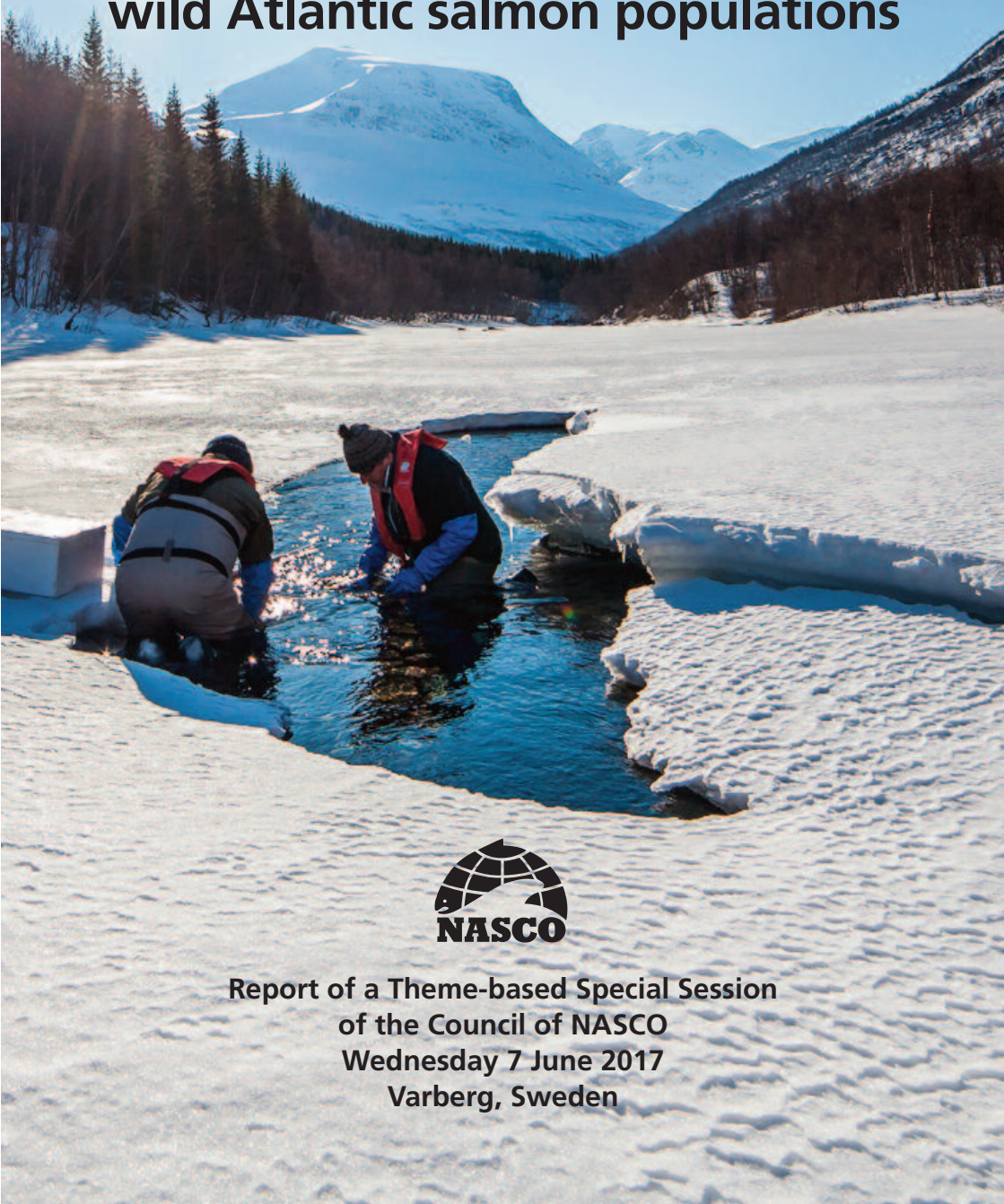


Understanding the risks and benefits of hatchery and stocking activities to wild Atlantic salmon populations



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of the Council of NASCO
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Cover photograph: Stocking eyed ova in the River Stordalselva, Norway. The River Stordalselva is a tributary of the River Signaldalelva which was chemically treated with rotenone against the parasite *Gyrodactylus salaris* in 2015 and 2016. Re-stocking commenced in April 2017 with eyed ova from the live gene bank. Courtesy of Kjell Magne Johnsen

Inside photograph courtesy of Genbank Hardangerfjord

Designed by Peter Lloyd Design Consultancy, Edinburgh, UK



Understanding the risks and benefits of hatchery and stocking activities to wild Atlantic salmon populations

Steering Committee

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Contents

	Page no.
Executive Summary	i
Introduction	1
Contributed Papers	5
• Risks and benefits to wild Atlantic salmon populations from hatchery and stocking activities, with particular emphasis on smolt-to-adult captive-reared supplementation, CNL(17)41	7
• Approaches to minimising unintended negative consequences to wild Atlantic salmon populations from hatchery and stocking activities, CNL(17)40	17
• Approaches used to prevent the loss of Atlantic salmon populations at high risk of extinction, including gene banks, adult captive-rearing, smolt-to-adult supplementation - Gene banking of wild Atlantic salmonids in Norway, CNL(17)43	33
• Policies and regulatory framework for stocking activities of Atlantic salmon in Canada, CNL(17)48	41
• The policy relating to hatchery and stocking activities in Wales - managing risks and benefits, CNL(17)46	61
• The policy relating to hatchery and stocking activities in France - managing risks and benefits, CNL(17)47	71
• The policy relating to hatchery and stocking activities in Norway - managing risks and benefits, CNL(17)44	77
Summary of the Discussions held during the Theme-based Special Session	83
Conclusions of the Steering Committee	95

Executive Summary

Abundance of salmon around the North Atlantic is low and in some southern parts of the range stocks are endangered. NASCO has recommended that Stock Rebuilding Programmes (SRPs) be developed for all stocks that are failing to exceed their conservation limits (CLs). An SRP is an array of management measures, possibly including habitat restoration/improvement, exploitation control and stocking, which is designed to restore a stock above its CL. The nature and extent of an SRP will depend upon the status of the stock and the pressures that it is facing and there is a need to evaluate and address the causes of the stock decline. Management decisions concerning the nature and extent of the SRP should be influenced by a range of factors including: uncertainty in assessments, nature of the CL failure (both duration and degree); recent stock status history; and stock diversity.

Under NASCO's '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'), Parties should minimise adverse genetic and other biological interactions from salmon enhancement activities and minimise the risk of disease and parasite transmission. To this end, Guidelines for Stocking Atlantic Salmon have been developed (Annex 4 of the Williamsburg Resolution). These Guidelines recognise that stocking can have negative impacts on wild salmon populations and that poor hatchery practices may negatively impact the characteristics of the wild salmon populations which the programme seeks to conserve. There is, therefore, a need to consider fully the risks and benefits arising from stocking.

In recent years, there has been a recognition of the risks of stocking in national/regional policy. Stocking programmes, including mitigation programmes, have been discontinued in Wales. Fisheries and Oceans Canada no longer operates enhancement facilities, but maintains two facilities aimed at maintaining genetic diversity. In Norway, stocking is mainly conducted to restore populations after rotenone treatment (to eradicate *Gyrodactylus salaris*) or following liming of acidified rivers and alternatives to mitigation stocking in relation to hydropower developments are being sought. In France, stocking is only used where stocks are considered to be at risk. Analyses

conducted by the ICES Working Group on the Effectiveness of Recovery Actions for Atlantic Salmon indicated that improvements in connectivity and freshwater quality and freshwater habitat restoration were most often reported as having a high or very high benefit to the recovery of salmon populations, so much can be achieved to rebuild stocks without the need for stocking. While hatchery programmes and stocking may have a role to play in kick-starting the restoration of stocks in rivers where they have been lost, or where the stocks are at critically low levels, stocking continues in some areas irrespective of the risks to the wild stocks associated with such activities and without evidence of benefits. Given the substantial information presented at the Theme-based Special Session, the Steering Committee believes that if the genetic integrity of wild salmon is a management priority, stocking of hatchery fish should only be contemplated after careful evaluation of the risks and benefits and only after other alternatives have been considered. There should be a strong presumption against stocking for socio-political reasons and the use of tools such as Population Viability Analysis should be used to inform decisions to stock where wild populations are considered to be at risk of extirpation, and then only as an interim measure while other rebuilding efforts are being implemented. New approaches to stocking are emerging that could offer benefits while avoiding some or all of the risks associated with current hatchery operations, but they need to be further evaluated.

These are challenging times for the Atlantic salmon, not least because of the uncertainty associated with a changing climate. ICES advises that environmental and genetic adaptation can facilitate adjustment to changing environmental conditions, if the rate of change in the environmental conditions does not exceed the capacity of the organism for genetic adaptation. Maintaining the genetic diversity present in the wild stocks is, therefore, vital and stocking programmes need to be considered with that in mind. The Steering Committee recommends that the Council may wish to consider the need for revisions to its Guidelines for Stocking Atlantic Salmon and options for improving exchange of information among Parties on the effectiveness of stocking programmes. In the interim, NASCO's Guidelines should continue to inform decisions relating to the initiation and conduct of stock rebuilding initiatives.

Introduction

NASCO is an intergovernmental organisation established with the objective of contributing, 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 information available to it.

Stocking of salmon at various life-stages has been conducted for more than a century for a variety of purposes including to support fisheries, to mitigate for habitat loss, to re-build populations affected by pathogens such as *Gyrodactylus salaris* and to re-build salmon populations at severe risk of demographic extinction. The current period of low marine survival of salmon in the North Atlantic has led to increased interest in actions to mitigate for the reduced abundance through stocking activities. Over the last decade, new information on the risks of stocking, including the domestication effects of hatchery interventions on the fitness of the cultured animals and the subsequent fitness consequences to wild Atlantic salmon populations exposed to stocking activities, has become available. There are many possible causes for the decline of Atlantic salmon populations and, given the potential risks involved, stocking may not be an appropriate solution in every situation. There may be other actions which can be taken to support stock re-building such as improving habitat or reducing exploitation.

In order to assist NASCO Parties and jurisdictions in establishing suitable Stock Rebuilding Programmes, NASCO has adopted 'Guidelines on the Use of Stock Rebuilding Programmes', CNL(04)55. These provide guidance on compliance assessment, evaluation of the problem, development of a management plan and monitoring and evaluation of progress. In those cases where it is deemed appropriate to implement a stocking programme, NASCO has adopted 'Guidelines for Stocking Atlantic salmon' (Annex 4 of the Williamsburg Resolution, CNL(06)48). These Guidelines recognise that while stocking programmes are sometimes successful, there can be negative impacts on wild salmon populations and other species and that poor stocking practices may negatively impact the characteristics of the wild salmon populations they are intended to conserve. The guidelines are designed to assist NASCO's Parties in applying the Precautionary Approach to the authorisation and conduct of any stocking of Atlantic salmon into the wild. Article 1 of the Williamsburg Resolution seeks co-operation among NASCO Parties in

order to minimise adverse effects to the wild salmon stocks from, *inter alia*, stocking activities. Furthermore, the Council's intention at the time of adopting its Stocking Guidelines was that these should be regularly reviewed and updated in the light of any new scientific information but this has not been done to-date.

NASCO's Theme-based Special Sessions are intended to allow for a greater exchange of information and sharing of best practice on a topic related to NASCO's agreements and guidelines. The Council had agreed that there were likely to be benefits from an exchange among the Parties given the concerns that have arisen on the potential negative consequences of hatchery programmes to wild Atlantic salmon populations, and the potential benefits to salmon populations that are at imminent risk of extinction in the absence of interventions including stocking. A half-day Theme-based Special Session was therefore held during NASCO's Thirty-Fourth (2017) Annual Meeting in Varberg, Sweden entitled 'Understanding the risks and benefits of hatchery and stocking activities to wild Atlantic salmon populations'. The Steering Committee for this session comprised Gérald Chaput (Canada), Paul Knight (NGOs), Ian Russell (European Union) and Arne Sivertsen (Norway) who worked with the Secretary in preparing a Programme, Objectives and Report of the Theme-based Special Session.

The over-arching objective for the Theme-based Special Session was to facilitate an exchange of information relating to understanding the risks and benefits of hatchery and stocking activities to wild Atlantic salmon populations by:

- reviewing the latest scientific information on the risks (genetic and ecological) and benefits (demographic, reduced extinction risk) to wild Atlantic salmon fitness of hatchery and stocking activities;
- reviewing the approaches used to prevent the loss of Atlantic salmon populations at high risk of extinction (e.g. by live gene banking, smolt-to-adult supplementation);
- reviewing the approaches used to minimise unintended negative consequences to wild Atlantic salmon populations from hatchery and stocking activities;
- sharing information on policy frameworks for assessing the risks and benefits and the decision-making process for stocking proposals; and

- reviewing NASCO's Guidelines for Stocking Atlantic Salmon and considering the need for any revisions to them in the light of new information.

The Steering Committee had requested that the overview presentations address the first three objectives. The presentations by the Parties and jurisdictions on the policy frameworks were to keep general background information to a minimum and provide specific information describing the current management and regulatory frameworks associated with stocking of Atlantic salmon and hatchery activities and how the risks and benefits are assessed and managed.

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



CNL(17)41

Risks and benefits to wild Atlantic salmon populations from hatchery and stocking activities, with particular emphasis on smolt-to-adult captive-reared supplementation

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Summary

This paper briefly outlines what is known of the risks and benefits of smolt-to-adult supplementation (SAS) in wild Atlantic salmon. Literature on the hatchery and stocking of wild Atlantic salmon populations is dominated by programmes that capture and spawn wild adults and release large numbers of hatchery-reared juveniles. Much less is known of SAS, wherein migrating smolts are captured, captive-reared until maturation and subsequently released in freshwater. The marine environment for Atlantic salmon is changing rapidly in many regions, particularly at the southern part of the species range. With these changes has been a dramatic decline in smolt-to-adult survival. Where this occurs, SAS has potential advantages over juvenile supplementation towards mitigating population declines. First, it provides a predictable input to adult population size. Second, it avoids well-documented genetic risks to captive-rearing at early life-stages. Third, SAS maintains free mate choice in the wild. However, SAS is not without risks or uncertainties. SAS may reduce marine adaptation (or adaptation to freshwater-marine linkages) through unintentional or relaxed selection. SAS may also cause negative carry-over effects on wild fitness. Several SAS programmes have been initiated on endangered salmon populations in North America, but the full results of these long-term experimental studies are still awaited. Possible maladaptation generated from SAS in the form of changes to wild phenotypic trait distributions should be minimised as much as possible. A balancing act also occurs between the number of wild smolts required for SAS to be effective, the proportion of SAS adults released relative to wild adults and maintaining at-risk wild populations.

Background

Hatchery stocking programmes are increasingly adopted to salvage endangered populations of salmon or to prevent populations from experiencing further decline. The ecological and genetic risks of these activities have long been discussed. Yet the science of conducting effective hatchery-rearing is still in need of further

development, specifically to determine how to achieve its desired demographic benefits whilst minimising its potential genetic or other ecological risks. Previous works on the risks and benefits of captive-rearing, including on salmonids, have recommended that the risks can be substantially reduced by using local populations for captive-breeding/supplementation, reducing the duration of captivity, minimising environmental differences between wild and captive environments, restricting captive breeding to life-history stages where natural mortality is not as severe in the wild and allowing free mate choice (O'Reilly and Doyle, 2007; Pitcher and Neff, 2007; Fraser, 2008).

Given these general recommendations, SAS is an attractive tool for stocking salmon populations where marine return rates are low. SAS would use local fish, it avoids captive-rearing at early life-stages that generally experience the most mortality in salmonids, it conceivably minimises some environmental differences between captive and wild environments if conducted in marine sea-pens, it would still allow adults to choose mates in the wild and it could provide a predictable input to adult population size and prevent the complete collapse of individual age cohorts. SAS programmes have recently emerged for endangered Atlantic salmon populations from southern Canada (Clarke *et al.*, 2016) and Maine, USA (Stark *et al.*, 2014) but, as yet, in only one case for supplementing wild population size where declines had not reached precipitous levels (Dempson *et al.*, 1999). However, as with juvenile-oriented supplementation, SAS is not without risks.

Genetic risks of SAS

Environmental conditions and selective pressures invariably differ between the hatchery (captive) and natural environments. Owing to such environmental differences, the hatchery environment causes plastic and genetic changes to phenotypes associated with fitness in natural environments, often resulting in reduced fitness in hatchery-reared fish when they are released back into nature (Araki *et al.*, 2008; Fraser, 2008; Christie *et al.*, 2012). These plastic and genetic changes can occur in all aspects of phenotypes, and they affect all life-stages; adaptive genetic changes to captivity can occur in only one or two generations. It is largely unknown whether such fitness reductions are irreversible in the longer-term, and how long it might take for wild populations to recover from these changes once supplementation is arrested.

Maladaptive genetic changes in captivity are manifested through a relaxation of natural selection or unintentional selection.

Unintentional selection in the captive-rearing process appears to be the most common mechanism, but both mechanisms can result in wild maladaptation. Captive-rearing can also generate carry-over effects on fitness in the wild. For example, in salmon, maternal provisioning in off-spring is heavily influenced by the environmental conditions that a female experiences. These maternal effects can also be genetically-based in Atlantic salmon and affect juvenile off-spring growth and survival (Araki *et al.*, 2008; Fraser, 2008).

The genetic risks of SAS have not been rigorously assessed empirically and reported in peer-reviewed literature on Atlantic salmon. This would require comparing the survival, reproductive success and off-spring survival of a sample of SAS adults relative to wild adults originating from the same population, in the natural environment. Preferably, the lifetime success of the off-spring would then be compared between the two groups of fish to rule out the influence of different parental environments (Fraser, 2016). Based on known genetic risks of hatchery-rearing, however, SAS is expected to elicit plastic and genetic changes to phenotypes that affect wild Atlantic salmon fitness. Changes to adult body size, maturation age, aggression, maternal provisioning, egg quality and/or spawning time have been documented in SAS programmes for Atlantic and Chinook salmon (Dempson *et al.*, 1999; Stark *et al.*, 2014). The degree to which average short-term (immediate generation) and long-term fitness (successive generations) in a population are affected will depend on whether SAS is practiced continuously or intermittently, the proportion of individuals in the population that experience SAS, SAS environmental conditions and, specifically, how much these conditions differ from those to which a wild population is normally exposed (Fraser, 2016).

SAS avoids captive-rearing at the early life-stages which experience the highest mortality (96.8% - 99.8%), but smolt-to-adult mortality is still very substantial in wild salmon (82.5% - 98.5%, 92.6% average for 1SW; Hutchings and Jones, 1998). As smolt-to-adult mortality will be much lower using SAS, relaxation of natural selective pressures is a likely possibility, especially associated with predation in the marine phase and with marine parasite/pathogen resistance if rearing is conducted in freshwater. Wild populations undergoing SAS may also experience relaxed selection for traits associated with migratory vigor and activity levels.

Unintentional selection in SAS facilities (tanks in freshwater facilities or marine cages) will arise if any non-random die-offs occur during captive-rearing, or through carry-over effects (Fraser, 2016). Under SAS rearing, individual growth, maturation and morphological shape trajectories, any correlated behavioural traits, female reproductive allotment, behavioural traits associated with living at higher densities and pathogen resistance will likely change whether fish are reared in marine or freshwater. These changes may affect subsequent reproductive success and/or off-spring survival in nature. Unintentional selection might also occur upon the earliest stage of SAS during the collection of smolts before they migrate out to sea. Smolt collections may not represent the full spectrum of smolt migration timing or body size if non-randomly sampled (Fraser, 2016). Survival rates of smolts in captivity might also depend on the timing of their physiological transformation for moving into seawater. Efforts to collect smolts may also run the risk of obtaining mixtures of populations beyond a focal population of interest, especially in larger river systems.

Atlantic salmon exhibit a considerable degree of local adaptation in freshwater at different geographic scales (Garcia de Leaniz *et al.*, 2007). Little is known of local adaptation in the marine phase, but undoubtedly adaptation exists to different marine areas (Fraser *et al.*, 2011; O'Toole *et al.*, 2015). Local adaptations and genetic polymorphisms in freshwater are also intimately linked to the marine phase in salmon. Management must consider how SAS affects the adaptive genetic characteristics of wild salmon during the marine phase and other linked life-stages. Marine maladaptation from SAS is critical to consider, because the marine phase is often the most limiting factor affecting salmon where SAS is desired. During population declines, salmon may be undergoing a lag period of adaptation to changing marine environmental conditions, so avoiding the marine phase might be very undesirable (Fraser, 2016).

