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Report of the Working Group on Effectiveness of Recovery Actions for Atlantic Salmon (WGERAAS)

9–13 November 2015

ICES Headquarters, Copenhagen, Denmark

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International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

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Executive summary

The Working Group on Effectiveness of Recovery Actions for Atlantic Salmon (WGERAAS) was established in 2012 in response to a question to ICES Working Group on North Atlantic Salmon (WGNAS) by the North Atlantic Salmon Conservation Organisation (NASCO). The NASCO question resulted in a new ToR for WGNAS: "provide a review of examples of successes and failures in wild salmon restoration and rehabilitation and develop a classification of activities which could be recommended under various conditions or threats to the persistence of populations".

WGERAAS met on 18–22 February 2013 in Belfast, Northern Ireland; 12–16 May 2014 at ICES HQ, Copenhagen, Denmark; and on 10–12 November 2015 for a third and final time at that same location.

At the 2013 meeting the Working Group decided that the development of a 'classification system' for rebuilding and recovery actions for Atlantic salmon (ToR a) would be best achieved by the development of a river-specific database; 'Database on Effectiveness of Recovery Actions for Atlantic Salmon' (DBERAAS). Local experts provided a range-wide overview of conservation status, programme goals, population stressors and the benefits of recovery actions. To further highlight the results from DBERAAS detailed case studies were compiled and presented on a number of rivers, providing 'on-the-ground' examples of the effects of stressors, benefit of actions, and the results of recovery and rebuilding programmes.

An analysis of DBERAAS suggested that Climate Change (resulting in low marine survival), barriers to migration, and habitat destruction were the most common stressors having a high or very high negative impact on Atlantic salmon populations. Improvements in river connectivity, improvements in water quality, and habitat restoration were the three actions most likely to have a high or very high benefit to recovery and restoration actions. The case studies were largely in agreement with the results from DBERAAS, and further highlighted that successful restoration and recovery actions are generally characterised by being conducted on stocks experiencing relatively high marine survival, with few stressors acting on the stock thereby reducing synergistic and additive effects, with actions addressing most or all stressors, and not relying (solely) on stocking.

The Working Group recommends that the primary principles of any recovery or restoration programme for Atlantic salmon should to be founded on habitat restoration and protection combined with sound management based on population monitoring. As stocking poses substantial risks to wild salmon populations a time-limited stocking programme should only be considered in cases where population extirpation is imminent and should not inhibit the use of other restoration and recovery actions. Also recommended is pre- and post-project evaluation and continuous monitoring of restoration/recovery programmes to assess costs, benefits and impacts. Outcomes of such studies should be published in order to inform stakeholders and contribute towards a better understanding of restoration/recovery action successes and failures.

The Working Group does not suggest any follow-up work. Suggestions for follow-up work should come from WGNAS or NASCO after review of this report.

1 Administrative details

Working Group name

Working Group on Effectiveness of Recovery Actions for Atlantic Salmon (WGERAAS)

Year of Appointment

2013

Reporting year concluding the current three-year cycle

2015

Chair(s)

Dennis Ensing, UK

Meeting venues and dates

18–22 February 2013; AFBINI Headquarters, Belfast, UK (Participants: 23)

12–16 May 2014; ICES HQ, Copenhagen, Denmark (Participants: 7)

10–12 November 2015; ICES HQ, Copenhagen, Denmark (Participants: 3)

2 Terms of Reference

a) develop a classification system for recovery / re-building programs for Atlantic salmon, including threats to populations, population status, life history attributes, actions taken to re-build populations, program goals, and metrics for evaluating the success of re-building programs;

b) populate the system by collecting data on recovery / re-building programs for Atlantic salmon populations from around the North Atlantic;

c) summarize the resulting data set to determine the conditions under which various recovery / re-building actions are successful and when they are not;

d) provide recommendations on appropriate recovery / rebuilding actions for Atlantic salmon given threats to populations, status and life history.

3 Summary of Work plan

At the first meeting the Working Group decided that the development of a 'classification system' for rebuilding and recovery actions for Atlantic salmon would be best achieved by the development of a river-specific database, DBERAAS (Data Base on Effectiveness of Recovery Actions for Atlantic salmon). This database would ideally list all salmon rivers in the North Atlantic and contain information on conservation status, population stressors, and recovery actions undertaken. An analysis of the completed DBERAAS, which fully completed would comprise of 2773 rivers, would allow for a North Atlantic wide assessment of conservation status and an overview and detailed analysis of population stressors, recovery and rebuilding actions, and the effects of recovery and rebuilding actions across varying spatial scales.

To further highlight the results from the DBERAAS detailed case studies were compiled and presented on a number of rivers, providing 'on-the-ground' examples of the effects of stressors and the results of recovery and rebuilding actions.

At the second WGERAAS meeting DBERAAS was further developed and a guide was produced to assist contributors in populating the database.

At the third WGERAAS meeting an analysis of a partially filled in DBERAAS was conducted in order to investigate the potential of a fully populated database. The results were discussed in detail in the 2014 Interim Report and the working group was of the opinion that the analysis presented in the report was a good example of the potential of the database to address the ToRs successfully. At the third meeting various case studies were also discussed and a standard format for case studies was adopted. Following this meeting requests went out to representatives from all countries contributing to WGNAS and WGBAST (Assessment Working Group on Baltic Salmon and Trout) to populate DBERAAS and to provide relevant case studies of successful and/or unsuccessful restoration and recovery actions for Atlantic salmon.

After discussions at WGNAS 2015 and a suggestion from NASCO the working group decided to address the ToRs by focusing on the case studies, with DBERAAS in a supporting role.

At the fourth WGERAAS meeting DBERAAS, as far as populated, was analysed. Case studies were discussed and used to answer the ToRs, with supporting information provided by peer-reviewed studies, ICES Working Group documents, and DBERAAS.

4 Summary of Achievements of the WG during 3-year term

- Presentation to ICES Working Group North Atlantic Salmon (WGNAS), Copenhagen, Denmark, 2013.
- Contribution to the Symposium: "What works? A Workshop on Wild Atlantic Salmon Recovery Programs." St. Andrews, New Brunswick, Canada, 2013.
- Presentation to ICES Working Group North Atlantic Salmon (WGNAS), Copenhagen, Denmark, 2014.
- Presentation to ICES Working Group on the Science Requirements to Support Conservation, Restoration and Management of Diadromous Species (WGRECORDS), A Coruna, Spain, 2014.
- Presentation to ICES Working Group North Atlantic Salmon (WGNAS), Moncton, New Brunswick, Canada, 2015.
- Presentation to ICES Working Group on the Science Requirements to Support Conservation, Restoration and Management of Diadromous Species (WGRECORDS), Copenhagen, Denmark, 2015.
- Data Base on Effectiveness of Recovery Actions for Atlantic Salmon (DBERAAS) completed, 2015. To be hosted permanently by NASCO?

- Presentation to ICES Working Group North Atlantic Salmon (WGNAS), Copenhagen, Denmark, 2016.
- Presentation to North Atlantic Salmon Conservation Organisation (NASCO) annual meeting, Bad Neuenahr, Germany, 2016.
- Presentation to ICES Working Group on the Science Requirements to Support Conservation, Restoration and Management of Diadromous Species (WGRECORDS), Riga, Latvia, 2016.
- Presentation to ICES Working Group North Atlantic Salmon (WGNAS), Copenhagen, Denmark, 2017.
- Presentation to North Atlantic Salmon Conservation Organisation (NASCO) annual meeting, Varberg, Sweden, 2017.

5 Final report on ToRs, workplan and Science Implementation Plan

5.1 Background

The Working Group on Effectiveness of Recovery Actions for Atlantic Salmon (WGERAAS) was established in 2012 in response to a question to ICES Working Group on North Atlantic Salmon (WGNAS) by the North Atlantic Salmon Conservation Organisation (NASCO). The NASCO question resulted in a new ToR for WGNAS: "provide a review of examples of successes and failures in wild salmon restoration and rehabilitation and develop a classification of activities which could be recommended under various conditions or threats to the persistence of populations". WGERAAS was established to answer this WGNAS ToR.

5.2 Data Base on Effectiveness of Recovery Actions for Atlantic Salmon (DBERAAS)

Introduction

For the data population of DBERAAS a template was developed including descriptive information for each Atlantic salmon river (name, location, ID) as well as general categories of information such as population status, threats to populations (i.e. Stressors), life history characteristics, actions taken to rebuild populations (i.e. Recovery actions), program goals and metrics for evaluating the success. Definitions for these categories and how they are assessed are provided below.

- Threats to populations (i.e. Stressor) – an agent or event that causes a demographic impact on the population. See table 1 for a list of stressors, table 2 lists assessment of stressor impacts and their definitions.
- Population status – categorical measure of population productivity against CL attainment based on adult monitoring/catch data, juvenile abundance measures, other stock status indicators or expert opinion.
- Life history attributes – this assessment was not segregated by individual population life history attributes given the difficulty in accomplishing the assessment for the population as a whole.

- Actions taken to re-build populations (i.e. Recovery action) – an action aimed to relieve or reverse the demographic impact of one or multiple stressors on the population. See table 3 for a list of recovery actions.
- Program goals – description of the overarching goals of the recovery actions.
- Metrics for evaluating the success – In an effort to reduce the workload associated with populating the database, a description of what metrics were used to assess the effect of the recovery action were not included, as the provided data are assumed to represent the best available information as provided by the regional experts. Metrics are presented within individual case studies (ToR c).

Atlantic salmon rivers listed in the NASCO Rivers database and in the HELCOM Baltic river database were combined to form a new database designed for WGERAAS called 'Database on Effectiveness of Recovery Actions for Atlantic salmon' (DBERAAS). Rivers identified by regional experts that were missing from the combined river databases were included in the database. Rivers from Iceland, currently not a NASCO member state, were also added to DBERAAS. For each individual river the impact of 12 stressors was assessed (Table 1), taking into account the stressor impact definitions (Table 2). Also required was an assessment of the benefits of 11 recovery/rebuilding actions (Table 3), taking into account the given recovery/rebuilding benefit definitions (Table 4). The recovery/rebuilding actions benefits were assessed against Conservation Limit attainment. The Working Group considered and discussed at length the various metrics against which the effects of recovery and rebuilding actions could be measured, and finally settled on using Conservation Limit attainment. The main reason behind the choice for CL attainment was that NASCO, who defines CL as the spawning stock level that produces maximum sustainable yield, requires that stocks are maintained above their CL. As a result CL attainment is annually assessed in many Atlantic salmon stocks and is therefore an appropriate biological reference point to measure the effects of recovery and restoration actions against. However, the Working Group acknowledges that in some countries and for certain restoration/recovery projects other metrics were used against which success was evaluated. The validity of different approaches is not disputed, but for the purpose of this study all projects were evaluated against CL attainment. This can, in some cases, result in different conclusions on project success of the same project evaluated here and in other publications.

