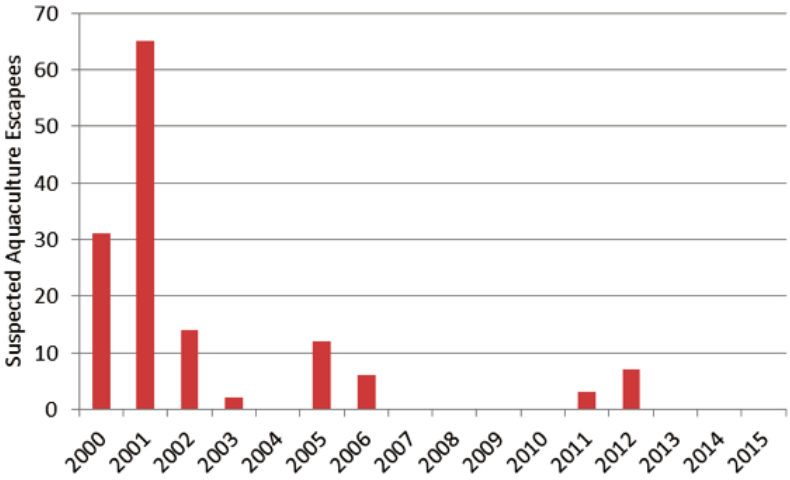


Figure 2: *Number of suspected aquaculture-origin escapees captured in Maine rivers from 2000 to 2015*

Particular challenges in achieving NASCO's international goals for sea lice and escaped farmed salmon

One of the particular challenges faced in terms of managing the impact to salmon in the wild relates to the international border between the United States and Canada. To a large degree, this challenge has been overcome by extensive collaboration and co-ordination among all interested parties on both sides of the U.S.-Canada border, including the regulated industry, industry trade groups (primarily the Maine Aquaculture Association) and multiple state, provincial and federal government authorities. Perhaps the best example of this collaboration is the Finfish Bay Management Agreement, which was formalized through permit requirements and regulations governing the U.S. salmon farming industry in Maine. This agreement is available on the internet at: http://www.greateratlantic.fisheries.noaa.gov/sed/aquaculture/ne/maine_aquaculture_assoc_finfish_bay_management_plan.pdf.

The foundation for this agreement was mutual recognition of the need for co-ordinated management of common bay areas. Under the agreement, the State of Maine and the Canadian province of New Brunswick manage the Cobscook, Campobello and Deer Island marine sites as one management area. There are several benefits to this approach:

1) better co-ordination of site fallows;

2) fewer overlapping year classes in production; and

3) reduced disease transmission between year classes.

This approach is critical to effective disease management and addresses several key factors in minimizing outbreaks of Infectious Salmon Anemia (ISA) and sea lice. This agreement and the associated guidelines also seek to control movements of fish and vessels within the bay to minimize disease transfer between the U.S. and Canadian marine sites. Further clarification regarding the bay-wide fallowing protocols (initially set forth in the Finfish Bay Management Agreement) has recently been provided by the U.S Department of Agriculture's ISA surveillance program (described in more detail below).

Further collaboration with Canada has also recently commenced at a broader level. The National Marine Fisheries Service and the Department of Fisheries and Ocean (Canada) have recently started work on a new initiative (referred to as the Regulatory Cooperation Council) to advance regulatory co-operation in the environmental management of the marine aquaculture sector under three specific work streams:

1) comparing regulatory objectives and outcomes of net pen aquaculture;

2) co-operating on farmed to wild fish interactions; and

3) co-operating on regulatory oversight and management of off-shore aquaculture.

The work of the Regulatory Cooperation Council is on-going; no reports from this work stream are yet available. Progress and timelines can be found at the following website: http://www.nmfs.noaa.gov/aquaculture/homepage_stories/08_noaa_dfo.html.

In providing data to NASCO and other international organizations, the United States must ensure it abides by its legal requirements

concerning confidentiality, which are enshrined in statute. These confidentiality requirements can, in some cases, limit the data that can be made publicly available, which can create a challenge in demonstrating U.S. progress toward achieving NASCO's goals regarding sea lice and escaped farm salmon. To clarify, the 'Rule of Three', must be applied when considering the release of data. This rule requires that any data presented to the public must have been reported by at least three distinct entities, such as fishermen or companies, and be appropriately aggregated before distribution to protect confidential business information. Data that can only be attributed to two or fewer entities may only be shared if the data can be aggregated to a higher level in a way that appropriately protects the confidentiality. Since 2011, only one salmon aquaculture company has been operating in the United States. Therefore, the data cannot be reported directly.

The approach to verifying compliance with regulations and codes of practice in relation to sea lice and escaped farmed salmon

The Atlantic salmon farming industry in Maine is required to employ a containment management system (CMS) at all production facilities supporting commercial salmon aquaculture; this includes both freshwater hatcheries and marine sites. The generic CMS template and framework was developed through collaboration between private industry, public interest groups, environmental NGOs and state and federal agencies. The Maine Aquaculture Association led the effort. These generic plans were used by the hatchery and marine site managers to develop site-specific actions and response plans based on the specific needs of each site. A hazard analysis was conducted to identify critical control points and appropriate equipment modifications needed to eliminate losses from each facility. The site-specific plans were refined during a one-year trial period, at which time state and federal agencies provided oversight to site managers to implement CMS plans at each site. The Maine Aquaculture Association, in co-operation with the salmon farming industry, developed equipment standards (referred to as a Code of Containment) which formed the basis of each plan. The Code of Containment was established using industry expertise and data collected through analyses of load exerted on cages during extreme weather and tide conditions and is available on the internet at: http://www.greateratlantic.fisheries.noaa.gov/sed/aquaculture/ne/me_salmon_code_of_containment_final.pdf.

The major components of the CMS plans include standard operating procedures specific to fish husbandry, stocking, harvesting, predator control, vessel operation, fish transfers, net changes and managing unique events such as storms and winter icing. Reporting of escapes, record keeping (e.g. cage and net numbers), corrective actions and annual training of employees and managers to explain how to implement CMS plans are mandatory components of each plan.

Specific and stringent containment requirements are in place for both freshwater and marine facilities alike pursuant to the CMS plan. Commercial freshwater hatchery facilities located on rivers with endangered salmon populations are required to eliminate losses of juvenile salmon by screening discharges from the hatchery. For example, a three barrier system is required to be installed on the outflow from each facility to prevent salmon from escaping into streams and rivers. For each marine grow-out site, CMS protocols are in place to prevent losses during all activities including stocking and harvesting. Seals and avian predators are controlled using predator nets. Farmed salmon are contained within their rearing facilities (e.g. floating net pens) by jump barriers and containment nets that meet gear requirements specific to moorings, nets and cage design found in the Code of Containment. Each aquaculture company maintains records of all gear deployed. These records are audited annually by a third party, and the results of these audits are reviewed by the permitting agencies for compliance. Non-compliant facilities are required to initiate corrective measures before smolts can be transferred. Any deficiencies found during the routine annual audits are addressed through a corrective action plan and, if major deficiencies are found, a follow-up audit is conducted to monitor the progress of implementing corrective actions. Mandatory audits and escape notification are required for losses greater than 25% of cage biomass (as indicated by appetite loss) or 50 fish greater than 2kg in size. As is illustrated in Figure 2, documented farm-origin salmon entering U.S. salmon rivers have decreased substantially since the implementation of these measures.

Finally, the U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service implemented an ISA indemnity, surveillance, biosecurity and epidemiological research program for farm-raised fish in the United States and the guidelines in place were revised in 2010. The current guidelines are available on the internet at: http://www.aphis.usda.gov/animal_health/animal_dis_spec/aquaculture/downloads/isa_standards.pdf.

Participation in this program is mandatory for all salmon growers and covers all salmon finfish farms in the State of Maine. The USDA's goal is to control and contain the disease through rapid detection and removal of salmon that have been infected with, or exposed to, ISA. The program is being interfaced with the State of Maine's husbandry and bay management program (described above) that is being implemented by the Maine Department of Marine Resources.

Methods used to support innovation to develop alternative production techniques to promote sustainable salmon farming

There are a variety of directives and initiatives with associated research programs and facilities in the United States that support innovation and promote sustainable salmon farming, including the Department of Commerce Aquaculture Policy, the National Cold Water Marine Aquaculture Center, the Aquaculture Research Institute at the University of Maine and the Maine Aquaculture Innovation Center.

Department of Commerce (DOC) Aquaculture Policy - Under the DOC, the National Oceanic and Atmospheric Administration's (NOAA) policy reflects its broad oceans mandate by 'reaffirming that aquaculture is an important component of NOAA's efforts to maintain healthy and productive marine and coastal ecosystems, protect special marine areas, re-build wild stocks, restore endangered species, support marine and coastal habitat, create employment in coastal communities, and enable the production of safe and sustainable seafood'. An important component of the policy is technology transfer. This seeks to move, to the private sector and others, NOAA-supported innovative technologies and practices that improve the economic and environmental performance of aquaculture. NOAA research has helped to develop several modelling tools to assist planners and businesses in siting aquaculture in locations which will result in maximizing returns economically and improve environmental performance. NOAA research (conducted in collaboration with the U.S. Department of Agriculture) has made several open-formula diets available to researchers worldwide as reference diets.

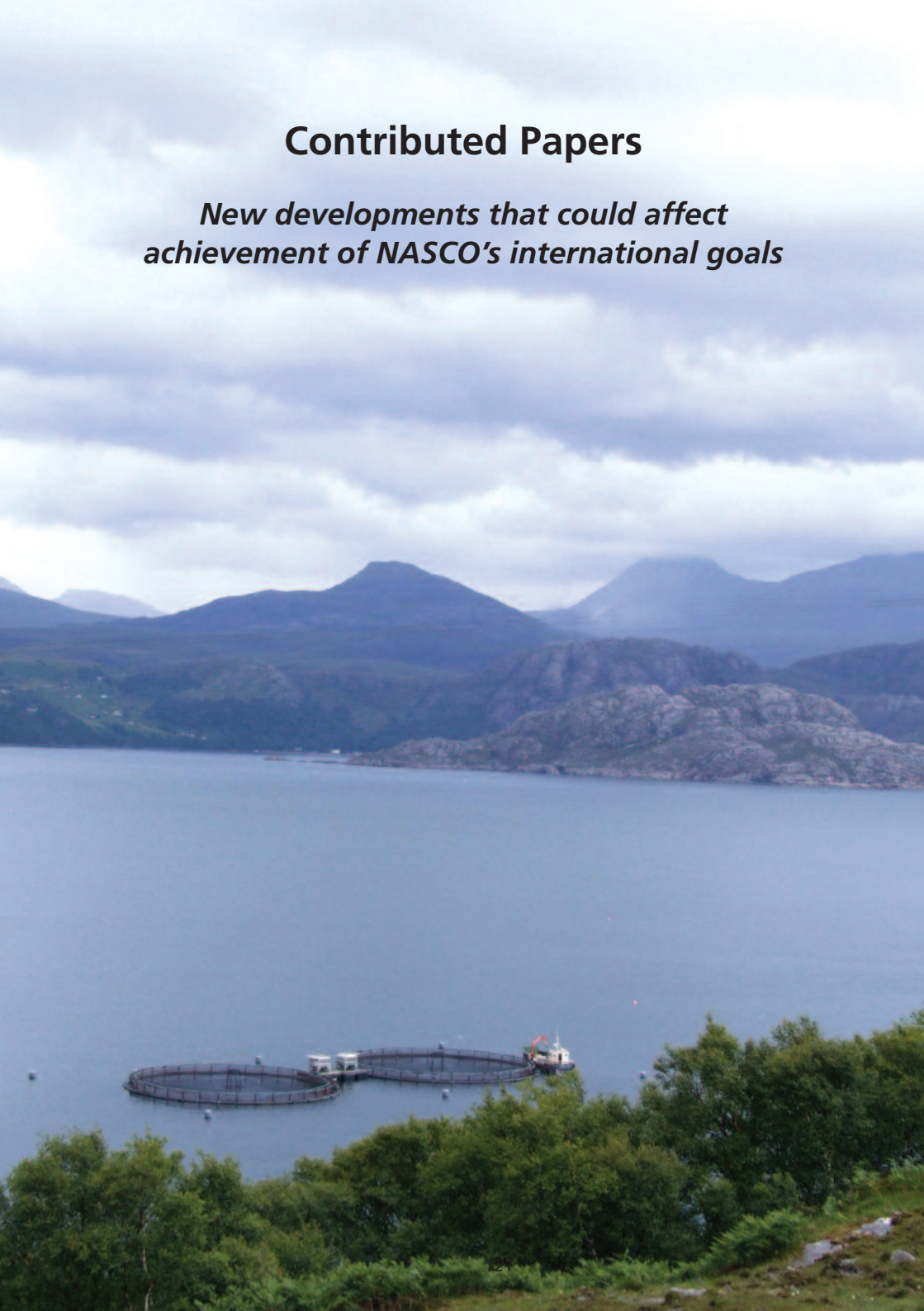
National Cold Water Marine Aquaculture Center - The mission of the National Cold Water Marine Aquaculture Center is to conduct research that will solve problems limiting production efficiency of coldwater marine aquaculture. The primary research focus is genetic improvement using an applied selective breeding program to increase efficiency and sustainability of Atlantic salmon culture.

Aquaculture Research Institute (University of Maine) - The Aquaculture Research Institute involves researchers and faculties from multiple disciplines at the University of Maine and a variety of industry partners. Some important components of the Aquaculture Research Institute include re-circulating or flowing fresh water or artificial seawater in a versatile laboratory. In addition to supporting faculty research and graduate thesis projects, this laboratory is also used for undergraduate training and public outreach. The Aquaculture Research Institute also partners with the Center for Cooperative Aquaculture Research (CCAR), a unique University of Maine aquaculture research and development facility with large-scale systems for the development of sustainable solutions to land-based aquaculture, alternative marine species technology and ornamental aquatics production. The Aquaculture Research Institute and the University of Maine's Animal Health Laboratory address urgent aquatic animal health issues through industry contracted services and strategic industry partnerships and has hypothesis-driven sponsored research. Finally, the recent US$20million, five-year grant (from the National Science Foundation) to establish a Sustainable Ecological Aquaculture Research Network (SEANET) program in Maine further builds research and education capacity in aquaculture. It involves professional staff and faculties across multiple Colleges at the University of Maine, and with multiple partners from other research and education institutions across Maine. SEANET is co-ordinated by the Aquaculture Research Institute and the Experimental Program to Stimulate Competitive Research (referred to as the Maine EPSCoR Office). Specific research objectives include environmental modelling to inform site location decisions in the future and non-chemical treatments for sea lice outbreaks.

Maine Aquaculture Innovation Center - The Maine Aquaculture Innovation Center was established in 1988 by the Maine Legislature with a mission to assist in developing economically and environmentally sustainable aquaculture opportunities in Maine. This center sponsors and facilitates innovative research and development projects involving food, pharmaceuticals and other products from sustainable aquatic systems; invests in the enhancement of aquaculture capacity in Maine; serves as a source of educational information to enhance public visibility and acceptance of aquaculture; and encourages strategic alliances tasked with promoting research, technology transfer and the commercialization of aquaculture research.

Contributed Papers

New developments that could affect achievement of NASCO's international goals



CNL(16)42

Drug resistance in sea lice and integrated lice management strategies

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Paper presented by Dr Armin Sturm, Institute of Aquaculture

Sea lice (Copepoda: Caligidae) are ectoparasitic crustaceans feeding on the mucus and skin tissues of wild and farmed marine fish. Sea louse infections constitute a major disease problem during the marine phase of Atlantic salmon (*Salmo salar*) culture (Torrissen *et al*., 2013). In the Northern hemisphere, most caligid infections of farmed salmon are caused by the salmon louse (*Lepeophtheirus salmonis*), which requires salmonid hosts to complete its life-cycle. In addition, the smaller species *Caligus elongatus* can occur on farmed salmon in the North Atlantic. In Chile, sea louse infections on salmon farms are caused by the species *Caligus rogercressyi* (Costello, 2006).