An additional genetic risk of SAS is the hybridisation of hatchery-reared SAS fish with remaining wild fish in a population. SAS-wild hybrids are expected to exhibit intermediate fitness in the wild relative to 'pure' wild and 'pure' captive fish; the extent to which such hybridisation will occur and generate maladaptation in wild fish will depend on a host of factors.

Manipulations during SAS-rearing might also generate chromosomal abnormalities or heritable epigenetic changes, such as DNA methylation, that may affect individual fitness in salmonids. This is

not a well-studied phenomenon in salmonids, and recent studies have offered mixed evidence that epigenetic changes induced by the hatchery affect life-history change that may influence fitness (Blouin *et al.*, 2010; Baerwald *et al.*, 2015).

Ecological risks of SAS

SAS might affect the fine-scale homing precision and breeding fitness of adults, which is often reduced in captive-reared fish relative to wild fish (Dempson *et al.*, 1999; Berejikian *et al.*, 2005). In general, captive-reared males are inferior to wild males in courting, in competing for females and in spawning behaviour (Jonsson and Jonsson, 2006). Adult Atlantic salmon males reared in sea cages can also display damage to their kypes and jaw distortion and this too can negatively affect subsequent performance (Jonsson and Jonsson, 2006). Captive-reared females, whether originating from juvenile supplementation or SAS rearing, may also be more likely to retain eggs and less likely to construct or cover nests in the wild (Jonsson and Jonsson, 2006). Overall, it has not been evaluated empirically whether the benefits of retaining free mate choice through adopting SAS are fully realised after captive-rearing.

Despite their often reduced breeding fitness, captive-reared adults can substantially outnumber wild adults and produce a considerable number of juvenile off-spring (Kostow, 2009; Stark *et al.*, 2014). Through density dependent mechanisms and when captive-reared fish differ strongly in characteristics from wild fish (e.g. body size, behaviour), captive-reared fish may displace wild fish to some extent and contribute to the depletion of wild populations through competition for space and breeding opportunities (Jonsson and Jonsson, 2006). For example, variation in growth rate, adult size, age at maturity, egg size and fecundity induced by hatchery-rearing can influence competitive ability, spawning behaviour, reproductive success and fitness, with effects on production of fish in nature (Berejikian *et al.*, 2005; Fleming *et al.*, 1997).

As hatchery-reared fish are reared at higher densities than in the wild, they are commonly susceptible to increased pathogen or parasite exposure and may experience genetic changes associated with differing pathogen/parasite regimes or loading. Hatchery-reared fish can act as a vector of disease to wild fish and may contribute to wild population depletion (Jonsson and Jonsson, 2006). SAS rearing could avoid some of these risks if conducted in freshwater tank facilities where certain pathogens can be controlled. However, freshwater

instead of marine rearing poses other risks, including relaxed selection for marine pathogen/parasite tolerance.

SAS rearing may also affect timing of upstream migration and spawning, given that hatchery-reared Atlantic salmon are known to enter rivers to spawn earlier or later in the season, move around more, and/or stay within the river for a shorter duration than wild fish (Dempson *et al.*, 1999; Stark *et al.*, 2014). Earlier spawning by captive-reared fish results in their off-spring emerging earlier, which may provide a short-term growth/survival advantage in occupying the best feeding territories at early life-stages before off-spring of later spawning wild fish arrive. Later spawning by captive-reared adults conversely may disturb wild fish redds and decrease hatching success (Kostow 2009).

Criteria and metrics for assessing SAS risks

Like juvenile supplementation, the severity of genetic and ecological risks from conducting SAS depends largely on: (i) how much captive-reared fish might deviate from wild phenotypes (and/or underlying genotypes); and (ii) the proportion of SAS fish relative to the total population size of a supplemented wild population (Fraser, 2016). Criteria and metrics for assessing the risk of SAS should be based on each of these two contexts. The first context accounts for how much maladaptation SAS generates in a species whose general biology is founded in the local adaptation of phenotypic traits. The second context accounts for how the magnitude of the effects of maladaptation from SAS might affect population productivity and persistence.

Wild fitness reductions would be expected to increase as trait deviations from the wild environment increase in the hatchery. Thus, for any phenotypic trait potentially linked to fitness, a deviation in mean and variance between SAS and wild fish would represent a simple, readily quantifiable metric by which to assess SAS risk; a statistically significant deviation would indicate specifically that there is a risk (Fraser, 2016). Reduction of both the mean and variance of this trait differential could be considered as a 'balanced' strategy to minimising risk, to account for the specific distribution of phenotypes within the focal wild population (Fraser, 2016).

With respect to the ratio of SAS fish to wild fish, risk is expected to increase with increasing phenotypic trait deviations as above but also, as this ratio increases in the population, based on what is known of long-term interactions between hatchery-reared and wild fishes

(Araki *et al.*, 2008; Fraser, 2008). Ecological risk from SAS is also expected to increase as the supplemented population more closely approaches its carrying capacity and when environmental conditions for salmon spawning and recruitment are poorer, primarily through density dependence and competition with wild fish (Kostow, 2009). However, due to a lack of empirical data, there is considerable uncertainty in providing simple quantitative criteria or metrics for assessing these specific risks with SAS.

Other risk metrics could monitor and quantify fitness in SAS fish and their progeny relative to wild fish, throughout the course of an SAS programme. This represents the only quantitative measure of: (i) risk to wild fitness and wild population productivity posed by a specific SAS programme; or, conversely (ii) supplementation 'success'. Such research typically requires more than a decade to complete based on the generation time of wild Atlantic salmon.

When do SAS programmes pose the least harm to fitness of wild Atlantic salmon?

With respect to population productivity, available modelling suggests that a short-term, intermittently conducted SAS programme will pose less risk to wild Atlantic salmon. In other words, the risks to wild population productivity increase, and likely cannot be mitigated by the wild population within one generation once ceased, when SAS: (i) generates greater reductions to wild fitness; (ii) is continuously practiced over successive generations; and (iii) represents a greater proportion of the total number of adults (or of either sex) in the population.

General recommendations on the application of SAS

A series of management recommendations have recently been put forth with respect to improved research, evaluation, and implementation of SAS in wild Atlantic salmon (from Fraser, 2016):

- conduct experimentation to effectively quantify and compare the lifetime fitness of SAS versus wild progeny and second generation progeny under natural conditions;
- minimise deviations from wild phenotypic trait distributions as much as possible in all SAS programmes currently underway (or being considered). Many aspects of phenotype should be considered beyond those currently assayed;

- conduct population viability analyses or analogous modelling exercises to explore what combinations of variables generate positive and negative demographic effects through SAS relative to traditional juvenile supplementation;
- use SAS only as a short-term approach to supplementing severely dwindled wild populations and avoid the use of SAS over successive generations;
- keep a low-to-modest ratio of SAS adults relative to wild adults in the population.

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CNL(17)40

Approaches to minimising unintended negative consequences to wild Atlantic salmon populations from hatchery and stocking activities

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Summary

This paper outlines a talk of same title presented at the Theme-based Special Session on '*Understanding the risks and benefits of hatchery and stocking activities to wild Atlantic salmon populations*' held at the NASCO Annual Meeting in Varberg, Sweden, 6 - 9 June, 2017. I draw freely on relevant theory and empirical data from species other than Atlantic salmon. I do not comprehensively review the vast relevant literature, but offer key references as entries into that literature. Unless otherwise qualified, I assume that the integrity (i.e. evolutionary and ecological *naturalness*) of wild salmon is a management priority. I begin by summarising the science underpinning the evidence-based consensus that stocking hatchery-reared fish into wild populations should be avoided. I then offer a few explanations for why we continue stocking despite this consensus and suggest that understanding, challenging and accommodating these socio-political drivers is essential for minimising the negative consequences of hatcheries and stocking to wild salmon. I next describe three types of existing guidance on hatcheries and stocking. I then present a new 'where, when and how' approach to stocking that accommodates the reality that we will likely continue stocking where and when we should not. The approach is built around simple rules informed by first principles, theory, empirical evidence and the recommendations of existing guidance. It departs from current guidance and practice by proposing that capturing and transplanting wild fry within and between populations offers a cost-effective alternative to stocking hatchery-reared fish that accommodates socio-political drivers while minimising risks to the integrity of wild salmon.

Background

We have been stocking Atlantic salmon since the time of Darwin. The apparent benefit is obvious; stocking can increase the number of adults, but not always, not always by a lot, and perhaps not for very long. The risks are nearly as obvious, and the contemporary scientific consensus that stocking hatchery fish threatens wild populations could have been predicted from the theory and empirical evidence

that spurred the Evolutionary Synthesis of the mid-20th century (Huxley, 1942). That prediction came in 1977, when Reisenbichler and McIntyre (1977) combined simple genetic techniques with one of evolutionary ecology's most informative experimental designs to provide the first compelling evidence that stocking hatchery fish threatens wild salmonids. They bred genetically identifiable hatchery and wild steelhead (*Oncorhynchus mykiss*) to create pure HH, pure WW, and crossed HW off-spring. Using a 'reciprocal transplant' experiment, they stocked these off-spring together in a hatchery pond and four sections of stream. Pure HH fish survived best in the hatchery pond, and pure WW fish survived best in natural streams. This empirical evidence that hatchery-imposed selection leads to the evolution of phenotypes that are maladapted to the wild led the authors to warn, 'that the short-term effect of hatchery adults spawning in the wild is the production of fewer smolts and ultimately, fewer returning adults than are produced from the same number of only wild spawners'.

Stocking science over the last 40 years has used a range of approaches to confirm, clarify and refine this prescient warning. Much of this research is from the Pacific Northwest (PNW) of the United States, where large and valuable salmon runs, severe and wide-scale habitat destruction, hundreds of industrial-scale hatcheries and the Endangered Species Act have provided the socio-political mandate, empirical data and resources required to advance the field. Empiricists compiled examples of (non)adaptive phenotypic divergence between hatchery and wild populations (Swain and Riddell, 1990, Fleming and Gross, 1993, Heath *et al.*, 2003). Theorists clarified the neutral and (non)adaptive evolutionary genetic consequences of hatcheries and stocking (Waples, 1991, Ford, 2002, Araki *et al.*, 2008). Applied ecologists studied the wider impacts of hatcheries and stocking on wild salmonids and their ecosystems (Rand *et al.*, 2012).

In the last decade, two types of evidence have firmly established the critical links between hatchery breeding/rearing and reduced individual fitness in the wild, and between stocking and declines in population productivity. Two studies tell the story. Christie *et al.* (2014) quantitatively synthesised the results of studies that used genetic parentage analysis to estimate the fitness of first generation hatchery-born adults (i.e. the off-spring of wild broodstock) and wild-born adults spawning in the wild. They compiled 51 estimates of mean reproductive success for these two types of fish from six studies

on four species (including Atlantic salmon). In 46 cases, adults born in a hatchery to wild parents had lower fitness than wild-born adults. These and other studies demonstrate that a single generation of hatchery rearing can drive the evolution of phenotypes maladapted to the wild (Christie *et al.*, 2012). Chilcote *et al.* (2011) used the vast data available from the PNW to estimate the population productivity (i.e. the slope at the origin of the adult-to-adult stock-recruitment curve) for 94 populations of three Pacific salmonid species. They found that productivity declined with the proportion of hatchery-born adults in the spawning population. Across species, using stocking to double adult population size reduced productivity by half, meaning there is no demographic benefit to balance the damage caused by stocking. Consistent with the evidence summarised by Christie *et al.*, they found that hatchery fish from wild-broodstock schemes reduced population productivity by the same amount as those from traditional multi-generation hatchery populations.

Forty years of research supports a simple, long-standing, evidence-based scientific consensus: if the integrity of wild salmon is a management priority, stocking hatchery fish should be avoided (Hilborn, 1992, Blanchet *et al.*, 2008, Araki and Schmid, 2010, Palme *et al.*, 2012). Understanding exactly how a single generation of hatchery rearing reduces fitness in the wild remains one of several interesting research challenges (Christie *et al.*, 2016), but the management challenge lodged in 1977 is unequivocally resolved.

The pathology of stocking

And yet we keep doing it.

Minimising the negative consequences of stocking requires understanding why, in the face of overwhelming scientific evidence, we continue stocking hatchery fish into wild populations. For a few notable exceptions (Meffe, 1992, van Poorten *et al.*, 2011), the stocking literature lacks explicit socio-political perspective. The glaring disconnect between scientific evidence and management practice suggests this is a mistake. We need to understand, challenge and accommodate the pathologies that compel and perpetuate irrational management interventions (Holling and Meffe, 1996, Rist *et al.*, 2013). I offer a few reasons why I suspect we continue stocking. The relative importance of these socio-political drivers depends on the degree to which management decisions are influenced by government agencies, scientists, anglers, NGOs and other stakeholders. Embracing alliteration, my 'Seven Hs' elaborate on one

of the 'Four Hs' threatening wild salmon more generally: Habitat, Harvest, Hydropower, *Hatcheries*.

Habit. We stock mostly because we stock. It is far easier to build a hatchery than close a hatchery. We have invested countless millions building and operating hatcheries. Hatcheries attract volunteers and fatten agency budgets. From anglers running a small wild-broodstock scheme to occupy their spring, to agencies releasing millions of hatchery fish to 'mitigate' a dam, old habits, no matter how wasteful and harmful, are hard to break.

High. People love fish. Playing with them gives us a bit of a high. Anglers love collecting, handling and spawning adults, then dumping buckets of fry into their favourite stream. Schoolchildren love visiting hatcheries and watching fry grow in their classrooms. Hatcheries and fish engage, inform and inspire.

Hubris. Meffe's (1992) original critique of hatcheries as manifestations of 'techno-arrogance' targeted the large hatcheries of the PNW. A similar arrogance contributes to stocking for any purpose by any name. We are wedded to the idea that we can use technological interventions to overcome the fundamental rules of population and evolutionary ecology.

Honour. Individuals and institutions have staked their reputations and resources on hatcheries and stocking. Intransigent pride can compel otherwise rational actors to behave irrationally. We must be sympathetic and sensitive to those who have, with best intentions, dedicated their careers to supporting and delivering management interventions that are more harmful than helpful.

Hope. No matter how much evidence accumulates demonstrating stocking hatchery fish compromises the integrity of wild populations, people will hope. They will hope that their broodstock collection, breeding designs, rearing environment and stocking strategy are different, that their river and fish are different, that what they do will help rather than harm. Blind faith sees no evidence.

Heresy. If well-intentioned hope is understandable, the cynical dismissal of evidence-based scientific consensus is inexcusable. Science denial afflicts society more generally, making it acceptable, even admirable, to dismiss scientific consensus as mere opinion. It does not help that fisheries managers long supported, even promoted, stocking into wild populations as a responsible and effective management intervention.

h-index. Scientists are judged in part by the impact of their papers. Increasing one's GoogleScholar *h-index* (the number of papers *h* with at least *h* citations) requires publishing more, and more interesting, papers. We are trained to amplify uncertainty, state our conclusions cautiously, and seize any funding opportunity. At best, we tacitly support stocking to advance our careers. It is a short and slippery slope from 'we may as well collect data if we're stocking' to 'we need to keep stocking because we're collecting data'. At worst, we prevent informed precautionary management by amplifying managerially irrelevant scientific uncertainty in the name of apolitical righteousness. Stocking science is political. Scientists who benefit from this fact have a responsibility to be so too.

Existing guidance

Nearly every agency and NGO involved in salmonid management offers guidance on stocking, much of which is focused on minimising negative consequences to wild salmonids. This guidance can be crudely grouped into three types.

The first addresses the challenge of minimising the impacts of traditional hatcheries with populations of proper 'hatchery fish'. This work has been led by the US National Oceanic and Atmospheric Administration's Northwest Fisheries Science Center, which guides the Hatchery Scientific Review Group (HSRG) in the PNW. While work began earlier, since 1999 HSRG members have been reviewing hatchery programmes, providing advice and publishing reports and peer reviewed papers (HSRG 2017). Minimising demographic and genetic interactions between hatchery and wild populations figures prominently. Large populations of hatchery fish are not going away. The idea is to keep hatchery fish away from wild fish using physical (e.g. weirs and traps) and behavioural (e.g. release and spawning times/places) methods, mark them with adipose fin clips and kill them when they are captured.

The second type focuses on smaller stocking schemes whose principal purpose, regardless of linguistic qualifier (e.g. mitigation, enhancement, restoration), is to provide more fish to catch. While the HSRG contributes, this type of guidance is often provided by fishery agencies and NGOs (e.g. NASCO 2006, RAFTS 2014). Beyond timid discouragement, the principal goal is to reduce the negative impacts of wild-broodstock schemes that, contrary to the above, *purposely* mix wild and hatchery fish. Advice is offered on, among other topics, selecting broodstock, breeding protocols, rearing

conditions and stocking locations and densities.

The final, and least developed, type of guidance is motivated by the observation that anadromous salmonids display some elements of meta-population structure (Levins, 1969, Hanski and Gilpin, 1991, Hanski, 1998); discrete populations are demographically and genetically connected to varying degrees by straying adults (Schtickzelle and Quinn, 2007). The idea is that some habitable patches are (functionally) vacant and stocking can be used to artificially increase inter-population migration rates, thus increasing the total number of adult fish, and the size and resilience of wild salmon meta-populations (Young, 1999, Schindler *et al.*, 2010, Anderson *et al.*, 2014).

A new approach to stocking

My suggested approach is based on four guiding principles, draws on existing guidance and the literature and challenges and accommodates the 7-Hs. It begins with the evidence-based presumption that stocking hatchery fish is bad for wild salmon. We should thus do it as little as possible, and in the least damaging way possible, where and when wild salmon matter. The approach combines simple rules for *where* and *when* (not) to stock with an operational step-change in *how* we stock. Accepting that we will continue stocking where and when we should not, it attempts to minimise the damage we inflict on wild salmon when doing so too.

Four guiding principles

All populations face inevitable extirpation. If ecological conditions render a population's growth rate perpetually negative, extirpation will be deterministic, unless such 'sink' populations are demographically rescued by immigrants from larger 'source' populations (Pulliam 1988). Extirpation can also occur because of environmental stochasticity (e.g. a volcano), demographic stochasticity (all individuals fail to replace themselves by chance) and genetic stochasticity (the chance accumulation of 'bad' or loss of 'good' genes through drift and in-breeding). Except for environmental stochasticity, these risks only threaten very small populations, which are likely to suffer extirpation by demographic stochasticity before genetic factors are important (Lande, 1993).

Adding individuals to a population will (almost always) decrease its growth rate. This decrease may be negligible and difficult to detect in small populations free of strong density-dependent effects.

Adding individuals can conceivably increase a small population's growth rate if it suffers from depensation, or 'Allee effects', whereby its deterministic growth rate *declines* as population size drops below some critical level (Courchamp *et al.*, 1999, Liermann and Hilborn, 2001).

Adding maladapted individuals to a population will decrease its growth rate *more*. Regardless of a population's size or growth rate, adding individuals with phenotypes mismatched to environmental conditions will decrease the population growth more than adding individuals whose phenotypes have evolved under similar selection regimes.

Adding (any) individuals may rescue small populations from extirpation by demographic stochasticity. For such populations, it is possible that the benefit of larger population size will outweigh the risk of a lower deterministic growth rate. A population's future may be brighter with 1,000 maladapted individuals than with 13 well-adapted individuals.

Where and when (not) to stock

Evolutionary theory and empirical evidence suggest the following scenario approximates reality. The threat to wild populations from stocking is the product (semi-literally) of three quantities: the ratio of hatchery to wild adults in the spawning population; the degree to which hatchery fish are maladapted to the wild; and the probability of hatchery fish breeding and inter-breeding with wild fish. All else being equal, the higher the ratio of hatchery to wild fish, the greater the risk is to the wild population. The more maladapted a hatchery population, the greater the risk is to the wild population. But as a hatchery population becomes more maladapted, the probability of hatchery fish successfully breeding declines. For a given ratio of hatchery to wild spawners, the threat from hatchery fish will be lowest when they are phenotypically extremely similar or divergent to wild fish. In the first case, hatchery fish will 'nudge' the wild population off its adaptive peak through inter-breeding. In the second case, the wild population would be 'shoved' off its adaptive peak through inter-breeding, but the probability of that happening is low. The greatest threat to wild populations likely comes when hatchery fish are maladapted, but still able to successfully reproduce. With a threat scaled to the ratio of hatchery to wild spawners, perpetually stocking hatchery fish parented by wild-broodstock will incessantly nudge the wild population off its adaptive peak, making it

less and less wild, leading to a 'semi-wild' broodstock scheme. Though intuitively appealing, socially engaging and increasingly popular, subjecting viable wild populations to wild-broodstock stocking schemes is ecologically and evolutionarily irrational.