In addition population status (Table 5) before the recovery/rebuilding actions commenced needed to be selected, as was the recovery programme goal (Table 6), for each population entered in DBERAAS.

A complete **list of all DBERAAS entry categories** is given below.

NASCO River ID

Helcom River ID

Party

Country

Region/Province

River name

E/W

Decimal latitude

Decimal longitude

Population status

Recovery action?

Program goals

Stressor 1	Pollution
Stressor 2	Barriers
Stressor 3	Water Regulation
Stressor 4	Exploitation
Stressor 5	Aquaculture
Stressor 6	Habitat Degradation
Stressor 7	Diseases/Parasites
Stressor 8	Climate Change
Stressor 9	Invasives
Stressor 10	Stocking
Stressor 11	Predators
Stressor 12	Other
Action 1	Stocking
Action 2	Improved connectivity
Action 3	Habitat restoration
Action 4	Improved water quality
Action 5	Reduction fishing mortality
Action 6	Predator control
Action 7	Invasive species removal/control
Action 8	Farmed fish removal
Action 9	Flow management
Action 10	Parasite/disease control
Action 11	Other

Comments stressors

Comments actions

Name assessor

DBERAAS was used to assess the conservation status of Atlantic salmon populations, assess the prevalence of population stressors, assess the application of recovery and rebuilding actions, and assess the efficacy of recovery and rebuilding actions in the North Atlantic and Baltic areas.

Stressors

In this section the 12 Stressors are discussed in more detail.

Pollution

The stressor pollution, in the context of this study, is defined as organic and inorganic pollutants having a negative effect on the abundance of adult Atlantic salmon in a particular river. For the purpose of this study this also includes acidification, which was not given a specific stressor category of its own. Other main categories of pollutants are halogenated and non-halogenated hydrocarbons, organometals, non-organic metals, and organic substances. Pollution has been widely reported as one of the main causes for the decline of Atlantic salmon stocks (Hindar, 2003, Parrish *et al.*, 1998).

Pollutants can affect fish directly or indirectly. An example of the former is damage to the DNA of an individual as a result of exposure to pollution. This damage caused by oxidative radicals or by mutagenic chemicals can result in mutations and tumour formation, which can lead to death of the individual, diseases and malformations in the next generation, or (in case of recessive mutations) have detrimental effects on the population viability in the long term (Cajaraville *et al.*, 2003). An example of pollutants having an indirect effect on salmon populations is eutrophication. Anthropogenic activities have increased the natural rate of nutrient input (nitrogen and phosphorous) in the earth's terrestrial and aquatic environments and atmosphere. In the case of nitrogen this has increased to which is double the natural input (Smith *et al.*, 1999). Sources of this increased nitrogen and phosphorous input include agricultural fertilisers, animal manures, combustion of fossil fuels (Smith *et al.*, 1999), and aquaculture activities (Cao *et al.*, 2007, Brown *et al.*, 1987). When these nutrients reach the aquatic environment they contribute to excessive weed growth, algal blooms, and blooms of cyanobacteria (Carpenter *et al.*, 1998). Algae and cyanobacteria can release toxins that are harmful to fish, and decomposing algae and weeds can cause deoxygenation of water which can be lethal to fish (Carpenter *et al.*, 1998), especially fish species with low tolerances to low oxygen conditions, such as Atlantic salmon (Davis, 1975). Eutrophication has been identified as a having a negative effect on salmonid juvenile densities in streams (Miltner *et al.*, 1998, McGarrigle, 1993) and is regarded as the most widespread water quality problem in the USA and many other countries (Carpenter *et al.*, 1998).

Acidification of aquatic habitats is caused by acid deposition, commonly referred to as 'acid rain', as a result of large quantities of nitrates and sulphites released into the atmosphere by coal-fired powerplants and other industries (McCormick *et al.*, 2009). Effects of acid rain on aquatic ecosystems range from increased water acidity (i.e. decreased pH), reduced buffering capacity of waterbodies and the surrounding soils, and increases in concentrations of aluminium and other metals (McCormick *et al.*, 2009, Mant *et al.*, 2013). In regions where the substrate is base-poor, effects of acid rain are particularly pronounced as the capacity to neutralise these acids is very limited. Examples of such regions are Scandinavia and eastern Nova Scotia (Canada). The gills of a fish, an organ involved in osmoregulation and respiration is the main site of aluminium and acid toxicity (Gensemer and Playle, 1999). Aluminium can accumulate on the surface and within the gill, where it can damage the branchial epithelium, resulting in loss of ion regulatory function as a consequence of increased permeability of the branchial epithelium and an inhibition of active ion uptake (Monette and McCormick, 2008). All Atlantic salmon life stages can be affected by acidification, but during the smoltification process, a period during which large physiological changes occur to facilitate the transition from a freshwater to a marine environment, salmon are particularly sensitive to exposure to increased acid/aluminium concentrations (Mant *et al.*, 2013, McCormick *et al.*, 2009, Monette and McCormick, 2008) and even short-term exposure to moderately acidified freshwater conditions can cause reduced seawater tolerance and higher mortality in the post-smolt phase (Thorstad *et al.*, 2013). Regions chronically affected by acidification such as Norway and eastern Nova Scotia have seen Atlantic salmon extirpated from some rivers as a result of this issue (Clair and Hindar, 2005). Even in regions which experience episodic acidification events, lasting only a few days, such events can cause mortality and thus negatively impact on salmon populations (McCormick *et al.*, 2009). The effects of acidification however vary quite considerably between rivers and regions as a result of differences in genetic variation between populations to tolerance to acidic water (Gjedrem and Rosseland, 2012) and between-river differences in the Total Organic Carbon (TOC) content, which can bind toxic inorganic aluminium and thus reduce its concentration (Rosseland and Kroglund, 2011). Hesthagen and Hansen (1991) reported the (near) extirpation of Atlantic salmon from 25 Norwegian rivers and estimated the annual losses of Norwegian salmon due to acidification in the late 1980s between 90 000 and 300 000 individuals.

Pollution through discharges from the mining industry into rivers and streams has also been reported as having a negative effect on Atlantic salmon populations (Saunders and Sprague, 1967). Laboratory experiments have confirmed that chemicals from mine discharges can be toxic to Atlantic salmon (Dubé *et al.*, 2005, Olsvik *et al.*, 2015), yet examples of this in peer-reviewed literature are relatively scarce in relation to Atlantic salmon.

Various other environmental contaminants have been shown to influence the osmoregulatory function of salmon, restricting the ability of smolts to adapt physiologically to saline conditions once they enter the marine environment (McCormick *et al.*, 2009). These contaminants include pesticides (Fairchild *et al.*, 2002; Moore *et al.*, 2007, 2008; Waring and Moore, 2004), oestrogenic compounds (Fairchild *et al.*, 1999) and brominated flame retardants (Lower and Moore, 2007). For example, the exposure of juvenile Atlantic salmon to the widely used pesticide atrazine during the parr–smolt transformation reduces gill Na^+K^+ATPase activity, reduces the ability to adapt to salt water, and increases the mortality of smolts on exposure to full-strength seawater (Moore *et al.*, 2003; Waring and Moore, 2004).

Barriers

There are many types of barrier to migration present in the habitat of Atlantic salmon. Examples of such barriers are weirs, shipping locks, fish traps, hydroelectric dams, diversion dams, closure dams, culverts, and (tidal) barrages.

Barriers can have various negative impacts on Atlantic salmon populations. A very obvious impact is the habitat loss due to dam construction. Especially when barriers completely block access (i.e. are impassable), large areas of a watershed can become inaccessible to migrating salmonids, with the resulting habitat loss causing extirpation of entire populations (Sheer and Steel, 2006). Other effects of barriers are increased mortality as a result of delayed migration of both adult and juvenile life-stages (Garcia de Leaniz, 2008, Marschall *et al.*, 2011, Stich *et al.*, 2015), increased predation due to aggregation of predators near barriers (Lawrence *et al.*, 2016), lethal injuries resulting from turbine blade strikes in hydroelectric dam (Ferguson *et al.*, 2008) or tidal barrage turbines, and delayed mortality effects as a result of behavioural and/or physiological stress of hydro dam passage (Budy *et al.*, 2002).

Even barriers that are partially passable to fish can have a significant effect on flow and temperature regimes, sediment transport, and water chemistry, and can for instance disrupt natural gravel recruitment downstream of the barrier causing degradation of spawning habitat, resulting in lower juvenile recruitment (Garcia de Leaniz, 2008). In addition the cumulative effects of a series of partially passable barriers may be very severe even if the negative effects of a single barrier are negligible (Naughton *et al.*, 2005, McKay *et al.*, 2013). Recent work in the US has demonstrated a significant latent mortality affect from passing multiple hydro-electric facilities being realized in later stages of migration. Stich *et al.* (2015) showed that estuarine mortality of outmigrating Atlantic salmon smolts increased by approximately 5–6% for each dam passed. It is estimated that in the USA alone there might be as many as two million in-river barriers of all sizes (Graf, 2003), while in Europe over 7 000 large (>15m) in-river barriers exist (Limburg and Waldman, 2009). The possible cumulative negative effects of all such structures combined on the connectivity of riverine habitat, and thus Atlantic salmon persistence, could be very significant.

Barriers are therefore commonly reported in the peer-reviewed literature as a major cause for the decline and extirpation of Atlantic salmon stocks throughout the range of this species (Parrish *et al.*, 1998, MacCrimmon and Gots, 1979). This process likely started with the expansion of watermill technology across Europe as early as the Middle Ages (Lenders *et al.*, 2016).

Water Regulation

Water regulation includes, in the context of this study, such actions as water abstraction and hydro-regulation. The effects of hydro-regulation are closely linked to hydrodams, discussed in the previous paragraph on barriers, but for the purpose of this study the regulatory effects of hydrodams on river hydrology are placed under this particular stressor.