During their life-cycle, sea lice go through host-associated and free-living stages. Adult females produce a series of paired egg strings, which remain attached to the female until the hatching of eggs. The larval development initially passes through three non-feeding planktonic stages, of which the third needs to find and successfully settle on a host fish to survive. While the first host-associated stages are attached to the skin of the host through a frontal filament, subsequent pre-adult and adult stages can move freely over the body surface of the fish. Mating occurs between adult males and freshly moulted females and is preceded by the formation of pre-copula pairs. Over their life-span females can produce up to 11 egg strings (Boxaspen, 2006).

Effects of sea louse infections on the host fish include stress, reduced growth and suppression of immune function. At high levels skin lesions and secondary infections may occur, leading to severe disease and, if left untreated, potentially death. Control of sea lice in salmon mariculture is key to assuring the health and welfare of farmed fish, and preventing potential impacts of farm-origin parasites on wild fish populations (Torrissen *et al*., 2013). The global costs of caligid infections to the salmon farming industry have been estimated to exceed €300million per annum, which mainly accounts for treatment costs, but further includes negative impacts of infections on growth rates and as a consequence of downgrading of the product (Costello, 2009).

In the salmon farming industry, sea louse control is maintained through integrated pest management strategies, which employ a broad range of tools to achieve control. Farm management measures consist of single-year class stocking, the regular fallowing of sites and area management agreements. Salmon delousing can be achieved by the use of licenced veterinary drugs, which are applied as topical bath treatments or through medicated feeds. In addition, a number of non-medicinal control strategies are available and are currently at different stages of commercial implementation. Such alternative approaches include biological control using cleaner fish, modified cage designs lowering infection rates, removal of lice by mechanical or laser technologies, use of semiochemicals and deterrents to disrupt host detection by infective larvae, and approaches aiming at lowering the susceptibility of host fish for infection through vaccination, administration of immunostimulants, or selective breeding (Torrissen *et al*., 2013).

A key non-medicinal approach to sea louse control, which is now widely applied commercially, involves the co-culture of salmon with wrasse or lumpfish ('cleaner fish'), which remove ectoparasites (Sayer *et al*., 1996). Initially, different wrasse species sourced from wild fisheries were used for sea louse control. Recently, methodologies for the intensive farm production of Ballan wrasse have been developed, allowing the deployment of cleaner fish at a large scale. In addition, current research efforts are focused on developing aquaculture of lumpfish, a species showing superior feeding activity at low ambient temperature compared to Ballan wrasse.

Veterinary drugs licensed for use as salmon delousing treatments comprise bath and in-feed treatments. Compounds administered as medicinal baths include the organophosphate azamethiphos (Salmosan ®), the pyrethroid deltamethrin (AMX ®) and the non-specific disinfectant hydrogen peroxide (Paramove ®), whereas the avermectin emamectin benzoate (SLICE ®) is available for oral treatment. An inherent problem of chemical control strategies is that the target species can develop drug resistance, a process known to be driven by the continual use of the same control agents with limited or no rotation between compounds having distinct modes of action. The ability of sea lice to develop resistance to chemical treatments is well documented. Losses of efficacy of drugs targeting *L. salmonis* have been reported, at least locally or temporally, for organophosphates, hydrogen peroxide, pyrethroid and avermectins (Aaen *et al*., 2016).

To ensure optimal farmed fish health care and disrupt potential resistance formation in sea lice, it is critical to base treatment choices on reliable knowledge of the drug susceptibility status of the parasite population causing the infection. This is currently achieved through so-called bioassays, which are small-scale treatments of sea lice in Petri dishes (Sevatdal *et al*., 2005). However, bioassays require large numbers of sea lice of specific developmental stages. Moreover, they are sensitive to interfering factors and show limitations regarding their sensitivity of resistance detection. In insects, genetic diagnostic tests based on the detection of specific resistance mechanisms have proven advantageous in drug susceptibility assessment. Such tests, which have started to become available for use with sea lice (Kaur *et al*., 2015) will provide important tools supplementing traditional bioassays.

At present, comparatively little is known about the molecular mechanisms of drug resistance in sea lice. In contrast, insecticide resistance in terrestrial arthropods is well understood, and typically involves either or both of two main mechanisms. First, mutations of molecular targets can affect the binding of the chemical, and second, mutations enhancing the efficiency of detoxification pathways can reduce internal exposure to the insecticide (Heckel, 2012). Taking into account the fact that crustaceans share evolutionary origins with insects, it may be hypothesised that similar molecular mechanisms are involved in sea louse resistance against chemical control agents.

A number of studies have investigated whether genes known to be relevant in insecticide resistance play roles in the resistance of sea lice to control agents. Recent results obtained by the group of Tor Horsberg show that azamethiphos resistance in *L. salmonis* is determined by a single non-synonymous mutation in the sequence of a gene encoding acetylcholinesterase, known to represent the target site for organophosphates (Kaur *et al*., 2015). Very similar missense mutations have been found in organophosphate-resistant populations of different insect species. Together, these findings provide an impressive example of parallel evolution in response to the same selection pressure, exposure to toxic organophosphates (Heckel, 2012).

A number of further potential resistance factors have been studied with regard to their involvement in resistance of sea lice against control agents. In particular, gene sequences of voltage-gated sodium channels and glutamate-gated sodium channels have been analysed in order to find mutations related to resistance against pyrethroids

and avermectins, respectively (Fallang *et al*., 2005; Tribble *et al*., 2007). Similarly, enzymes and transporters involved in detoxification pathways have been investigated in sea lice showing resistance to emamectin benzoate and deltamethrin (Fallang *et al*., 2004; Heumann *et al*., 2012). However, these studies have so far not led to the identification of resistance mechanism.

In contrast to the candidate gene approach, which focuses on gene(s) suspected to be involved in a biological function of interest, broad-scale genomic and transcriptomic studies make no *a priori* assumptions of mechanism. Instead they consider the entirety of gene or transcript sequences, as far as is possible using the specific methodology employed. Different research teams are currently applying genomic methodologies to sea lice, and it can be expected that in the near future a wider array of genetic resistance markers will become available. Such markers will allow the systematic testing of parasite populations from salmon farms in order to optimise sea louse control and avoid resistance formation.

Successful resistance management relies on the use of measures to reduce selection pressure for resistance development (Aaen *et al*., 2015; Denholm *et al*., 2002). This can be achieved first by reducing the overall number of treatments through increased use of farm management and other non-medicinal control approaches. However, where treatments are required, it is important to avoid under-treatments, as these can favour the enrichment of partially resistant parasites in the population. Moreover, rotation between drugs showing distinct modes of action should be applied. Finally, refuges where parasites remain unexposed to control agents, such as populations parasitising wild fish, play a key role in keeping non-resistant genotypes in the gene pool. The greater number of wild as compared to farmed salmonids in marine systems of the Canadian West coast as compared to the North Atlantic is likely to be one factor explaining the few resistance problems reported from sea lice affecting salmon farms in this region.

In summary, effective sea louse control is an essential element of environmentally sensitive, sustainable salmon farming. Traditionally, sea louse control has relied strongly on the use of veterinary drugs; however, the potential of sea lice to develop resistance against chemical control agents is a potential threat to this approach. Recently, a number of non-medicinal control approaches have been developed far enough to allow their wide industrial implementation. Current research by different scientific groups focuses on resolving

the molecular mechanisms of drug resistance. First, genetic tests to detect resistance have been developed, and more diagnostic tests can be expected to become available in the near future. The increased use of non-medicinal control strategies, combined with a targeted and restricted use of chemotherapeutants, supported by resistance monitoring using novel tests, will contribute to reducing the environmental impacts of salmon farming and improving the sustainability of this industry.

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Development of lice dispersal models and their utility in predicting impacts on wild Atlantic salmon

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Paper presented by Dr Ørjan Karlsen, Institute of Marine Research

Lice dispersion

Salmon lice (*Lepeophtheirus salmonis*) drift passively with the water currents in fjords and along the coast for days to weeks before they are no longer able to infest fish. These currents may transport lice considerable distances both prior to and during the period during which they are infectious (Asplin *et al*., 2014) and their vertical behaviour has implications for how lice are transported horizontally (Johnsen *et al*., 2014; 2016). Detailed information on water currents, temperature and salinity is, therefore, important in providing a precise description of how the infectious copepodids are distributed in space and time.

The Institute of Marine Research, Norway, uses hydrodynamic models based on the Regional Ocean Model System (ROMS, www.myroms.org) to predict the dispersal of salmon lice. NorKyst800 is a model for Norwegian near-shore waters and has an 800m horizontal grid resolution and 35 terrain-following vertical layers (Albretsen *et al*., 2011). Results from NorKyst800 provide a reasonably good description of conditions along the coast and in most fjords, but it is necessary to use a higher grid resolution in narrower fjords. The NorFjords fjord model has a horizontal grid resolution of 50-200m and receives open boundary values from NorKyst800. Realistic forcing of the ocean model from atmosphere, tides and rivers are included (Asplin *et al*., 2014; Johnsen *et al*., 2014). Freshwater input from a hydrological model developed by the Norwegian Water Resources and Energy Directorate (NVE) and atmospheric wind fields from the mesoscale WRF wind model (www.wrf-model.org) with a 1 km horizontal grid are fed into the model. The hydrodynamic model was verified by comparing outputs with measured physical data such as temperature, salinity and water currents.

There are some differences in the output, in that the 800m model underestimated the peak velocities. However, the authors concluded that the comparison of the models with observed currents showed a good correlation and concluded that the models were able to realistically recapture the actual currents (Johnsen *et al*., 2014).

NorKyst800, with ca. 2,600x900x35 volumetric units in the computational grid, is close to the practical size that a model simulation to cover the entire Norwegian coast may have. The main constraint in the current NorKyst800 model system is the model resolution which limits what is practically feasible nationwide with the current availability of computing resources. This challenge is partly addressed in that the finer NorFjord model can be nested into the Norkyst800 model for selected production areas as required. Performance computing, through access to supercomputers, is sufficient to run the current model systems. High-performance computing is, however, a bottleneck for further development towards higher resolution.

The hydrodynamic model results consist of hourly values of three-dimensional currents, salinity and temperature and serve as input to the salmon lice dispersion model. The salmon lice advection and growth model is based on the Lagrangian Advection and Diffusion Model (Ådlandsvik and Sundby, 1994). The salmon lice model simulates the vertical behaviour of salmon lice with swimming up during day and down during night. The first three pelagic stages are simulated, the duration of the two non-infective nauplii stages are set to 50 daydegrees (days x temperature), while the copepodids are assumed to be infective between 50 and 150 daydegrees (Asplin *et al*., 2011). The data on salmon lice abundance used in the model is based on weekly reported mean number of female salmon lice, temperature on 3m depth and monthly data on the number of fish in the farms along the coast. From this information, the number of hatched nauplii is calculated (Stien *et al*., 2005). The output from the salmon lice model is hourly information on the particle position, age of lice, temperature and salinity. Combined, these models estimate the density of salmon lice along the Norwegian coast.

Validation of the lice dispersion model

Salmon lice copepodids are mainly distributed in the upper few meters of the water column during the day, tending to aggregate in shallow estuarine areas. The highest density of lice is often found along the shore. In the Faroe Islands, the density was highly variable from shore and 200m outwards, indicating a patchy distribution. Hydrodynamic models often predict that the distribution of sea lice tends to be patchy. This is also the general picture that emerges from field studies.

At present there are no data available to validate the simulated density of nauplii and copepodids in the water column. Therefore, in order to validate the infectious dose, indirect measures are used based on infestations on either wild fish caught using traps, nets or trawled, farmed post-smolt salmon stocked in sentinel cages or farmed salmonids.

While both fish farms and sentinel cages are positioned in fixed positions for a known period of time, wild fish move freely. A major difference between fish in sentinel cages and farmed fish is that in sentinel cages the fish are left for a limited period of time and lice can be accurately counted in the laboratory. Counting of salmon lice on farms is divided into sessile, pre-adult and adult male or female lice. Counting of sessile lice on farmed fish is considered to be less reliable due to difficulties in counting these small stages. Therefore, the pre-adult and adult male lice are used, and the infestation is calculated either as an increase in lice population or back-calculated to the time of infestation. Both methods rely on known temperature dependent development and assume a mortality during the free-swimming nauplii and copepodid stages and mortality on the fish after attachment. The number of farms that may be used is limited, in particular during periods of the year when anti-lice measures are in use. These measures include anti-parasitic chemicals prior to stocking in the sea, lice nets or cleaner fish. Despite this, the number of farms and their distribution along the coast makes this an interesting approach. Statistical models appear to be able to predict, at least to some degree, the increase in lice abundance based on infection pressure calculated among other variables from sea distance (Kristoffersen *et al*., 2014). An attempt to predict infestation at farms during the winter in western Norway using the NorFjords 160m model indicated that predicted infestation was correlated to back calculated estimated infestation ($R = 0.48$). This indicates that present farm data may predict, to some extent, the lice infestation in an area but the variability does not allow for precise estimates. However, it is assumed that reliable counting of sessile lice on the farms may improve the estimates.

Sentinel cages are small cages (about $1m^3$) into which farmed post-smolt salmon are stocked for 2-3 weeks before the infestation on the fish is counted. These cages are hung 0.5m below the water surface and are used to estimate infestation pressure in fixed positions and time periods. The exact position and the period for which the fish have been exposed is known. However, as the period between

attachment and moulting to the chalimus 1 stage takes some time, there will be uncertainties in when the lice attached to the fish. Generally, the correlation between predicted copepodid density using the hydrodynamic model and observed infestation was relatively high (R^2 = 0.56 for linear regression) and these analyses also indicated that the model should include temperature and salinity (Karlsen *et al*., 2016). In all cases where the model predicted very high lice density, the infestation was relatively high. However, in situations where the model predicted low copepodid density, there were occasions when high infestations also occurred. The data used in this analysis were mainly from the Hardangerfjord in 2014. A larger dataset currently covers four fjords (see below) and the years 2012-2015 are being analysed, and including other factors such as region and season. It is anticipated that this may influence the mortality during the planktonic stages, in particular. Assuming that the infestation is directly related to lice density in the water (i.e. infestation pressure), these initial analyses indicate that the model is able to predict infestation in these areas. However, there are some limitations with these analyses. The sentinel cages are only positioned in a few fjords (Hardangerfjorden, Romsdalsfjorden, Namsen/Vikna and Altafjorden) which are subject to fallowing regimes resulting in synchronous development of biomass and lice within the fallowing zones, and fjords protected from salmon farming where infestation is low. Whether they are valid under other conditions, such as along the open coast, is not known. However, by comparing qualitatively the predicted infestation pressure with observed infestation on sea trout caught using traps or nets, the observations indicate that the models should be able to predict the infestation pressure in regions, though validation should be extended to more positions and into coastal areas.

Utility of the models in predicting impacts on wild Atlantic salmon

The models predict the density of infectious salmon lice in time and space. However, in order to predict their effect on wild fish this infestation pressure needs to be translated into either abundance on wild fish or a measure of the increased risk of mortality in a population due to the density of salmon lice. In the 'Risk assessment of Norwegian Aquaculture' a salmon lice risk index is used which attempts to estimate the increased mortality due to salmon lice infestations. This assessment is based on the assumption that small salmonid post-smolts (<150g body weight) will suffer:

- 100% lice-related marine mortality, or return prematurely to fresh water for sea trout, if they are infected with >0.3 lice/g fish weight;
- 50% mortality if the infection is between 0.2 and 0.3 lice/g;
- 20% mortality if the infection is between 0.1 and 0.2 lice/g; and
- 0% mortality if the infection is <0.1 lice/g fish weight (Taranger *et al.*, 2015).