Where and when TO stock

Where and *when* there are no wild salmon, or *where* and *when* the integrity of wild salmon is not a management priority.

or (possibly and rarely)

Where there is a wild salmon population and *when*: it is at immediate risk of extirpation; there is no targeted harvest; it does not receive immigrants from other wild populations; ecological restoration is, and will continue to be, funded and delivered. Importantly, extirpation risk should be determined using Population Viability Analysis (PVA) and our knowledge of salmon population dynamics. It should not be determined using status assessments such as: 'there are fewer fish than before', 'there are not enough fish to catch', 'a dam removed half the habitat', 'it's below its conservation limit', or 'its 10-year growth rate is negative'. In the absence of formal PVA, a reasonable rule might be: if there are enough adults to support a stocking programme, then don't stock.

Where and when NOT TO stock

Where and *when* there is a wild salmon population that does not meet the conditions above.

These simple 'where' and 'when' criteria allow us to continue stocking hatchery fish to support fisheries in some areas, while protecting wild populations from stocking in other areas. Angling regulations can be adapted to support these management objectives. This stocking-angling 'portfolio' approach has been recently implemented on the Oregon coast of the PNW (ODFW 2014). Doing so will be more challenging where rivers and fisheries are not managed by government agencies as shared and freely accessible public resources.

How to stock

Where and when wild salmon don't matter

In the first case, we accept, and aim to minimise, the risk posed to wild salmon by hatchery populations designed to support fisheries. The goal is to create maladapted hatchery fish and keep them away from wild fish. Physical isolation (distance and barriers) and release protocols should be used to minimise demographic straying and

genetic introgression into wild populations. To allow monitoring, all hatchery fish should be adipose-clipped, and a sub-set can be code-wire tagged. All fin-clipped fish should be killed when captured.

Where and when wild salmon do matter

How to stock in the second case, where and when wild populations matter, is the more interesting challenge. The current vogue is to stock hatchery-reared off-spring of wild-broodstock, but first principles and evidence suggest this approach can be demographically ineffective (Young, 2013, Bacon *et al.*, 2015) and evolutionarily damaging (Chilcote *et al.*, 2011, Christie *et al.*, 2014). Neither research into molecular minutia nor tweaking hatchery and stocking practices will change how the fundamental processes of population and evolutionary ecology operate.

We need a new approach to *how* we stock *where* and *when* wild salmon matter.

Three features of Atlantic salmon ecology (Aas *et al.*, 2011) suggest capturing, transporting and stocking wild fry may be that *how*. First, adult spawners tend to be spatially clustered across river channel networks, which results in emergent fry being spatially clustered (Finstad *et al.*, 2010, Foldvik *et al.*, 2010). Second, most emergent fry belong to the 'doomed majority' that will die quickly, and the chance of dying increases with fry density (Einum and Nislow, 2005). Third, emergent fry do not get far alive (Einum and Nislow, 2005), so early density-dependent population regulation operates at fairly small spatial scales (10 to 100s, not 1000s of metres) (Einum *et al.*, 2006, Einum *et al.*, 2008). Together, these observations suggest we can remove thousands of emergent fry from high-density source areas, transport them, and stock them into target areas that would otherwise be stocked with hatchery-reared fish. By culling from the doomed majority at small spatial scales during the earliest post-emergence life-stage, we are unlikely to reduce the adult-to-smolt productivity of source populations, even when they are relatively 'small'. Because stocked fish are wild, and exposed to un-natural environments for only hours to days instead of months to years, we will dramatically reduce the phenotypic and genetic 'footprint' of stocking.

Depending on the locations of source and target areas, wild fry stocking can be implemented at spatial scales ranging from reach (intra-deme), to river (intra-population), to basin (meta-population), to inter-basin (inter-stock). A reasonable first step for identifying

source fry is to ask: 'From where would fall fry and parr emigrate?' or 'From where would adult colonists most likely come?'. As a default, it is sensible to collect wild fry from as close to the target area (in river km) as possible. Still, while the population genetic structure of wild salmon conforms loosely to 'isolation by distance', the 'nearest neighbour' might not always be the 'nearest phenotype' (Fraser *et al.*, 2011). The choice of source area should be informed by matching environmental variables (e.g. hydrology, migration distance, thermal regime, geology, water chemistry) and phenotypic traits (e.g. life history, body size, spawning time, parr maturation rates) to the target area. We can also use genetic distance indices like F_{st} to select source fry, but caution is required (Whitlock and McCauley, 1999). The genetic effective migration rate between two populations depends on both the number of migrants exchanged *and* their reproductive success. Two populations may have a low F_{st} value (exchange lots of genes) because they exchange lots of migrants, but those migrants may have relatively mismatched phenotypes and low fitness. Given these general principles, in some cases it will be reasonable to hedge our bets by collecting fry from various source areas, even those that might offer phenotypic mismatches.

Operationally, stocking wild fry is cheaper and simpler than stocking hatchery fish. We are replacing a hatchery with perpetual staff and running costs with a few person-months of fieldwork. To ensure low capture efficiency, wild emergent fry can be collected using casual, low-power, single-pass electrofishing (or in some habitats pole seines). Fry can be collected from multiple sites throughout the emergence period to 'neutralise' capture-imposed selection on emergence location and time. During each morning capture session, fry can be held in live wells before being transferred to a tank filled with source water (and a block of ice or aerator if needed) for transport to the target area. Target water can be mixed into the tank during lunch, and the wild fry can be stocked in the afternoon. More elaborate holding and transport methods can be used as terrain and distances require.

Wild fry stocking is a natural extension of 'meta-population guidance' aimed at artificially increasing colonisation rates from occupied to vacant habitat patches (Young, 1999, Anderson *et al.*, 2014). To date, 'active colonisation' interventions have relied principally on transporting adults and stocking hatchery juveniles. In their recent review of Pacific salmonid re-introductions, Anderson *et al.* found 'no direct evidence that these approaches have established a

demographically independent, self-sustaining population'. The wide non-native distribution of many salmonid species suggests this conclusion should elicit reflection rather than dismay, though Atlantic salmon does seem to be a particularly poor colonist by salmonid standards.

In the current context, there are a number of reasons why it makes more sense to stock wild fry than transplant wild adults. First, fry emergence is more synchronised than adult spawning time, so it will take less time to sample across the phenological range of source-area fish. Second, stocked fry are much less likely than transplanted adults to swim out of the target area. Third, collecting fry will provide a better sample of the genetic and phenotypic diversity of the source area. Fourth, unless adults are collected on the spawning grounds, we have little idea of their destination (i.e. an area of low or high emergent fry density?). Fifth, when disaster strikes, it is better to lose a batch of fry than a truckload of adults. Sixth, wild fry stocking will support a much richer range of study designs to inform adaptive management.

Will wild fry stocking be better for wild salmon?

It can't be worse. While there is an overwhelmingly compelling body of evidence suggesting traditional and wild-broodstock approaches harm wild salmon, I know of none suggesting they have either saved a wild population from extirpation or increased wild population productivity or size.

Regardless of benefit, the risks to wild salmon are almost certainly lower. Instead of imposing fish to serial episodes of artificial selection through much of their life history (selecting broodstock, breeding, incubation, rearing, release), wild fry will spend a few hours (or at most days) in captivity. The target area will be stocked with what are wild fish by any but the strictest definition. For the source area, it seems unlikely that removing a small proportion of the doomed majority from areas of high emergent fry density will be tangibly more damaging than removing adults to support hatchery-based stocking. Obviously, initial wild fry stocking programmes should be well monitored, and ideally conducted in areas with spatio-temporally relevant data for one or more life-history stage.

Will wild fry stocking accommodate the 7 Hs?

We stock to satisfy people, not to benefit salmon. Wild fry stocking must compellingly challenge and accommodate relevant socio-

political drivers.

Habit. We still get to stock fish, and even use hatchery staff and equipment. Wild fry stocking provides ample opportunities for stakeholder participation and education.

High. Electrofishing is way more fun than picking dead eggs or cleaning silt from intake screens. We still get to play with fish. Admittedly, we will miss catching, touching and stripping adult salmon.

Hubris. We still get to satisfy our techno-arrogance by improving nature with clever interventions.

Honour. We are still stocking, and could not be doing so without the knowledge and contributions of hatchery staff and stocking proponents.

Hope. We have a fresh target for our bottomless reservoir of hope.

Heresy. Winning over stocking science deniers is tough work. Wild fry stocking offers a new means to engage and educate.

h-index. Wild fry stocking can be used to address a wide range of pure and applied questions. If funding is available, researchers will do exciting science that will inform adaptive management and produce career-enhancing publications.

Conclusion

The persistent disconnect between scientific evidence and management practice suggests that stocking is in a conceptual and operational rut unlikely to protect or improve the integrity of wild salmon. I have offered an alternative approach that accommodates socio-political drivers, is unlikely to be worse, and likely to be better for wild salmon. I encourage those controlling research funding and stocking management to embrace this new approach in the spirit of adaptive management.

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CNL(17)43

Approaches used to prevent the loss of Atlantic salmon populations at high risk of extinction, including gene banks, adult captive-rearing, smolt-to-adult supplementation - Gene banking of wild Atlantic salmonids in Norway

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Introduction

In 1986, the Norwegian Environment Agency established the National Gene Bank for wild Atlantic salmon in Norway. The main purpose of the National Gene Bank is to contribute to the nationwide preservation of the genetic diversity and characteristics of natural salmon stocks in the face of threats to wild populations from, *inter alia*, acidification, the parasite *Gyrodactylus salaris* and, more recently, escaped farmed salmon. This National Gene Bank comprises a frozen sperm bank (established in 1986) and a living gene bank (established in 1990).

As a response to inter- and intra- riverine differences in natural conditions, Atlantic salmon stocks have developed phenotypic and life-history variation among populations, some of which reflect local adaptations. Analysis of molecular genetic markers has revealed significant population genetic structuring. As a consequence, salmon stocks are managed as individual population units.

Stocking of fish in Norwegian lakes and rivers still occurs. The motivation for stocking has gradually changed from purely for stock enhancement purposes towards an increased focus on preserving biological diversity. Under certain circumstances, stocking of fish could have positive effects. However, if not conducted in a well-planned manner, that takes into account the risks to the wild stocks, the unintended side-effects of stocking can result in loss of genetic variation and genetic integrity of fish populations.

Negative effects from stocking can be minimised by adherence to some general rules and guidelines, see for example the paper entitled 'The policy relating to hatchery and stocking activities in Norway - managing risks and benefits', CNL(17)44. However, in order to minimise the negative effects, and to adapt established stocking practices accordingly, it is necessary to build stocking practices upon population-specific knowledge.

Objectives and strategies

During the initial developmental phases, the Gene Bank was based exclusively on frozen sperm. The goal was to preserve genetic material from more than 100 stocks and from at least 50 individual fish from each stock.

The Environment Agency considers live gene banks as a temporary measure to be used only in cases where salmonid stocks are threatened by extinction. At present, five live gene banks are operational and one more is being planned. These live gene banks will be able to hold live fish from a maximum of 50 stocks in total.

The basic gene bank strategy for Atlantic salmon in Norway is shown in Figure 1. Within this strategy, strong emphasis is placed on measures to prevent transmission of fish disease organisms.

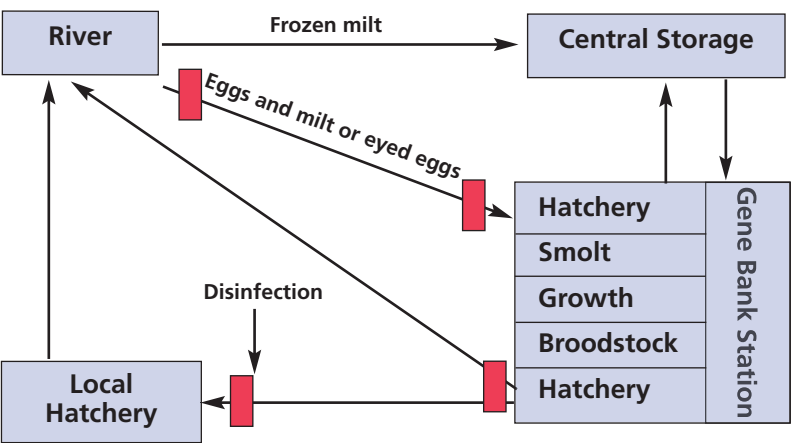


Figure 1: The gene bank strategy and transfer of biological material (red boxes - disinfected eggs) in and out of the gene bank

All parent fish are maintained in a health-control programme and protocols for how each operation (handling of the fish, transportation of ova and sperm) is to be carried out have been established by the Norwegian Veterinary Institute. Only disinfected eggs can be exported from the station in order to minimise the risk of spreading diseases to rivers. All fish production for stocking is carried out at local fish culture stations and the entire production is based on fresh water, as sea water is often contaminated with pathogens.

Adult fish caught in individual rivers are kept in fish tanks at local stations for a few months until they become sexually mature. The sperm is collected from these fish, frozen and then transported to a

central storage facility. In addition, fresh milt and ova are transported to a disinfection facility. After disinfection, the fertilised ova (single pair mating) are transported to the regional gene bank station where ova from each female are kept in quarantine in separate hatching cylinders. Ova are removed from the quarantine when diseases which could be transmissible to the interior of the eggs are discovered.

Within the gene bank station, each family group is maintained in separate tanks until the fish can be marked. Thereafter, the families are pooled and each stock is kept in separate tanks throughout their life-cycle. The station is divided into four sections: (1) hatchery and initial feeding stage; (2) parr; (3) smolt; and (4) older fish. These divisions facilitate disease management and the management of family groups and stocks.

Each of the captive stocks spends two generations in the station. The production is based on the following guidelines aimed at retaining genetic diversity of the stocks:

- maximum survival;
- long generation time;
- identification;
- equal size of family groups;
- a minimum effective population size of 50 for each generation;
- surplus fish-production for safety; and
- mating schemes including the use of frozen sperm.

Cryopreservation and sampling strategy

Cryopreservation (deep freezing) of sperm enables the preservation of genes for a virtually unlimited period.

A new cryopreservation method, developed by Cryogenetics AS in Norway, was adopted for the Gene Bank Programme in 2010. Larger volumes of sperm, more suitable for broodstock production, can now be preserved:

- one sample stored in liquid nitrogen contains enough sperm cells to fertilise approximately 4,000 ova with an expected fertilisation percentage of >90% (average numbers from Atlantic salmon);

- gonad extraction of sperm significantly increases the amount of sperm available for freezing in situations where regular stripping of fish is difficult or not possible.

The following sampling strategy has been employed by the Gene Bank Programme:

- sperm from at least 50 individuals from each stock is frozen. Since the sampling cannot be carried out on identifiable stocks, each river is considered a sampling unit. Large tributaries are sampled separately. This choice of strategy is based on the empirical evidence that genetic differentiation along a single watercourse is minor compared to the among-river variation;
- sampling is carried out for a period of at least two years in each river to reduce the chances of gross over-representation of a single year-class;
- emphasis is placed on sampling from stocks representing a wide geographical and ecological range;
- stocks which are threatened by extinction are given priority over other stocks;
- stocks which are of particular scientific value, or valuable for fishing purposes, are also given priority;
- autopsy of the brood is conducted to identify any diseases; and
- genetic testing is conducted.

The Norwegian National Gene Bank now contains material from more than 6,000 wild salmon individuals from about 200 distinct stocks. It also contains genetic material from 26 different anadromous trout stocks and 2 stocks of anadromous Arctic charr. Collection is carried out over several seasons, years, and in different parts of the watercourse, to avoid collecting material from fish that are closely related. The sperm-bank also contains sperm from 6,300 individuals from 35 populations of self-produced brood from the live gene bank.

Live gene banking

Administration of genes and fish in the live gene bank

FAGER is the management system and database. FAGER is the operational tool for control and overview of kinship in the facilities' practical activities, where individual-based historical data are significant. PIT tags are applied to all fish and provide an effective and unintrusive way of handling fish and optimal control of kinship.

When handling, each fish is registered and selected data are stored in the database. Pedigree is available for each individual and constitutes a basis for the determination of new combinations in production or to new generations in the gene bank or other stocking activity.

At the age of 7 - 10 years, selected fish are, if necessary, used for production of new generations of brood stock. To protect the genetic variation that exists between individuals in the same family group, the crossing regime shown in Figure 2 is applied. This gives 32 different crossing combinations of the new family group.

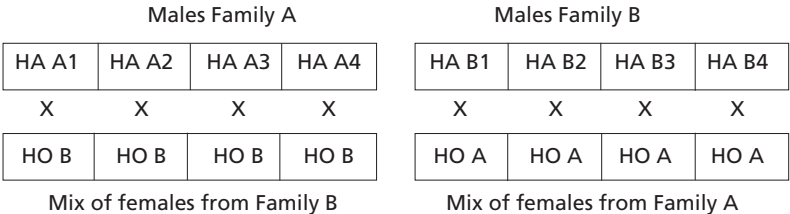


Figure 2: Creating new generations. Every male fish from Family A is mated with a mixture of eggs from four females from Family B etc. The quantity of eggs from each female is standardised. After fertilisation is over, all eggs are gathered into a single unit that will constitute the new family group

With individual marking and family structure, mating can be controlled so that genetic breadth is maintained over time in a gene bank. Active mate choice is not permitted in the gene bank. In the materials returned to rivers, all family groups, genders and individuals should be equally represented. The crossing regime is, to the extent practicable, intended to maximise the number of variants, which mitigates the negative effects of lack of mate choice. The probability of losing rare alleles is reduced by crossing individuals which are potentially related. This is evaluated by assessment of relatedness among new individuals from the founding population using molecular genetic markers and full pedigree information for each offspring (brood stock).

Unintentional selection (domestication) is counteracted by limiting mortality. Domestication may also be counteracted by supplementing with new families from the founder population or by supplementation with frozen sperm from previously captured wild fish and first generation broodfish.

Restoration of fish stocks through the use of live gene banks

Most of the anadromous fish restoration projects are related to the eradication programmes for *Gyrodactylus salaris* in which the National Gene Banks play a major role. The main goal of re-stocking is to establish sustainable populations in the affected watercourses. The likelihood of withstanding threats and challenges in the natural environment increases with the amount of genetic variation. To maximise maintenance of this variation, material from the live gene bank is re-introduced to the rivers in as many genetic combinations as possible from the brood stock ('F1 generation' in the gene bank). Re-building stocks is, therefore, a long-term process with a time horizon of five to ten years. The return of off-spring from the gene bank does not end until all the family groups and available individuals in the gene bank have contributed and the number of adult fish in the stock has reached the natural spawning target estimated for the specific river.

Re-establishment of anadromous salmonid stocks from the National Gene Banks is mainly achieved by planting ova. Other life-stages, including smolts, may be used in re-stocking in the first years of the re-establishment to catalyse the process and also to avoid, displace and minimise negative genetic effects of the presence of individuals of unwanted origin, e.g. farmed salmon and strayers.

After the release of off-spring has commenced in the different watercourses, the local river-specific selection starts again and nature decides which variations are viable.

Evaluation of results

The marking method

Since 1993, the Norwegian Gene Banking Programme has used Alizarin otolith group marking of Atlantic salmon. This approach has enabled group marking of a high number of individuals in a fast, simple, secure and affordable way. For code marking, repeated marking at different ontogenetic stages of the eyed ova can be employed. In the period 2005 - 2015, more than 25 million eyed ova were marked in this way.

Organisation of the Gene Bank Programme

The Gene Banking Programme for salmonids in Norway is administered by the Norwegian Environment Agency. The practical field-work is planned in co-operation with the National Veterinary Institute, local county administrators and other local contacts.

The National Veterinary Institute is the National Competence Center for all practical implementation in the field and standardisation of routines at the gene bank facilities.

The permanent sperm bank is run by Cryogenetics AS and is divided into two equal separate units located in two different regions of the country.