Changes in water discharge regime is one of the effects hydrodams have on the riverine habitat both upstream and downstream of the structure. Rapid changes in flow (hydropeaking) can cause dewatering of habitat resulting in loss of ova, alevins (Casas-Mulet *et al.*, 2016), and juveniles (Saltveit *et al.*, 2001) which can have negative effects on the productivity of populations of salmonid fish (Harnish *et al.*, 2014). Another effect of hydrodams can be a reduction in water temperature of the river downstream of the dam if water releases are from deep hyperlimnetic reservoirs. Water temperatures are positively correlated to growth rates in salmonids and any reductions in water temperature can result in lower growth rates which can cause a size reduction in juveniles (Saltveit, 1990). It is well documented that smaller smolts experience higher marine mortality compared to larger ones (Kallio-nyberg *et al.*, 2004, Saloniemi *et al.*, 2004) and can thus cause reductions in adult returns, potentially compromising population resilience.

Water abstraction can be for use as drinking water, in agriculture and aquaculture, for industrial purposes, or to feed hydropower stations. The timing and the intensity of high and low flows can have negative effects on the biodiversity of rivers and flow regimes can be altered as a result of water abstraction (Poff *et al.*, 1997). Water abstraction for use in hydropower is mostly associated with run-of-river (ROR) schemes. In contrast to large scale hydropower stations ROR schemes operate without water storage (i.e. no need for hydrodams with reservoirs) and use the river flow in-channel. In ROR schemes a portion of the river flow is deflected, often by using existing weir-type structures, into a secondary channel to a turbine before being returned to the river further downstream. Such schemes are often viewed as having less of a negative impact on the environment compared to large scale storage-type hydro schemes (Bilotta *et al.*, 2016, Tranell *et al.*, 2012). Through European Union and national renewable energy subsidies and targets there has been a surge in ROR hydro scheme development in Europe in recent times (Bilotta *et al.*, 2016). Peer-reviewed sources on the impact of ROR schemes are scarce and studies often suffer from an opportunistic post-hoc approach and it is likely that impacts will vary significantly among scheme type (Anderson *et al.*, 2015) and could depend to a great deal on the local legislation regulating ROR schemes. For example Bilotta *et al.* (2016) only found statistically significant change in one of six metrics of fish community composition in a UK stream after a ROR scheme, while Kubečka *et al.* (1997) reported very clear changes in the composition of the fish community after the introduction of a ROR scheme on a Czech river, before the adoption of more developed environmental legislation in that country. For ROR schemes, just like any in-river type of partially passable barrier, the cumulative effects of a series of ROR schemes in sequence on the same river could have very strong effects on connectivity, even though the passability of individual schemes is fairly good. Other potential effects of water abstraction are increases in temperature (Webb *et al.*, 2003) which can negatively impact aquatic fauna and flora (Richardson *et al.*, 1994), water quality changes due to lesser dilution of harmful substances (Armitage and Petts, 1992), and reduced growth in aquatic flora having a knock-on effect on aquatic fauna (Franklin *et al.*, 2008).

Water regulation has frequently been reported in the peer-reviewed literature has having a negative effect on salmonid populations, yet extirpations mainly attributed to this stressor are rare. A very early Atlantic salmon extirpation event on the River Lagan in Northern Ireland in the 18th century can possibly be attributed to water regulation as the entire river flow was deflected into a canal with no access to fish leaving a substantial part of the riverbed dry and the spawning areas inaccessible to diadromous fish species (pers. comm. R. Rosell).

Exploitation

Exploitation of Atlantic salmon occurs in freshwater, transitional waters, and in the marine environment in commercial, recreational, and subsistence fisheries. Exploitation rates can vary per year and per stock but with reported exploitation rates ranging between 12 and 44% in 2016 for NEAC stocks exploitation is a major cause of mortality in Atlantic salmon, even taking into account the much reduced current exploitation rates compared to the 1980s when exploitation rates on some stock components were as high as 72% (NASCO, 2016). Overexploitation is fishing a spawning stock to below the management target, causing reductions in ova deposition, smolt production, and ultimately resulting in fewer returning adults thus compromising population resilience. A secondary effect of exploitation in general is fisheries induced evolution as a result of removing a large part of the spawning biomass before it had a chance to reproduce causing changes in traits like run timing and body size in some salmon stocks (Hard *et al.*, 2008). The possible consequences of this fisheries induced selection are not clearly understood, but as adaptation of the fish stocks through natural and sexual selective processes is disturbed this could in some instances negatively influence population viability in the long term (Hard *et al.*, 2008). However, strict adherence to MSY should ensure minimisation of the probability of fisheries induced evolution for commercially exploited species such as Atlantic salmon (Hutchings, 2009).

Overexploitation has been suggested as one of the historic stressors to have caused extirpation of Atlantic salmon stocks from the River Rhine (de Groot, 2002) and River Elbe (Andreska and Hanel, 2015, Wolter, 2015), and severely depleted salmon stocks in the Bay of Fundy (Jackson, 2008). Hoffmann (2015) reports overexploitation as a cause for significant reductions in spawning stock in salmon populations across Western Europe (excluding Scotland) in the Middle Ages. In other salmonids overexploitation has been identified as a major threat to population persistence in *Oncorhynchus nerka* (Rand *et al.*, 2012), as well as diadromous *O. mykiss* (Katz *et al.*, 2013).

Aquaculture

The effects of aquaculture on Atlantic salmon stocks can be divided into four categories; pollution, water abstraction, genetic effects of escapees, and issues related to sea lice. The effects of the former two are discussed in the sections 'pollution' and 'water regulation' respectively, the latter two in this section.

The sea- or salmon louse (*Lepeophtheirus salmonis*) is a naturally occurring ectoparasitic copepod that can affect growth, fecundity, and survival of their hosts by causing skin lesions leading to osmoregulation problems and secondary infections, as a result of their feeding (Boxaspen, 2006). The ICES Workshop WKCULEF (Workshop to address the NASCO request for advice on possible effects of salmonid aquaculture on wild Atlantic salmon populations in the North Atlantic) recently reported (ICES, 2016b) on the effects of sea lice on Atlantic salmon. This Workshop concluded that there is substantial and growing evidence that salmon aquaculture activities can affect wild Atlantic salmon. ICES noted that salmon farming can increase the local abundance of lice and the infection risk in wild populations, and that mortality measured as losses in returning adults to rivers in areas with open-cage salmon farming varied considerably, ranging from 0.6% to 39% across populations.

ICES WKCULEF also reviewed the genetics effects of Atlantic salmon escapees from aquaculture facilities in both fresh- and marine waters. The Workshop concluded that in some areas escapees make up over 50% of spawners, but have reduced spawning success compared to wild fish, however introgression of farmed genetic material into wild populations is common. The latter has also been confirmed by other authors (Glover *et al.*, 2012, Skaala *et al.*, 2006), even in areas with limited open-cage salmon aquaculture (Ensing, 2015). Further, a recent study (Shephard and Gargan, 2017) which analysed 26-year time series reported that adult returns were >50% lower on the River Erriff (Ireland) in years following high lice levels on nearby salmon farms during the smolt out-migration. Cultured salmon and wild/cultured hybrids have lower fitness compared to their wild counterparts (McGinnity *et al.*, 2003, McGinnity *et al.*, 1997), compete together with recent escapees with wild fish for territory and food, which can lead to decreased population productivity in the long-term and could ultimately threaten population persistence, especially in combination with other stressors (ICES, 2016b). In a recently published study, Bolstad *et al.* (2017) demonstrated that individuals with high levels of introgression (domesticated ancestry) have altered age and size at maturation for a large number of studied populations in Norway, which may threaten their productivity by inducing genetic changes in fitness-related traits.

Furunculosis, a bacterial pathogen, has also been reported to transmit from salmonid aquaculture to wild stocks, causing contractions in the size of salmonid populations resulting in concerns regarding population persistence (Johnsen and Jensen, 1994).

Habitat Degradation

Habitat degradation can take many forms, some of which have already been covered in previous sections under 'pollution', 'water regulation', and 'barriers'. These will not be covered in this section. In the context of this report 'habitat degradation' refers to changes to the habitat such as in-river gravel extraction, siltation, substrate removal for river arterial drainage schemes, and removal or introduction of aquatic or riparian vegetation, etc.

In-river gravel extraction and substrate removal for the benefit of arterial drainage schemes have quite similar effects; they can alter geomorphology, increase sedimentation, change turbidity, cause changes to the biota, and ultimately reduce the quality of salmonid habitat (Brown *et al.*, 1998, Kennedy *et al.*, 1983). Results are general reductions in the numbers of fish in affected rivers, notably of siltation-sensitive species (Brown *et al.*, 1998). On the River Bush in Northern Ireland an arterial drainage scheme is estimated to have degraded Atlantic salmon habitat to a degree where current natural smolt production is about ⅓ to ½ of the production capacity from before the scheme was implemented (pers. comm. R. Kennedy). This is likely to have severe knock-on effects on the number of returning spawners, and possibly population persistence.

Atlantic salmon is a species sensitive to siltation (Lapointe *et al.*, 2004), whether caused by gravel extraction or river drainage, or by such causes as bank erosion through agricultural activities, road construction, mining, forestry or reservoirs (Wood and Armitage, 1997). Siltation can increase turbidity, limit light penetration, reduce primary production, modify the surface of substrate, increase fine sediments in the groundwater, and can in extreme cases smother the entire riverbed changing channel morphology, kill flora, clog the substrate, increase invertebrate drift, and reduce habitat for benthic organisms (Wood and Armitage, 1997). The most visible effect of siltation on salmonids is the silting of spawning gravels which can lead to higher mortality in ova and fry (Collins *et al.*, 2010, Lisle, 1989) by restricting oxygenation or, in extreme cases, entombation of fry and ova (Wood and Armitage, 1997). In some reported cases losses of ova and fry can be extremely severe, to a degree where it limits recruitment and prevents recovery of depleted salmonid populations (Turnpenny and Williams, 1980).

Diseases and Parasites

For the purpose of this study 'diseases and parasites' are defined as naturally occurring diseases and parasites, and not pathogens associated with open-cage salmonid aquaculture.