By using this method, and assuming a mean salmon post-smolt weight, the number of lice or infestation pressure may be translated into the probability of lice-related marine mortality.

The only direct measurement presently made on infestation on out-migrating salmon post-smolts is by trawling in the outer parts of the fjords during the migration period using a specially designed fish-lift trawl. This method gives an estimate of the infestation these fish have accumulated since leaving the rivers. Since it is not known which river each fish originates from, when it left the river, how long it has spent in the fjords or which route it has taken, it is not straightforward to use trawl data to validate modelled infestation pressure.

However, it should be possible to assess the risk of infestation a population experiences by using the modelled infestation pressure during migration from the river to the sea and register the infestation pressure the fish experience. Although there are uncertainties, the timing and duration of the migration from the rivers may be estimated. By simulating the migration period, travel distance, path and speed and the estimated infestation pressure experienced by the fish, the risk of lice-related marine mortality may be estimated. The infestation pressure may be estimated as the probability of encountering a salmon louse, or the probability of encountering a patch with a high density of salmon lice as the latter is more likely to inflict higher mortality. Preliminary analysis has shown that such a procedure may be conducted for all known Norwegian salmon rivers with relatively little effort and, by including the model predictions of lice density, the risk of lice-induced marine mortality may be estimated together with estimates of uncertainty.

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CNL(16)52

Closed containment: Recent developments - costs and benefits

Ivar Warrer-Hansen – Inter Aqua Advance AIS, 8250 - Egaa, Denmark

Paper presented by Mr Ivar Warrer-Hansen, Inter Aqua Advance

Since the mid-1980s, aquaculture has been the fastest growing industry within the food production sector. Salmon farming has experienced rapid growth gaining a foothold in all global markets. The main salmon farming countries are Norway, Chile, Scotland and Canada.

With the predicted future demand for salmon, and other fish species, alternative production methods and strategies will be required so the industry can produce fish sustainably and be able to service all markets.

One such alternative production method is land-based salmon production in contained systems, i.e. re-circulation aquaculture systems (RAS). RAS offers many advantages including the following:

- complete control of the rearing environment;
- potential for disease-free production;
- production facilities can be located close to markets; and
- minimum environmental impact.

A number of pilot and commercial scale RAS plants for land-based salmon production have been built in recent years.

The production systems currently in operation incorporate different concepts and, perhaps as would be expected, not all have been free from problems. However, based mainly on the experiences from two pilot scale projects in North America (Namgis on Vancouver Island and the Freshwater Institute in West Virginia) some very important observations have been made. The conclusion drawn is that RAS technology for land-based salmon grow-out is available, i.e. systems exist in which it is technically possible to produce salmon of a high quality salmon in RAS.

There are however, still a number of technical and biological obstacles to overcome with production to-date in both pilot and commercial scale RAS. The first is the phenomenon of precocious or early maturing males. A relatively large proportion, up to 30%, of males mature early in RAS when the fish are around 1.5 to 2kg in weight.

They stop growing (despite being fed) and have poor condition (they lose their silver colouration and their flesh quality deteriorates) making them unsuitable for the market. This is a loss factor and is inconvenient for any operation. The main reason for early maturation is most likely accumulation of female sex pheromones in RAS. In a self-contained system there is no flushing or dilution effects such as occurs in ambient systems. To-date no means of eradicating pheromone accumulation has been found but one commercial RAS has been able to reduce the occurrence of early maturing male fish by introducing certain lighting regimes. Trials are also being undertaken with different salmon strains and most recently with all-female stock.

The second constraint associated with RAS relates to the use of certain bio-filters (submerged stationary filters) which are probably not optimum for saltwater RAS. Apart from biological filtration, these filters are intended to trap solid waste and fish faeces. This can create pockets in the bio filters where oxygen levels are inevitably lowered with the potential for Sulphate Reducing Bacteria (SRB) activity and the risk of sulphide formation in concentrations that could inhibit fish growth. In saltwater RAS it is recommended that mechanical filtration is used in which solid material is removed from the system.

As with all animal production, to be viable aquaculture has to be conducted at an industrial or commercial scale. This paper considers an RAS capable of an annual production of 6,000 tonnes in a stand-alone system with the ability to supply the markets weekly.

The capital cost for this system described is €35,000,000. This figure corresponds well with capital costs pro rata with existing projects and other projected ones. In comparison, and when the shorter replacement period for net cage systems is taken into consideration, this is approximately 2.5 times that of net cage systems. The total capital requirement for production of 6,000 tonnes per annum is around €50million as shown in Table 1 below. In this example, it is assumed that there is private equity of €12million.

Capital needs: CAPEX (incl. incubation and smolt prod, DN, EOPT)		€37,000,000
	1st year direct production costs	€13,000,000
		€50,000,000
Financing:	Private equity	€12,000,000
	Loan equity	€38,000,000
Depreciation: CAPEX €37,000,000 15 years		€2,466,677
Financial costs: €38,000,000 10 years 5%		€4,921,173

***Table 1**: Financial requirements for an annual production of 6,000 tonnes of farmed salmon*

The operational costs and cost to market are shown in Table 2 below.

		6,000 tonnes/a	(2,000 tonnes/a)
Direct OPEX costs	€13,200,000	€2.19/kg	(€2.53/kg)
Depreciation 15 years	€2,466,667	€0.41/kg	
Financial costs 10 years 5%	€4,920,000	€ 0.82/kg	
Total OPEX whole weight fish			€3.42/kg
Price HOG (88% yield) – 5,280,000kg		€3.89/kg	
Processing (€0.30/kg) + Freight (€ 0.20/kg)		€0.50/kg	
Total cost to market (Brussels from mainland Europe)		€4.39/kg	(€4.77/kg)

***Table 2**: Operational costs and costs to market*

Fish processing and dispatch to markets are anticipated to be carried out externally. The operational cost before depreciation and financial costs is €2.19/kg whole weight and allowing for depreciation and financial costs it is €3.42. With an anticipated gutting loss of 12% of whole weight, this equates to €3.89/kg head on gutted (HOG), which is the form in which salmon are sold. When the costs of gutting, boxing, icing and dispatch of €0.50/kg (on mainland Europe) are included price to market is €4.39/kg HOG. The standard price, and which is given in the weekly salmon prices and forecasting indices, is delivered to Brussels. To break even a price delivered to Brussels of €4.39/kg HOG would need to be achieved.

The price for salmon varies during and among years depending on supply and demand. The prices obtained for salmon in Brussels for 2014 and 2016 are shown in Table 3

	ROI% on €12 million private equity	
Sales price	6,000 tonnes/a	2,000 tonnes/a
€4.84/kg*	19.9%	(2.9%)
€5.50/kg**	48.0%	(31.9%)

Table 3: **Average price achieved for farmed salmon in Brussels for 2014. ** indicative price for 2016*

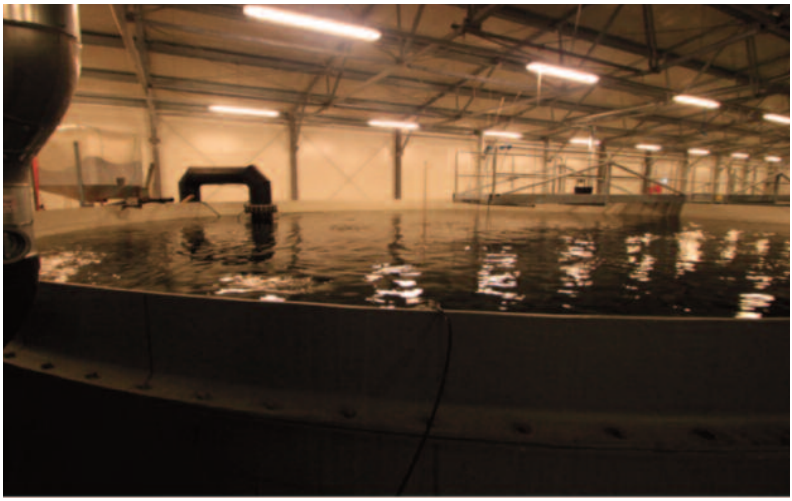
It can be seen from Table 3 that when prices are low, as in 2014, there is a borderline acceptable return on the investment. Prices in 2016 have so far been high, between €5.50 to €6.50, and returns on investment can be attractive.

RAS technology and economics are gradually improving although sudden breakthroughs are rare. There are, however, some recent developments such as the so-called concentric tank concept that could well change the economics in RAS production quite significantly. The new concentric tank concept is based on shared tank walls both between tanks and for treatment systems. This type of plant is erected on a flat concrete slab, with no need for expensive underground pipe work. Additionally, there is no need for expensive concrete constructions, which at times has been a major cost of some RAS constructions.

It can be concluded that RAS concepts suitable for land-based salmon production exist and can produce high quality salmon. At present, operational costs, excluding of depreciation and financial costs, can compare with cage rearing.

Capital costs are relatively high for RAS and hence also capitalisation and depreciation. When market prices for salmon are high as at present, land-based production will be economically viable and a very good business proposition. Low market prices (as seen in 2014) could, however, leave a land-based facility vulnerable. New RAS concepts are emerging that will have a positive effect on land-based salmon production in future.

Another alternative to conventional salmon farming is off-shore farming. This is, however, not a cheap solution in terms of capital costs either (maybe even more costly than RAS) and with an expensive farm infrastructure, will be more costly than land-based production.



Recirculation Aquaculture System (RAS). Courtesy Inter Aqua Advance A/S

CNL(16)45

The NGO Perspective

Paper presented by Mr Niall Greene, Salmon Watch Ireland

NASCO and salmon farming

It may be useful to commence by reiterating the extensive and insightful things NASCO itself has had to say over many years about the impacts of salmon farming on wild Atlantic salmon. *The Resolution by the Parties to the Convention for the Conservation of Salmon in the North Atlantic Ocean to Minimise Impacts from Aquaculture, Introductions and Transfers and Transgenics on the Wild Salmon Stocks*, CNL(06)48, 'the Williamsburg Resolution', is the main text on the subject. In considering that Resolution it is important to remember that it was developed from its original formulation in the 1994 *Resolution by the Parties to the Convention for the Conservation of Salmon in the North Atlantic Ocean to Minimise Impacts from Aquaculture on the Wild Atlantic Salmon Stocks* 'the Oslo Resolution', from 2000 onwards in liaison with the salmon farming industry; it is not just a wish list of those of us concerned with the welfare of wild salmonids.

The Williamsburg Resolution states*, inter alia:*

- 'Each Party, in accordance with the Precautionary Approach, should require the proponent of an activity covered by this Resolution to provide all information necessary to demonstrate that the proposed activity will not have a significant adverse impact on wild salmon stocks or lead to irreversible change' (Article 3);
- 'Each Party shall take measures to….minimise escapes of farm salmon to a level that is as close as practicable to zero through the development and implementation of action plans as envisaged under the Guidelines on Containment of Farm Salmon (CNL(01)53)' (Article 5);
- 'Each Party shall take measures to….minimise the risk of disease and parasite transmission between all aquaculture activities, introductions and transfers and wild salmon stocks' (Article 5).

In addition to the principles set out above, the Williamsburg Resolution goes into some detail on how they should be implemented. The measures in Annex 2 of the Resolution in respect of salmon farming cover issues dealing with location of farms, the

establishment of 'wild salmon protection areas', the designation of exclusive 'aquaculture regions', separation distance between sites and the disposal of dead and dying fish and infectious material. Notable among these guidelines and measures are those that propose that:

- '…tagging or marking or inventory tracking systems will be used to facilitate the identification of farmed salmon in the wild and their separation from wild fish, to determine the source of escapes and to assess the interactions of escaped salmon with wild stocks. These systems could be coupled with river monitoring and recapture systems that allow holding and close examination of returning fish in the rivers';
- 'Procedures should be established for the early identification and detection of, and rapid response to, an outbreak of any new disease or parasitic infection likely to affect wild Atlantic salmon';
- '...there is a need to strengthen and amend disease controls to minimise disease transfer between aquaculture activities and wild fish'.

Finally, Annex 3 of the Williamsburg Resolution goes into considerable detail on *Guidelines on Containment of Farm Salmon* covering site selection, equipment and structures, operations, verification and record keeping, action plans and reporting and a requirement that 'each jurisdiction should advise the Liaison Group [of NASCO and salmon farming industry representatives] annually on progress in implementing its action plan(s)'.

In 2009, NASCO adopted further more precise guidelines on sea lice and containment in consultation with the salmon farming industry. The *Guidance on Best Management Practices to address impacts of sea lice and escaped farmed salmon on wild salmon stocks,* SLG(09)5, was intended to supplement the Williamsburg Resolution and to assist the Parties and jurisdictions in managing salmon aquaculture and in preparing IPs and FARs. The 'International Goals' of the guidance are stated to be:

(a) '100% of farms to have effective sea lice management such that there is no increase in sea lice loads or lice-induced mortality of wild salmonids attributable to the farms'; and

(b) '100% farmed fish to be retained in all production facilities'.

Precise courses of action are then set out under each objective which, if rigorously applied, would make a major impact on reducing the negative effects of salmon farms.

The conclusions of at least two further NASCO-related documents need also to be taken into account:

The report of the Conveners of a NASCO/ICES conference held in Bergen in 2005 stated that 'The Convenors propose that interactions between farmed and wild salmon need to be virtually eliminated, not just reduced….progress in addressing the sea lice problem has been made….but it is clear that difficulties remain, particularly with regard to protecting wild sea trout populations….The prospect of resistance developing to the available sea lice treatments are a real concern....Progress has 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….If physical containment cannot be achieved then the use of sterile salmon may be necessary' (Hansen and Windsor, 2006).

The rapporteurs of the 2011 NASCO/ICES 'Salmon Summit' in La Rochelle note that 'the following international goals will need to be vigorously pursued: 100% of farms to have effective sea lice management such that there is no increase in sea lice loads or lice-induced mortality of wild salmonids attributable to the farms [and] 100% farmed fish to be retained in all production facilities' (Windsor *et al*., 2012).

The reality

It is clear that at a formal level in NASCO there has, over quite a long time, been no lack of awareness of, in particular, sea lice and escapee problems, and no lack of the formulation and adoption of objectives, policies and operating guidelines. The salmon farming industry has been involved in much of this. Why, therefore, has there been so little change at the level of many of those jurisdictions that are party to the NASCO Convention?

The reactions of the salmon farming jurisdictions within NASCO range from openly recognising that there are sea lice, escape and disease problems and attempting to find technical and management solutions; to not caring about whether there is a major threat to wild salmonids; to living in a fantasy land where it is believed that all the problems have been solved. In none of these jurisdictions, even the best, has policy or practice come even close to the 'minimise escapes… to zero' and the 'minimise risk of disease and parasite transmission' goals of the Williamsburg Resolution.

Why is this the case?

One reason, maybe the dominant one, is that many governments (or at least those parts of government promoting salmon farming) have got themselves into a position where they believe that wild salmon conservation and farmed salmon development cannot be reconciled and that the socio-economic and, therefore, political benefits of farming trump all else. The deep advertising and PR pockets of the salmon farming industry help to bolster the benign image of salmon farming as a form of regional development.

It would be wrong, of course, to deny that salmon farming does bring some benefits, not major ones but some, to remote coastal communities. But as the production of salmon becomes ever more automated and more and more concentrated in the hands of major multinationals, those benefits are increasingly confined to relatively small pockets of highly marginalised employment which is prey to a vast array of market, technical and disease risks. These are not reasons for abandoning salmon farming but they are factors that must be taken into account in comparing the socio-economic impacts of wild and farmed salmon.