The live gene bank stations are owned and operated by private companies, hydropower boards, research institutes and others. Contracts govern the relationship between the Environment Agency and the owners. All production costs and investments are financed by the Agency. The Environment Agency decides upon all issues concerning the use of the stations' facilities and also provides instructions.

Acknowledgements

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CNL(17)48

Policies and regulatory framework for stocking activities of Atlantic salmon in Canada

Paper presented by Doug Bliss, Fisheries and Oceans Canada, New Brunswick, Canada

1. Introduction

As per the definition of 'Stocking' in Annex 4 of the Williamsburg Resolution, stocking and hatchery interventions for anadromous Atlantic salmon in eastern Canada are currently conducted by the Government of Canada (Fisheries and Oceans Canada (DFO) and Parks Canada), by provincial governments, and by Non-Government Organisations. Stocking and hatchery interventions are undertaken for three reasons:

- conserving biodiversity for populations at high risk of extinction;
- mitigating or compensating for habitat degradation or loss (e.g. the case of the Saint John River where hydro development has reduced production capability) (Mitigation stocking as per the definition in the Williamsburg Resolution Annex 1);
- conducting maintenance stocking with the objective of supporting fisheries (Salmon enhancement as per the definition in the Williamsburg Resolution Annex 1).

Between the late 1860s and the 1990s, enhancement facilities in Newfoundland and the Maritime Provinces and Quebec were used to augment production of salmon for enhanced economic returns in the commercial and recreational fisheries. These practices were terminated by DFO in the 1990s. Most hatcheries in the Maritime Provinces and the associated enhancement opportunities conducted by DFO were divested to not-for-profit stakeholders and an Aboriginal organisation. The two facilities that are retained and operated by DFO are now focused on the maintenance of genetic diversity within those populations that are either listed as 'endangered' under the Species at Risk Act (SARA) or in the view of departmental staff have population trajectories which may lead to extirpation in the near future.

This change in policy direction within DFO in the mid 1990s did not, however, discourage (as borne out by the divestitures) the private sector, provincial governments and First Nations and other Aboriginal organisations from maintaining or becoming involved in Atlantic

salmon enhancement for social, economic or other reasons. In the province of Quebec, the single facility is now also used for conservation and restoration purposes, whereas modest Atlantic salmon enhancement programmes in the provinces of Nova Scotia, New Brunswick and Prince Edward Island are directed at supporting public fisheries. DFO continues to collaborate with private sector interests, provincial governments and Aboriginal groups on salmon enhancement initiatives that require DFO licensing and to help ensure that the products for those enhancement initiatives meet DFO regulatory requirements for release into fish habitat (Section 3).

There is no federal policy that guides stocking and enhancement activities for Atlantic salmon in eastern Canada. Some provincial governments (New Brunswick, Quebec) have developed policies that guide their sponsored activities. The stocking activities by governmental and non-governmental organisations are reviewed by defined oversight committees and are authorised under the relevant acts and regulations (Section 3).

2. Current stocking activities

2.1 Federal Government

2.1.1 Fisheries and Oceans Canada

Until the mid-1990s, DFO owned and operated several hatcheries in the three Maritimes provinces of eastern Canada. DFO was also involved in restoration programmes on a few rivers in Newfoundland, the most important being the enhancement of the Exploits River. In the mid-1990s, following programme review, the majority of DFO hatcheries were divested where possible to NGOs with the understanding that the NGO groups would continue the stocking activities at similar levels to those of the recent years prior to divestiture.

DFO currently owns and operates two fish culture facilities for Atlantic salmon. Hatchery activities supported by DFO are directed at recovery actions of endangered populations and to mitigate for habitat loss associated with the construction of the Mactaquac Dam in the lower portion of the Saint John River (New Brunswick).

Conservation programmes

The conservation programmes for the endangered Atlantic salmon populations of the Inner Bay of Fundy (iBoF) and the Outer Bay of

Fundy (OBoF) consist of captive breeding and rearing activities; details of this programme are provided in DFO (2008, 2010, 2016a) and the scientific basis is described in O'Reilly and Doyle (2007) and O'Reilly and Harvie (2010). Live Gene Banks (LGB) for the iBoF salmon population were initiated in 1998 with activities currently centered at the DFO Mactaquac and Coldbrook Biodiversity Facilities, in New Brunswick (NB) and Nova Scotia (NS) respectively (DFO 2016a). The goal of the LGB is preserving the remnant populations and remaining genetic diversity of the species (DFO 2010). The LGB is designed to have multiple year classes (a 'year class' being those fish in a population born in the same year) of each of the principal LGB populations. The number integrated into the LGB for each population annually is 200 - 300 fish. Genetic data is used to develop annual mating plans (to minimise the risk of losing genetic variation and to avoid in-breeding by mating of genetically closely-related individuals). Mating plans include a family equalisation process (process that equalises each mating cross to a known number) thus giving each family an equal opportunity for survival.

A variety of life-stages of iBoF salmon have been held in captivity or released. Monitoring of juvenile salmon in the wild has confirmed that the population can be maintained through this process of bypassing the marine phase of the life-cycle. The programme has been successful at increasing the abundance of juveniles in the wild and substantially reducing extinction risk. However, the LGB programme alone is not expected to achieve recovery of this population.

Mitigation programmes

The mitigation programme produces and releases salmon at various life-stages to mitigate the effects of hydro-electric development on salmon in the Saint John River associated with the construction of Mactaquac Dam hydro-electric facility in the lower portion of the Saint John River in the late 1960s (Jones *et al.*, 2014). From the early 1970s to the mid-2000s, hatchery broodstock for the programme has consisted of 200 - 300 wild sea-run adults each year (Clarke *et al.*, 2014). The intensity of smolt rearing and stocking has declined, from a range of 200,000 to just over 300,000 smolts annually between 1978 and 2002 to less than 50,000 smolts since 2009 (Jones *et al.*, 2014). Since the early 2000s, the programme at the Mactaquac Biodiversity Facility was re-focused with the objective of conserving and restoring a declining resource (Jones *et al.*, 2004). The current programme replaces a large portion of the traditional smolt production with production of age-0 fall parr. The programme has also changed from

collecting returning anadromous salmon as broodstock, to a captive-reared programme in which smolts or pre-smolts from the headwater areas are collected, reared at the biodiversity centre and a portion of these (90 males, 90 females) are spawned in the hatchery to produce smolts for mitigation stocking. The surplus juveniles (i.e. those that will not become one-year old smolts) are released in headwater areas in locations from which the juveniles that produced the parental stock were collected.

2.1.2 Parks Canada (Federal Agency)

Prior to 2010, adult salmon, which were collected as juveniles from either Big Salmon River or Point Wolfe River, were released into the Point Wolfe River to spawn naturally and contribute to the production of the next generation of iBoF salmon. LGB operations for Fundy National Park (FNP) stocks also resulted in annual releases of fry and parr to the Upper Salmon River in FNP from approximately 2006 - 2011. FNP initiated a change to its iBoF salmon recovery programme in 2010 based on evidence suggesting that the unique Point Wolfe River genetic stock was being lost over generations of mating Big Salmon River and Point Wolfe River salmon. The new programme focused on Point Wolfe River ancestry salmon selected from the mixed groups to minimise further loss of this unique genetic strain, and will produce high ancestry stock for release at various stages into FNP rivers. This approach is expected to continue until both FNP rivers contain only the unique Point Wolfe River high ancestry stock for broodstock collection.

In addition to the approach above, surplus high ancestry fish are reared to adults for release back into FNP rivers to spawn naturally in order to produce progeny free of captive exposure and to supplement the in-river populations. Wild juveniles collected in excess of those required for the live gene banking programme (100 annual captive matings), are now transferred as smolts to a dedicated marine farm for rearing wild salmon. Wild smolts are reared to maturity at this marine farm operated by Cooke Aquaculture, which is isolated from the commercial aquaculture industry within Bay Management Area 5 of the Bay of Fundy. They are then transferred back to native rivers in FNP to spawn naturally. The resulting off-spring are free of any captive exposure. Considering the iBoF population depends on supplementation to avoid extinction, migrating smolts from this programme are anticipated to provide optimally fit individuals going out to sea as well as samples for perpetuating live gene banking activities.

Currently, FNP collects wild juvenile cohorts annually at the parr stage in late fall and at the smolt stage the following spring. Parr are held at a DFO Mactaquac Biodiversity Centre over winter and transferred to the marine farm in spring depending on the number of smolts captured for LGB requirements. Mature adults are released back into FNP rivers in October. Numbers of individuals released in each river are targeted to exceed estimated minimum viable effective population size of 300 - 475 individuals. The programme currently focuses on one river, but is planned to include both FNP rivers eventually. In 2016, 845 mature adult salmon were released to the Upper Salmon river in FNP. Of note, Fort Folly First Nation, iBoF recovery team members and long-term partners on the FNP recovery programme, lead a similar programme on the Petitcodiac River, the largest river system in the iBoF. The programme similarly collects juvenile salmon, rears at the same wild salmon farm until mature and releases the adults back to the Petitcodiac River. Transfer of fish to and from the wild and rearing facilities occurs under permit from DFO Introductions and Transfers Committee which requires health screening to be completed and approved for each transfer.

2.2 Provincial governments

2.2.1 Province of New Brunswick

In the late 1970s, the New Brunswick Department of Energy & Resource Development (DERD) (formerly Natural Resources) began rearing fish for stocking purposes using its own provincial fish hatchery to support public fisheries. These fish included species such as anadromous Atlantic salmon, landlocked Atlantic salmon, brook trout, arctic char, lake trout and splake to name a few. In 2004, budget constraints forced the decommissioning of the provincial fish hatchery. In an effort to maintain the programme, a mandatory five dollar 'Fish Stocking Conservation Fee' was added to the cost of most angling licenses to generate revenue for the purchase of fish rearing services from outside sources. In light of the changes, DERD established a Fish Stocking Policy that specifies a number of conditions, including only stocking fish that are: 1) native to NB; 2) of wild NB strain; and 3) certified disease free. The policy also states there would be no stocking where stocked fish could harm other species at a population level and, generally, where the species to be stocked is not native to those waters. The focus of the revised stocking programme is on landlocked Atlantic salmon and brook trout only; as well as prioritising lakes over streams, rivers and brooks.

Lakes stocked with landlocked salmon are generally stocked on an alternate year basis with nine lakes stocked every odd year and 16 lakes stocked every even year, for a total of 23 different lakes stocked (2 lakes are stocked every year). Each year, roughly 40,000 landlocked salmon are stocked, after being marked with an adipose, left ventral or right ventral fin clip.

2.2.2 Province of Newfoundland and Labrador

There is limited to no stocking activities in Newfoundland and Labrador. There are no hatcheries, either government operated or private that collect, hold, spawn or release Atlantic salmon to public waters.

2.2.3 Province of Nova Scotia

The Province of Nova Scotia owns and operates three hatcheries which stock brook trout, brown trout, rainbow trout and anadromous Atlantic salmon in support of the Province's sport fishery. Only two of the three provincial hatcheries culture anadromous Atlantic salmon.

Atlantic salmon are raised from wild broodstock captured annually and released at fry, parr and smolt stages specific to rivers from which the parents were collected. There are currently five rivers in the province that are supplemented with hatchery produced Atlantic salmon: Baddeck River and Middle River in eastern Cape Breton, Mabou River, Margaree River and West River Antigonish in the Gulf region of Nova Scotia. The annual collections from each river are modest, with the largest collection from the Margaree River of 25 pairs annually. All parr and smolt are adipose fin-clipped for identification as returning adults. To reduce the impact of the hatchery environment on natural selection, fin-clipped adults are not used as broodstock. Mating is carried out with a 1:1 male/female sex ratio. Atlantic salmon broodstock collection and release of juvenile fish is carried out under permit by DFO. The province regulates commercial aquaculture under the Fisheries and Coastal Resources Act and two separate sets of regulations, including Aquaculture Lease and Licensing Regulation and Aquaculture regulations. These regulations address aquatic animal health, fish containment, environmental monitoring and farm operations.

2.2.4 Province of Prince Edward Island

There are no government owned or operated fish culture facilities in the Province of Prince Edward Island (PEI). Priority stocking activities are for brook trout. The limited stocking of anadromous Atlantic

salmon that occurs is from production contracted to private facilities. The current stock enhancement programme on PEI has two primary goals: to supplement natural populations and to improve recreational fishing opportunities. Currently, the emphasis for stocking of Atlantic salmon is the Morell River, which receives the first 50,000 salmon fry, with any additional fry available to stock another system. Less than 50 adults are collected annually from the wild as broodstock. To monitor the success of stocking using fed-fry, a tributary of the West River (Brookvale) was chosen as a test site. Salmon fry were stocked in 2015 and 2016 and electrofishing surveys indicate good survival over the two years. The site will continue to be monitored and the ultimate indicator of success will be evidence of spawning.

2.2.5 Province of Quebec

Since 1875, the province of Quebec has owned and operated one fish culture facility which is primarily used for Atlantic salmon. With the exception of a few activities related to hydro-electric mitigation projects, this is the only facility in which spawning and rearing of juvenile salmon for enhancement purposes takes place. In all instances, the objectives of the enhancement activities are for conservation and restoration of Atlantic salmon populations.

In addition to the acts and regulations described in section 3 for regulating enhancement activities, a number of administrative processes have been developed to maximise the benefits and to reduce the risks associated with enhancement activities. These are presented in the recently revised Atlantic Salmon Management Plan 2016 - 2026 (MFFP 2016) and in internal policy documents.

With the objective of reducing intra-specific competition, enhancement activities are only permitted on rivers which are below their optimal conservation level, as defined in the management plan. Salmon stocking is only permitted in sections of the rivers that are under-utilised by wild salmon. To maximise the survival of stocked fish, candidate rivers for enhancement must also have sufficient quantities of high quality habitat as defined by the Index of Habitat Quality.

The impacts associated with the loss of genetic diversity are reduced by using a number of broodstock in the hatchery that represents a significant proportion of the wild population; at least 30 spawners for populations with less than 500 wild anadromous salmon or 10% of the total wild anadromous population if the wild population exceeds 500 fish. To further safeguard the genetic diversity, the broodstock

must be comprised of equal numbers of male and female spawners with spawning crosses of a minimum of 3 females and 3 males. One-third of the broodstock held in captivity is replaced on an annual basis and no individual is spawned more than three times.

Since 2012, the number of juveniles stocked in rivers identified in the Government of Quebec's five-year enhancement programme for salmon is determined based on an analysis of the expected demographic gains and on theoretical genetic concepts for each river. The analysis, based on a mathematical model described by Ryman and Laikre (1991), provides a stocking number that will result in at least a 15% increase in abundance while limiting the reduction in the effective population size, a genetic diversity parameter, to less than 10%. The loss of genetic integrity is further controlled by using broodstock specific to the river that will be enhanced. In the rare instances where the number of spawners in the wild is insufficient to respect this objective, and in order to prevent extirpation of the population, broodstock from another population that is genetically related may be used. Since the initiation of this condition, only enhancement activities in the Sheldrake River required the use of non-river specific broodstock as the most recent assessments indicated that the wild anadromous returns to the river were less than 10 adults. Before this decision is made, other options for enhancement are considered including recourse to live gene banking or the use of juvenile-to-adult supplementation.

In order to assess the results of the enhancement activities undertaken by the government of Quebec, all stocked juvenile salmon since 2012 are marked in a way that allows them to be distinguished from wild salmon at enumeration facilities or in recreational fisheries catch.

2.3 Non-Governmental Organisation (NGO) activities

2.3.1 Juvenile stocking programmes

Since the divestiture of the DFO hatcheries, a number of watershed and conservation groups have continued or initiated modest stocking programmes in support of public fisheries in several rivers in Gulf Region New Brunswick. Stocking activities currently occur primarily at early juvenile stages, most at the unfed fry stage. No inter-river transfers are allowed and in the larger Miramichi River, no intra-river transfers occur. Wild anadromous broodstock are collected specific to the river for which stocking is proposed and in the Miramichi River, the collections and subsequent releases take place specific to

tributaries. The financial costs of the operations are borne by the NGO groups.

2.3.2 Smolt-to-captive-reared adult supplementation

In response to particularly low returns of Atlantic salmon to the Northwest Miramichi River in 2012 to 2014, a group of NGOs in New Brunswick proposed a stock supplementation programme consisting of the capture of wild Atlantic salmon smolts, rearing these in captivity in freshwater to the adult stage, and subsequently releasing the adult captive-reared fish back to the river. This activity is intended to circumvent the low marine smolt-to-adult return rates of Atlantic salmon and to increase spawning escapement. As a precedent-setting activity for supplementation of Atlantic salmon populations, DFO undertook a science peer review of the risks and benefits of such programmes to wild Atlantic salmon fitness in order to provide advice to DFO Fisheries and Aquaculture Management, the sector responsible for issuing the permits for such activities (DFO 2016b). Smolt collections for captive rearing occurred in 2015 and 2016, but no captive-reared adults have been released to date. Regulatory decisions on authorising further collections of smolts and the release of captive-reared adults are pending.

The first smolt-to-adult supplementation programme in the province of Quebec has been initiated on the Romaine River by the Société Saumon de la Rivière Romaine. The number of spawners in this river was estimated to be in the range of 50 to 100 adults and the removal of broodstock was considered to pose a risk to the viability of the population. The spawners reared in captivity from smolt collections were spawned in a hatchery with stocking of unfed fry to the river.

2.4 Compliance with directives in Annex 4 of the Williamsburg Resolution

With few exceptions, the Atlantic salmon stocking programmes in eastern Canada are consistent with the guidelines for conducting stocking as detailed in Annex 4 of the Williamsburg Resolution:

- rivers where stocking has recently occurred or is currently occurring are classified as Class II rivers (having had some alterations to habitat, primarily associated with land use activities);
- non-indigenous salmon (European origin, including Icelandic origin) have never been used in stocking activities in eastern

Canada;

- prior to any transfer of eggs, juveniles or broodstock, health inspections of the products are required (see Section 3);
- hatchery programmes for release of Atlantic salmon to the wild are conducted according to the following principles:
 - o wild fish are used as broodstock;
 - o broodstock removals represent a small proportion of the wild salmon runs;
 - o broodstock collections represent all phenotype age groups and components of a donor population;
 - o matings are generally one male per female, or in some cases paired matings occur without prior mixing of milt before fertilisation;
 - o juvenile stages are generally released in areas where there are low densities of wild salmon juveniles and the habitat is considered to be under-utilised;
 - o stocking programmes take account of population structuring and no inter-basin transfers are allowed. In large rivers such as the Miramichi and Restigouche, hatchery programmes target specific tributaries and juveniles are stocked in the parental origin tributaries (no intra-basin transfers).

The only guideline that is generally not respected relates to the number of broodstock. Activities conducted by provincial governments (except Quebec) and NGO groups are modest in scale and the number of broodstock collected are generally low, and with few exceptions, less than 10 pairs for the river-specific or tributary-specific programmes. As such, the recommendation that a minimum of a random group of 50 pairs be used for each cohort is not achieved. Due to the modest scale of the river-specific supplementation programmes, this is not considered to be a risk to the genetic integrity of the salmon populations. The activities directed at mitigation and for conservation/restoration of endangered salmon populations (section 2.1.1, 2.1.2) exceed the minimum guideline for broodstock numbers and in the case of the live gene bank programme, hatchery mating is guided by a plan informed by genetic analysis pre-mating.

3. Regulatory Framework

Guidelines for authorising stocking are described in the following section and conform to the directives described in Annex 4 of the Williamsburg Resolution. Fish health and genetic protocols are followed and risk assessments, where required, are conducted on the basis of health, genetic and ecological factors.

Except in Quebec, permission under the Fisheries Act or the Fisheries (General) Regulations is required to obtain wild fish for stocking or artificial breeding purposes and for releasing Atlantic salmon (eggs, larvae or fish) into habitat:

- authorisation under Section 4 of the Fisheries Act is required from DFO to collect fish for broodstock from the natural producing waters;
- a License under Section 56 of the Fisheries (General) Regulations is required from DFO to release or transfer live fish into fish habitat or to a fish rearing facility. A report of the number of fish released or transferred is a condition of the License;
- a provincial Aquaculture License is required to operate a fish culture facility. The exceptions to this requirement are those hatcheries operated by federal and provincial governments and, in Nova Scotia, facilities exclusively for enhancement purposes;
- satellite sites of any hatchery operation also require an Aquaculture License.