Atlantic salmon are host to as many as 80 known parasites and pathogens (McVicar, 1997), reviewed by Bakke and Harris (1998), but few have been reported to have significant impacts on wild populations (Bakke and Harris, 1998). There are however some notable exceptions. Furunculosis, caused by the bacterium *Aeromonas salmonicida*, is one of the best known and most important diseases of salmonids, and has been reported widely in the peer-reviewed literature (Johnsen and Jensen, 1994). A first phase of freshwater epidemics occurred in the first part of the 20th century (Bakke and Harris, 1998) causing high mortality in European salmon stocks (Austin and Austin, 1987). In the UK, the threat of Furunculosis to the survival of salmon stocks was perceived as so severe that a national Furunculosis Committee (1930) was set up to investigate ways to combat the disease (McCraw, 1952). A second wave of epidemics occurred in the 1980s in Scotland and Norway, of a marine strain of Furunculosis, with salmonid aquaculture playing a role in the spread of this epidemic (Austin and Austin, 1987, Johnsen and Jensen, 1994).

Gyrodactylus, a genus of parasitic flatworms, contains several species that can infect Atlantic salmon, but only *G. salaris* is pathogenic in populations outside the Baltic Sea basin (Bakke and Harris, 1998). In populations where *G. salaris* is pathogenic, effects can be severe, causing high mortality in juveniles and reducing the size of adult returns (Johnsen and Jensen, 1991). Extermination of the entire river stock appears the only effective way to eradicate the pathogen from rivers and to stop further spread of the disease (Johnsen and Jensen, 1991).

Ulcerative Dermal Necrosis (UDN) is a condition of the head and skin of adult Atlantic salmon and sea trout which occurs just prior to entering freshwater and during their upstream migration (Roberts, 1993). The disease starts with lesions on the head that rapidly ulcerate and become infected with a number of opportunistic pathogens which extended the lesions by fungal activity, resulting in death due to secondary bacterial and/or fungal infection or circulatory failure resulting from the osmotic haemodilution induced by the large area of ulceration (Roberts, 1993). The condition was first described in the 19th century, but resurfaced in the 1960s in Britain and Ireland, after which it disappeared again in the 1970s. Despite several attempts it has been impossible to isolate a specific viral or bacterial agent from the lesions, or from other organs (Roberts, 1993), shrouding the exact causes of the disease still in mystery.

Climate Change

Climate change is (together with 'stocking') unique in the list of stressors here because it is the only stressor without a corresponding recovery/restoration action. This is because there is no realistic direct short/medium term action available to mitigate for this global stressor.

Climate change manifests itself as a stressor in Atlantic salmon populations mainly as decreased marine survival (Friedland *et al.*, 2014). This increased marine mortality may be a result of changes in seaward migration timing of smolts (Kennedy & Crozier, 2010; Russell *et al.*, 2012), altered marine conditions (Friedland *et al.* 2011), or issues with feeding in the marine environment (Beaugrand & Reid, 2012; Mills *et al.*, 2013). Other temperature and flow effects are also expected to increase mortality in the freshwater phases of the Atlantic salmon's lifecycle (Jonsson & Jonsson, 2009). Higher temperatures and increased climate variability are predicted to affect all components of the global freshwater system, with temperature increases over land expected to exceed those over the surface of the oceans (IPCC, 2007). Among the changes, rainfall levels are expected to increase with "wet" areas typically becoming even wetter, but with increased variability such that the risk of both floods and droughts will increase. Increasing trends in river water temperatures are also predicted (IPCC, 2007).

As a result, salmon stocks that experience very strong decreases in marine survival as a result of climate change have virtually no chance of successful stock restoration or rebuilding until the situation in the marine environment changes to allow for better marine survival. As will be discussed later in this document this does not mean that no restoration actions should be undertaken in such rivers, but that management and stakeholders should be aware of the limited effects of not being able to mitigate for the strongest stressor acting on the stock. In Canada the Department of Fisheries and Oceans (DFO) has conducted Recovery Potential Assessments (RPAs) to provide scientific information and advice on population viability and recovery potential for populations with enough information to model population dynamics, as well as information on threats to persistence and recovery (ICES, 2014). Such approaches are very useful in determining the extinction risk and recovery potential of salmon populations under different environmental scenarios. This allows pre-project analysis of the most likely outcomes of recovery and restoration actions, and direction of efforts where populations are most threatened or where success is most likely. An example is given in the West River case study in the Case Study section of this report.

Invasives

Little evidence exists in the peer-reviewed literature of studies indicating clear negative effects of invasive species on Atlantic salmon populations, with the possible exception of *Gyrodactylus*. In regions where this parasite is invasive (i.e. outside the Baltic Sea basin) the impact is much greater compared to impacts on salmon population within the natural range of the species (Johnsen and Jensen, 1991). There are however suggestions from various studies that there might be impacts of other invasives on certain salmon stocks. With current general worldwide increases in the introduction and spread of non-native and invasive flora and fauna this stressor might become relatively more important in the near future.

There are indications that non-native smallmouth bass (*Micropterus dolomieu*) in Atlantic Canada could be a competitor for resources, and could predate on juvenile salmon (DFO, 2009). ICES WGNAS (ICES, 2013) reviewed the impacts of non-native salmonids on Atlantic salmon stocks and reported some cases that cause concern. One example is the establishment and range expansion of non-native rainbow trout (*Oncorhynchus mykiss*) in Quebec, Canada. Competition for food resources is evident between these species when living in sympatry, as well as predatory interactions (Coghlan *et al.*, 2007) and therefore the presence of rainbow trout in rivers containing Atlantic salmon could negatively impact on juvenile production. Non-native brown trout (*Salmo trutta*) were introduced in Newfoundland, Canada, in the 1880s and are currently expanding their range (Westley and Fleming, 2011). Impacts of this range expansion are believed to include displacement of native Atlantic salmon (Van Zyll De Jong *et al.*, 2005) and hybridisation between the two species (Verspoor, 1988). Other possible effect of non-native salmonids have been reported from Norway where non-native rainbow trout might play a role in the spread of Gyrodactylus (Bakke *et al.*, 1991) and sea lice (Skilbrei, 2012), and Sweden where spawning rainbow trout have been reported to dig up native salmonids redds (Landergren, 1999).

Further evidence of non-native invasive species impacting negatively on Atlantic salmon stocks comes from a study on signal crayfish (*Pacifastacus leniusculus*) in a stream in England which suggests that population densities of juvenile salmonids decreased after the appearance of the invading crustacean (Peay *et al.*, 2009). Finally the report from the symposium "What works? A Workshop on Wild Atlantic Salmon Recovery Programs" held in 2013 in St. Andrews, New Brunswick, Canada, suggests non-native species might have played a role in the lack of success of recovery actions for Atlantic salmon in both the St. Croix and Magaguadavic rivers (Carr *et al.*, 2015).

Stocking

Stocking, in this study, is both listed as a potential action and a potential stressor. The stocking of Atlantic salmon can negatively impact the wild stock in three ways; 1) by competition of stocked fish with wild fish for resources, 2) by the introduction of parasites or diseases through the stocked individuals into the wild population, and 3) by genetic interactions between wild and stocked fish.

Stocked (hatchery origin) and wild juvenile Atlantic salmon display different habitat use living in sympatry; wild fish actively avoid habitat used by stocked fish and occupy glide areas with substantial vegetation cover (Laffaille, 2011). This is in contrast to habitat use by wild and stocked fish living in allopatry, under which conditions habitat use between wild and stocked fish is similar (Laffaille, 2011). This intra-species competition could have negative impacts on wild salmon populations, especially when survival of less adapted stocked fish is (much) lower compared to that of wild fish (Araki *et al.*, 2008). The use of local origin broodstock, which is currently favoured by managers instead of using non-native broodstock, can increase fitness of the stocked component to a degree (Araki *et al.*, 2008), but as even locally sourced stocking material can already experience loss of fitness after only one generation of captive breeding (Milot *et al.*, 2013) stocking hatchery fish can be a very real threat to the persistence of wild Atlantic salmon due to displacement of individuals with higher fitness by individuals with lower fitness.

The spread of diseases and parasites into wild populations through stocking of hatchery fish has been suggested as a potential threat, but examples in the peer-reviewed literature are lacking. However, as juvenile cultured salmon have been responsible for the spread of Gyrodactylus from Sweden to Norway (Johnsen and Jensen, 1988) it is certainly possible for hatchery fish to spread diseases and parasites to wild populations too.

Genetic interactions between wild and stocked Atlantic salmon have been reported on in peer-reviewed publications, and stocking has recently come under increased scrutiny from management and scientists as a potentially harmful recovery action for Atlantic salmon. Stocking of hatchery material impacts on the genetics of original wild populations in several different ways. In the first place, interbreeding of hatchery fish with the indigenous wild stock can change the neutral genetic structure of salmonid populations (Marie *et al.*, 2010), reducing the genetic differentiation between the wild and the hatchery genepools (Finnegan and Stevens, 2008). In addition, interbreeding of hatchery fish with the wild stocks can also cause changes to adapted genetic variation in the wild stock, causing loss of local adaptation, and ultimately to genetic fitness reductions in the introgressed hybrid stock (Perrier *et al.*, 2013, McGinnity *et al.*, 2003). In some instances, however, poor performance of the introduced stock (and possibly wild/stocked hybrids) relative to the locally adapted autochthonous stock (Milot *et al.*, 2013) can lead to low levels of introgression and a rapid recovery of original genetic structure of the wild population (Perrier *et al.*, 2013). Another factor potentially affecting rates of introgression is the relative abundance of stocked and wild fish, where low numbers of stocked fish in a relatively large population of wild fish can limit the level of introgression significantly (Currat *et al.*, 2008). Conversely however, large numbers of stocked fish relative to the wild population size could significantly increase the level of introgression. Dispersal and colonisation from near-by populations can also dilute the number of stocked fish, and reduce the level of introgression in wild salmon stocks (Vasemagi *et al.*, 2001).

It is safe to conclude that the effects of stocking of hatchery fish on wild populations vary widely as many additional factors determine the level and persistence of the genetic disturbance of the wild genepool. However, the effects can be severe and long lasting, and can be detected on vast geographical scales in areas where stocking has long been a traditional method to augment, restore, and recover depleted Atlantic salmon populations such as in France (Perrier *et al.*, 2013).