Arguments about bio-diversity, the protection of heritage and wild salmon conservation generally find it hard to get any real traction in this world.

In most of our jurisdictions, those of us with a wild salmon interest, both inside and outside government, are fighting with at least one arm tied behind our backs. The system of licensing and regulation of salmon farming, such as it is, largely sidelines wild salmon advocates whether governmental or private. For those of us who are members of the European Union, the European Commission may offer a route to a more objective assessment of the competing interests. The NGO Group notes that Salmon and Trout Conservation (both UK and Scotland) have recently lodged a complaint with the Commission, pursuant to the Marine Strategy Framework Directive about the Scottish Government's failure to address the impacts of sea lice produced by salmon farms. We look forward with interest to seeing how this develops.

What is to be done?

The NGO Group is not necessarily opposed in principle to salmon farming but it is vigorously opposed to the manner in which it is currently conducted. Something approaching 2million tonnes of

farmed salmon are produced in the North Atlantic each year and, however much we might wish it, that is not going to be dismantled overnight in a world where wild fish food stocks are rapidly declining.

What we do want is:

- a coherent plan by each of the Parties to transition salmon farming to closed-containment systems. We acknowledge that the technology is still evolving and that the business and financing models are different from open cage farming. However, even if there were no problems associated with what open cages export to the environment, there are problems of diseases and parasites that the cages import and which in an environment of rising temperatures demand solutions that closed containment can offer to the industry itself. It is interesting that some large farmers in Norway seem to be recognising this and are moving in towards closed containment - but with little sign of them doing likewise in the other jurisdictions in which many of them operate;
- a regime of enforced hard law must be initiated to govern the location, operation and regulation of fish farms. We recognise that, on the one hand, we cannot dismantle all current farms overnight but, on the other hand, we cannot live with the extremely lax arrangements that currently exist in most of our jurisdictions. What we are asking for here is no more than the style of law which applies to terrestrial farming in most countries and not one based, as it is in many salmon farming countries, on soft law non-justiciable protocols, guidelines and calls for the adoption of best practice. Just because salmon farming takes place beneath the waves (and 'out of sight, out of mind') is no justification for the absence of effective regulation;
- if Parties are in any doubt as to what the legal regime should incorporate then they will find it specified in some detail in the *Guidance on Best Management Practices to address impacts of sea lice and escaped farmed salmon on wild salmon stocks,* NASCO document SLG(09)5;
- wild salmon interests, official and private, need to be given a direct and legitimate role in the licencing and regulation processes, which must include statutory protection of wild salmonids and not just the welfare of farmed fish. As an absolute minimum, the NGOs call on all Parties to make mandatory:

- complete transparency of sea lice numbers per farmed fish on an individual farm basis, together with a maximum allowable number of lice per fish, with particular attention paid to setting limits during the period when wild salmonid smolts enter the marine environment; and
- compulsory culling/early harvest of farmed fish if lice levels exceed the agreed trigger level.

- the Williamsburg Resolution needs to be revisited in the light of scientific, technical and managerial developments since it was adopted, so that it can be a more influential guide to the framing of law and the more prescriptive measures set out in the 2009 *Guidance on Best Management Practices to address impacts of sea lice and escaped farmed salmon on wild salmon stocks* incorporated into it. Issues arising from climate change, the more pervasive incidence of certain diseases, treatment resistance, the identification of escaped fish, etc. need to be addressed.

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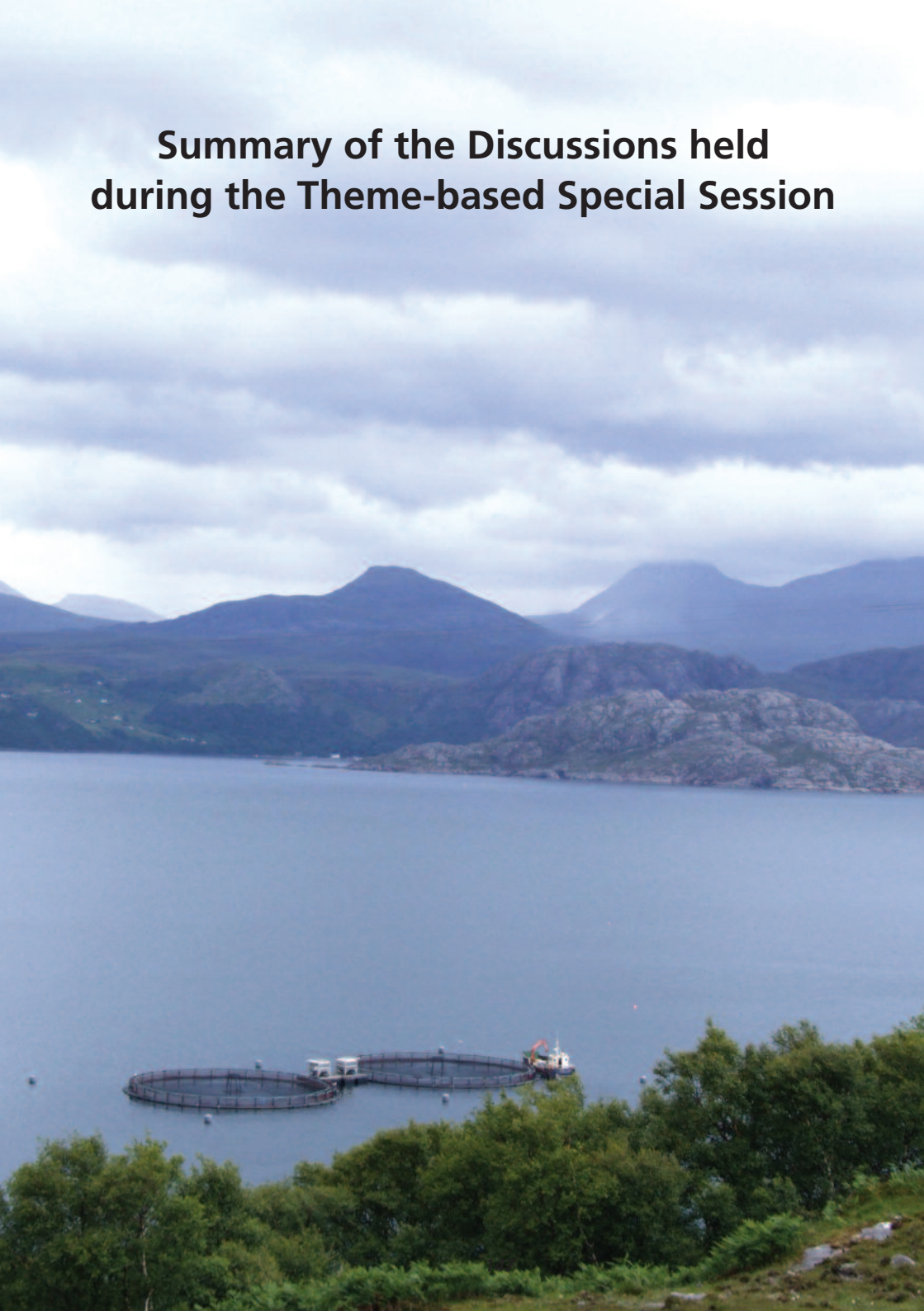
Summary of the Discussions held during the Theme-based Special Session



Summary of the Discussions held during the Theme-based Special Session

Armin Sturm (Institute of Aquaculture, University of Stirling): Thanked Dr Finstad for his presentation and noted that one of the components used in this very interesting study is known to be a wide-spectrum parasiticide which not only protects the fish against sea lice, but also potentially against other parasites such as nematodes. He noted that emamectin benzoate is known to have been used extensively in the farming industry with resistance reported since about eight years ago and that Substance EX had been used as a treatment in these studies. He asked if any loss of protection has been seen in these studies.

Bengt Finstad (Norwegian Institute for Nature Research): Responded that Substance EX was used for releases in experiments in the late 1990s, but researchers then switched to SLICE (emamectin benzoate). However, after using SLICE for a period of time, there was evidence of resistance to the treatment in both fish farms and wild fish, and the researchers reverted to Substance EX. Dr Finstad agreed that treatment might influence other parasitic nematodes in the released fish but noted that the overall results, in terms of the difference between treated and untreated fish, are so significant that he and his team are confident in the findings.

Dave Meerburg (Atlantic Salmon Federation): Asked Dr Finstad how quickly the mortality occurs on smolts affected by sea lice, as this may be relevant to the trawl studies in the Hardangerfjord given that the fish being caught and categorised in the trawls are only the survivors, rather than fish that have already died.

Bengt Finstad (Norwegian Institute for Nature Research): Responded that this was a very good point. He indicated that in the study it is mainly chalimus larval stages that are found on the trawled fish, and survival of the larval stages can be up to 60%. Mortality will occur when lice reach the pre-adult stages, after about 20 days. If, for example, there are 10 lice larvae, it is likely that there will be 6 adult stages on the fish after 20 days. At this level, the infestation will influence the death rate of the fish, but sea lice copepodites will also immediately create an immune response in the fish resulting in an imbalance in the cortisol level and white blood cells, so it is a two-step process.

Phil Thomas (International Salmon Farmers Association (ISFA)): Noted that the technical approach referred to in Dr Finstad's presentation

should be supported, because it involves building up a risk-management system step-by-step. However, he indicated that he had some difficulties when looking at the results over a number of years, as the findings from the laboratory studies are very clear cut and, for example, would suggest that once a critical level is reached the fish will simply die. He indicated that he believed there was an almost incoherent jump between the results of these laboratory studies and what is happening on the ground because, whether the numbers are expressed in terms of percentage mortality or the other way around, when compared to the results of the laboratory studies the mortality figure is actually quite low. While in the laboratory studies relatively few sea lice kill fish, in field-scale studies the implication is that most fish survive. He further noted that although relatively few studies have been conducted on treated fish in areas where there are no fish farms, where these studies have been carried out the figures, in terms of survival rates, look similar to those in areas where there are fish farms. He indicated that while he thought he encouraged the management-system approach, he had difficulties as he believes that what is identified in the laboratory studies is a better and better defined hazard, but the translation of that hazard into the probability and quantitative nature of the risk has not yet begun.

Bengt Finstad (Norwegian Institute for Nature Research): Agreed that this was correct. He indicated that this is a first generation measurement method, which commenced in 2012, using a traffic light system. He agreed that it is also correct that it is based on the physiological experiments in the laboratory. However, he noted that there is a report produced every year in Norway containing a table in which the different levels of physiological responses are translated into the population-reducing effect, validated through sampling at sea, to indicate the total overall effect on populations. He reiterated that this is a first generation measurement approach which is the best available to-date and should improve in future.

Éric Gilbert (Canada): Congratulated Dr Hindar and his colleagues on a very interesting study. He referred to the conclusion that seemed to suggest that the closer salmon rivers are to fish farms, the greater the level of introgression. He indicated that, while not an expert on the Norwegian salmon farming industry, he understood that production was spread out across the west of the country. He asked if escapees were travelling long distances and introgressing in many rivers, or remaining in the regional or sub-regional production area causing localised effects.

Kjetil Hindar (Norwegian Institute for Nature Research): Responded that this depends on when the fish escape from the farms. If they escape as smolts from net cages in spring, they seem to return to the general area from which they escaped and enter rivers fairly close to the fish farm, perhaps within 200km. If the salmon escape as 1-4kg fish around Christmas, they are essentially homeless. Releases from the southwestern coast of Norway have been recaptured from as far away as Gothenburg in Sweden to Murmansk on the Kola peninsula in Russia, perhaps as much as 900km from the escape (release) site. However, he indicated that other factors also influence where escaped farmed fish occur, for example, they may choose to enter only large rivers and ignore small rivers.

Yngve Torgersen (Norway): Thanked Dr Hindar for his excellent presentation and asked for clarification as the presentation referred to the number of rivers studied, while the ICES report referred to populations. He asked if Dr Hindar considered one river to be one population.

Kjetil Hindar (Norwegian Institute for Nature Research): Replied that in the Tana system, for example, there are around 30 distinct Atlantic salmon populations. When wild fish that have been caught by anglers in the summer in the lower stretches of the main stem are sampled, it is not known which tributary they are returning to and, therefore, which population they belong to, so the data must be presented in this way. He noted that in some rivers scales can now be assigned to specific tributaries, and that it is hoped that this can be further expanded. Dr Hindar also indicated that in some juvenile samples, it is possible to estimate the introgression in different parts of the river. He stated that, subject to the continuation of funding, it is hoped that it will be possible to apply this method at a finer-scale. Dr Hindar referred to a major new research programme looking at spawners one season, the zero age group the next year and the one-year age group the following year etc. He noted that natural selection is known to act against farm offspring and that it is believed that the most extreme farm genotypes have the least likelihood of surviving in the wild. It is therefore expected that the programme will show that, if there are many farm fish on the spawning ground, high introgression will occur in the zero age group and then lower and lower introgression in the older age groups as the fish are exposed to the natural selection process.

Torfinn Evensen (Norske Lakseelver): Thanked Mr Torgersen for his presentation. He asked for more action and governmental

commitments to progress the transition to closed-containment systems and mandatory tagging of all farmed salmon, as referred to in the previous presentations. He noted that the Norwegian Government had committed to sustainability goals under which no mortality of wild salmon due to sea lice from fish farms is acceptable, nor is any genetic impact from escaped farmed salmon on wild salmonids. He stated that those commitments are in contrast with Mr Torgersen's presentation, which indicated that a mortality of up to 30% of salmon stocks was acceptable. Furthermore, he noted that there is a commitment that no aquaculture license should be issued, or development project approved, without an assessment of both the local environmental impact and the potential contribution to the overall national and regional environmental impact. He also referred to the 'polluter-pays' principle, noting that earlier in the month more than 60,000 smolts had escaped from one cage in Norway. He asked how these escapees could be distinguished from wild salmon when they return as spawners in 1-3 years' time, as they will look like wild salmon and are unlikely to be tagged. He asked how the polluter can be made to pay if the escapees cannot be traced back to the responsible fish farm in three years' time.

Yngve Torgersen (Norway): Responded that the presentation provided an outline of the decisions taken by the Norwegian Parliament on how to address these issues and these decisions must be complied with. With regard to the tagging of farmed salmon, he advised that there are reasonably accurate ways of distinguishing between farmed and wild salmon without the use of tags and that Kjetil Hindar may be able to provide a more detailed answer.

Andrew Graham-Stewart (Salmon and Trout Conservation Scotland): Noted with concern that there was very little mention of the impact on wild fish during the presentation by Scotland, particularly when lice threshold levels are set at three and eight lice per farmed fish and up to three lice per farmed fish appears to be deemed acceptable. He indicated that he believed that the new measures outlined are going to make very little difference to wild fish, unless they are accompanied by: the provision of a statutory duty to protect wild salmonids and the introduction of an upper-tier sea lice threshold, above which an immediate cull is required by law; the closure or relocation of persistently failing farms and greater weight given to wild fish interests in planning applications; the immediate publication of individual farm sea lice data and compulsory independent monitoring of lice counts; tougher regulation and inspection of fish

farms; replacing the voluntary Code of Good Practice on lice with a statutory code; and ending farmed smolt production in river systems that have wild salmon. He indicated that he had reviewed the paper on the management of the salmon farming industry in the Faroe Islands and felt that the contrast with Scotland in the way farms are regulated is most striking. He noted that in the Faroe Islands there is independent monitoring of sea lice numbers, when the lice threshold is reached treatment is compulsory and there are regular orders for slaughter whereas none of this happens in Scotland. He indicated that the Faroe Islands are now intending to reduce the threshold for treatment of lice, but in Scotland three lice per fish is acceptable. He noted that it seemed very odd that the Faroe Islands, with no natural wild salmon rivers, have a much tighter regulation of the salmon farming industry than Scotland. He asked when Scotland would be taking proper responsibility, in line with NASCO guidelines, specifically for protecting wild fish.