In Quebec, the capture of wild fish or gamete extraction for stocking for artificial breeding purposes and the release of live fish into fish habitat is governed by the Règlement sur l'aquaculture et la vente des poissons ('Regulations Respecting Aquaculture and the Sale of Fish', hereinafter called RAVP) and the Règlement sur les catégories de permis d'aquaculture ('Regulation respecting the classes of aquaculture licences', hereinafter called RCPA), which both derive from the Loi sur la conservation et la mise en valeur de la faune (Act respecting the conservation and development of wildlife). When supplementation is entirely assumed by the government (capture, production and stocking), no license is required. Stocking must nevertheless respect the activities authorised by the RAVP. In those rare cases not completely conducted by the Quebec government, licences are required under the RAVP and RCPA.

3.1 *National Code for Introductions and Transfers*

In Canada, DFO issues licences under Section 56 of the Fishery (General) Regulations to intentionally release and transfer live aquatic organisms into fish bearing waters or fish rearing facilities. The issuance of these licences is managed through an Introduction and Transfers Committee (ITC) which is responsible for considering the three key provisions of Section 56 of the Fishery (General) Regulations:

1. Is the request in keeping with the proper management and control of fisheries?
2. Do the fish have any disease or disease agent(s) that maybe harmful to the protection and conservation of fish?
3. Will the fish introduction or transfers have an adverse effect on local fish stock size or genetic characteristics of fish?

In 2010, under the legislative authority of the Health of Animals Act and Regulations, the Canadian Food Inspection Agency (CFIA) began to implement the National Aquatic Animal Health Program (NAAHP). Under the NAAHP, CFIA assumed a new federal leadership role in managing the disease risks associated with movements of aquatic animals - a federal leadership role that had traditionally resided with DFO. The CFIA implemented the final portion of NAAHP, the Domestic Movement Control Program (DMCP), which came into effect on December 31, 2015. Under DMCP, CFIA will enact new measures, such as zonation and permitting, to support domestic movements of aquatic animals.

CFIA assesses disease risks associated with aquatic animal imports and domestic movements under a risk framework based on the internationally accepted principles of the World Organisation for Animal Health (OIE). This framework provides the foundation for assessing permit applications under the NAAHP. CFIA carries out the management of disease risks associated with importations and domestic movements of aquatic animals in collaboration with the provinces, territories and industry.

While federal roles and responsibilities have changed with regards to the management of disease risks, the goal has not: the Code's signatories and the federal-provincial-territorial governments remain committed to delivering an effective and integrated Code that effectively manages ecological, disease and genetic risks. The foundation of the Code remains the utilisation of science-based,

objective risk assessment frameworks to inform the licensing/permitting process required to move aquatic organisms.

3.1.1 Introductions and Transfers Committees

Introductions and Transfers Committees (ITCs) operate in each province or territory with representation from DFO and the provincial/territorial government. DFO and provinces/territories collaborate to manage disease risks pertaining to the intentional movement of aquatic organisms falling outside the scope of the NAAHP as specified in each committee's Terms of Reference. Currently, the guiding policy followed by each ITC is the 2013 Code on Introductions and Transfers (the Code) that establishes an objective decision-making framework and consistent national process for assessing and managing the potential ecological, disease and genetic risks associated with intentionally moving live aquatic organisms into, between or within Canadian watersheds and fish-rearing facilities. The Code recognises and reflects the shared federal-provincial-territorial jurisdiction in managing the intentional movements of live aquatic organisms and responsibilities under the advisory and liaison function of the ITCs established in each province/territory. While the roles, responsibilities and legal authorities of jurisdictions may differ within the committee structure, the collective expertise in managing these movements ensures a well-coordinated, nationally consistent management structure.

3.1.2 Aquatic Organism Risk Assessment Process

To evaluate the risks associated with the introduction or transfer of aquatic organisms, it is necessary to assess both the probability that a species will become established and the consequences of that potential establishment. The assessment process addresses the major environmental components. It provides a standardised approach to evaluating the risk of genetic and ecological impacts, as well as the potential for introducing a 'fellow-traveller' or parasite that might impact the native species of the proposed receiving waters. The risk assessment process is to be conducted recognising the existing industries and the historic transfers of the species that have been approved for use.

The quantity and quality of information required to complete the formal risk assessment is at the committee's discretion and is factored into the level of certainty associated with the risk assessment.

- the formal risk assessment - based on classifications of high, medium and low risk - will form the basis of the evaluation provided by the ITC to the decision-making authority on all requests for introductions and transfers of aquatic organisms that are subject to the assessment process;
- where the proposed introduction or transfer is deemed to be medium- or high-risk, the ITC may offer the applicant the opportunity to identify further mitigation measures that could be used to reduce the risk;
- the ITC will provide the risk assessment and the certainty surrounding the risk assessment, as well as how and why it was determined, to the decision-making authority;
- in addition to science-based information, the ITC may draw on relevant local ecological knowledge, such as from Aboriginal groups, aquaculturists, local groups or fishers;
- the decision-making authority will consider the risk assessment and level of certainty provided by the ITC. The decision-making authority may take into account socio-economic factors and Aboriginal considerations and will determine whether the risk is acceptable.

3.1.3 Audit and monitoring activities

The 2013 Code enhances commitments on the part of all jurisdictions to maintain, store and share information on introductions and transfers. A National Introductions and Transfers Database and Risk Assessment Library enables the ITCs to share information across jurisdictions and support Canada's domestic and international reporting requirements.

Data is provided to the Aquaculture Management Directorate from each ITC to submit to the North American Commission and NASCO to meet reporting requirements on movements of salmonids.

3.1.4 Compliance

DFO promotes compliance with the Fisheries Act and other related acts and regulations through education and awareness activities directed at both industry and the public. Fishery officers conduct inspections to validate licence reporting and to determine compliance with licences, conditions of licence and other applicable legislation.

3.1.5 Service Delivery

Service delivery under the 2013 Code incorporates defined service standards for each stage of the application, review and decision-making process for authorisations to move aquatic organisms. Jurisdictional collaboration in delivering introduction and transfer licences under a measurable set of standards provides the transparency, predictability and responsiveness that Canadian companies and institutions moving aquatic organisms expect.

3.1.6 Other regulations, policies and guidelines

DFO can issue licences and conditions pursuant to resource access requests for stocking and enhancement purposes. Section 7(1) of the Fisheries Act can be used to provide access to fish outside of the normal fishing season. Section 4 of the Fisheries Act authorises collection of fish for the purposes of stocking or artificial breeding or for scientific purposes.

ITCs also refer to other domestic and international regulations, policies and guidelines when assessing risks or identifying mitigation measures for stocking activities, including:

- Recovery Potential Assessments (RPA) and Action Plans developed under the Species at Risk Act;
- Food and Agriculture Organization of the United Nations (FAO) Codes of Practice and manual of procedures for consideration of Introductions and Transfers of marine and freshwater organisms;
- International Council for the Exploration of the Sea (ICES);
- 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).

The North American Commission (NAC) of NASCO recognises the potential effects that introductions and transfers of aquatic species can have on fish health, genetics and their ecology. In 2003, NASCO adopted the Williamsburg Resolution which referenced the NAC Protocols as contained in NAC(92)24 and ancillary document NAC(94)14. In Canada, the National Code on Introductions and Transfers of Aquatic Organisms was adopted in 2001. It is acknowledged that Canada and the United States utilise different methods for authorisation of introductions and transfers. This

Memorandum of Understanding is meant to reconcile these differences while recognising that the common goal is the conservation and protection of wild Atlantic salmon. Canada and the United States have agreed to record the following in connection with the introductions and transfers of salmonids in the North American Commission area: i) authorisations of introductions and transfers; ii) requirement to report; iii) requirement to consult; and iv) need for review.

4. Acknowledgements

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Figure 1: Map of eastern Canada showing the provincial jurisdictions mentioned in text

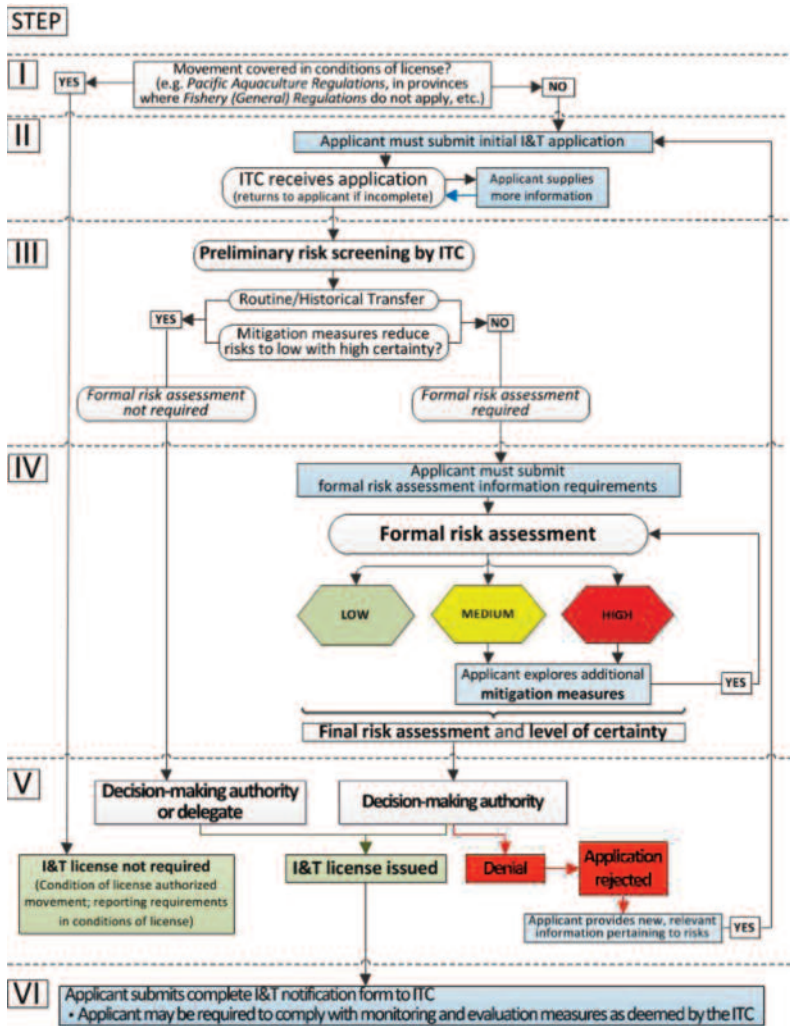


Figure 2: Flow chart illustrating the introduction and transfer (I&T) licensing process

CNL(17)46

The policy relating to hatchery and stocking activities in Wales - managing risks and benefits

Peter Gough, Natural Resources Wales, Monmouth, UK

Summary

In 2013 Natural Resources Wales undertook a review of stocking programmes for Atlantic salmon and sea trout in Wales. We concluded that stocking was inherently risky to wild populations, largely ineffective and did not support new priorities for the sustainable management of natural resources. Stocking programmes were therefore brought to an end in 2014 and the financial resource re-invested in initiatives to restore rivers to higher levels of ecological quality.

Our decision took account of important principles of risk and the Precautionary Approach, as later included in new Welsh legislation, and was intended to protect sustainability and productivity of wild salmon and sea trout stocks in Wales.

This paper and the accompanying presentation set out the background to this transformation.

Introduction

Natural Resources Wales (NRW) is a Welsh Government sponsored body, created in 2013 by merging the roles and responsibilities of three predecessor bodies (Environment Agency Wales, the Countryside Council for Wales and Forestry Commission Wales). Our principal roles are as advisor to Welsh Government on matters relating to the environment and natural resources; regulator of a broad set of environmental permits and licences; statutory consultee to a broad range of planning applications; and management of approximately 7% of Welsh land including waters, forestry estates, national nature reserves and other designated sites.

Our role includes delivery of fisheries statutory objectives and duties on which the following statutory advice from Welsh Government is particularly relevant. NRW is required:

- to ensure the conservation and maintain the diversity of freshwater and migratory fish and conserve their aquatic environment;

- to enhance the contribution migratory and freshwater fisheries make to the economy, particularly in remote rural areas and in areas with low levels of income;
- to enhance the social value of fishing as a widely available and healthy form of recreation;
- to contribute to the aims and objectives for freshwater fisheries management (as described by the Welsh Government's fisheries strategy).

Recent legislation in Wales underpins these roles, and includes the Environment (Wales) Act 2016 that enshrines the principles of the 'Sustainable Management of Natural Resources' (SMNR) throughout the way that we work. Of particular relevance is the need to take account of ecosystem resilience and in particular ecosystem diversity, connectivity, condition and adaptability. The Act requires us to take action 'that promotes the achievement of that objective' and, conversely, not to take action 'that hinders the achievement of that objective'.

Further, the Wellbeing of Future Generations (Wales) Act 2015 requires public bodies in Wales to 'improve social, economic, cultural and environmental well-being in accordance with the principle of sustainable development'.

From this we draw our vision for the management of our salmon and sea trout resources that states:

- fisheries of Wales are iconic and highly valued;
- fish are valued as an important natural resource for Wales and are to be managed within sustainable limits;
- the status of Welsh fisheries is an indicator of the health and resilience of the natural resources of Wales;
- fisheries contribute to viable, vibrant communities in Wales.

Status of salmon stocks in Wales

There are 23 principal salmon rivers in Wales, including 3 rivers that cross the border with England. The performance of our stocks has deteriorated significantly over the past few decades, as it has largely throughout the geographic range of salmon populations. Our most recent assessment is that 20 of our 23 stocks are predicted to be at risk of failing to achieve their management targets in 2021.

Salmon support the designation of 6 Natura 2000 sites in Wales and

the last report in 2013 sets out the status of Atlantic salmon in the United Kingdom as 'Unfavourable-Inadequate', because both population and future prospects were assessed as inadequate, especially in Wales and England. Further recent declines in stocks mean that it is now very likely that we will see further decline in the population and future prospects of salmon, and deterioration in Conservation Status to 'Unfavourable-Bad' in the 2019 reporting cycle. It is therefore important that we explore and implement available management actions to prevent further deterioration and where possible reverse it.

Our management principles and associated decision structure for fishing controls for salmon fisheries require us to urgently achieve zero exploitation for stocks deemed 'At Risk', and to restore stocks to a lower probability of failure within 5 years for stocks deemed 'Probably at Risk' of failing to achieve their management targets.

A brief history of salmon stocking in Welsh rivers

From the early 20th century there are records of salmon stocking programmes in Welsh rivers. With the exception of rivers damaged by the industrial revolution, most stocks were performing well at that time, however as in other countries a general perception appears to have been that rivers could be improved to greater levels of productivity through operation of a catchment hatchery and stocking programme. Additionally, the construction of upland impounding reservoirs often resulted in an off-setting regime in the form of compensatory stocking of salmon (but for no other species).

The interest and support for salmon stocking appears to have been widely popular amongst anglers and fishery owners, who were presumably anxious to undertake management actions to improve their fisheries and to implement what was then good contemporary management action. It is however clear that these initiatives were largely un-informed by:

- any clear and specific objective of a stocking programme;
- the negative impact of removing wild spawners from rivers and the failure to account for this and off-set it;
- any evidence of results, through the wide-scale failure to monitor the outcome of stocking;
- any understanding that there are differences in stocks between rivers that reflect local adaptations to local factors and that there is a need to conserve these;

- any uncertainty that the popular characteristics of one river's stock, e.g. a spring run, could not be created in another by stocking;
- any consideration of the selective pressure of artificial handling, crossing strategies and rearing protocols of juvenile fish;
- any recognition of the comparative performance of wild and hatchery fish.

Although commitment to hatchery programmes varied over the years for a range of reasons, there were still 7 salmon hatchery and stocking programmes in Wales until 2014:

Summary of most recent stocking programmes in Wales

River Catchment	N2K Site?*	Reason for stocking	Approximate number of salmon stocked each year
Dee	Y	Reservoir off-setting programme	100,000 (0+ parr and smolts)
Seiont	N	Local compensation scheme	300 smolts
Mawddach	Y	Pollution response programme	1 'tank full' of fish
Cleddau	Y	Reservoir off-setting programme	15,000 smolts
Tywi	Y	Reservoir off-setting programme	6,000 smolts
Taff	N	River impoundment mitigation and stock restoration	50,000 (0+ parr)
Wye	Y	Reservoir off-setting programme	100,000 (0+parr)

* sites designated under the EC Habitats Directive (Council Directive 92/43/EEC)

Review of stocking programmes

Following the creation of NRW, reviews of certain areas of work were undertaken to ensure that they were delivering value for the environment and the economy. This included a review of operations at the 3 NRW hatcheries and the 7 stocking programmes extant at that time.

The policy reasons for stocking adopted by NRW's predecessor organisation were:

- mitigation stocking, where the reasons for damage could not be reversed;

- stocking as part of a programme of research or investigation;
- stocking for restoration of extinct stocks.

Stocking was not deemed acceptable for enhancing a stock (also known as ranching) beyond the natural carrying capacity of a river system.

The review consisted of three discrete areas:

Legal basis for programme

In the case of 3 of the 7 programmes, NRW has obligations to provide or contribute towards mitigation measures for historic damage to fisheries. However, review of the legal commitment to provide mitigation for lost habitats due to reservoirs revealed that in all cases the requirement for mitigation by stocking was not obligatory. Alternative means of delivering mitigation could, with agreement, be adopted.

Review of practice

Unfortunately, the widespread failure to objectively and effectively monitor outcomes of stocking programmes was generally also the case in Wales. All of the programmes in Wales were small on an international scale, and it was deemed likely that the adult returns generated would also be very small making monitoring difficult, and probably ineffective.

However, it was evident from past programmes intended to restore populations following their extinction in the industrial revolution that stocking could produce adult returns to initiate restoration. This was demonstrated by sparse catch returns but also, on the River Taff, an intensive programme to monitor adult returns.

We concluded that:

- stocking juvenile salmon and, to a lesser extent, sea trout into rivers often yielded adult returns but that success was highly variable, was not guaranteed, and did not off-set risk; and that
- in some cases stocking played an important part in triggering restoration of salmon stocks from extinction.

Review of scientific evidence

The evidence considered by NRW consisted of:

Literature review of published and grey-literature

NRW undertook a comprehensive review of evidence related to stocking of salmon and sea trout. There is a relatively large literature for salmon but little for sea trout, however it was concluded that the principles of stocking of juvenile anadromous salmonids were common for the two species (and probably also for certain species of Pacific salmon).

On-going research, consultations and discussion with research academics

NRW worked in partnership with the University of Swansea on a set of projects to explore the relative fitness of hatchery-reared salmon, and implications for receiving stocks.

Outcome of the Atlantic Salmon Trust conference on salmon stocking held in Glasgow in 2013

NRW attended and debated contemporary evidence for the risk and benefits associated with stocking programmes and noted the subsequent scientific consensus on stocking.

Key points of evidence

All evidence was considered against the overall objective of our review and the new emerging principles of SMNR, risk management and a precautionary approach to environmental management, to each of which NRW is committed. We noted the following matters for concern:

- declines in salmon stocks are evident across all Welsh rivers, whether they have been recently stocked or not. The Cleddau received the highest stocking, on the basis of comparative catchment size, but showed the greatest decline in stock status;
- removing adults from the wild for use as hatchery broodstock reduces the production of wild, fit and adapted juvenile fish;
- selection of mates for crossing in hatcheries generally cannot take account of the natural spawning destination of fish. The artificial crossing decisions result in crosses highly unlikely to have occurred naturally. This over-rides natural mate selection processes, placing at risk factors that preserve and protect genetic variability and adaptations and natural disease resistance;
- the hatchery environment ensures high survival of juveniles, but with minimal and different selection pressures to those of the wild

environment. Research at Swansea University has shown that hatchery fish differ markedly to wild fish in terms of morphology and behaviour and that this reduces their fitness to survive in the wild;

- there is a rapid mortality of hatchery salmon after stocking. Most monitoring also shows that hatchery fish have higher rates of marine mortality than wild fish;
- work at Swansea University has shown that 62% of hatchery pairings in the River Taff programme resulted in no adult returns at all;
- even though the numbers of surviving adults derived from hatchery releases may be low, any subsequent contribution to wild spawning represents a risk to population fitness.

We compared this to the literature for wild salmon where:

- there is a relatively low rate of survival of eggs and early fry life-stages;
- later juvenile life-stages and adults show relatively high survival in comparison;
- natural selective pressures result in fit and adapted individuals;
- this contributes to a high population fitness and resilience.