Predators

Predation is a natural occurring phenomenon in all of nature, and Atlantic salmon is not an exception. Predation on salmon occurs in all life stages, by a variety of predators; birds (Hawkes *et al.* 2013, Vilches *et al.*, 2013, Kennedy and Greek, 1988), mammals (Carss *et al.*, 1990, Heggenes and Borgstrøm, 1988, Jounela *et al.*, 2006) , fish (Jepsen *et al.*, 1998, Palm *et al.*, 2009, Svenning *et al.*, 2005, Ward *et al.*, 2008), and crustaceans (Findlay *et al.*, 2015, Peay *et al.*, 2009). The effects that these predators have on salmon populations varies considerably. For example predation rates on migrating smolts by cormorants (*Phalacrocorax carbo*) in an Irish river were estimated to be around 65% (Kennedy and Greek, 1988), 1% on parr by kingfishers (*Alcedo atthis*) in an English river (Vilches *et al.*, 2013), 56% of smolts migrating through a Danish reservoir being predated by pike (*Esox lucius*) (Jepsen *et al.*, 1998), and between 2 and 20% predation by striped bass (*Morone saxatilis*) for migrating smolts in the Miramichi river in Canada (ICES, 2017). Predation by seals can be substantial too, but quantifying this predation has proven difficult, just as other forms of marine predation are currently poorly understood (Jonsson and Jonsson, 2004). It is exactly this marine predation that is very likely an important factor in marine survival of Atlantic salmon (Fleming *et al.*, 1996).

Other stressors such as barriers (Gauld *et al.*, 2013) and parasites and diseases (Krkošek *et al.*, 2011) can have a synergistic effect with predation, increasing losses due to predation because the other stressors restrict predator avoidance success.

Other

Listed here are all stressors that are not given discrete categories of their own. At WGERAAS meetings experts suggested that this category might include stressors like: noise pollution, light pollution, and shipping. But for the purpose of this study and the population of DBERAAS this can include any uncategorised stressor.

For example Artificial light at night (ALAN) is known to cause stress in juvenile Atlantic salmon (Newman *et al.*, 2015), but effects on mortality are not known. Recent studies on Atlantic salmon also report delay and disruption by ecologically relevant intensities of ALAN to both the dispersal of fry from artificial redds (Riley *et al.*, 2013 & 2015) and the diel migratory pattern of smolts leaving their natal stream (Riley *et al.*, 2012). Hansen & Jonsson (1985) have also observed a reduced speed of descent in hatchery-reared Atlantic salmon smolts under river illumination. As the synchronous nocturnal dispersal of fry and the diel migration timing of smolts are predator avoidance tactics, any alteration or disruption to these processes may affect recruitment in the population.

In an example relating to noise pollution underwater noise did not appear to affect salmonids in a study on the effects of piling during construction work (Nedwell *et al.*, 2006), possibly as a result of poor hearing in Atlantic salmon relative to other fish species (Hawkins and Johnstone, 1978).

Actions

In the sections below the DBERAAS action categories will be discussed on more detail.

Stocking

Stocking for the purpose of this study is defined as introducing cultured fish or ova, of any life stage, into the wild. The source of the donor material can be local broodstock, exogenous, or a combination of the two.

Stocking as a means to recover or enhance Atlantic salmon populations has a long history in both Europe and North America. In Europe, stocking was recorded to have commenced in the upper reaches of the River Elbe catchment in Bohemia (now the Czech Republic, then Austro-Hungarian Empire) in the early 1870s (Andreska and Hanel, 2015), and in the 1860s on the River Rhine in Germany and The Netherlands (de Groot, 2002). In North America, stocking was initiated to re-establish the extirpated salmon population of Lake Ontario in the 1860s (Crawford, 2001) and on Prince Edward Island, Canada in the 1880s (Cairns *et al.*, 2010). Stocking in the US has been ongoing since the late 1800s (Fay *et al.* 2006). Since the late 19th century stocking has become a very common management measure throughout the (former) natural range of Atlantic salmon (Wang and Ryman, 2001).

Improved connectivity

This action is about improving the connectivity of water bodies where the construction of any kind of barrier or obstacle impaired or blocked access previously. The most simple of these is the removal of the obstacle, as has happened for example on the Penobscot River in Maine, USA (Hogg *et al.*, 2015). In North America, dam removal is a more commonly used restoration/recovery action, with over 600 dams removed before 2005 (Garcia de Leaniz, 2008). In Europe, this method is less practiced compared to North America, but is increasingly used to improve connectivity for diadromous fish species, for example in France (van Ast, 2000) and Germany (Weyand *et al.*, 2005).

A second method of increasing connectivity, without (total) removal of the obstacle, is the construction of fish passages. These can be either upstream or downstream. There are three major categories of upstream fish passage systems; fishways, fish lifts or locks, and trapping and trucking (Larinier and Travade, 2002). Fishways are artificial flow passages that fish negotiate by swimming or leaping in order to bypass a single obstacle. Fish lifts and locks are passive fish passage systems where fish are attracted to a chamber at the base of the obstruction which rises and empties upstream (fish lift) or is connected to an upstream chamber by a vertical shaft with sluice gates at either end which moves fish upstream in a similar way as ships in a shipping lock. Trapping and trucking is another example of a passive fish passage system where fish are trapped at the base of the obstruction and transported by truck upstream of the barrier, or sometimes upstream both of the barrier and the associated impoundment lake. Downstream passage of obstacles concerns mainly measures designed at preventing downstream migrating fish (smolts or kelts) from passing through a hydroelectric turbine. These systems aim for the migrating fish to bypass the turbines through an alternative channel by either physically (screens or filters) preventing fish from passing through the turbine, or by behavioural barriers (visual, auditory, hydrodynamic, or electric stimuli) that attract or repel fish (Travade and Larinier, 2002). With downstream migration too, trapping followed by transport by truck or barge is also an option for passage of the obstacle. Another way to improve downstream fish passage through hydroelectric facilities are modifications to the turbines to increase survival of fish that pass through.

Habitat restoration

This action, in the context of this study, includes categories such as riparian rehabilitation, floodplain rehabilitation, and instream habitat improvements.

Riparian rehabilitation actions can be aimed at improving fencing and limiting grazing by (farm) animals, and restoring and protecting vegetation. Floodplain rehabilitation includes restoration of existing floodplain habitat, re-meandering of rivers, introduction of constructed habitats such as side channels, and restoration of natural flood regimes. Instream habitat improvements typically involve the introduction of artificial (weirs and stream deflectors) or natural (logs, boulders, or gravel) structures into the streamchannel to improve habitat. The latter is a very common habitat restoration action taken, with some references to this type of action dating back as far as the 1930s (Roni *et al.*, 2008).

Improved water quality

This action includes any measures taken to improve water quality in order to recover or restore Atlantic salmon stocks.

Often actions that are aimed to improve water quality are in response to legislative measures on local, national, or trans-national scale such as the European Union Directive on Integrated Pollution Prevention Control (IPPC) (O'Malley, 1999), the EU Urban Waste Water Treatment Directive, and the EU Water Framework Directive (Page and Kaika, 2003, Kallis and Butler, 2001). Legislation can either be aimed at preventing polluting substances to be released or to ban the production and/or use of the substance.

Examples of practical actions to improve water quality, whether or not in response to legislation, are domestic wastewater treatment, filtering out polluting chemicals from water used in industrial processes, reducing emissions from motor vehicles, industry, and power stations, reducing the release of nitrous and phosphorous into the environment by agricultural activities.

Reduction in fishing mortality

Reducing fishing mortality includes measures against illegal fishing and bycatch of Atlantic salmon in other fisheries, as well as reducing the exploitation of salmon in commercial, recreational, and subsistence fisheries in marine-, transitional-, and freshwater. Reducing exploitation in salmon is a very common measure taken with the aim to recover or restore Atlantic salmon stocks. Exploitation in distant-water commercial fisheries has been substantially reduced since the signing of the NASCO convention in 1984 and the setting on quotas. Exploitation in the home-water commercial fisheries across the North Atlantic has also seen major reductions since exploitation peaked in the 1970s (ICES, 2016a). Exploitation by recreational fishers has followed the same trend as the commercial equivalent with current exploitation rates the lowest since time series began in the 1960s, in addition to current catch & release figures the highest since records began (ICES, 2016a).

Predator control

Recovery and restoration actions aiming to control predation on Atlantic salmon by either removing predators or by limiting access of the predators to their salmon prey. This action has a long history with removal of predatory fish (pike, trout, grayling) from waters inhabited by Atlantic salmon a common practice in management of salmonid fisheries until fairly recently (Craig, 2013). Licences have been issued to enable limited shooting of avian predators in England and Wales (and other countries) in order to protect salmonid fish from predation (Harris *et al.*, 2008) and non-lethal harassment measures have been attempted in the US (Hawkes *et al.* 2013). Such efforts are commonly targeted at areas where fish are thought to be particularly vulnerable, for example migration bottlenecks. Grey seal (*Halichoerus grypus*) culling has also occurred in areas such as the Gulf of Bothnia in the Baltic Sea (Stenman, 2007).

Invasive species removal/control

The removal or control of invasive species in rivers and streams is an action that has been reported on, albeit not often with the sole purpose of conserving Atlantic salmon populations. Such actions are more often part of a holistic approach to remove or reduce the negative effects of the invasive on the native flora and fauna as a whole, which can include salmonid fish species. Examples are attempts to remove or control invasive signal crayfish (*Pacifastacus leniusculus*) in the river North Esk in Scotland (Peay and Hiley, 2006), smallmouth bass (*Micropterus dolomieu*) in Canada (Loppnow *et al.*, 2013), and chub (*Squalius cephalus*) in the river Inny in Ireland (pers. comm. K. Gallagher). In general, however, the preferred approach to avoiding potential unwanted interactions is to adopt a precautionary approach to potential new introductions, based on the simple edict that prevention is better than cure.