Alastair Mitchell (European Union - UK (Scotland)): Responded that the Scottish Government considers that there is a balanced and proportionate regulatory regime fit for Scotland, but noted that it is always willing to learn from others. He indicated that Scotland is part of a quadrilateral arrangement with Canada, Norway and Chile working together to look at the regulatory approaches and whether changes can be made. He indicated that the Scottish Government would be happy to speak to the NGOs about possible changes, but that the current situation is that wild fish are properly protected within the Scottish context. He further noted that the vast majority of the wild fish are on the east and north coasts of Scotland and have no particular interaction with fish farms.

Niall Greene (Salmon Watch Ireland): Indicated that the session was like Hamlet without the Prince, in that the presentation by Ireland was the only one that was not made by the Government department responsible for promoting, siting, regulating and managing aquaculture. He noted that the presentation outlined some critical aspects of what is happening in Ireland regarding salmon farming and then discussed challenges and necessary actions and he asked if there was any hope that Ireland would get anywhere close to meeting the international goals in the next few years.

Cathal Gallagher (European Union - Ireland): Responded that as the question related to policy he could not deal with it, but that he would raise it with the appropriate department and revert once a response is provided.

Denis Maher (European Union - Ireland): Confirmed that the question would be transmitted to the Department of Agriculture, Food and the Marine (DAFM), which is the statutory authority responsible for aquaculture. That department had been asked if it could be represented at the Theme-based Special Session but, due to other commitments, that had not been possible. However, he indicated that there would be meetings with DAFM in the near future and he would be happy to engage with the NGOs in terms of any questions they would like to see raised with the responsible authority.

Dave Meerburg (Atlantic Salmon Federation): Noted that 30-35 escapes were identified in the monitoring programme referred to in the US presenation, 5 of which were of US origin and could probably be traced to the sea-pen from which they originated. He asked if it is possible to identify where the other 30 escapes came from.

Rory Saunders (United States): Indicated that it is possible to say that the other fish did not come from the US salmon farming industry but he could not be more specific with the science currently available. He noted the importance of collaboration with Canada as there is a large aquaculture industry located just across the border with the US and, potentially, the other fish may have come from there.

Gérald Chaput (Canada): Asked Mr Saunders if additional information could be provided on the approach to traceability, as this seems like a complex system involving considerable paperwork. He asked if there is any kind of verification or auditing undertaken to make sure the tracking is correct.

Rory Saunders (United States): Confirmed that there is and that his understanding is that parentage analysis is conducted. He indicated that as part of the permit requirements, traceability must be 95% accurate before fish can be stocked out. He further stated that geneticists with the US Fish and Wildlife Service work very closely with the industry and the parentage analyses run by the industry laboratories are verified by conservation geneticists at the US Fish and Wildlife Service working on wild salmon interactions. Therefore, the industry laboratory results are backed-up by government laboratories as well.

Steve Sutton (Atlantic Salmon Federation): Indicated that before responding to Mr Gilbert's presentation, he wished to make a statement drawing on the collective wisdom of the NGOs detailing what they believe Canada needs to do to begin to address the issues of aquaculture on wild salmon. This includes: avoidance by salmon

aquaculture of wild salmon migration routes and important habitat; specific limits to parasites, with sea lice levels allied with farm-specific mortality reduction plans; prompt reporting of parasite outbreaks to other local operators and the public; avoidance of parasites and diseases being spread to wild populations by implementing aggressive measures such as complete culling of farm pens; a requirement for contributions to collaborative research and environmental enhancement work with NGOs and research institutions; adoption of area-based sea lice thresholds; implementation of consistent high standards in Canada and internationally; and restoration of lost protections to wild populations through modern safeguards in the Fisheries Act, including strengthened provisions for protecting wild salmon from the impacts of salmon aquaculture.

He then raised some issues related to the presentation. First, he noted that a map of wild salmon populations and aquaculture in eastern Canada had been presented but that, in his view, the analysis was overly simplistic as it was stated that aquaculture only occurs in a limited area and there are plenty of other salmon populations in Canada that may or may not be doing well. He indicated that the presentation did not mention that in every place in eastern Canada where there is aquaculture, salmon populations are either threatened or endangered and Fisheries and Oceans Canada has identified aquaculture as one of the factors threatening those populations. Furthermore, he noted that with a couple of minor exceptions, everywhere in eastern Canada where salmon populations are considered threatened or endangered there is aquaculture. Therefore, he sees a very strong overlap between aquaculture and the status of wild salmon populations. He noted that this in itself does not mean aquaculture can be blamed as the cause, nor does it mean that aquaculture is the only cause of those declines, as there are other known factors. However, it does mean that there are good reasons to address the impacts of aquaculture on those salmon populations. He noted that a lot of information had been presented at the session regarding the potential impacts salmon aquaculture can have on wild stocks and that those impacts need to be addressed in eastern Canada. He emphasised the need to act now, on the basis of the information available, rather than waiting until there are good data on the relative contribution of aquaculture to the decline of those populations.

Secondly, he noted that at the end of the presentation an example was given of a collaborative research project in which the aquaculture

industry is partnering with governments and NGOs to address some salmon conservation issues. He noted that the Atlantic Salmon Federation is part of that programme and is very pleased to have the aquaculture industry involved, and hopes that it will move things forward in terms of the collaborative approach to addressing the issues facing wild salmon. However, he indicated that this research project has nothing to do with aquaculture impacts as it is on the Miramichi river, which is not affected by aquaculture. He indicated that the aquaculture industry needs to come to the table with projects to address that industry's impacts on salmon as well. He noted that there have been a few examples of small-scale projects in Canada, but there is plenty more room for that to happen and it would not be acceptable to let the aquaculture industry fail to address their own impacts because they are contributing funds to address issues elsewhere.

Éric Gilbert (Canada): Responded that his first reaction was to agree. He noted his pleasure that Dr Sutton had agreed that the Miramichi River is too far from any aquaculture production for there to be any significant impact on the wild salmon population and yet the company still agreed to be involved in a project concerning wild salmon. Based on discussions with the company, he believed that it would be willing to be involved in other projects and is not trying to compensate its negative impact in one region through conservation efforts in another. He stated that there may have been some misunderstanding of his presentation, because as the lead agency responsible for both the protection of the marine environment and the aquaculture sector, Fisheries and Oceans Canada is not waiting for more information before acting. Many measures have already been introduced by Fisheries and Oceans Canada and the provincial governments in order to directly tackle the major issues being discussed in the session, but more needs to be done and more knowledge is required. He noted that these measures may not satisfy the Atlantic Salmon Federation but he felt that it is unfair to say that nothing is being done.

Steve Sutton (Atlantic Salmon Federation): Indicated that he believes that the presentation was a very broad overview of the types of measures being taken in Canada in relation to aquaculture, but it was not a true reflection of the situation on the ground and the way that some jurisdictions and members of the industry within Canada are approaching the development of the industry. By way of an example, he noted that in late 2015 the Newfoundland Government signed a

Memorandum of Understanding (MoU) with a Norwegian company for a major expansion of the aquaculture industry in Newfoundland. The Government is putting $45million into that project, so they are now a regulator and also a proponent of the project. The project will be sited in a bay in which there is currently no aquaculture and where wild salmon have been classified as threatened. The bay is located in a wider area in which Fisheries and Oceans Canada has identified aquaculture as one of the processes threatening wild salmon. He noted that as part of the MoU, the Newfoundland Government, in contravention of their own environmental legislation, did not require the company to submit the entire project, including the sea cages, for environmental assessment. The land-based closed-containment hatchery, which would not have impacts on wild salmon, was subject to an environmental assessment. He stated that the company was only required to submit the entire proposal for environmental assessment when court action was threatened by the Atlantic Salmon Federation and others.

Éric Gilbert (Canada): Noted that the project in Newfoundland is a major initiative that many participants in the session may not be aware of. He indicated that the current level of farmed salmon production in Newfoundland is approximately 20,000 tonnes and this project alone is around 33,000 tonnes of additional production and, furthermore, for the first time in Canada the proponent is proposing to use triploid eggs.

Steve Sutton (Atlantic Salmon Federation): Indicated that European-strain triploid eggs would be used.

Éric Gilbert (Canada): Commented that the Newfoundland initiative is being taken very seriously. The risk-assessment that was conducted through the regular process will be peer-reviewed by Canadian experts and others with relevant experience and expertise and this process is on-going. He indicated that he understood that the province had not refused to do an environmental assessment of the overall project, but rather it had delayed its decision pending a decision from Fisheries and Oceans Canada on the egg transfer from Europe to Canada. That decision would influence the nature of the environmental assessment that will be conducted: either by using existing knowledge or a more thorough assessment that would require the company to present new data in support of the assessment. He noted that this process is on-going and, as reported in the North American Commission meeting, Canada will ensure that it respects its mandate to protect the marine environment and the

fisheries, that it will closely adhere to the commitment under NASCO's Williamsburg Resolution concerning import of foreign-origin eggs into Canada and that it will follow the measures in its National Code on Introductions and Transfers, so that the decision taken will minimise the risks to a level acceptable to Canada.

Bill Hicks (Salmon and Trout Conservation UK): Asked for clarification from Mr Mitchell about the regulatory framework in Scotland. Document CNL(16)47 indicated that Scotland has a legislative and regulatory framework in place which provides the right balance between growing aquaculture and protecting the environment. He noted that in relation to the regulation of existing fish farms, both the document and Mr Mitchell's presentation relied on the 2007 Act, as amended by the 2013 Act, and that the clear implication is that the Scottish Government will use the 2007 Act to control sea lice from salmon farms to protect wild fish. He indicated that there was some confusion over this because other sources of information suggest that is not the position and he asked Mr Mitchell to clarify the situation.

Alastair Mitchell (European Union - UK (Scotland)): Responded that he agreed and that he had seen the letter presented the previous night, the content of which is in relation to fish farming. He suggested that this was the nature of the questions posed and the answer that Mr Hicks had received from Marine Scotland Science.

Bill Hicks (Salmon and Trout Conservation UK): Stated that the response indicated that the 2007 Act cannot be used for the protection of wild fish.

Alastair Mitchell (European Union - UK (Scotland)): Replied that in strictest terms he believed this to be correct, but that it was not the only mechanism that exists.

Bill Hicks (Salmon and Trout Conservation UK): Asked for confirmation that the position is that the Scottish Government believes it cannot, or will not, use the 2007 Act for the protection of wild fish.

Alastair Mitchell (European Union - UK (Scotland)): Indicated that the primary purpose of the 2007 Act is in relation to farmed fish.

Bill Hicks (Salmon and Trout Conservation UK): Stated that he was not asking about just the primary purpose, and that he understood from the response given that the Scottish Government will not use the 2007 Act at all for the protection of wild fish; indeed it is not allowed to.

Alastair Mitchell (European Union - UK (Scotland)): Indicated that it was rather difficult to have such a conversation because so many people in the room had not seen the letter.

Bill Hicks (Salmon and Trout Conservation UK): Replied that Mr Mitchell should know whether that is the position and asked again if the 2007 Act could be used at all to control fish farms to stop them harming wild fish with sea lice.

Alastair Mitchell (European Union - UK (Scotland)): Responded that the focus of the 2007 Act is in relation to farmed fish.

Bill Hicks (Salmon and Trout Conservation UK): Replied that he assumed that meant that the 2007 Act could not be used and that would mean that the presentation was slightly misleading.

Alastair Mitchell (European Union - UK (Scotland)): Apologised if that was the case.

Bill Hicks (Salmon and Trout Conservation UK): Indicated that people could judge for themselves and asked whether, if there are not the powers under the 2007 Act, proper powers had urgently been sought through some other Act or some other source.

Alastair Mitchell (European Union - UK (Scotland)): Stated that the controls in relation to the broader environment are well rehearsed. For example, an application under planning for a new fish farm or an amendment thereto would involve a number of statutory consultees.

Bill Hicks (Salmon and Trout Conservation UK): Indicated that his question had related to existing fish farms.

Alastair Mitchell (European Union - UK (Scotland)): Asked if the question could be repeated.

Bill Hicks (Salmon and Trout Conservation UK): Asked what other powers referred to by Mr Mitchell are available to the Scottish Government if the 2007 Act cannot be used, or, if there are no other powers, if these are urgently being sought. He asked if there is a document that describes what these powers are and what is being done if there are no powers.

Alastair Mitchell (European Union - UK (Scotland)): Replied that the requirements are broader than those included in the letter, and that there are a number of facets to the regulation of fish farms in Scotland.

Bill Hicks (Salmon and Trout Conservation UK): Asked if there was somewhere he could see these in writing.

Alastair Mitchell (European Union - UK (Scotland)): Indicated that he would be happy to discuss the issue further after the meeting and noted that he had not seen the letter in question until today.

Bill Hicks (Salmon and Trout Conservation UK): Asked for confirmation that Mr Mitchell had referred to an average of three female lice per fish and an eight louse limit in his presentation and document.

Alastair Mitchell (European Union - UK (Scotland)): Agreed that he had.

Bill Hicks (Salmon and Trout Conservation UK): Asked whether it was referred to in the context of the 2007 Act.

Alastair Mitchell (European Union - UK (Scotland)): Indicated that it was.

Bill Hicks (Salmon and Trout Conservation UK): Asked for confirmation that the three and eight louse limit referred to could not relate to, or take into account, wild fish if those limits are being developed under the 2007 Act.

Alastair Mitchell (European Union - UK (Scotland)): Stated that the three and eight louse limits are being introduced as significant enhancements to the risk-based management regime already in place, which will allow sharper reporting and enable the risk-based regime to be improved and made more timely. He hoped that environmental NGOs would welcome that as an enhancement within Scotland to improve the management of sea lice on farms.

Gérald Chaput (Canada): Thanked Dr Hindar for his excellent presentation. He indicated that he was curious about the suggestion that there may be a higher proportion of multi-sea-winter salmon and the size of one-sea-winter salmon might be increased as a result of introgression by farmed salmon. He asked if there were any studies that would provide evidence that there is improved fitness of a salmon population as a result of introgression.

Kjetil Hindar (Norwegian Institute for Nature Research): Replied that there is no evidence of increased fitness by introgression in any of the controlled studies, but, looking at fitness components, it is possible to envisage situations where fish that have been selected for a higher metabolism and growth rate would out-grow and out-compete

smaller fish for food in the river. It is believed that this has been seen in early life-stages in some experiments, and could be one explanation for the potentially lower productivity of wild fish when co-existing with farm offspring than when there are no farm offspring present, even though farm offspring are known to have lower survival rates in the long-term than wild fish. Dr Hindar further noted that in his opinion, if it is accepted that salmon populations in general are adapted to their local environment, any change resulting from introgression is likely to make them less fit or to lower the average fitness of the population.

Dave Meerburg (Atlantic Salmon Federation): Noted that he found the information presented regarding the extent of introgression in salmon populations in Norway extremely interesting. He asked Mr Gilbert if Canada was undertaking similar studies to detect introgression in rivers in areas where there is salmon aquaculture and, if such studies are being carried out, what the results are to date.

Éric Gilbert (Canada): Thanked Mr Meerburg for his question. He noted that he is neither a scientist nor an expert, but that he understood that a review of the genetic composition of many of the south coast rivers in Newfoundland had been undertaken, although he did not think that the study focussed on introgression. He added that Fisheries and Oceans Canada monitored any escapement that would bring farmed salmon into a river with a wild salmon population. He noted that it would be fair to say that Canada is not as advanced as Norway in this respect, but that it was important to remember that the number of escapes in Canada is only a few thousand fish per year, which is very low compared to Norway.