We also considered what this means for any Habitats Regulations Assessment of stocking plans and projects:

- stocking is not a necessary part of Natura 2000 site management;
- the balance of evidence is that on-going stocking programmes would undermine the aims and objectives of the EC Habitats Directive (or is at best neutral);
- for designated N2K rivers (5 of 7 stocked rivers in Wales), it is not possible to reconcile stocking plans with the required absolute conclusion of 'no adverse effect' on site integrity;
- our overall objective is most important: protect sustainability and productivity of wild salmon and sea trout stocks in Wales.

The consensus of evidence considered was clearly that intervention of artificial stocking programmes introduced risk to the over-riding objectives for wild stock management that are implicit in the philosophy of SMNR.

Public consultation

Following our evidence review, and noting the strong and often polarised opinions and views of those stakeholders who supported stocking as a management tool, NRW elected to launch a formal consultation. This ran for a period of 12 weeks and was intended to seek evidence that might further inform the background to our conclusions. We received 112 responses, 77% of which were from individual anglers and the remainder from organisations including academic institutions and NGOs with interests in rivers, their ecology and angling potential.

Individual anglers who responded generally favoured on-going stocking, whilst other bodies generally supported our conclusions. The most controversial elements were the equivocal nature of the overall evidence-base drawn from studies over the past 40 years or so, and the proposed end to mitigation actions through stocking.

No single study addressed the combined matters of need, benefit, risk and environmental outcomes that we sought to address. Nonetheless it was notable that the more recent studies provide increasingly persuasive evidence of risk to population fitness.

We note that the balance of evidence is increasingly towards recognition that the risks of stocking are incompatible with an approach that seeks to secure the principles of SMNR. We believe that in order to secure our objective of sustainability in our wild stocks of fish, we cannot take the risks associated with intervention by an artificial stocking programme. Instead we should focus on achieving conditions that conserve local adaptations and therefore maximise smolt production and stock resilience.

We support the views supported by many attendees at the 2013 Atlantic Salmon Trust conference on salmon stocking and summarised in a subsequent consensus by Young *et al.*, (2014):

‘Where the integrity of wild salmon is a management priority, stocking hatchery fish into wild populations is unlikely to contribute to management objectives.’

NRW also adopted the logic that, if stocking was not compliant with contemporary management principles underpinning what is referred to as SMNR, then a decision to cease stocking should be applied in all cases.

The position of NRW was that the risks associated with stocking and the potential compromise to the principles of sustainability were

sufficient to confirm our proposals to end stocking. Since that decision, contemporary evidence continues to grow and our conclusion is that this invariably supports our decision to cease potentially damaging hatchery operations and to pursue other alternative more effective management actions.

NRW continues to support the role of salmon stocking as part of any justified research and investigation programme, and will continue to consider it as an option to restore stocks from any catastrophic loss where natural recovery is deemed unlikely.

This view was agreed and the proposal to end stocking was adopted by the NRW Board in October 2014.

Alternative mitigation programmes

The decision to cease stocking was not taken on the basis of cost, although the benefits in relation to costs were considered to be very poor given the perception of environmental risk associated with the programmes.

Nevertheless, in recognising certain enduring obligations to mitigate for damage to fisheries arising from historic impoundment schemes, NRW made the commitment to re-invest financial resources in new river restoration programmes. These schemes, debated and agreed with catchment partners, consist of river restoration projects tackling such matters as migratory barriers and riparian habitat quality.

Overall conclusions

- Our guiding ambition is to secure ‘Sustainable and productive wild salmon and sea trout stocks in Wales’;
- We reviewed stocking programmes and recent and contemporary literature on the benefit and risk of stocking programmes, and took advice from those involved in research in this area;
- We concluded that stocking programmes were often ineffective and represented risk to local adaptations and stock resilience;
- Our public consultation provided no new evidence to support a different conclusion;
- We therefore ceased salmon and sea trout stocking programmes in Wales and will not normally permit any scheme proposed by third-parties;

- Instead we are re-investing our resources in 'Alternative Mitigation' programmes that will deliver broader and more sustainable benefit. This involves:
 - a range of approaches including removing barriers and improving stream habitats;
 - adopting an ecosystem approach, delivering broader environmental benefit under the principles of SMNR.

Reference

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CNL(17)47

The policy relating to hatchery and stocking activities in France - managing risks and benefits

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Introduction

There are approximately thirty salmon rivers in France, some of which are covered by stocking programmes aimed at:

- boosting an existing stock which has fallen below its conservation limit, even restoring a residual stock;
- taking interim measures to ensure protection of the stock until other related management measures have taken full effect.

These measures are financed by the French Government with the support of local and regional authorities. The populations concerned are not yet viable without continued stocking.

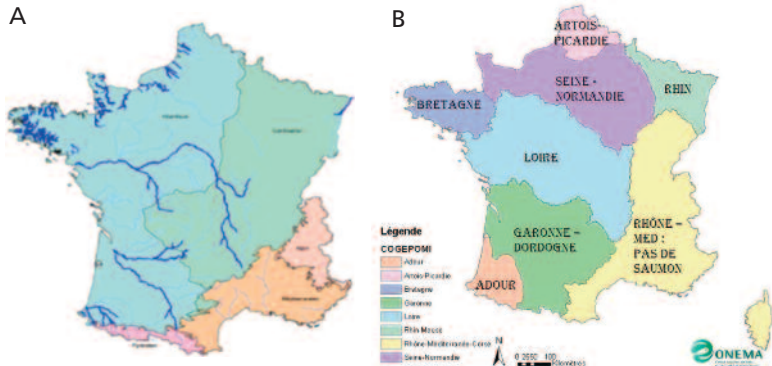


Figure 1: Current distribution of salmon in France (A) and breakdown by river basin (B)

The measures to be implemented are set out in a Migratory Fish Management Plan (*plan de gestion des poissons migrateurs*, PLAGEPOMI) for each major river basin (Figure 1). The plans take into account any measures that can be taken locally to protect anadromous fish species such as salmon. The stocking strategies in question, which complement other management measures, are aimed at sustaining stocks. This means that they may have to be adjusted to take account of any improvement or deterioration in stock levels, and that assessment tools must be developed and implemented.

In line with France's plan for implementing NASCO measures, the programmes comply with the following general principles:

- selecting broodstock that is as representative of local stocks as possible to avoid genetic drift;
- preserving the genetic diversity of the stock;
- ensuring that fish to be used for stocking spend as little time in hatcheries as possible, i.e. stocking-out at early stages;
- ensuring that there is no interaction between hatchery and wild juveniles;
- studying the benefits of stocking;
- not releasing adult fish that cannot contribute to the natural cycle.

Stocking programmes in France (Figure 2)

These include a number of stock support programmes that allow a loss of habitat and/or weak natural production to be compensated. This is the case for the Elorn (Brittany), the Gave d'Oloron (Adour) and the Loire.

Most of the programmes, however, are actual restoration programmes for rivers with very low or no natural production. This is the case for the Aulne (Brittany), the Garonne, the Dordogne, the Gave de Pau (Adour) and the Rhine.

Stock support programmes

In Brittany, following good results in wild juvenile abundance indices, stocking programmes were suspended for the Léguer, the Odet, the Leff and the Thieux between 1995 and 2000. In the Thieux in particular, between 20% and 46% of the adult salmon caught between 1994 and 1998 originated from stocked fry. The Programme is on-going in the Elorn as it is intended to compensate for the filling of the Drennec dam in 1982. The broodstock comes from the Elorn and the juveniles are released as smolts from the Quinquis fish farm. Since 2006, the abundance of young salmon has increased considerably, reaching a peak in 2011. Upstream in the Elorn, the extent to which the available production area is utilised is low.

In the Adour basin, stocking was first carried out in 1970 with imported strains. Since the mid-1990s, only broodstock of local strains have been used in the Gave d'Oloron and its tributaries from the Cauterets fish farm. Today, adult reproduction is mainly observed in the Gave d'Oloron where the stock, although fragile, is considered

viable, and stock support has ceased.

In the Loire, stocking operations began in the 1970s and were reinforced in the early 2000s in line with Government policy, with the creation of the National Conservatory of Wild Salmon which incorporated the Chanteuge fish farm. Adult salmon are of local strain, and in recent years fry have been used rather than smolts. While the stock has not yet reached a sufficient level of autonomy, the stocking contribution to adult returns has been around 40% over the past fifteen years. A model of stock dynamics shows that discontinuing stock support now would not allow the stock to become viable.

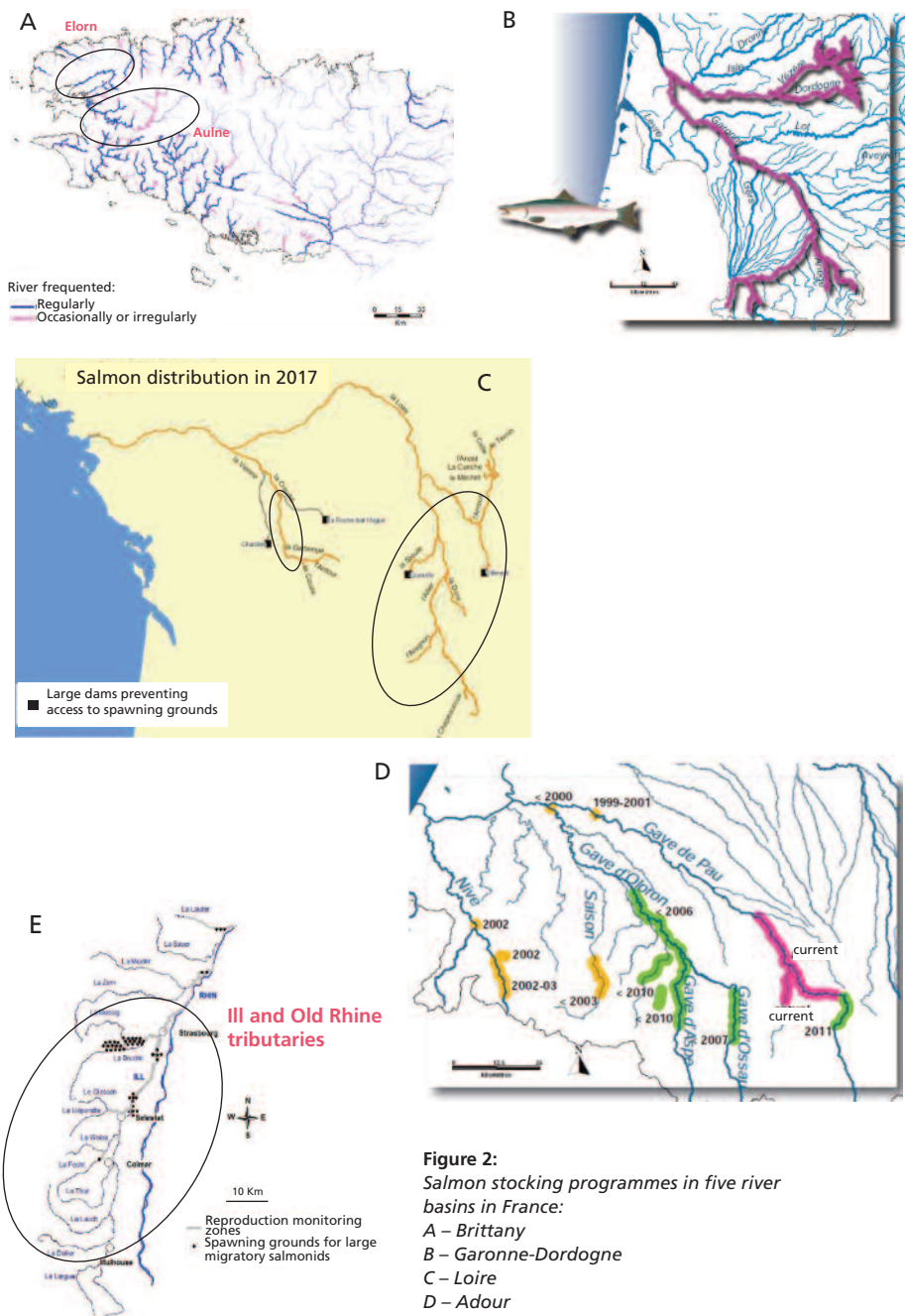
Restoration programmes

In Brittany, a restoration programme for the Aulne was launched in 1984. Adult salmon have been caught in the Aulne basin since 2002, and 200,000 juveniles have been released as parr from the Favot fish farm. The rate of return is low (0.04 - 0.11%). Since 2011, juveniles are being released as smolts to reduce competition for space and food with native fish. Moreover, although releases were doubled from 1984 - 2001 to 2002 - 2011, this has failed to produce higher returns to-date.

The restoration programme for the Garonne and the Dordogne was launched in the 1980s, after salmon had entirely disappeared in the early 20th century. Since 2007 broodstock from local strains have been used for releases at five different stages depending on the habitat at the release-site: 70,000 smolt equivalents in the Dordogne and 50,000 smolt equivalents in the Garonne. Four fish farms are involved: Castel, Bergerac, Pont-Crouzet and Cauteret. The stock is recovering but not yet viable. The return rate is 1%, but the stocking plan needs to be better co-ordinated with other measures.

In the Adour basin there was a shift in 2004 from supporting the Gave d'Oloron stock (80% of releases) to re-introducing salmon in the Gave de Pau (85% of releases). The results were satisfactory with a good adult return and strong homing between the different mountain streams.

In the Rhine basin, stocking has taken place in both Switzerland and France since the 1990s. It has allowed the return each year of around 100 spawners to a few dozen spawning sites in the Upper Rhine. The Allier strain used since 2003 in the Upper Rhine allows MSW fish to be selected, in line with the original stocks (Huningue fish farm).



Following the planned restoration of habitat continuity in the Rhine, the available habitat for this species is expected to increase by 500% by 2020. Stock support is included as an accompanying measure in the strategy for long-term restoration of a self-sustaining stock in the Rhine.

Risk of genetic drift

The impact of stocking rivers with non-native strains has been presented in a study (Perrier, 2010). This was mainly done before the 1990s, but has had the effect of altering the genetic characteristics of the stocks.

In France there are five genetically distinct groups (Figure 3), but due to the use of non-native strains the genetic distance between the groups has diminished. For example, a high degree of introgression can be found in the current salmon stock of the Couesnon, where stocking began in the 1970s.

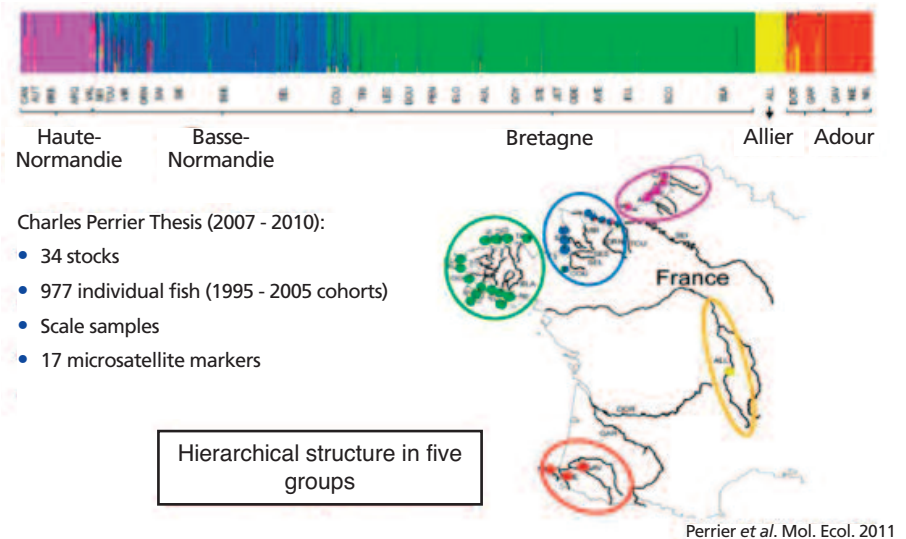


Figure 3: Genetic structure of French Atlantic salmon stocks

Further, as mentioned above for the Aulne, stocking could limit the development of the wild stock as the bigger and more aggressive fish as part of the stocking programme compete for food or living space with native fish (Einum and Fleming, 1997).

The benefits of knowledge

As the risk of genetic drift is now well known, it is essential that co-ordinated management, tailored to each of the large genetic groups identified, is implemented.

All the migratory fish management plans share the following objectives in terms of stock support or recovery:

- any stocking operation is subject to an assessment and approval by the Migratory Fish Management Committee (*Comité de gestion des poissons migrants*, COGEPOMI);
- stocking is prohibited in rivers where the stock is not at risk;
- scientific monitoring of stocking operations must be carried out;
- stocking must be accompanied by measures to help restore habitat continuity;
- all operations must be assessed in the light of how they contribute to the restoration plan.

These guiding principles are in line with the NASCO guidance which recommends that all restoration measures should be planned; stocking should be part of an overall programme; clear objectives should be set; and the results should be monitored in terms of catches, production and impact on wild stocks.

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CNL(17)44

The policy relating to hatchery and stocking activities in Norway - managing risks and benefits

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In 2014, the Norwegian Environment Agency developed new guidelines for stock enhancement for anadromous salmonids in Norway. The guidelines seek to implement new scientific knowledge on the risks and benefits of stock enhancement, taking into account NASCO's Guidelines for Stocking Atlantic Salmon contained in the 'Williamsburg Resolution', CNL(06)48.

Stocking activity in Norway

Stocking of salmon has a long history in Norway. The first hatchery was established in the 1850s. In the years that followed, local landowners and fishermen established many hatcheries to stock yolk-sac fry but, as little or no increase in the salmon stock was evident, most of this activity ended around 1900.

In the 1940s, salmon stocking commenced again with support from the Government. Knowledge of feeding and production of parr, and later smolts, increased in the 1960s and 1970s, and eventually led to more and more stocking of one-year old parr and smolts. The stocking activities increased due to an increasing requirement to compensate for environmental impacts including hydropower developments and acidification. However, stocking was also conducted for other reasons, including to increase production and, consequently, the harvestable surplus.

Improved understanding of the negative effects associated with stocking along with research documenting that stocking had little or no effect on the number of returning fish, contributed to a stricter policy on stocking from the start of the 1980s. In 1992, the Salmon Act introduced a general ban on all stocking, and any stocking that was approved was under permit from the authorities. The new act required that all stocking must use local stock and provide documentary evidence that the broodfish used were free of infectious diseases.

As a result of the new regulations, stocking activity in Norway has decreased drastically since the 1980s. Today, stocking of anadromous

salmonids mainly involves salmon. A review by the Norwegian Scientific Advisory Committee for Atlantic Salmon Management indicated that in the period 2005 - 2009, there were annual releases of approximately eight million stocked salmon, mainly eggs (65%) and juveniles (16%).

Currently, the main reasons for stocking in Norway are to restore populations after rotenone treatment (to eradicate *Gyrodactylus salaris*) or following liming of acidified rivers and these activities account for approximately 4.5 million of the 8 million fish stocked annually. The live gene bank plays an important role in these activities. Mandatory stocking in rivers with hydropower developments involve annual stocking of approximately 2.2 million salmon. This number is decreasing because restoration of habitat and other biotope enhancing measures are replacing mandatory stocking. Voluntary stocking accounts for approximately 1.3 million salmon annually. The new guidelines seek to shift the focus from stock enhancement towards conservation measures and all stocking permits are in the process of being reviewed to see if there are other biotope enhancing measures that could replace stocking.

Why new guidelines?

In 2010, the Norwegian Scientific Advisory Committee for Atlantic Salmon Management presented a review of the knowledge on fish stocking as a measure to conserve and enhance populations (Anon, 2010). This review stated that:

'The international knowledge of fish stocking clearly shows that such measures rarely meet the intended short term goals and have repeatedly been shown to have negative long term effects on the recipient populations. With a few exceptions, releases of fish from hatcheries are thus not an efficient measure to protect threatened wild populations, or to enhance reduced populations. The Committee recommends that stocking of fish should be terminated and replaced with alternative measures wherever possible, and that the quality of the remaining stocking programmes should be evaluated and significantly improved.'

Based on this report, the Norwegian Environment Agency established a Committee to review stocking activities in Norway for anadromous salmonids and to develop recommendations for new guidelines. The recommendations from this Committee provided the scientific basis for the new guidelines (Report in Norwegian: Innstilling fra utvalg om kultivering av anadrom laksefisk, 2011). The previous guidelines from

1998 also included guidelines for stocking of non-migratory brown trout and charr but the 2014 guidelines relate only to stocking anadromous fish.