Farmed fish removal

Removal of farmed fish is an action that has to date, to the knowledge of the Working Group, primarily been applied in Norway for Atlantic salmon. A transportable, semi-permanent, system called the 'Resistance Board Weir' (Tobin *et al.*, 1994) for catching adult salmonids in rivers has been successfully trialled on the River Etne in Norway as a means of removing escaped aquaculture fish from the wild (Skaala *et al.*, 2015). Other methods, such as harpooning, angling, and various ways of netting have also been trialled in Norway (Skaala *et al.*, 2014). Farm escaped adult fish were also routinely removed using a permanent fish trap on the Magaguadavic River in Canada (Carr and Whoriskey, 2006). Similarly, in a more-or-less opportunistic way, farmed salmon were removed when encountered in a fish trap on the River Bush in Northern Ireland (pers. comm. R. Kennedy). Efforts to remove farmed fish encountered in fish traps or opportunistic in-river removals are also employed in the USA (pers. comm. T. Sheehan).

Flow management

In most cases measures aimed at a more natural flow regime are part of a holistic approach at improving conditions in riverine habitats for a whole range of flora and fauna. Legislation exists at national and supra-national levels to ensure regulated rivers retain a certain level of natural flow characteristics (Acreman and Ferguson, 2010) which should also be beneficial to Atlantic salmon.

An example of a flow management action specifically taken to assist in the restoration of an Atlantic salmon stock is the so-called 'Kierbesluit' in the Netherlands. Here the Haringvliet, the major migration route for diadromous salmonids between the River Rhine and Meuse catchments and the North Sea, will have the sluices between the freshwater and the marine environments set permanently partly open to facilitate unrestricted movement in and out of the River Meuse and Rhine delta (Hop, 2011).

Parasite/disease control

This action has been fairly widely reported on in the peer-reviewed literature. For example, *Gyrodactlyus* in Norway is combated by destroying all possible hosts in an infected river, after which the river is repopulated with hatchery fish or by natural re-colonisation (Mo *et al.*, 2006). Vaccination against furunculosis and sea lice is possible in salmon and can be successful to a degree, but is usually applied to aquaculture fish and not to wild individuals (Midtlyng *et al.*, 1996, Torrissen *et al.*, 2013). However, vaccinations of aquaculture fish can sometimes stop the spread of diseases and parasites in wild populations as open-cage Atlantic salmon aquaculture facilities can act as a vector in the spread of the pathogen (McVicar, 1997). For disease outbreaks like UDN there is no known treatment and the infection will have to run its course, after which it can disappear for long times before resurfacing again sometime in the future (Bakke and Harris, 1998).

The control of the impact of salmon lice (*Lepeophtheirus salmonis*) originating from open-cage salmon aquaculture is reliant on the efforts to reduce infestation levels in farmed fish, through use of for example cleaner fish (Powell *et al.*, 2017) and chemical methods (Skilbrei & Wennevik 2006). Such measures should become more effective if implemented as part of a comprehensive multifaceted large scale approach, such as in the Norwegian National Action Plan against Salmon Lice on Salmonids (Heuch *et al.*, 2005). However, in 2017 review of threats to the persistence of Norwegian salmon populations salmon lice originating from open-cage salmon aquaculture are still listed as one of the top two threats (Forseth *et al.*, 2017).

Other

Actions in response to the examples of 'other stressors' are not known to the members of the Working Group.

Analysis of DBERAAS

Out of the total of 2 773 rivers in DBERAAS, data were received for 568 rivers from USA, Iceland, Sweden, Finland, Estonia, Denmark, Germany, Spain, Ireland, UK (England & Wales), and UK (Northern Ireland). These entries cover a large part of the natural range of the Atlantic salmon, including the north west and north east Atlantic areas as well as the Baltic area.

The entries for the 'population status' category indicated 40% of rivers had full or substantial populations, 8% were extirpated, and for 19% population status was unknown (Fig 1). Overall, 45% of entered rivers had a restoration or recovery action taken, 26% had no restoration or recovery action taken, and for 29% of rivers it was unknown if a restoration or recovery action had been taken (Fig 1). Over half (54%) of rivers had 'rebuilding' as the programme goal, about a quarter (26%) 'recovery', 13% 're-establishment', and 7 % to maintain a fishery (Fig 1).

Stressors

Pie charts showing the reported proportions of the impact categories of each of the stressors on the river stocks can be found in Figure 2. A good way to demonstrate the relative impact of the stressors is to rank the stressors based on the combined scores of the 'very high impact' and 'high impact' categories. In this ranking (Table 7) the stressor 'Climate Change' tops the list with 46%, followed by 'Barriers' (26%) and 'Habitat Degradation' (22%). The stressors 'Aquaculture', 'Diseases/parasites', and 'Invasives' all scored 0% in the 'very high impact' and 'high impact' categories and were lowest ranked on the list. Under the 'Other' category problems with ice cover, peat mining, and drainage were reported. These were however limited to one or two rivers.

Actions

Pie charts showing the reported proportions of the effect categories of each of the actions on the river stocks can be found in Figure 3. Similar to the stressors listed above the relative effects of the actions can be demonstrated well by ranking (Table 8) based on combined scores of the 'very high effect' and 'high effect' categories. In this ranking the action 'Improved connectivity' scores highest with 34%, followed by 'Improved water quality' (23%) and 'Habitat restoration' (14%). The list was concluded with 'Invasive species control', 'Parasite/disease control', 'Farmed fish removal', and 'Other' all scoring 0%. Not a single entry was made under the 'Other' actions suggesting that the list presented here was comprehensive.

DBERAAS Discussion

Population status

Analysis of DBERAAS showed that about one-third (30%) of rivers in the database had a CL at or above 100%. This suggests that Atlantic salmon stocks in a large number of rivers in this study were at full reproductive capacity at the time of the assessment and might currently not be under threat. Eight percent of river stocks were extirpated, and the stock status of 19% of river stocks was unknown. The latter highlights the general need for a better knowledge on stock status of many rivers, and rivers that are the focus of recovery and restoration actions in particular.

Recovery actions taken

Nearly half (45%) of the river stocks in the database were known to be the subject of recovery or restoration actions. On almost one-third (30%) of rivers it was unknown if recovery/restoration actions had taken place. This suggests the urgent need for a better availability of very basic information on the existence of recovery/restoration actions to national and/or international fishery management bodies.

Programme goals

Over half (54%) of recovery/restoration actions programme goals were in the 'Rebuild' category. This could be expected as most river stocks in DBERAAS are below their biological reference points. Seven percent of entered programme goals were in the 'Fishery' category. These stocks are all confined to the Baltic area, with the Danish River Gudenå, which flows into the Kattegat west of Denmark, as the single exception.

Stressors

Climate change is ranked as the most important stressor (46%) on stocks in DBERAAS. The effects of climate change on marine survival of Atlantic salmon are increasingly reported on in the scientific literature as being a major driver of reductions in population size, especially so for the stocks towards the southern end of the species' range (Chaput, 2012, Mills *et al.*, 2013). This ranking is probably a fair reflection of the impact that climate change has on the conservation status of the Atlantic salmon stock as a whole. In addition, climate change has also been reported as a major factor in the declines in recently restored salmon populations in the New England region of the USA (Gephard, 2008).

Barriers have been reported as strong or very strong stressors throughout the Atlantic salmon's range and was the second most important stressor according to the DBERAAS at 26%. It is no surprise barriers are often reported in the scientific literature as having severe impacts. Without highly successful fish passage systems barriers can result in large sections of rivers having reduced or completely eliminated access for spawners and thus significantly reduced production in those areas. In addition, the cumulative effects of a sequence of partially passable barriers can also be very significant, as discussed earlier in this document. Therefore the high rank of 'barriers' in the DBERAAS list of very strong and strong stressors appears to be supported by reports in a wide range of scientific studies, many of which are quoted and discussed in previous chapters of this document.

Habitat degradation and pollution were ranked third (22%) and fourth (14%) respectively on the list of high to very high impact stressors. The scientific literature provides many examples of how degradation of salmon habitat and pollution of watercourses impacts on salmonid populations, resulting in decreasing population sizes or even extirpations. In review papers on global stock status of Atlantic salmon both Hindar (2003) and Parrish *et al.* (1998) reported pollution as one of the most important agents responsible for the decline in salmon stocks. This view appears to be supported by the results from the DBERAAS analysis.

Water regulation ranked fifth (12%) on the list of stressors with a high or very high impact. From the literature it is known that this stressor can have a negative impact on salmon populations, yet actual extirpations, which are a realistic probability if a stressor has a strong or very strong impact, as a direct result of this stressor appear to be very rare. It might be possible that the effects of this stressor are underestimated in the scientific literature, as it appears that from the DBERAAS results that water regulation is an important and high-impact stressor on salmon stocks.

Under 'other stressors' (ranked sixth at 9% in the list of high to very high impact stressors) it was mainly rivers from Finland that periodically suffered from low pH as a result of natural sulphite deposition. As this is a natural phenomenon it cannot be listed under the stressor 'pollution' with the rest of rivers that suffer from acidification and it warrants listing in the 'other' category.

Exploitation ranked seventh out of 12 stressors. From reports in the scientific literature it might have been expected that this stressor would rank higher. A possible explanation is that the relatively low rank might have been an artefact of data from countries reporting some of the most substantial remaining homewater commercial fisheries for Atlantic salmon (ICES, 2016a) are missing from DBERAAS (Canada, Scotland, Russia, and Norway). Alternatively, it could be that exploitation of Atlantic salmon, which has been greatly reduced since the late 2000s (ICES, 2016a), is not a very common 'very strong' or 'strong' stressor any more in many stocks that were assessed for DBERAAS.

Stocking and predators are stressors that only very occasionally got listed as having a high or very high impact. Stocking, introgression of domesticated genetic material in wild populations, and their negative impacts on wild fish has been proven both theoretically and also been observed in the wild (e.g. Christie *et al.*, 2014, 2016). However, reports on this being a major impact in declines of wild salmon stocks have thus far not appeared in the literature. But considering the mounting body of evidence that stocking can have very negative effects on the genetic composition and persistence of wild salmon populations over time this could be currently unreported. If new studies can link these effects with population declines in the wild stocking might have to be reassessed as an action that 'if it doesn't work it certainly does not harm' to an action that can potentially become an actual stressor.

From the literature it becomes apparent that the exact impact of predation on wild salmon stocks is very difficult to determine and thus currently poorly understood, despite every salmon population being subjected to predation in various degrees. In the few cases where reliable data exists it becomes clear that predation can, in some circumstances, have strong impacts on salmon population sizes as shown for example by Kennedy and Greer (1988). It appears however that these effects are of a local, and not global nature. It has to be noted too that predation is a natural phenomenon and it is very difficult to determine what 'natural' and 'un-natural' levels of predation are, especially since predation levels are not naturally temporally stable.