Ken Whelan (Atlantic Salmon Trust): Stated that there is now approximately 20 years of practical management experience and that it is very clear, in relation to protecting wild fish, that there can be no more than between 0.1 and 0.2 lice during the critical period. He noted that he felt that some of the presentations were so far removed from that figure to be unreal. He indicated that the situation is that there are two different streams: figures set for fish farmers that they can meet and that they feel is adequate for their needs; and another set of figures to protect the wild fish. He noted that the figures given in the Irish presentation in relation to the early 2000s were in place when he was involved in both aquaculture and the protection of wild fish in Ireland. He noted that he had been involved in meetings with fish farmers and that the figure of 0.2 was agreed jointly. Farmed salmon production in Ireland was at its

highest level at that time, yet disease and lice levels were at their lowest. He asked, therefore, if it would be possible to try to focus on a single figure. That figure is not for the benefit of wild fish; it actually helps all salmon. He stated that he believes that this is very important as there are so many figures being discussed. He further indicated that, in his view, consideration of 2 and 3 lice during the critical period is nonsense and far beyond an acceptable level in the context of protecting wild fish. He asked Dr Finstad whether, under the traffic light system referred to in his presentation, 10% - 30% mortality of salmon smolts going to sea would mean that the salmon farming industry did not have to change its management protocols in the bay.

Bengt Finstad (Norwegian Institute for Nature Research): Replied that Professor Whelan's understanding was correct. He noted that the traffic light system, as presented, was based on the results of physiological experiments which have been translated into population-level risks. He advised that the traffic light system had been developed in 2012 and is a first generation method for analysing risks to wild fish. He agreed that between 10% - 30% mortality of wild fish means that capacity of farmed production could not be increased but would not need to change, and that a 30% loss of a population is very high. He stated that the percentage is set too high in this first generation method, but would be further developed in future.

Noel Carr (Federation of Irish Salmon and Sea Trout Anglers): Noted that in Ireland there has been poor information flow over many years between the Department of Agriculture, Food and the Marine and the Department for Communications, Energy and Natural Resources. He would like to see the restoration of the position of wild salmon and sea trout interests in the license awards and regulatory process and, with a new Government now in place, a commitment to review and adopt some new closed-containment measures. He asked if there was a commitment from the Department for Communications, Energy and Natural Resources to explore new closed-containment technology.

Cathal Gallagher (European Union - Ireland): Replied that he could not reply for his agency's parent department, but noted that the responsibility for the development of aquaculture lies with the Department of Agriculture, Food and the Marine. He advised Mr Carr that he would pass that question to them. He asked Denis Maher to answer Mr Carr's question on behalf of the Department of

Communications, Climate Action and Environment, as the Department for Communications, Energy and Natural Resources is now known.

Denis Maher (European Union - Ireland): Agreed with Dr Gallagher that the Department of Agriculture, Food and the Marine is the competent authority and that he would take Mr Carr's question to them along with the previous question from Mr Greene.

Phil Thomas (ISFA): Indicated that he felt Professor Whelan's comment was confusing. He noted that there is a total incoherence between the laboratory studies in terms of the quality and the mortality percentages and the results from studies actually carried out at sea. He indicated that there is confusion because the same terminology has been used in the policy statements from Norway and it is very important to make the distinction that those percentages are based on the laboratory studies while none of the sea-based studies have resulted in similar figures.

Bill Whyte (Association of Salmon Fishery Boards): Asked Mr Mitchell who was involved in the criteria for selecting the figure of 8 adult female lice as the Association of Salmon Fishery Boards in Scotland is under the impression that the figure was selected for the welfare of farmed rather than wild fish. He indicated that as far as he was aware, no wild fish interest was consulted in reaching that figure and noted that in Norway, the maximum lice figure is 0.5 before enforcement action is taken.

Alastair Mitchell (European Union - UK (Scotland)): Replied that Mr Whyte was correct that it relates to fish farming. He noted that the Scottish Government sees this figure as an enhancement to the existing risk-based approach currently in place for the management of Scottish fish farms and derives from the Fish Health Inspectorate in conjunction with himself and others. He indicated that the intent was to introduce triggers to identify where problems are beginning to occur at the level of 3 lice as a management tool for the FHI. He stated that once that level is reached, a monitoring regime would be put in place, run by the company, to address the problem in order to get back down below that level. The figure of 8 is the point at which it is recognised that the effort by the company has failed and FHI will need to take enforcement action to address the problem. He further stated that those triggers did not exist before and are, therefore, enhancements to the risk-based approach by enabling FHI to do its job better.

Bill Whyte (Association of Salmon Fishery Boards): Noted that the Association of Salmon Fisheries Boards would welcome the opportunity for consultations with the Scottish Government in relation to the figure of 8 lice because it, and the majority of wild fish stakeholders, believes that in a production area containing 2-3 million fish, the figure of 8 adult lice per fish is too high for the protection of wild salmonids.

Alastair Mitchell (European Union - UK (Scotland)): Thanked Mr Whyte for the offer and indicated that the Scottish Government would be delighted to speak to the Association of Salmon Fishery Boards about the entire process, and suggested that this could be incorporated into similar consultations already arranged with the ASFB.

Paul Knight (Salmon and Trout Conservation UK): Indicated that he welcomed the proposals for greater co-ordination, co-operation and liaison between the Parties and the NGOs arising from the session.

Andy Walker (Scottish Anglers National Association): Asked if the sea lice on sea trout are genetically the same as those on salmon.

Armin Sturm (Institute of Aquaculture, University of Stirling): Confirmed that current data from both studies suggest that it is the same species.

Mark Saunders (North Pacific Anadromous Fish Commission): Asked if the programme referred to by Dr Karlsen was actively sampling wild fish in order to ground-truth the models and for an indication of the cost of this programme. He further asked how it was being funded and whether it was a user-pay model.

Ørjan Karlsen (Institute of Marine Research): Replied that with regards to funding, the Institute of Marine Research is a Government institute, so it is funded by the Government, both directly and through other governmental agencies with an interest in the programme. With regards to verification of the model, three different methods are used to collect data. One method involves salmon smolts migrating out of rivers being caught in trawls. However, this information cannot be used to directly verify the models, because it is a cumulated effect and it is not known which river the smolts originate from and most fjords contain several rivers. Traps are also used to catch wild trout all along the coast and the information derived can be used as an indirect measure to indicate how good the models are. However, this presents difficulties as the

mortality of lice in the ocean is not known, and there is further uncertainty regarding regional or seasonal effects on lice mortality. More detailed data would therefore be valuable. For the purpose of these studies, the only published rate (17% a day) is used in the model. The third method is by using sentinel cages in fjords, with 18-25 cages in each fjord. However, the distance between these cages is too large to be accurate enough to use as a measure. He noted that it would have been very helpful to have a method of frequently sampling lice in the ocean that could be verified against the model outputs.

Dave Meerburg (Atlantic Salmon Federation): Asked Dr Karlsen why it is not possible to count lice in an area directly using plankton tows or other means.

Ørjan Karlsen (Institute of Marine Research): Responded that it is possible, but very labour intensive so approaches are being explored to increase the efficiency of these methods.

Paddy Gargan (European Union - Ireland): Thanked Mr Warrer-Hansen for his interesting presentation and noted that closed containment is at the point where it might become economically viable. He indicated that a slight variation of the full land-based production system is to rear smolts for longer in fresh water, before these so-called 'super smolts' are placed to sea and asked if this might offer benefits.

Ivar Warrer-Hansen (Inter Aqua Advance): Indicated that there is a new and very exciting trend known as post-smolt production, with rearing on land in re-circulation systems to a larger size of fish before they are stocked into sea cages. It began in Northern Norway (Finnmark) where sea temperatures meant that the rearing-cycle at sea was more than two winters. Compared to stocking 100g smolts, stocking of 500g post-smolts, pre-adapted to sea water, would result in a reduction in the duration of the production-cycle of about 25% (132 days) and stocking 1kg post-smolts would reduce the production-cycle by 40% - 50%. This offers huge benefits in terms of sea lice impacts and greater flexibility with regard to timing of stocking sea cages and fallowing periods. He suggested that the rearing of post-smolts could be used as a stepping-stone towards full land-based production but thought that it was only occurring in Norway and not in Scotland or Ireland.

Willie Cowan (European Union - UK (Scotland)): Confirmed that larger smolts are being reared in Scotland.

Noel Carr (Federation of Irish Salmon and Sea Trout Anglers): Asked Mr Warrer-Hansen if the costs associated with sea lice treatment had been extracted from the cost-benefit analysis relating to land-based production.

Ivar Warrer-Hansen (Inter Aqua Advance): Indicated that this was not the case but for some farms or companies facing major problems there could be large savings in production costs. He stated that rather than investing in large structures 200km off-shore, which are very expensive and difficult to run and maintain, closed-containment would offer considerable savings.

Kjetil Hindar (Norwegian Institute for Nature Research): Asked Mr Warrer-Hansen if there was any experience of mixing fresh water and salt water to give salinity that is closer to the isotonic salinity.

Ivar Warrer-Hansen (Inter Aqua Advance): Indicated that two systems are being built in Norway, with a third already built in Finnmark, which are designed to operate from 12 parts per thousand salinity up to full sea water.

Dave Meerburg (Atlantic Salmon Federation): Indicated that the Atlantic Salmon Federation has been sponsoring research on closed-containment aquaculture for a few years and understood that some of the producers in the field believe that they can get an increased price for their product by being able to market it as a 'green product'. He asked Mr Warrer-Hansen to comment.

Ivar Warrer-Hansen (Inter Aqua Advance): Noted that organic status can be granted for conventional salmon farming but would not be given to land-based closed-containment systems. However, sustainability accreditation by the Aquaculture Stewardship Council could be awarded. He indicated that he would not rely on this accreditation in budgeting in the longer term as novelty wears off with consumers.

Sarah Bayley-Slater (Atlantic Salmon Trust): Noted that Mr Mitchell had referred to a policy against further development of aquaculture on the north and east coasts of Scotland where the majority of wild salmon and recreational fisheries are based. She stated that this indicates an awareness of the impacts of aquaculture on wild salmonids and implies that the west coast is being sacrificed. She asked if it was a coincidence that the conservation limits are Grade 3 throughout the west coast, indicating that there was less than 60% probability of the conservation limits having been met in the last 5

years. Given the information presented in the session, the evidence of sea lice impacts on sea trout and the growing body of evidence of impacts of lice loadings on wild salmonids, she asked if it was now time to apply a precautionary approach and re-assess the threshold limits for the Scottish traffic light system, as Norway had indicated that it needed to do, recognising that this is not just an issue for the fish farms or the Fish Health Inspectorate but also for the wild fish.

Alastair Mitchell (European Union - UK (Scotland)): Referred to the earlier discussion about the 2007 and 2013 Acts which he had indicated he would be happy to carry on. He indicated that he did not think that the west coast was being sacrificed but that there is a robust system in place for all finfish developments. There are added controls on the north and east coasts, but that is not a sacrifice of the west coast. All finfish farms on the west coast and the islands are subject to a rigorous appraisal as part of their planning, including complying with Environmental Impact Assessments. That process, which is the jurisdiction of local authorities, involves all the regulators together with statutory consultees and the District Salmon Fisheries Boards. He considered that in Scottish terms there is a proportional, reasonable and robust regulatory system for control of the sector. With regard to the recent introduction of lice levels, the numbers set are there to add value to, and supplement, the existing risk-based approach to sea lice control. He stated that it is in the interests of fish farmers to have adequate controls in place so this is a supplement to that and the Scottish Government believes this will make a substantive difference. He indicated that the Scottish Government would be happy to discuss any further views the NGOs may have on this and to engage in that debate further beyond NASCO.

Sarah Bayley-Slater (Atlantic Salmon Trust): Noted that in the traffic light system in Scotland the threshold seems to be higher than that used in the Faroe Islands and Ireland.

Alastair Mitchell (European Union - UK (Scotland)): Reiterated that in Scotland the traffic light system is being used as a supplement to the existing risk-based approach, to prompt the Fish Health Inspectorate in terms of the management of farmed fish above and beyond the existing controls. It forms part of what the Scottish Government hopes will be a continuum of improvements in the overall management approach.

Andrew Graham-Stewart (Salmon and Trout Conservation Scotland): Indicated that having listened to all of the presentations it is

depressing to conclude that no country has lower standards on sea lice control than Scotland. He commented that the line of response from Mr Mitchell is completely unsustainable with the bar being set lower in terms of standards and the industry being given carte blanche to continue in the way it has over many years. He stated that Scotland's shame is now exposed for all to see.

Alastair Mitchell (European Union - UK (Scotland)): Stated that he did not agree.

Phil Thomas (ISFA): Indicated that he believed that the reality is that the fish farming industry in Scotland is massively regulated compared to agriculture, contrary to what was suggested in Mr Greene's presentation. He stated that it is not a matter of lower standards in aquaculture, but rather the opposite. He also noted that looking at the distribution of aquaculture and of salmon catches in Scotland, the figures for total catch in salmon farming areas have been about 10% or 12% of the total catch overall since 1952, with little change. He indicated that a significant issue is that information is lacking for the wild fish on, for example, fishing effort. Consequently, if catches in an area fall, it is not known if that is actually due to a fall in the popularity of that area for fishing, and that comparing stock levels through monitoring systems to catches provides some peculiar findings. He noted that there is a real need for the wild fish sector to put together a detailed case to make this point.

Dan Morris (United States): Thanked the Steering Committee for developing the Programme for the session allowing the different perspectives to be shared. He referred to the North American Commission where there is an on-going transparent and candid dialogue between the United States and Canada regarding aquaculture, escapes, lice, disease, introductions and transgenics. He referred to the report of work underway in Nova Scotia, which seems to be leading the way amongst the Canadian provinces, regarding standards and practices for containment and traceability. He indicated that is certainly something that has been worked on in the United States and asked if the Canadian Federal Government might play a role in the expansion of that enterprise amongst the provinces.

Éric Gilbert (Canada): Responded that Canada is always looking for improvements in the regulatory regime and a traceability system for escapement is something that he personally strongly supports. He indicated that under the Regulatory Cooperation Council, comparative analysis is being conducted of the two regimes in force

on both sides of the Canada/US border, stimulated by the traceability system in Maine. He noted that a Canadian company operating in Maine is part of that system so it may be supported by the industry in Canada. A recent workshop, called by the Minister responsible for aquaculture, had concluded that a traceability system would be a part of the solution, but there are also other options that need to be considered. From a Federal perspective, there is a responsibility under the Fisheries Act to protect marine resources. Mr Gilbert felt that such a system would provide some advantage and indicated that he personally believed that there is a need in Canada to have a more standardised approach across all Atlantic provinces. He noted that in Nova Scotia an advisory panel has been established to consider this and other provinces are also giving it consideration. He indicated that he believed that Canada is moving towards such a system under the Regulatory Cooperation Council initiative and at the end of the process he would like to see a kind of equivalency declaration between the two countries on how the sector is managed which would be beneficial for everyone.

Niall Greene (Salmon Watch Ireland): Responded to the comment by Professor Thomas by indicating that in referring to the law governing terrestrial farming, he was not comparing the quantum of regulation but rather the nature of the law. He noted that farmers on land, particularly in the EU, are subject to lots of regulation, perhaps more or less than salmon farmers, but in the case of terrestrial farming it is real regulation through primary legislation, secondary legislation, ministerial orders, all the way down and there are prosecutions for non-compliance. He indicated that he might be generalising on the basis of one or two jurisdictions with salmon farming, but taking Ireland as an example, the regulation is encompassed in protocols. Further, it is not clear that these protocols are properly attached to the licenses and no court has had to pronounce on the quality of the protocols, because no salmon farmer has been prosecuted. He believed that the case for a harder law regime is unanswerable, as is the need for enforcement of both hard and soft law. He accepted the point about the North American Commission and the United States, recognising that jurisdictions with salmon farming run a spectrum of good to bad practice and are not all in the same barrel. Certainly Maine and the Faroe Islands are at one end of the spectrum and the rest are scattered along it with some doing better than others.