Legislation and regulations

Several authorities regulate stocking activity. The Norwegian Environment Agency is responsible for three acts that regulate stocking activity: the Pollution Control Act, the Nature Diversity Act and the Salmonids and Freshwater Fish Act. The Norwegian Food Safety Authority and the Norwegian Water Resources and Energy Directorate also regulate hatcheries.

Permission from the environmental authorities (the Norwegian Environment Agency or the County Governor) is needed both to catch broodstock and to release anadromous and freshwater fish in rivers, fjords and the sea. Specific conditions are set for the activity, e.g. the number of broodfish permitted, the number of fish stocked and the site of the release. The guidelines are used as a basis for those conditions.

Stock based management

Norway has 465 rivers with salmon stocks. Each river has one or more distinct population. Analysis of molecular genetic markers has revealed significant population genetic structuring. The stocks are managed on an individual river level and, in some rivers, at the tributary level.

Atlantic salmon stocks in Norway are declining and some stocks are presently not achieving their conservation limits. The reasons for this decline are complex and linked to natural fluctuations and adverse human impacts.

New guidelines

In general, stocking is considered to be a temporary measure and the goal is to secure natural production in all rivers. Nevertheless, there are some exceptions. Stocking undertaken to mitigate the effects of hydropower developments might lead to more permanent stocking measures if natural production cannot be restored. Even so, stocking by hydropower companies is now under review in order to identify alternative measures, such as habitat restoration, that could replace stocking.

The new guidelines seek to implement new scientific knowledge on the risks and benefits of stock enhancement, taking account of

national and international recommendations. The guidelines are founded on conservation biology principles. This implies that the focus should change from stock enhancement towards conservation. To preserve the original population and its genetic variability, measures to remove limits on natural production (like habitat restoration) must be prioritised. Where this is not sufficient to ensure the long-term viability and productivity of the local population, other measures including stock enhancement measures can be considered.

New requirements

The guidelines include specific requirements for stock enhancement activities. Future stocking must be based on an approved plan specific to the river concerned and must contain documentation on the river system, the stock and bottlenecks to natural production. The plan must describe why stock enhancement is necessary and provide a description of the objective for the activity. Importantly, the plan must detail the aims of the activity and a plan for when the stocking will end. All activity undertaken must be documented so the measure can be evaluated.

Another new requirement requires stricter broodfish control to ensure that the genetic variability in the population is maintained. In 2016, the guidelines were supported by publication of a guidebook on how to minimise the negative effects from stocking in terms of the loss of genetic variation and genetic integrity of fish populations (report in Norwegian: Veileder for utsetting av fisk for å ivareta genetisk variasjon og integritet - NINA Rapport 1269). The guidebook provides an introduction to the principles concerning preservation of genetic variation and integrity and practical guidance on conducting stocking.

The guidebook describes:

- how to choose the right broodfish;
- why the relationship between number of broodfish, number of stocked fish, and the size of the natural population is important, and how the right balance between these can be found;
- why and how to conduct crosses of broodfish to gain the maximum positive effect;
- why the life-stage at which fish are being stocked is important; and

- the importance of documenting and evaluating the stocking practice for the development of an optimal strategy in each situation.

Negative effects from stocking can be avoided by following some general rules and guidelines but, in order to minimise possible negative effects and to adjust established stocking practices accordingly, it is necessary to build upon population-specific knowledge.

The use of local broodfish has been required since 1985. If the local stock is lost, a nearby population with comparable traits, or a mix of stocks from local rivers with comparable traits, should be used for re-establishing a population in the river.

Primarily, only wild broodfish should be used, not returning hatchery fish. Only where the natural stock would be negatively affected by collecting wild broodfish may first-generation returned stocked fish be considered as broodfish.

Another important new requirement is a genetic test to exclude escaped farmed salmon or the off-spring of escaped farmed salmon. It is not easy to tell the difference between an escaped farmed fish and a wild fish and, of course, it is almost impossible to identify hybrids of wild/escaped fish. The growth pattern on fish scales can distinguish between wild and farmed salmon. Scales are analysed and categorised into wild salmon, escaped farmed salmon, stocked salmon or uncertain. Broodfish that are categorised as (recently) escaped farmed salmon are not approved for use in stocking, while broodfish-samples that are categorised as wild, stocked or uncertain are sent for genetic testing. As farmed salmon differ genetically from wild salmon, a set of genetic markers (SNPs) is used to exclude the off-spring of farmed salmon as broodfish. This genetic test has been a mandatory requirement for the last three years. The results show that the percentage of broodfish with genes from farmed salmon differs between 0% and 57% between rivers. On average the tests revealed that ~20% of the broodfish are classified as off-spring of farmed salmon (report in Norwegian: Stamlakskontroll 2016. - NINA Rapport 1330).

In general, the use of the earliest life-stages possible is preferable. The river-specific plan is important when deciding the life-stage which is appropriate in the river concerned. The individuals that survive in a hatchery environment are probably not the ones that would survive

under natural conditions. The earlier the fish is stocked into a natural environment, the higher the chance that the genetic variability of the stocked fish will be characterised by natural selection. Stocking of smolts in rivers that have reached their conservation limit/spawning target in order to enhance fishing represents the greatest deviation from natural production. Research shows that maturing fish derived from stocked smolts have a much higher straying rate and thus can have negative impacts on other populations. Such negative impacts may include genetic influences and spread of diseases. Large-scale stocking of smolts in order to enhance a fishery are not consistent with national and international recommendations and contrary to national and international legislation and regulations.

Furthermore, all fish stocked in rivers must be identifiable to facilitate evaluation of the stocking activity. When stocking early stages, alizarin marking (colouring the otolith) or genetic marking (SNPs) are the only options.

Finally, effective health control of the broodfish is important and is regulated by the National Food Safety Authorities.

In summary, the latest scientific evidence suggests that stocking in most cases is ineffective as a tool to improve stock status, and has many possible hazards. It should therefore be used with caution and in general seen as a last resort, rather than a first choice of measure. Even when few or no other options are left, stocking has to be based on scientifically sound principles and practices. Implementing the revised guidelines with the new requirements, aiming to minimise the possible negative effects that stocking might lead to, is therefore an absolute requirement.

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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

Siegfried Darschnik (Der Atlantische Lachs): Stated that there seems to be a black hole on the Rhine, where only 300 adults return from 2.5 million stocked fry. He indicated that any stocking programme should ask where the black hole is, and on the Rhine it clearly occurs during downstream smolt migration. Successful tracking of approximately 200 smolts has shown that 95% - 100% are consumed by cormorants. He noted that there has been no other research into downstream migration over the past 15 years, and no improvement in adult returns, except for a short period when there was some shooting and management of the cormorant population in North Rhine-Westphalia during 2007 - 2010. He noted that if stocking is to be carried out, all parts of the problem must be considered, and the main problem on the Rhine is cormorant predation. He indicated that there are currently no measures in place to address this problem and it is not recognised by the International Commission for the Protection of the Rhine (ICPR) which is the body responsible for stocking the Rhine. He asked if the French authorities were aware of this.

Bénédicte Valadou (European Union - France): Replied that the French authorities are aware of the issue and that she had been present at discussions on this topic at the ICPR. Not all countries have the same goals with regards to this issue and she noted that the French authorities were unable to do anything if other member countries of the ICPR did not want to do more. However, she stated that the other countries have ideas for future work on the Rhine and were considering downstream restoration issues, such as improving passage at the large dams on the Rhine, but indicated that she could not answer on their behalf.

Siegfried Darschnik (Der Atlantische Lachs): Responded that there are hundreds of kilometres of spawning grounds on the lower Rhine which are not affected by dams, but the population has not recovered.

Bénédicte Valadou (European Union - France): Explained that the removal of upstream dams is necessary to support a healthy salmon population, as the spawning grounds are mainly located upstream. France is currently working on this matter with Switzerland, Germany and the Netherlands but it is a long process.

Siegfried Darschnik (Der Atlantische Lachs): Noted that the process has been on-going for twenty years.

Simon Dryden (European Union - UK (Scotland)): Asked if there had been any studies that show that hatchery smolts have impacts in the marine environment, including if hatchery smolts out-compete wild smolts.

Kyle Young (University of Zurich): Replied that he was aware of one old study related to survival, although not specifically competition, which was possibly carried out in Scandinavia. This study measured survival of wild and hatchery smolts and showed that hatchery smolts, which were substantially larger, survived better than wild smolts in years with good ocean conditions. He noted that in general, hatchery fish survival will be lower than wild fish regardless of the life-stage they are stocked at, but where survival is size-based they will have an advantage as they are almost always bigger. There had been similar results with coho salmon in Oregon: when the hatchery smolts are big enough, their ocean survival rates approximate those of wild smolts in high production years. He indicated that measuring competition is difficult in fresh water, and even more so in the ocean.

Paul Knight (Salmon and Trout Conservation UK): Stated that Salmon and Trout Conservation UK strongly supported the work carried out by Natural Resources Wales, but asked how the loss of 50% of spawning area as a result of building a dam can be mitigated without stocking.

Peter Gough (European Union - UK (England and Wales)): Responded that half of the spawning and nursery areas had not been lost due to the construction of the impoundments. He stated that there are other things which can be done in the catchment area to mitigate the effects of lost habitat, which might not be done otherwise. He stated that Natural Resources Wales is re-investing all the money it would have spent on stocking on alternative mitigation measures, such as opening-up other parts of the catchment. This would be a capital investment which would contribute to 'writing-off' the mitigation commitment. Natural Resources Wales is also involved in other schemes such as habitat restoration, which it classifies as revenue projects, and those would continue. He stated that a commitment to continue working is in place and Natural Resources Wales knows there is an obligation to do so. Wherever there are legal mitigation agreements there are always caveats allowing alternatives to be introduced if Natural Resources Wales believe they will be more effective.

Paul Knight (Salmon and Trout Conservation UK): Responded that some would say that those actions should be taken anyway when a dam is constructed and habitat has been lost.

Peter Gough (European Union - UK (England and Wales)): Replied that there are some things which would be done anyway, typically under the Water Framework Directive, but there are also plenty of schemes which would fail the Cost-Benefit Assessment for Water Framework Directive projects and so would otherwise not be done. Natural Resources Wales is currently mapping and quantifying these and has no doubt that they can deliver an alternative package of mitigation through opening-up and improving habitat.

Bud Bird (Canada): Referred to a major smolt-to-adult supplementation (SAS) programme that is being implemented in New Brunswick and asked what happens to a smolt that has never been to sea and experienced the transition to saltwater and which is subsequently released as an adult under an SAS programme. He asked if this would make it a different animal.

Dylan Fraser (Concordia University): Replied that the simple answer is probably yes, it is a different animal, but there is still a lot of uncertainty as to how much change is elicited in a smolt that is not exposed to marine conditions. He indicated that his concern is that, as many factors affect smolts at sea and during the transition to marine waters, changes are probably being induced inadvertently as SAS smolts do not go through these experiences.

Kyle Young (University of Zurich): Noted that as far as the evolutionary impact of relaxed selection and artificial selection that is inevitable in any rearing programme is concerned, SAS is probably less damaging than traditional hatcheries. The strength of freshwater selection is severe: 10% of adults produce 90% of smolts. By letting that occur the weakest fish are culled. If ocean survival is 1% or 2%, a female producing 5,000 eggs needs 100 smolts to replace the population. When marine survival is 1% or 2%, that is still much better than freshwater survival. The principal selective events in salmon life-history occur in the river so letting that happen naturally might be less damaging than letting mortality in the ocean occur naturally.

Erika Axelsson (European Union - Sweden): Asked whether stocking should occur in a threatened population in a small river and how to estimate whether a population is threatened. She asked if there are specific plans in place for each river.

Doug Bliss (Canada): Replied that in Canada there is a National Committee that assesses the risk-level of both terrestrial and aquatic species. There is a very good scientific review process and, in the case of salmon, the Committee considers all the information for each stock. Then, following prescribed criteria, the Committee will determine the level of risk of extinction or extirpation using a graduated scale including Endangered, Threatened and Special Concern categories. At that point, Regulatory Measures under the 'Species at Risk Act' can be implemented in some cases. Even where that does not occur, if the stock is assigned to one of the worst two categories (Endangered or Threatened), further details would be assessed and the Committee would determine recovery targets and what needs to be done to reach those recovery targets.

Erika Axelsson (European Union - Sweden): Asked if this was done at the federal level.

Doug Bliss (Canada): Replied that both federal and provincial governments are often involved and there is almost always some form of partnership.

Ian Russell (European Union - UK (England and Wales)): Referred to the 'horror' and 'hostility' from those who support stocking that had been referred to in the presentations and asked if in Wales this had diminished now that stocking has been stopped.

Peter Gough (European Union - UK (England and Wales)): Replied that it had diminished. He stated that after the review referred to in his presentation, National Resources Wales carried out a public consultation and received just over 100 responses. Approximately two thirds of those were from individual anglers. Overall, about 25% were supportive of the proposal to end stocking. Those who opposed the proposal were very energetic and passionate and had complained both to the Government and the EU. He stated that he felt that they simply did not like being told what they could and could not do rather than being opposed to the ending of stocking. The number of people who were frustrated at the decision has declined considerably and there is probably less than half a dozen of them now.

Paul Knight (Salmon and Trout Conservation UK): Noted that there was a similar issue with regards to trout fisheries in England and Wales about twenty years ago. People were openly hostile to no longer being able to stock, or having to stock triploid fish in order to prevent introgression. Now that has changed drastically and in the

last ten years fishing clubs and riparian owners are much more eager to have wild trout fisheries and that might well be replicated in the salmon world although it might take longer. He stated that he felt it might be like catch and release fishing and that anglers will eventually accept it and, perhaps in another generation's time, it will be generally accepted.

Peter Gough (European Union - UK (England and Wales)): Agreed that this had also been the case in Wales with regards to brown trout stocking. He stated that people go through the classic phases of denial and anger etc. and then arrive at opportunity. He said that for some people, this is changing the nature of Fisheries Management and they will not like it in the beginning.

Paul Knight (Salmon and Trout Conservation UK): Referred to Kyle Young's presentation and the proposal for a new approach to stocking and asked for feedback on this from a scientific and policy perspective.

Alan McNeill (Canada): Stated that he thought Kyle Young had an interesting concept, but that it would break one of the Canadian tenets in that each river has a distinct population and introducing an alternative population would compromise the genetic integrity of the recipient river. He asked how that could be reconciled.

Kyle Young (University of Zurich): Replied that population genetic structure in Atlantic salmon is undeniable. That is why it is necessary to find the nearest 'doomed majority', whether that is in a gravelly reach 3km away or in an adjacent tributary or further. If there is no spawning 'hot spot' in the entire basin, there are essentially no salmon and the next nearest basin should be considered. He stated that a good rule for knowing when to stock is that if there are enough fish to initiate a wild broodstock programme, stocking should not take place. If it is possible to take 50 adults from a population for a broodstock programme that population does not need stocking. However, he noted that the nearest population may not always be the best. For example, in southern England there are two rivers which are 5km apart in an area where there is a very clear change in geology. Those two rivers have a very high F_{st} and will be much more closely related to basins further away in either direction. There is a need to pay attention to the geology but the nearest spawning 'hot spot' is just that.

Cathal Gallagher (European Union - Ireland): Stated that Inland Fisheries Ireland found Kyle Young's idea to be a very interesting

concept from a number of angles. He indicated that there have been many genetic-type garden experiments introducing genetic progeny from different areas into catchments. IFI is concerned about what is shown in some of the graphs and the potential impacts. Therefore, the possibility of using one of the Irish index catchments, the National Salmonid Index Catchment, to conduct a practical experiment of this approach has been discussed. The river in question has both a smolt trap and an adult trap and could be used for a practical experiment that might assist. He noted that it is very early, but it is certainly something IFI would like to consider. Should it prove successful it could be considered in future policy.

Kyle Young (University of Zurich): Noted that the rivers Mr Gallagher referred to were the right kind of river for the experiments: small, with a few decades of adult return and smolt escapement data, along with annual electrofishing data throughout the catchment. Therefore, the number of adults coming in and the number of smolts going out are known and the fry distribution and densities throughout the catchment are also known. He added that spawning surveys would provide further information on where the redds are located. Using this baseline data, five 'hot spots' and five 'cold spots' can be chosen as a treatment group and another five 'hot spots' and 'cold spots' as a control group. Emerging fry can then be moved for 10 years and the adult:smolt relationship of the corresponding cohorts can be established. This will show whether there has been any improvement in the treatment group over the control group. He reiterated that it cannot be worse than at present.

Steve Gephard (USA): Stated that he could not argue with the logic of Kyle Young's concept, but suggested that the logistics involved may have been underestimated, especially when focusing on emerging fry. He noted that it is very difficult to electrofish for emerging fry in US rivers, especially in small rivers at the time of year when the fry are emerging, and that netting them without damaging them would also be difficult. Therefore, while he is intrigued by the possibility, he feels that it would be extremely challenging to carry out.

Kyle Young (University of Zurich): Replied that it was important to pick the right river, which would not be an extremely peaty, low-conductivity river. The river should ideally have baseline data, and the electrofishing should not be carried out on high-flow days. This should allow the fry to be caught quickly. He indicated that there will be constraints on where the electrofishing can be carried out, and it may not be possible to move as many fish as could be reared in a

hatchery. However, if the labour costs and the costs involved in running a hatchery building are taken into account, his concept should require much less time and money.

Steve Gephard (USA): Noted that the fish are caught in a trap in a fish-way, but he agreed that Kyle Young's approach would cost less. However, the fry must arrive in the 'cold spots' alive and in good condition or there will be no benefit. He stated that with regards to the idea that it cannot be any worse than at present, it would be necessary to know how many fry were in the donor area. If 8,000 fry are taken from an area with 10,000 fry, and most died before arriving at the recipient area, harm is being done to the source area.

Kyle Young (University of Zurich): Agreed that the situation described by Steve Gephard is conceivable, but it would not be a sensible way to proceed.

Paul Knight (Salmon and Trout Conservation UK): Asked why fry would be killed when, in a hatchery situation, the fish are also put in a bucket and transported in a vehicle.

Steve Gephard (USA): Advised that emerging fry are found in gravelly streams, which poses a risk when netting them. He also stated that there are risks involved in electrofishing for emerging fry so there is a risk that some may be killed.

Kyle Young (University of Zurich): Agreed but noted that this would not involve intense electrofishing such as when carrying out population estimates. In this situation, the idea is not to catch all of them. He suggested that if 15 fry appear, 5 could be collected and then another spot could be targeted.

Dennis Ensing (European Union - UK (Northern Ireland)): Stated that as an evolutionary geneticist he was delighted that evolutionary theory was being discussed and could form the basis of Atlantic salmon management policy in a practical way. He indicated that the Agri-Food and Biosciences Institute in Northern Ireland might be interested in applying Kyle Young's idea as a pilot in an index river in Northern Ireland. The river in question is a small spate stream in Antrim, with limited spawning in the lower reaches. There is a lot of nursery habitat upstream but with no corresponding spawning habitat. It has a fish counter and 25 - 30 sites where electrofishing has been carried out for the last 25 years. He also noted that he has chaired the ICES Working Group on Effectiveness of Recovery Actions for Atlantic salmon for the last four years. This Group has developed

a database of enhancement and recovery actions carried out on most of the rivers in the NASCO Rivers Database. A striking finding was that in about 20% of the cases where stocking had been conducted, the rivers were regularly attaining their conservation limits. He questioned why this stocking was being conducted and why there was an addiction to stocking and suggested that radical change is needed and that this knee-jerk reaction without knowledge of population size needed to end.

Gérald Chaput (Canada): Noted that all the speakers, and the NASCO Williamsburg Resolution, make reference to the importance of using wild broodstock, yet Kyle Young's presentation indicated that this is the worst thing that can be done. He asked Dylan Fraser if he agreed with Kyle Young regarding the potential damage caused by using first-generation wild broodstock and, if so, should we be re-thinking collecting wild broodstock every year?

Dylan Fraser (Concordia University): Replied that it depends on the conditions and the goals of the hatchery programme. If the goal is to salvage a wild population, that is a different situation to hatchery production for increasing harvest. If the latter, the use of local wild broodstock is not of such concern. The risks of stocking a fish that is very different, and hatchery-orientated, need to be traded-off against using wild fish to supplement a wild population.

Gérald Chaput (Canada): Asked if Kyle Young could also respond as it was the first time he had heard of this and every country has the same principle of using wild broodstock and reducing the number of generations in the hatchery. He suggested that this approach might need to be re-considered.