Aquaculture, diseases/parasites, and invasives were not once reported as having a very strong or strong impact on stocks. It is known from the literature discussed earlier in this report that aquaculture, diseases like UDN, and parasites like *Gyrodactylus salaris* can be strong stressors on stocks. The fact that the countries where aquaculture (Canada, Scotland, and Norway) and diseases and parasites (Norway) are most regularly encountered did not submit data must be regarded as a plausible explanation for these stressors not being identified as 'very strong' or 'strong' in DBERAAS. Outside of this WGERAAS report information on the impact of the stressors 'aquaculture' and 'diseases/parasites' does exist for example for Norway in the shape of the annual '*Status for Norske laksebestander. Rapport fra vitenskapelig råd for lakseforvaltning*' (Status of Norwegian Salmon Stocks. Report of the Scientific Council for Salmon Management). In 2015 this publication (Anon, 2015) reported a strong effect of aquaculture escapees on wild Norwegian salmon stocks, with genetic introgression levels of domesticated genetic material ranging between 2 and 47%. Especially small and depleted stocks were reported be at risk, the larger stocks being more resilient to introgression. Annual numbers of escaped aquaculture salmon in Norway alone were estimated to be between one and two million individuals. Various studies on the number of escaped fish ascending Norwegian rivers are discussed in Anon (2015), with one large study reporting 21% of rivers having >10% of the adult spawners comprising of aquaculture escapees. This indicates that in countries like Norway, with a large indigenous open-cage salmon aquaculture industry, escapees from such facilities can pose a substantial threat to the persistence of the local salmon populations. In fact the Norwegian Scientific Council for Salmon Management classifies both aquaculture escapees and sea lice as the two most severe 'non-stabilised' population threats to Norwegian wild salmon stocks, also reported by Forseth *et al.* (2017). A 'non-stabilised' threat is defined as a threat that affects populations so severely that it can reduce populations to critically low numbers or even total population loss, and with a high probability of causing further loss if implemented measures are not sufficient to control or reduce the factor's effect and prevalence. If this assessment by Norwegian scientists generally applies to other regions with high levels of open-cage salmon aquaculture but not present with data in DBERAAS (e.g. Scotland and some parts of Canada), aquaculture is probably a strong to very strong stressor on salmon populations in areas where salmon aquaculture is concentrated, despite not being reported as such in this study on a frequent basis.

The parasite *G. salaris*, discussed in detail on page 12 of this document, is regarded by the Norwegian Scientific Council for Salmon Management as one of the greatest threats against Norwegian salmon populations, albeit that the threat of this parasite appears to be reduced as a result of successful eradication measures in many salmon rivers in recent years (Anon, 2015). With 50 Norwegian rivers reported to having been infected with *G. salaris* and the parasite having had a very strong negative impact on the salmon stocks of those rivers it would appear that in certain countries that were not included in DBERAAS diseases and parasites are having 'strong' or 'very strong' impacts on salmon populations and thus the impacts of diseases and parasites are most likely underestimated in DBERAAS. *G. salaris* has thus far had a heavy impact mainly on wild Norwegian stocks (Bakke *et al.*, 2007) with additional infections reported from rivers on the Swedish west coast (Alenäs *et al.*, 1998), and a river in the White Sea in the Russian Federation (Ieshko *et al.*, 1995). In countries outside the native Baltic range such as Poland (Rokicka *et al.*, 2007), Denmark (Lindenstrøm *et al.*, 2003), and recently Romania (Hansen *et al.*, 2016), the species has been reported infecting brown- and rainbow trout in aquaculture facilities. It appears therefore that the effects of this stressor can be locally extremely severe, but do not act globally on a range-wide scale.

Actions

Improved connectivity was most often reported as an action having either a 'very strong' or 'strong' effect. As the equivalent stressor ('Barriers') to this action was also reported as the most common 'strong' or 'very strong' stressors after Climate Change it is perhaps not surprising that actions aimed at reducing the stressor 'Barriers' results in a strong positive effect on the conservation status of stocks. In the absence of a clear action against climate change, 'Improved connectivity' is the action most likely to have a positive effect, especially considering this action also scored very highly in the 'Moderate effect' category (42%) resulting in 76% of all reported improved connectivity actions in DBERAAS indicating at least a moderate effect or higher. Improvements in water quality was ranked as the second most successful action on the basis of entries in the 'very high effect' or 'high effect' categories. This is probably an effect of the equivalent stressor ('Pollution') ranking as fourth in the list of strongest stressors, just as with the previous action 'Improved connectivity'. When comparing the list of strongest stressors to the list of most effective actions this rule generally applies; if the stressor is strong, a successful action mitigating for or removing the stressor will result in an improved population status of the stock in question. In the list of ranked actions too equivalent actions to the stressors 'Aquaculture' and 'Diseases/parasites', 'Farmed fish removal' and 'Disease/parasite control' respectively, are not reported a single time in the 'very strong' or 'strong' categories. This is again very likely a result of the countries with the largest Atlantic salmon aquaculture production (Norway, Canada, and Scotland) and regular reports of local problems with outbreaks of parasite infestations (Norway), not supplying data for DBERAAS. It could be possible that the actions 'Farmed fish removal' and 'Disease/parasite control' can have very strong or strong positive effects in areas where 'Aquaculture' and 'Disease/parasites' are commonly occurring strong or very strong stressors on some river stocks.

5.3 Case studies

Introduction

The WGERAAS case studies are supported by the results from DBERAAS and are intended to form the basis of the study to answer the ToRs of this working group.

In 2015, the suggestion from NASCO was received in relation to the answering of the ToRs to focus on the case studies. WGERAAS interpreted this suggestion by changing the focus from DBERAAS supported by case studies to using the case studies as the primary tool to answer the ToRs, with support of an analysis of DBERAAS.

The case studies cover both successful and less successful examples of recovery and restoration actions for Atlantic salmon and the aim was to collect examples from a broad geographical range. This resulted in the 15 well documented case studies presented in Annex 3, and summarised in Table 9. Successes and failures are both present, as are examples that lie somewhere between these two extremes. The geographical spread ranges from the south of France to the north of the Russian Federation, and from Maine in the USA to the Gulf of Bothnia in the Baltic Sea.

All case studies were documented using a standard template in order to facilitate a common approach. This template utilises the same Stressor and Action definitions as used in DBERAAS. In addition details on the actions taken are required, as is information on project duration, evaluation (pre-, mid-, and post project), metrics used, project goals, and project success.

Discussion – case studies

Of the 15 case studies presented here five achieved the project goals, nine did not achieve project goals, and two claimed partial success. However, it has to be noted that the two projects that claim partial success (Rhine and West River) did not achieve goals (yet) and should therefore be currently classified as not having achieved pre-project objectives. Both projects did achieve some level of success (small increases in adults returns, smolts, or improved water quality), but all nine case studies that did not achieve project goals also reported improvements in some metrics as a result from the actions taken. Therefore, both the Rhine and West River recovery/restoration actions, for the purpose of this study, should be regarded as currently not achieving project goals.

The Working Group wants to explicitly stress that 'project goals' and the achievement of those is assessed within the specific context of this study. Some of the case studies presented here as not having achieved project goals might have achieved project goals as defined by their respective national fisheries management bodies. But for WGERAAS project goals are linked to CL attainment, and project success is assessed on that basis. The Working Group acknowledges that certain projects that did not achieve WGERAAS project goals have had some measure of success, even though CL attainment might not be a realistic possibility. There can certainly be value in projects that do not achieve WGERAAS defined project goals, such as decreasing of population extinction risk and gaining of knowledge on what measures work best in restoration and recovery actions.

What common characteristics defined the successful case studies? Firstly, all the successful case studies had fewer stressors listed compared to unsuccessful and partially successful case studies. Secondly, four out of five successful case studies were found in Northern NEAC countries, where currently marine survival estimates for stocks are on average higher compared to Southern NEAC countries and the southern part of NAC. It was in these latter two areas where all unsuccessful and partially successful case studies in this study were confined. Thirdly, successful restoration and recovery projects managed to address all stressors acting on the population, in contrast to many unsuccessful ones where not all stressors were, or could be, addressed. Finally, projects that just use stocking and do not take actions specifically aimed to address certain other stressors that are known to act on a population are not likely to be successful. However, in four out of five successful case studies (Mandalselva, Testeboån, and Tornionjoki) stocking was reported among the principal restoration actions. This might indicate that in certain circumstances stocking can be an effective action, or that the strength of certain stressors acting on the population decreased unobserved during the study. It would also be possible that because stocking has been such a widely used, almost ubiquitous, conservation measure, restoration and recovery programmes almost by default will have had a stocking element present. It is therefore very difficult in many cases to single out the effect of the stocking versus the effects of other conservation measures. This might result in an overestimation of the benefits of stocking, or an underestimation of the benefits of alternative restoration actions.

The River Tyne case study in this report is a good example of this. Although claimed in some grey literature as having recovered mainly through stocking, research has shown that stocking may largely have contributed to stabilising the population in the early stages of recovery. However, the main reason for the recovery was the much improved water quality in the lower river (Milner *et al.*, 2004, 2008). These conclusions could only have been reached because of a number of scientific studies on the details of the salmon stock recovery in this river. Such extensive scientific studies on recovering salmon stocks are by no means the norm, as this report has shown. There is therefore a risk that in situations where scientific studies are lacking stock recovery is incorrectly (solely) attributed to stocking efforts, which in turn can lead to the perpetuation of an inefficient restoration action not only locally, but also in general when stocking remains the first reaction of management to a perceived reduction in stock size. Carr *et al.* (2015) also observed this and suggest that 'the 'stock first' approach is knee-jerk and could eventually inflict more harm than good'.

Another argument against the use of stocking given by Carr *et al.* (2015) is that stocking large numbers of hatchery origin fish also can disguise the negative effects that stressors such as overexploitation, pollution, and loss of connectivity are having on a salmon population. Such a situation would be very undesirable as it would give the false impression that the stressors on the population have successfully been addressed, whilst in reality population persistence relies on the continuation of a large scale stocking programme. If the stocking programme was to be scaled down or discontinued population numbers will most likely collapse once more in such cases. Further caution for using stocking as the main action against population declines comes from a study from Spain: Horreo *et al.* (2011) reported that habitat restoration and improved connectivity were the most efficient measures to increase salmon numbers, in contrast to supportive breeding programmes, which were deemed ineffective and possibly harmful by reducing natural variation in local salmon stocks and the threatening the survival of sympatric trout (*Salmo trutta*). These conclusions are supported by both the case studies and the analysis of DBERAAS in this study.