Paddy Gargan (European Union - Ireland): Responded to Professor Thomas' comment that the wild fish side needed to come forward

with more hard evidence. He stated that there is a quantum of information available, including a major paper published in 2015 which had reviewed over 300 existing publications on the impact of sea lice on sea trout and it incontrovertibly described the impact of lice on sea trout in salmon farming areas. Furthermore, the ICES representative clarified the issue that has been debated for a number of years as to the impact of lice from salmon farms on wild fish, indicating that it is about a 20% loss in spawners, ranging from 1% - 39%. He did not, therefore, accept that additional research is necessary because the information already exists. The mortality varies from location to location depending on the amount of lice being produced, whether the farms are fallowed and the weather conditions etc., but if the circumstances come together there can be a very serious impact. He stated that there is enough information available to make proper management decisions on how lice should be controlled. He stated that if it is not possible to control lice there needs to be a different strategy: perhaps only putting the fish to sea for 6 months or harvesting them before the wild fish go to sea. He noted that there are plenty of options yet the industry continues to farm in the way it has done traditionally, including in sensitive areas such as Special Areas of Conservation for salmon. He stated that there is a need to look at different approaches to management with regulators adopting an approach that recognises the potential hazards.

Phil Thomas (ISFA): Indicated that there have been many rounds of debate on defining hazards and the issue of translating that into a quantifiable risk at a particular location is important. However, the kind of evidence needed of impacts is not available at a regional level. He noted that if there was an impact in the areas where salmon are farmed in Scotland it would be on a localised basis, but efforts to get angling interests to come forward and work with the industry and provide detailed information for particular locations have not been successful. One difficulty would arise for example if there is a problem with a particular farm and a case was made for moving it: where would it be moved to without making the problem worse? He stated that the problem needs to be clearly defined and that he considered that the wild fish interests had not been proactive enough at this. With regard to fishing effort data, for example, which he believes are absolutely crucial, he stated that it is not appropriate to work only on the basis of catches without effort data.

Bill Whyte (Association of Salmon Fishery Boards): Responded that details of fishing effort had been provided to a company operating farms in Wester Ross but individual farm lice numbers were not provided, so there needs to be a two-way system of information flow. He indicated that without that two-way flow, data provided by the wild fish interests will be used against them by the SSPO and the Scottish fish farming industry. He indicated that there is currently an acute lack of water in the rivers of Wester Ross, delaying smolt migration so they will now have to swim past fish farms with relatively high numbers of lice. He stated that the situation will deteriorate if action was not taken instead of just talking about the issues.

Ken Whelan (Atlantic Salmon Trust): Suggested that there might be a collective practical commitment in relation to the contribution that juvenile fish make, in terms of leakage into the wild population and wild genomes. The technology for rearing in closed-containment systems exists and he asked if financial support or encouragement could be given to the aquaculture industry across the North Atlantic over the next 2-3 years, in order to ensure that, for the freshwater phase of the life-cycle of farmed salmon at least, there is absolute containment as that is now achievable and there is no justification for any sort of leakage from that source. He noted that in many cases this leakage is unquantified and unnoticed but a number of studies have indicated that it can be significant in comparison to the more obvious escape of adult salmon from cages. He suggested that NASCO Parties should require closed-containment for juvenile stages of farmed salmon within 3-5 years.

Torfinn Evensen (Norske Lakseelver): Asked Mr Torgersen what right the Norwegian Parliament has to reduce the production of wild salmon by 30% in contrast to the Quality Norm law. He also referred to the major threat posed by escaped farmed salmon to wild salmon stocks, as indicated by the findings that two thirds of the wild salmon stocks have been changed genetically due to introgression by escaped farmed salmon. He indicated that a tagging programme is required to allow traceability of escaped farmed fish and there is good experience of using both adipose fin clipping and Coded Wire Tagging for cultivated salmon in the Pacific parts of Canada and the US. Very large numbers can be tagged and the cost is low, perhaps 0.2% or 0.3% of production costs, so it is not a question of cost but the industry will not do this on their own without government intervention. He further asked what Norway should do to remove

farmed salmon more efficiently from the spawning grounds.

Yngve Torgersen (Norway): Responded that the Quality Norm had been adopted by a Royal Decree, while the Parliament decides on the laws which he understood to be one step above a Royal Decree in legal terms. The Parliament has to find a balance between differing interests and, in this case, that is what has been done in order to strike a balance between what was considered to be an unacceptable impact and the possibility for further aquaculture growth. With regard to escapees, the risk of escape incidents does not change if farmed fish are tagged, but it would make it easier to identify the owner following an escape incident. He indicated that it is the policy of the Norwegian Government to apply the principle of prevention is better than cure, i.e. it is far better to put effort into preventing the escape of fish. He referred to a planned public consultation process for a new standard for land-based fish farming similar to the NYTEK standard, which specifies the requirement for technical construction in order to prevent or reduce the risk of an escape incident. The Norwegian Government wishes to enforce the 'polluter-pays' principle such that if farmed fish escape and the prevalence of farmed fish in the river is too high, then the aquaculture industry should pay for their removal.

Torfinn Evensen (Norske Lakseelver): Reiterated that the question was what could Norway do to remove farmed salmon more efficiently from the spawning grounds, not about measures to prevent escapes.

Yngve Torgersen (Norway): Responded that the prevalence of escaped farmed salmon in rivers is monitored through a national government financed surveillance programme. In rivers identified as having unacceptably high proportions, there is a legal obligation for the fish farming industry to pay to reduce the numbers or pay for mitigation measures.

Paul Knight (Salmon and Trout Conservation UK): Noted that there had been many references to the balance of interests and asked which interests are to be balanced. The Atlantic salmon is a wild creature that is threatened in many parts of the northern hemisphere. He asked Mr Torgersen and the other Parties whose interests would be considered if the debate concerned polar bears or Siberian tigers and why the angling or fisheries interests are referenced when the issue concerns protection of a wild creature.

Yngve Torgersen (Norway): Responded that he would put nature's interests first because it would be unfair to compare the value of the

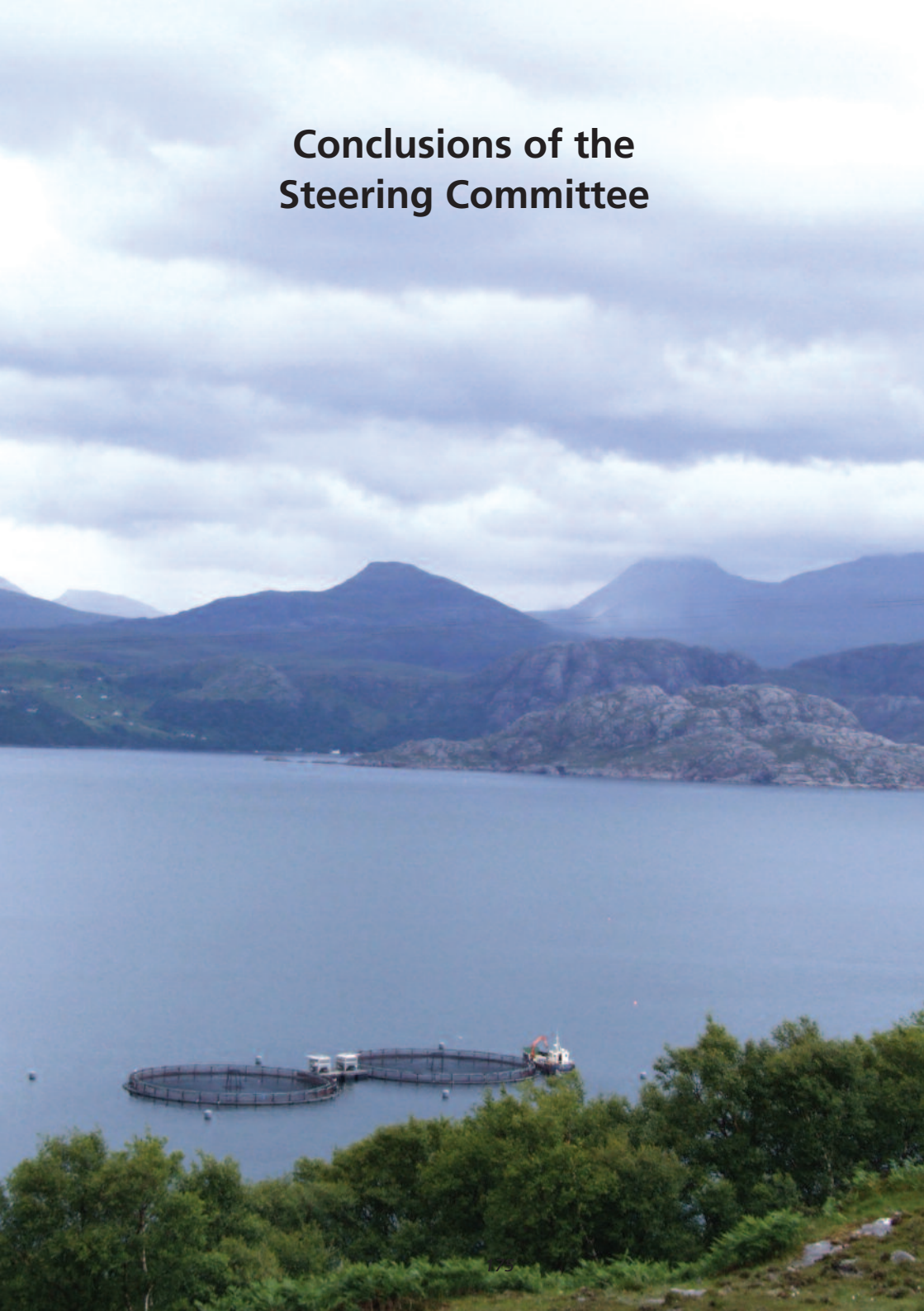
tourism and the angling industry in the rivers, which is around NOK2billion, with the value of aquaculture production, which is around NOK30billion and which would always then win. He noted that his department is also responsible for the capture fishery which would also lose out in balancing the interests of fishermen with the oil and gas industry. When reference is made to balancing interests that means ensuring conservation of salmon through measures such as National Salmon Rivers and Fjords.

Dave Meerburg (Atlantic Salmon Federation): Referred to the situation in Norway and the scientific advice and asked Mr Torgersen if, given the evidence of genetic introgression, it would be possible to improve the situation in future or if the horse has already bolted.

Yngve Torgersen (Norway): Indicated that there is a need to consider what can be achieved in future which is why the government is seeking to facilitate and encourage the development and use of triploid salmon. Several fish farms have been issued with 'green licences' and are using triploids on a commercial scale. If this is not successful, the licence will be revoked. He noted that this again is about balance; in this case the balance is between the carrot and the stick.

Kim Damon-Randall (United States/Steering Committee Chair): Thanked all speakers and participants for their contributions to a very valuable session which, as with previous Theme-based Special Sessions, had allowed for a detailed exchange of information on domestic management approaches and presentation of new research. She referred to the importance of the aquaculture industry as an economic driver, often in rural areas, and the challenges in meeting NASCO and ISFA's international goals of 100% of farms to have effective sea lice management and 100% of farmed fish to be retained in all production facilities. However, she noted that some good success stories had been highlighted, such as some areas where there are zero escapes, and new approaches that are being used in order to meet the challenges. She noted that progress is being made but more needs to be done and that NASCO's Theme-based Special Sessions provide a very good forum for exchanging information and ideas and today was a great step forward in continuing to progress this issue.

Conclusions of the Steering Committee



Conclusions of the Steering Committee

Introduction

The NASCO Convention requires that, in exercising its functions, the Organisation takes into account the best scientific information available to it. In response to concerns about interactions between salmon aquaculture and the wild salmon stocks, NASCO and ICES have convened a series of international meetings over the last 25 years to review scientific understanding of interactions and provide guidance on appropriate management responses. The most recent of these symposia was held in 2005. While it was recognised at that symposium that progress was being made in managing salmon farms, the growth in farmed production meant that challenges remained and the scientific information that was presented highlighted concerns, in particular regarding the impacts of sea lice and escaped farmed salmon. These concerns were recognised and accepted by the industry representatives present. Having reviewed all the scientific information presented at that 2005 symposium, the Conveners concluded that impacts of salmon farming on the wild stocks needed to be eliminated not just reduced. They highlighted the challenge and concern for both the industry and the wild fish of the prospect of sea lice developing resistance to the available therapeutants and the need for urgent progress on containment because the escape of fertile farmed salmon was putting at risk the stock structure and diversity of the wild stocks.

In response to these findings, NASCO amended its 2003 Williamsburg Resolution (CNL(06)48) and in 2009 NASCO and ISFA jointly developed, and agreed, Guidance on Best Management Practices to address impacts of sea lice and escaped farmed salmon on wild salmon stocks, the BMP Guidance.

Since 2005, production of farmed salmon in the North Atlantic has approximately doubled from 800,000 tonnes to more than 1.6 million tonnes. In contrast, wild salmon abundance has declined throughout the North Atlantic. Increased marine mortality has been identified as a major contributing factor in the decline in abundance of the wild stocks and climate change poses significant challenges and uncertainties for their future management. The main conclusion from the 2011 NASCO/ICES 'Salmon Summit' was that, in this challenging global environment, the objective should be to maximise the number of healthy wild salmon that go to sea and that this entails addressing all the impact factors in fresh, estuarine and coastal

waters. These factors include degraded habitat, barriers to migration, over-exploitation and salmon farming. The 'Salmon Summit' further recognised that the goal should be to protect the genetic diversity of the wild Atlantic salmon in order to maximise their potential to adapt to the changing environment.

NASCO has developed agreements to address the wide range of impact factors affecting wild salmon, particularly in relation to the management of salmon fisheries, habitat protection and restoration and aquaculture and related activities. The objective of NASCO's Theme-based Special Sessions is to allow for greater exchange of information and sharing of experience of best practice on a topic related to these agreements. Previous Theme-based Special Sessions have been held in relation to management of fisheries (2014) and impacts of hydropower (2015) which allowed for a valuable exchange of information and consideration of best practices. The Council had, therefore, agreed that it was appropriate and timely that the 2016 Theme-based Special Session should be on the theme of minimising impacts of farmed salmon on wild salmon stocks. This is consistent with examining the wide range of factors that could impact wild Atlantic salmon, as proposed at the 'Salmon Summit' and in accordance with NASCO's Strategic Approach (CNL(05)49).

In developing the objectives for the Theme-based Special Session, the Steering Committee sought to facilitate: presentation of the latest scientific information on impacts of salmon farming on the wild stocks; consideration of progress and challenges in managing these impacts; and identification of developments and best management practices that could facilitate achievement of NASCO's international goals. It should be noted that interactions between wild and reared salmon are not restricted to salmon farming. Through the Williamsburg Resolution, NASCO has agreed Guidelines for Stocking Atlantic Salmon and the 2017 Theme-based Special Session will consider the risks and benefits to Atlantic salmon populations from hatchery and stocking activities.