Kyle Young (University of Zurich): Agreed with Dylan Fraser. He referred to an example of hatchery and wild winter Steelhead co-existing in the Pacific Northwest with very little inter-breeding. When the hatcheries were set up, a determined amount of eggs was collected when the Steelhead arrived. The hatchery Steelhead fishery on the Oregon coast runs from November until the end of December and the wild fish arrive in mid-January. The phenotypes of the hatchery fish are so maladapted that they arrive too early, spawn too early and their eggs are washed out before the wild fish arrive. This is an example of a hatchery population on the extreme right of the 'threat-o-gram' semi co-existing with a wild population. He stated that when faced with a desperate situation such as the choice between 10 well-adapted fish or 1,000 maladapted fish, the

population may benefit from a generation or two of maladapted fish, although his preference would be first to find where those 10 well-adapted fish are spawning and transport their emerging fry. He indicated that he was shocked when he created the 'threat-o-gram' in Excel and saw the projections. The orange curve shown in the presentation is empirical. The fitness of first-generation hatchery fish is 60% of that of their wild counter-parts. He stated that it is a dramatic and fast change and that it was not known that evolution could be so rapid in the 1970s when the first warnings of the potential genetic damage caused by stocking hatchery fish were made by Reisenbichler and McIntyre.

Conclusions of the Steering Committee



Conclusions of the Steering Committee

Background

Abundance of salmon around the North Atlantic is low and in some southern parts of the range salmon stocks are endangered. The scientific advice from ICES, CNL(17)8, states as follows:

North-East Atlantic Commission area: despite management measures aimed at reducing exploitation in recent years, there has been little improvement in the status of stocks over time. This is mainly a consequence of continuing poor survival in the marine environment.

North American Commission area: the continued low abundance of salmon stocks in USA and in three regions of Canada (Scotia-Fundy, Gulf, and Québec), despite significant fishery reductions and generally sustained smolt production, strengthens the conclusions that factors acting on survival in the first and second years at sea are constraining the abundance of Atlantic salmon. All salmon populations within USA and the Scotia-Fundy regions have been, or are being considered for, listing under the country-specific species-at-risk legislation.

In these circumstances of low abundance, with many stocks failing to achieve their conservation limits and some stocks, particularly in the southern part of the range, threatened with extinction, there has been increasing interest in actions to mitigate for the reduced abundance, including the use of stocking activities. However, at the 2011 ICES/NASCO Salmon Summit, it was recognised that the risks as well as the benefits associated with stocking need to be considered before considering such actions. Furthermore, the Salmon Summit noted that managing salmon in the face of the uncertainty about future environmental changes will be challenging and the goal should be to protect the genetic diversity of wild Atlantic salmon in order to maximise their potential to adapt to the changing environment.

NASCO's International Guidelines for Stocking and Stock Rebuilding

Many agencies and organisations have developed guidance on stocking. It was noted that this falls into three broad categories:

- guidance aimed at minimising impacts by keeping hatchery and wild fish apart through physical (weirs and traps) and behavioural (release and spawning times/places) methods, with all hatchery fish marked so they can be separated from wild fish;
- guidance aimed at minimising impacts through recommendations

relating to selection of broodstock, broodstock protocols, rearing conditions and stocking methods; and

- guidance limiting stocking to habitable areas that are vacant in order to increase inter-population migration rates.

In 2003, NASCO adopted 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'. The Williamsburg Resolution contains Guidelines for Stocking Atlantic Salmon (Annex 4 of the Resolution) which fall into the second of the three categories referred to above. The Williamsburg Resolution recognises the threats to wild stocks from the activities covered by the Resolution and requires that NASCO Parties should minimise adverse genetic and other biological interactions from salmon enhancement activities and minimise the risk of disease and parasite transmission.

The Guidelines for Stocking Atlantic Salmon note that stocking can have negative impacts on wild salmon populations and that poor hatchery practices may negatively impact the characteristics of the wild salmon populations which the programme seeks to conserve. There is, therefore, a need to consider fully the risks and benefits arising from stocking. The Guidelines note that there are many possible causes of decline of salmon populations and that stocking may not be an appropriate solution.

The Guidelines are intended to assist NASCO's Parties/jurisdictions in applying the Precautionary Approach to the authorisation and conduct of any stocking of Atlantic salmon in the wild. In accordance with the Precautionary Approach, appropriate risk assessment methodology should be developed and applied by the Parties to proposals for stocking. Proponents must provide all information necessary to demonstrate that a proposed stocking activity will not have a significant adverse impact on wild salmon populations or have an unacceptable impact on the ecosystem. The Guidelines define three classes of river based on the extent to which the salmon populations and their habitats have been affected by human activities. Some guidance applies to all river classes (including hatchery rearing protocols, health inspections prior to transfers, and a prohibition on releasing European origin salmon in the North American Commission area and North American origin salmon in the North-East Atlantic Commission area), while other guidance relates to

each class of river with the most restrictive guidance applying to Class I (pristine) rivers. In general, no Atlantic salmon reared in a fish culture facility are to be released into a Class I river, but stocking is permitted in Class II and III rivers provided that fish health and genetic protocols are followed and risk assessments indicate that negative impacts on local populations will be minimal. The Guidelines state that they should be regularly reviewed and updated as appropriate in the light of new scientific information. This has not happened to date and one of the purposes of the Theme-based Special Session was to allow for consideration of new information relating to impacts of stocking that has become available since the Guidelines were adopted in 2004.

NASCO has recommended that Stock Rebuilding Programmes be developed for all stocks that are failing to exceed their conservation limits (CLs) and has developed Guidelines on the Use of Stock Rebuilding Programmes in the Context of the Precautionary Management of Salmon Stocks, CNL(04)55, hereinafter the 'SRP Guidelines'. The SRP Guidelines note that a Stock Rebuilding Programme is an array of management measures, possibly including habitat restoration/improvement, exploitation control and stocking, which is designed to restore a stock above its CL. It notes that the nature and extent of the programme will depend upon the status of the stock and the pressures that it is facing and that there is a need to evaluate and address the causes of the stock decline. In evaluating the status of a stock, the SRP Guidelines state that management decisions on the nature and extent of the SRP should be influenced by a range of factors including: uncertainty in assessments, nature of the CL failure (both duration and degree); recent stock status history; and stock diversity. Proposals for remedial measures should be developed based on a full assessment of the pressures faced by the stock and stakeholders should be involved in the development of the Stock Rebuilding Programme. Management actions may include environmental management or fishery management and the establishment of gene banks in the event that the stock declines to critically low levels. Research may be needed if there is insufficient information on the nature of the problems. The SRP Guidelines note that when stocks are seriously depleted, and full recovery is likely to take several generations, there may be a need to develop a staged approach to the recovery programme and to adopt certain interim measures. These measures could include stocking to circumvent particular bottlenecks, although the SRP Guidelines indicate that other actions should be taken to address the cause of the decline.

The SRP Guidelines also stress the importance of monitoring and evaluating progress of any Stock Rebuilding Programme.

National and regional stocking policies

The presentations during the Theme-based Special Session provided examples of some national policies related to stocking of Atlantic salmon in different Parties/jurisdictions.

Canada

In eastern Canada, between the late 1860s and the 1990s, enhancement facilities were used to augment production of salmon to enhance economic returns in commercial and recreational fisheries. Fisheries and Oceans Canada ended these practices in the 1990s and now only has two facilities on the east coast of Canada focussed on maintaining genetic diversity within endangered or threatened Atlantic salmon populations. The private sector, provincial governments and Aboriginal organisations are still engaged in stocking. While there is no federal policy guiding stocking, some provincial governments have developed policies that guide activities and all stocking activities are reviewed by defined oversight committees and are authorised under the relevant acts and regulations. Stocking and hatchery interventions in eastern Canada are undertaken for three reasons: to conserve biodiversity of populations at high risk of extinction; to mitigate or compensate for habitat degradation or loss; and to support fisheries. A smolt-to-captive-reared adult supplementation programme in the Northwest Miramichi River has been proposed by a group of NGOs and smolts were collected in 2015 and 2016, but regulatory decisions on authorising further collections of smolts and the release of captive-reared adults are pending.

With few exceptions, stocking of Atlantic salmon in eastern Canada is consistent with NASCO's guidelines other than with regard to the recommended number of broodstock, which is not always followed due to the small-scale nature of many of the stocking programmes. Except in Québec, permission is required under the Fisheries Act or Fisheries (General) Regulations to obtain wild fish for stocking or artificial breeding programmes and for releasing Atlantic salmon (eggs, larvae or fish). Québec has its own regulations which govern the capture and the release of live fish in stocking programmes. In Canada, issuing of licences is managed through an Introductions and Transfers Committee which is required to consider three key provisions:

- is the request in keeping with the proper management and control of fisheries;
- do the fish have any disease or disease agent(s) that may be harmful to the protection and conservation of fish; and
- will the introduction or transfer have an adverse effect on local fish stock size or genetic characteristics of fish.

Wales

Records of stocking rivers in Wales date back to the early twentieth century. With the exception of rivers damaged by the Industrial Revolution, most stocks were performing well at that time but, as in other countries, there was a perception that rivers could be improved to higher levels of productivity through stocking, which was supported by anglers and fishery proprietors. However, these initiatives were largely un-informed by: any clear and specific objectives; the negative impact of removing spawners; monitoring to assess the benefits of the initiative; an appreciation of the differences in stocks between rivers; recognition of the comparative performance of wild and hatchery-reared fish; and consideration of the selective pressure of rearing fish. In 2013, Natural Resources Wales conducted a review of stocking Atlantic salmon and sea trout which included the legal basis for mitigation stocking programmes, a review of practice and a review of the scientific evidence. It was concluded that stocking inherently posed risks to wild populations, was largely ineffective and did not support the priorities for the sustainable management of natural resources. Following public consultations stocking programmes were ended in 2014, although Natural Resources Wales will continue to consider it as an option to restore stocks from any catastrophic loss where natural recovery is deemed unlikely. The financial resources which were previously invested in stocking programmes are now re-invested in initiatives to restore rivers to higher levels of ecological quality. Although there was initial opposition to the proposal to end stocking, particularly from individual anglers, the decision has now largely been accepted.

France

In France, a Migratory Fish Management Plan has been developed for each major river basin. Consistent with NASCO guidance, stocking programmes must comply with the following principles: selection of broodstock representative of the local stocks; preserving the genetic diversity of the stock; minimising the time spent in the hatchery by

stocking early life-stages; monitoring the outcome of stocking; and not releasing adult fish. The Migratory Fish Management Plans stipulate that: any stocking activity must be subject to an assessment and grant approval; stocking should only be carried out where the wild population is at risk; scientific monitoring of the stocking programme must be undertaken including how stocking is contributing to the overall restoration plan; and any stocking must be accompanied by habitat restoration measures. Currently, stocking is carried out in five areas/river basins in France: Brittany rivers, the Garonne-Dordogne, the Loire, the Adour and the Rhine. Stocking is carried out to mitigate for a loss of habitat and/or weak natural production, or as part of a restoration programme for rivers with very low or no natural production and can be used as an interim measure to ensure protection of a stock until other measures have taken effect. In the past, imported strains were used and this has resulted in genetic introgression. Local strains are now used, wherever possible, although the Multi-Sea-Winter River Allier (Loire) strain is still used in the Rhine since the original Multi-Sea-Winter salmon stock has been lost. Stocking is carried out at the earliest life-stage possible; this ranges from fry to smolts in different rivers (no adult fish are released).

Norway

The first hatchery was established in Norway in the 1850s. Improved understanding of the limited benefits of stocking, in terms of the number of returning fish, and of the negative effects on the wild stocks resulted in the development of a stricter policy on stocking in the 1980s and subsequently, under the 1992 Salmon Act, a general ban on all stocking unless approved under a permit issued by the authorities. The new act required that all stocking must use local stock and provide documentary evidence that the broodfish used were free of infectious diseases. Currently, the main reasons for stocking in Norway are to restore populations after rotenone treatment (used to eradicate *Gyrodactylus salaris*) or following liming of acidified rivers. These activities account for approximately 4.5 million of the 8 million fish stocked annually and a live gene bank facility plays an important role in these programmes. Mandatory stocking in rivers with hydropower developments (statutory mitigation requirements) involves annual stocking of approximately 2.2 million salmon annually, but restoration of habitat and other biotope enhancements are replacing mandatory stocking, so the number of stocked fish is declining. Voluntary stocking accounts for

about 1.3 million salmon annually. In 2014, new guidelines for stocking were developed by the Norwegian Environment Agency to take account of the risks and benefits of stocking and NASCO's guidelines. These new guidelines seek to shift the focus from stock enhancement towards conservation measures and all stocking permits are in the process of being reviewed to see if there are other biotope enhancing measures that could replace stocking. The new guidelines introduce specific requirements for stock enhancement activities. Future stocking must be based on an approved plan specific to the river concerned and must contain documentation on the river system, the stock and identified bottlenecks to natural production. The plan must describe why stock enhancement is necessary and provide a description of the objective for the activity. Importantly, the plan must detail the aims of the activity and a plan for when the stocking will end. All activity undertaken must be documented so the measure can be evaluated. Another new requirement requires stricter broodfish control to ensure the genetic variability in the population is maintained. The use of local broodfish has been required since 1985 but, if the local stock has been lost, a nearby population with comparable traits or a mix of stocks from local rivers with comparable traits should be used for re-establishing a population in the river. Primarily, only wild broodfish should be used and not returning adult fish of hatchery origin. Only where the natural stock would be negatively affected by collecting wild broodfish may first generation returned stocked fish be considered as broodfish. Another important new requirement is a genetic test to enable escaped farmed salmon, or the off-spring of escaped farmed salmon, to be excluded from any broodstock. In general, stocking fish at the earliest life-stages possible is considered preferable. Further, all fish stocked in rivers must be identifiable to facilitate evaluation of the stocking activity. When stocking early stages, alizarin marking (colouring the otolith) or genetic marking (SNPs) are the only options. In summary, the position in Norway is that given the latest scientific evidence, which suggests that stocking in most cases is ineffective and has many possible risks, stocking should be used with caution and in general be regarded as a last resort.

Scientific considerations

Stocking of salmon has been undertaken for more than a century. The first compelling evidence that stocking hatchery-reared fish poses a threat to wild salmonids was published in 1977. Since that publication, further research has led to an evidence-based consensus

that, if the integrity of wild salmon is a management priority, stocking of hatchery fish should be avoided. A number of suggestions were made as to why stocking continues including: the large investments that have been made in hatcheries; hatcheries can engage and inspire; and, despite the scientific evidence, there is still a belief that individual stocking programmes that are well-planned will make a positive difference.

The ICES Working Group on the Effectiveness of Recovery Actions for Atlantic Salmon (WGERAAS, see CNL(17)8), recently undertook an analysis of 15 case studies and a total of 568 individual river stocks which had been included in a Database on Effectiveness of Recovery Actions for Atlantic Salmon (DBERAAS). Successful restoration and rehabilitation was characterised by: a limited number of stressors acting on the population; successfully addressing all stressors acting on the population; and a river stock with moderate to high marine survival estimates. Based on the analysis of 'Stressor' entries identified in the DBERAAS the following stressors were most often reported as having a high or very high impact: climate change; barriers; and freshwater habitat degradation. Similarly, based on the analysis of 'Action' entries identified in the DBERAAS, the following recovery and restoration actions were most often reported as having a high or very high benefit: improvements in connectivity; improvements in freshwater quality; and freshwater habitat restoration.

At the Theme-based Special Session, it was suggested that stocking should be restricted to where and when there are no wild salmon or where and when the integrity of wild salmon is not a management priority. Additionally, stocking may be appropriate when there is a wild salmon population that is at immediate risk of extirpation (as determined using Population Viability Analysis), there is no directed harvest, it does not receive immigrants from other populations and ecological restoration is, and will continue to be, undertaken. When the wild population does not meet the conditions above, it was suggested that stocking should not occur. In short, the view was expressed that if there are enough returning adults to establish a broodstock then stocking should not occur.

New approaches

Two new approaches to stocking were described. The marine environment for Atlantic salmon has changed, with impacts felt particularly at the southern part of the species' range. There has been

a dramatic decline in smolt-to-adult survival. This has given rise to the idea of smolt-to-adult captive-reared supplementation (SAS). It has been suggested that this has potential advantages over juvenile supplementation for mitigating population declines including: providing a predictable input to adult population size; avoiding well-documented genetic risks to captive-rearing at early life stages; and maintaining free mate choice in the wild. However, SAS is not without risks or uncertainties since it may reduce marine adaptation (or adaptation to freshwater-marine linkages) through unintentional or relaxed selection and cause negative carry-over effects on wild fitness. A key consideration is that possible maladaptation generated from SAS in the form of changes to wild phenotypic trait distributions should be minimised as much as possible. A balancing act also exists between the number of wild smolts required for SAS to be effective, the proportion of SAS adults released relative to wild adults and maintaining at-risk wild populations. Several SAS programmes have been initiated on endangered salmon populations at high risk of extirpation in North America, but the full results of these long-term experimental studies are awaiting final results.

The second approach concerned the possible re-distribution of wild fry. Capturing, transporting and stocking wild salmon fry was proposed as a way of avoiding the demographical inefficiencies and evolutionary damaging effects of stocking hatchery-reared off-spring. The rationale for this approach is that adult spawners tend not to be evenly distributed, emergent fry do not move far from their natal site and resulting competition results in very high levels of mortality. Thus, emergent fry could be moved from high-density source areas to target low-density areas that might otherwise have been stocked with hatchery-origin fish. It was proposed that the choice of source area should be informed by matching environmental variables and phenotypic traits and that fry should be collected from multiple sites throughout the emergence period to avoid selection. This approach, although it has not yet been tested, may be less expensive and simpler than stocking hatchery fish.

Concluding remarks

The current period of low abundance has resulted in increasing interest in rebuilding actions for Atlantic salmon, including the potential for stocking. However, as recognised in NASCO's Guidelines for Stocking Atlantic Salmon, there are risks and benefits associated with such interventions and understanding of these has increased since their development in 2004. There has been a recognition of this

in national/regional policy. Stocking programmes, including mitigation programmes, have been discontinued in Wales. Fisheries and Oceans Canada no longer operates enhancement facilities, but maintains two facilities aimed at maintaining genetic diversity of salmon populations at high risk of extirpation. In Norway, stocking is mainly conducted to restore populations after rotenone treatment (to eradicate *Gyrodactylus salaris*) or following liming of acidified rivers and alternatives to mitigation stocking in relation to hydropower developments are being sought. In France, stocking is only used where stocks are considered to be at risk. It is clear from the findings of the ICES Working Group on the Effectiveness of Recovery Actions for Atlantic Salmon that improvements in connectivity and freshwater quality and freshwater habitat restoration were most often reported as having a high or very high benefit to the recovery of salmon populations, so much can be achieved to rebuild stocks without the need for stocking. While hatchery programmes and stocking may have a role to play in kick-starting the restoration of stocks in rivers where they have been lost or where the stocks are at critically low levels, it was suggested that much stocking continues for socio-political reasons irrespective of the risks associated with such activities and without evidence of benefits.

Given the substantial information presented at the Theme-based Special Session, the Steering Committee believes that if the genetic integrity of wild salmon is a management priority, stocking of hatchery fish should only be contemplated after careful evaluation of the risks and benefits and only after other alternatives have been considered. There should be a strong presumption against stocking for socio-political reasons and the use of tools such as Population Viability Analysis should be used to inform decisions to stock where wild populations are considered to be at risk of extirpation, and then as an interim measure while other rebuilding efforts are being implemented.

New approaches to stocking have been proposed which could offer benefits while avoiding the risks associated with current juvenile stocking hatchery operations, but they need to be further evaluated. These are challenging times for the Atlantic salmon, not least because of the uncertainty associated with a changing climate. ICES advises that environmental and genetic adaptation can facilitate adjustment to changing environmental conditions if the rate of change in the environmental conditions does not exceed the capacity of the organism for genetic adaptation. Maintaining the genetic diversity

present in the wild stocks is therefore vital and stocking programmes need to be carefully considered with that in mind. The Steering Committee recommends that the Council may wish to consider the need for revisions to its Guidelines for Stocking Atlantic Salmon and options for improving exchange of information among Parties on the effectiveness of stocking programmes. In the interim, NASCO's SRP Guidelines should continue to inform decisions relating to the initiation and conduct of stock rebuilding initiatives.