Co-operation with the Salmon Farming Industry

The Steering Committee had used the occasion of the Theme-based Special Session to invite the International Salmon Farmers Association (ISFA) to make a presentation in order to have an industry perspective of progress in implementing the jointly agreed BMP Guidance since its adoption in 2009. Although ISFA was unable to accept this invitation, representatives of ISFA, together with representatives of NASCO

Parties/jurisdictions with responsibility for aquaculture management, did participate in the session. The Steering Committee notes the statement made by the representative of ISFA to the 2016 Annual Meeting of the Council of NASCO that the industry is developing rapidly but that advances in relation to minimising impacts of farmed salmon on the wild stocks had not been reflected in the presentations at the Theme-based Special Session. The Steering Committee notes that since 2013 the Council has retained an item on its agenda entitled 'Liaison with the Salmon Farming Industry' specifically to allow for an exchange of information on issues concerning impacts of aquaculture on wild salmon. The Steering Committee recommends that ISFA use this opportunity to provide relevant information to the Council each year commencing in 2017. As will be clear from the conclusions drawn by the Steering Committee, it considers that there is a need for urgent progress towards the international goals given the latest scientific advice.

New scientific advice

In 2015, NASCO had requested that ICES advise on possible effects of salmonid aquaculture on wild Atlantic salmon populations, focusing on the effects of sea lice, genetic interactions and the impact on wild salmon production. The response from ICES, which provided new information to update that reviewed at the 2005 NASCO/ICES Symposium, concluded that there is substantial and growing evidence that salmon aquaculture activities can affect wild Atlantic salmon, through the impacts of sea lice as well as farm escapees. While both factors can reduce the productivity of wild salmon populations, there is marked temporal and spatial variability in the magnitude of reported effects. The scientific information presented at the Theme-based Special Session is summarised below.

Sea lice

Sea lice are a serious problem for the salmon farming industry. Salmon farms have also been shown to increase the abundance of sea lice in the marine environment and increase the risk of infestation among wild salmon populations, although impacts vary both spatially and temporally. Several studies have demonstrated a link between fish farming activity and sea lice infestations on wild salmonids; however, there are challenges in quantifying effects at the population level, particularly for salmon which exhibit variable survival linked to environmental variables. The greatest impact from lice is likely to occur on post-smolts during the early period of marine migration.

Laboratory studies, supported by field studies, show that very low lice levels on Atlantic salmon smolts (0.04 - 0.15 lice per gram fish weight) can increase stress levels, reduce swimming ability and disturb water and salt balance. Infestations of 11 lice per smolt (0.75 lice per gram fish weight) can be lethal if all the lice develop into pre-adult and adult stages. Studies of wild salmon post-smolts indicate that only those with infestations of less than 10 lice survived. Paired releases of treated and control groups of salmon smolts have demonstrated an overall improved return rate for treated versus control groups, but with significant spatial and temporal variability in the magnitude of the treatment effect. Current marine mortality rates are often at or above 95% and ICES advises that if considered against this mortality, the 'additional' marine mortality attributable to lice is estimated at around 1%. However, if considered in terms of returning adult salmon to rivers, estimates of loss range from 0.6% - 39%, with baseline marine survival being the most important predictor variable. This suggests that sea lice induced mortality has an impact on returns of wild Atlantic salmon which can influence achievement of conservation requirements for affected stocks.

Escaped farmed salmon

ICES advised that very large numbers of domesticated salmon escape from fish farms each year and escapees are observed in rivers in all regions where salmon farming occurs. While the number varies both spatially and temporally, escapees have comprised 50% or more of the spawning population in some rivers in some years. Farmed salmon display substantial differences to wild salmon in a wide range of fitness-related traits as a consequence of breeding programmes designed to enhance their performance in commercial production.

Studies of gene flow from farmed to wild salmon are difficult because the two groups belong to the same species and the domestication process is still in its infancy; however, modern molecular genetics, employing thousands to hundreds of thousands of Single Nucleotide Polymorhisms (SNPs) and the availabilty of the genome sequence of Atlantic salmon facilitate such investigations and have supported studies that have provided new insights into impacts of farmed salmon on wild fish. Despite the much lower spawning success of escaped farmed salmon compared to wild salmon, a large number of Norwegian wild salmon populations exhibit widespread introgression of farmed salmon genomes. A study of the genetic integrity of 125 salmon populations in Norway indicated that 35% of the populations showed no genetic changes, 33% showed weak genetic changes, 7%

showed moderate genetic changes and 25% showed large genetic changes as a result of introgression from escaped farmed salmon. In other words, approximately two-thirds of the Norwegian Atlantic salmon populations sampled showed signs of genetic changes, with the highest levels of genetic introgression identified in the fish farming regions along the west coast of Norway. There is a highly significant correlation between genetic introgression and the long-term average proportion of escaped farmed salmon in the rivers. ICES indicates that introgression has also been detected in other countries with salmon farming and that the consequences of these genetic changes in wild salmon populations are likely to be depression of fitness, decreased overall productivity, erosion of genetic diversity and decreased resilience. Repeated invasions of farmed salmon in a wild population may cause the fitness of the native population to seriously decline and potentially enter an 'extinction-vortex' in extreme cases. Preliminary analyses of non-introgressed and introgressed adult wild salmon from more than 50 populations in Norway suggest that ecological and life-history changes are widespread in Atlantic salmon populations where there has been introgression. This is a very worrying development.

Progress and challenges in achieving NASCO's international goals

The Steering Committee had asked that each Party/jurisdiction contributing to the Theme-based Special Session:

- provide quantitative information to demonstrate whether or not there has been progress towards NASCO's international goals for sea lice and escaped farmed salmon;
- identify particular challenges in achieving NASCO's international goals for sea lice and escaped farmed salmon;
- describe the approach to verifying compliance with regulations and codes of practice in relation to sea lice and escaped farmed salmon; and
- describe methods used to support innovation to develop alternative production techniques to promote sustainable salmon farming.

The information provided is contained in the contributed papers provided by the Parties/jurisdictions.

Sea lice

Effective control of sea lice in salmon farming is vital in ensuring the

health and welfare of farmed fish and in preventing impacts of farm-origin lice on wild salmonid populations. The global costs to the salmon farming industry of sea lice infestations have been estimated to exceed €300million per annum. These are mainly treatment costs but also include costs associated with reduced growth rates and downgrading of the product due to visible damage. Effective sea lice management requires systematic monitoring at farms and implementation of effective measures to reduce the lice burden to acceptable levels both for the health and welfare of the farmed fish and the protection of wild salmon stocks in the vicinity.

The BMP Guidance identifies a number of best management practices to support the Williamsburg Resolution and achievement of the international goal of 100% of farms to have effective sea lice management such that there is no increase in sea lice loads or lice-induced mortality of wild salmonids attributable to farms. These are as follows:

- area management, risk-based, Integrated Pest Management (IPM) programmes that meet jurisdictional targets for lice loads at the most vulnerable life-history stage of wild salmonids;
- single year-class stocking;
- fallowing;
- risk-based site selection;
- trigger levels appropriate to effective sea lice control;
- strategic timing, methods and levels of treatment to achieve the international goal and avoid lice resistance to treatment;
- a comprehensive and regulated fish health programme that includes routine sampling, monitoring and disease control;
- lice control management programmes appropriate to the number of fish in the management area; and
- adaptive management in response to monitoring results to meet the goal.

Lice management strategies utilising a broad range of these tools were described during the Theme-based Special Session including fallowing, separation of generations, co-ordinated treatments and salmon delousing using licenced veterinary drugs often linked to Treatment Trigger Levels. Different Treatment Trigger Levels were reported and some are currently being re-assessed, but it is important

that these levels are biologically relevant, taking into account the farmed biomass produced in an area and the international goal that there is no increase in sea lice loads or lice-induced mortality of wild salmonids attributable to the farms. Where treatment levels are exceeded compulsory slaughtering can be required.

A number of challenges were identified in the presentations in relation to managing sea lice including: availability of only a few known therapeutants to treat sea lice; increasing resistance of sea lice to therapeutants; effective treatment doses near toxic/lethal levels to farmed salmon; effects of recurrent treatment and treatment at high doses on the welfare and health of salmon; rapid spread of lice between farm sites; farms located too close to salmonid rivers; mixed year-class production (smolts and growers reared in close proximity); rearing of two-sea-winter fish resulting in difficulties in controlling lice in the second year of the production cycle; lack of sea lice control due to protracted harvesting; lack of synchronised sea lice treatments between sites; incomplete separation of generations and insufficient fallowing; fallowing not aligned with wild smolt runs; and confidentiality requirements limiting the data that can be made available.

Containment

The BMP Guidance identifies a number of best management practices to support the Williamsburg Resolution and achievement of the international goal of 100% of farmed fish to be retained in all production facilities. These are as follows:

- Codes of Containment including operating protocols;
- technical standards for equipment;
- verification of compliance;
- risk-based site selection;
- mandatory reporting of escape events and investigation of causes of loss; and
- adaptive management in response to monitoring results to meet the goal.

In many countries, there is a requirement that equipment is fit for purpose and in good working condition and that escapes are reported promptly to the authorities. Codes of Practice and Technical Standards have been developed, or are under development, in several Parties/jurisdictions. New data were presented on the reported

number of escapes and progress was noted concerning the accuracy of reporting, in a reduction in the number of fish escaping and in the number of escaped farmed salmon identified in the wild, although it was noted that in some countries monitoring in rivers does not extend beyond the fishing seasons. Challenges remain because, despite the measures introduced, ICES still advises that very large numbers of domesticated salmon escape from fish farms each year. Information was presented on the widespread dispersal of escapees which has implications for the scope and cost of monitoring programmes. Tagging or marking of farmed fish, while not contributing to containment, does allow identification of escapees in the wild and, depending on the method used, identification of their farm of origin. This raises the question of who should fund these monitoring programmes and efforts to remove escaped farmed salmon from rivers, e.g. should the 'polluter' pay? Where efforts are made to re-capture escaped farmed salmon, it is important that these do not have unintended negative consequences for the wild salmon stocks.

Developments that could facilitate achievement of NASCO's international goals

Loss of efficacy to sea lice therapeutants has been reported and is a worrying development and major challenge for both the industry and those charged with protecting the wild fish. A number of non-medicinal control strategies were described and these are currently at different stages of commercial implementation. They include hydro-licers and thermo-licers (fresh and warm water treatments), vaccines, use of hydrogen peroxide and the use of 'cleaner' fish (such as wrasse and lumpfish) which may assist in controlling lice numbers. Hatcheries have been established to produce 'cleaner' fish in the quantities needed by the industry and that are better adapted for use in aquaculture. Rearing of larger 'super smolts' can result in a reduction in the production cycle and, therefore, a reduction in the problems encountered in controlling lice in the second year.

Monitoring of lice levels on wild fish is demanding of resources and, therefore, expensive to implement but lice dispersion models have been developed that allow predictions to be made of the density of the infectious lice stages in time and space. This information can be used to estimate lice-induced mortality of wild fish and in establishing limits on production in farms. These limits should be consistent with the international goal of ensuring that there is no lice-induced mortality of wild salmonids attributable to the farms.

The Williamsburg Resolution notes that the methodology and techniques for sterilisation of farmed fish are well developed and that trials should be encouraged to evaluate the performance of strains of sterile fish under production conditions. The use of sterile fish in salmon farming would reduce the risk of inter-breeding and other interactions between farmed and wild salmon and they are now being used in some countries, including under 'green licences'. It was noted that all-female triploid salmon may offer greater protection from ecological interactions.

Recirculation Aquaculture Systems (RAS) have many advantages over cage systems including: complete control of the rearing environment; potential for disease- and parasite-free production; opportunity for location close to markets; and minimum environmental impact including avoidance of impacts on the wild stocks from sea lice and escaped farmed salmon. A number of pilot and commercial scale RAS plants of varying designs are in operation and, while there are some technical and biological challenges to address, RAS technology and economics are gradually improving. Capital costs are relatively high for RAS and hence also capitalisation and depreciation but when market prices for salmon are high, production in RAS can be economically viable. New RAS concepts are emerging that should have a positive effect on closed-containment salmon production. While there is a strong argument in favour of closed-containment salmon farming from the perspective of protecting wild salmon populations and progress in this regard is needed, the Steering Committee recognises that the most imminent challenge is to better manage impacts from the industry which is not currently based on closed-containment systems.

Concluding remarks

NASCO's 'Action Plan for taking forward the recommendations of the External Performance Review and the review of the 'Next Steps' for NASCO' (CNL(13)38), states that aquaculture remains a focus area for NASCO in terms of concerns over impacts on wild Atlantic salmon. The Action Plan recognises that it is for the Parties and jurisdictions to identify and implement appropriate measures to minimise impacts.

Under NASCO's Williamsburg Resolution, the Parties agree to co-operate in order to minimise adverse effects to the wild salmon stocks from aquaculture, introductions and transfers and transgenics. The Theme-based Special Session allowed for a valuable exchange of information and for sharing of best practice on measures to minimise

impacts of salmon farming on the wild salmon stocks. The Steering Committee believes that a co-operative approach and enhanced exchange of information on measures to address impacts of salmon farming on the wild stocks is important if the wild stocks are to be protected from the impacts highlighted during the Theme-based Special Session.

It is clear that scientific understanding of the impacts of salmon farming on the wild stocks has increased since the 2005 NASCO/ICES Symposium. While there have been developments in managing impacts from salmon farms, the growth of the industry is a challenge in terms of its environmental impacts and in particular with regard to sea lice and escapes. The advice provided by ICES in 2016 confirms that salmon farming activities can have significant negative impacts on wild salmon stocks. The predictions made by scientists at earlier NASCO/ICES symposia about the consequences of escapes appear to have materialised despite efforts to improve containment measures. The Steering Committee notes with great concern the confirmation of widespread introgression of wild salmon populations by farmed salmon in Norway, with the highest levels in salmon farming areas, and the detection of introgression in other countries. ICES advises that the consequences of these genetic changes in wild salmon populations are likely to be depression of fitness, erosion of genetic diversity and decreased resilience. This is consistent with the stark warning from the Conveners of the 2005 NASCO/ICES Symposium who concluded that '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'. The Conveners indicated that such loss would not be consistent with obligations under either the NASCO Convention or the Convention on Biological Diversity which aims to conserve genetic diversity within and among species.

The latest advice relating to sea lice is also worrying as it indicates that for salmon stocks experiencing poor marine survival, there could be a reduction in salmon returning to the river of up to 39% as a consequence of sea lice infestations. The warning signs noted at the 2005 NASCO/ICES Symposium that resistance to therapeutants was developing have materialised and this is a concern for both the industry and those charged with protecting the wild stocks.

It is almost 20 years since NASCO Parties agreed to apply the Precautionary Approach to the conservation of salmon and the recognition that measures taken in accordance with the Williamsburg Resolution need to be consistent with this approach. The Precautionary Approach requires that more caution is exercised when information is uncertain, unreliable or inadequate and that the absence of adequate scientific information should not be used as a reason for postponing conservation and management measures. The wild stocks are currently vulnerable because of reduced marine survival all around the North Atlantic. The Steering Committee believes that there is now sufficient evidence of significant impacts having occurred that all Parties/jurisdictions with salmon farms must implement further, more stringent measures to protect the wild stocks from the impacts of salmon farming if they are to meet their obligations under the NASCO Convention. The Williamsburg Resolution states that where significant adverse impacts on wild salmon stocks are identified, the Parties should initiate corrective measures without delay and that these should be designed to achieve their purpose promptly. New approaches that could assist in addressing impacts are at various stages of development and implementation, but there are undoubtedly substantial challenges to be addressed if the international goals for salmon farming are to be achieved. In the Steering Committee's view, there is now an urgent need for all Parties/jurisdictions to adopt stronger measures if their international responsibilities are to be met which it believes is not currently the case. The Steering Committee reiterates that the agreed international goals are that:

- **there is no increase in sea lice loads or lice-induced mortality of wild salmonids attributable to the farms; and**
- **100% of farmed fish are retained in all production facilities.**