As mentioned above, from the case studies is appears populations from the Northern NEAC area were more likely to be successfully recovered or restored compared to Southern NEAC. This is probably caused by the current cycle of low marine survival experienced by many southern stocks compared to more northerly stocks, on both sides of the Atlantic (ICES, 2016a). The theoretical effects of marine mortality on a restoration programme for Atlantic salmon are very well illustrated by an equilibrium modelling approach of population dynamics predicting the population-level response to potential recovery and restoration actions in the Nashwaak River (Gibson *et al.*, 2009). What becomes apparent from this particular analysis is that at very low marine survival rates (3.2% for 1SW, 0.9 for 2SW) actions in freshwater have little to no effect on potential ova deposition and smolt production, and the population remains well below conservation requirements. Only in scenarios where marine survival rates were more than doubled, in combination with significant improvements in freshwater production and connectivity did the population exceed conservation requirements.

This exercise is very useful in determining the possible benefits of recovery actions which can help the decision making process in selecting the most effective measures, as well informing what the likely causes are when actions are failing to effectively recover depleted stocks. It would be very beneficial for all cases where recovery or restoration actions are considered to undertake similar modelling exercises as part of a pre-project assessment. This would enable the design of a maximum impact strategy where resources are committed in areas where the greatest benefits can be achieved, as well as inform stakeholders of possible limited (short term) benefits of actions taken in cases where not all stressors can immediately be addressed. It has to be noted that limited (potential) benefits of actions should not automatically result in a rejection of implementing certain actions. As Gibson *et al.* (2009) have shown, situations where multiple stressors are acting simultaneously on a population are extremely complex and that disentangling the effects of the individual stressors needs careful analysis and, most of all, good quality population data. Under some conditions, like for example low marine survival (Gibson *et al.*, 2009), only a partial population recovery might be possible in the short-to-medium term. Such an outcome would be preferable to taking no actions and increasing the chances of a complete loss of the population. An example of this can be found in the Penobscot River in the USA where ongoing restoration actions such as dam removal, improved passage efficiency at existing dams, improved connectivity throughout the watershed, and stocking are primarily aimed at decreasing the extirpation risk of the local salmon stock as persistently low marine survival prevents this population of attaining CL (pers. comm. T. Sheehan). Pre-project modelling of population responses to actions under various environmental conditions can prevent projects from aiming for unrealistic goals, in addition to the already mentioned selection of the most effective actions.

As was shown by the case studies, populations with few stressors acting on them appeared to have a higher success rate of successful restoration compared to populations that face a multitude of stressors. The example by Gibson *et al.* (2009) shows the complexity and difficulty of mitigating for situations where multiple stressors affect a salmon population, and it can be easily envisaged how a single stressor situation can be much more easily mitigated. An added problem with multiple stressor situations is that interactions between multiple stressors are not always simply additive in nature, but can display synergistic (where effects of the combined stressors are greater than the sum of the individual stressors) or antagonistic (where effects of the combined stressors are lesser than the sum of the individual stressors) effects as well. In a study of multiple human stressors on fish assemblages in European rivers, Schinegger *et al.* (2016) reported 40% of stressors interactions were additive, 30% synergistic, and 30% antagonistic. Brown *et al.* (2013) reported that the greatest benefits are achieved if local (i.e. not global), synergistically interacting stressors are addressed. Benefits were smaller, or even negative, when local stressor interactions were antagonistic in nature. The authors also reported addressing local stressors had little effect on the impact of global stressors like climate change, and concluded that focussing on local synergistic stressors could at best buy time to allow evolutionary adaptation, development of alternative management strategies, or global warming mitigation. This research highlights the importance in multi stressor scenarios of understanding the nature of stressor interactions (additive, synergistic, or antagonistic) as well as the scale on which the stressors operate (local or global). Only when these factors are known and understood can realistic predictions be made on the likely outcome of restoration and recovery actions.

Brown *et al.* (2013) thus offers an explanation why recovery and restoration actions in the southern parts of the Atlantic salmon's range have often been unsuccessful; in these areas the effects of the globally acting stressor climate change manifest themselves to a greater extent than in more northern areas. Modelling exercises (Brown *et al.*, 2013) predict that in these areas addressing locally acting stressors will provide little benefit to populations, whereas addressing local synergistic stressors in areas where global stressors are largely absent (northern range of Atlantic salmon) will likely result in substantial benefits. This was exactly what has been observed in the case studies where recovery and restoration actions taken in more northern areas (Norway, Finland, and Russia) generally resulted in very substantial benefits. The report from the Salmon Summit held in La Rochelle, France, in 2011: "Salmon at Sea: Scientific Advances and their Implications for Management" echoes Brown *et al.* (2013) suggesting that salmon populations are currently adapting to climate change effects, and that this takes time and comes at a cost of high mortality at sea (Anon., 2011). This could suggest that conservation measures aimed to conserve stocks affected strongly by climate change should primarily be taken with the intention of buying time to allow evolutionary adaption to the new climatic conditions to occur. Inherent phenotypic plasticity (especially when transgenerational) could act as an initial buffer to climate change in fish, allowing evolutionary adaption (taking multiple generations) time to 'catch up' (Shama *et al.*, 2016), even though evidence of actual evolutionary responses to climate change in fish remain rare in the literature (Crozier and Hutchings, 2014). It should be clear that any activities that can disrupt or delay this process of evolutionary adaptation (such as stocking or translocation of fish) should not be undertaken as it can seriously jeopardise population persistence.

Based on the case studies, it appears that a successful recovery or restoration programme for Atlantic salmon is characterised by:

- A limited number of stressors acting on the population;
- Recovery/restoration actions that successfully address all or most stressors acting on the population;
- Conducted in an area of high average levels of marine survival;
- Does not mainly rely on stocking as a recovery/restoration action.

It has to be reiterated that a restoration or recovery programme that does not reach its goals (e.g. (re)establish a self-sustaining population, increase population to attain CL) can nonetheless be very valuable. As the previous discussion showed, programmes that do not result in meeting the defined pre-project goals can still reduce short-term extirpation risks and allow populations time to adapt to global stressors such as climate change. The value of such outcomes should not be underestimated.

Recommendations

The report of this Working Group is not the only document published in recent times on the topic of restoration and recovery actions for Atlantic salmon. For example a conference on salmon stocking organised by the Atlantic Salmon Trust and IBIS (Integrated Aquatic Resources Management Between Ireland, Northern Ireland and Scotland), an European Union Interreg IVA funded collaboration between the Loughs Agency, University of Glasgow and Queen's University Belfast in 2013 produced a report titled 'To stock or not to stock', which summarises the advice on stocking from various salmon management organisations (Anon, 2013). The Atlantic Salmon Federation (ASF) organised a workshop in that same year in St. Andrews, Canada, on restoration and recovery actions for salmon titled "What works? A Workshop on Wild Atlantic Salmon Recovery Programs". The proceedings of this workshop were published by the ASF (Carr *et al.*, 2015). In the peer-reviewed literature too examples can be found of studies on recovery and restoration actions for Atlantic salmon, such as Palmer *et al.*, 2005.

The aforementioned publications all produced a set of recommendations or guidelines on how to increase the chances of conducting a successful restoration or recovery programme of Atlantic salmon. The "To stock or not to stock" report concluded (Anon, 2013, see Annex 5) that stocking poses substantial risks to wild salmon populations and a time-limited stocking programme should only be considered in cases where population extirpation is imminent and all other appropriate and possible fishery management and habitat restoration interventions have been realised. The authors also highlight the need for a well-planned monitoring programme to accompany stocking programmes in order to assess costs, benefits and impacts of the programme on the wild salmon populations.

The main recommendations from the symposium "What works? A Workshop on Wild Atlantic Salmon Recovery Programs" (Carr *et al.*, 2015, see Annex 4) mirrored the "To stock or not to stock" report regarding stocking and the use of hatcheries. They also highlight that stocking in itself is unlikely to produce results and should not inhibit the use of other restoration and recovery actions. In addition, they generally suggest a holistic approach based on the knowledge that healthy and diverse habitat is needed to support healthy and resilient salmon populations. Emphasised is that the first principles of any recovery program will need to be founded on habitat restoration and protection combined with sound management based on population monitoring. Habitat restoration should aim for a healthier and dynamic natural state compared to current conditions, to measurably improve the ecological condition of the system or population, to build resilient and self-sustaining populations minimising the need for future interventions, to ensure no lasting harm is inflicted on the ecosystem, and to publicise pre- and post-project assessment data (Palmer *et al.*, 2005).

This Working Group endorses all the above as the results of this study suggest that implementing the recommendations made would likely increase the success of restoration and recovery programmes, would reduce the risk of actions that are potentially harmful to salmon populations, and would result in more available data supporting scientific work on salmon restoration and recovery. In addition this Working Group is of the opinion that modelling population responses to actions under different stressor scenarios as part of the pre-project phase can be a very informative exercise to determine possible outcomes of different actions. If sufficient population data is available such studies should be considered as part of the project evaluation, both before and during the project. Although already mentioned in other publications (Anon, 2013, Carr *et al.*, 2015, Palmer *et al.*, 2005) the Working Group recognises the need for improved documentation relating to all restoration and recovery projects for Atlantic salmon, and recommends that after completion an in-depth evaluation and analysis exercise should be conducted, and results published so others can benefit from lessons learned

5.4 Tables and Figures

Table 1. The 12 stressors (i.e. threats to populations) against which populations will be assessed in DBERAAS.

1. Pollution (organic and chemical pollution, incl. acidification)
2. Barriers (in-river obstructions; e.g. dams, weirs)
3. Water Regulation (e.g. abstraction, hydro-regulation)
4. Exploitation (e.g. legal & illegal fishing)
5. Aquaculture (e.g. escapees, sediments, sea lice)
6. Habitat degradation (e.g. gravel extraction, siltation)
7. Diseases/parasites (e.g. furunculosis, gyrodactylus, UDN)
8. Climate change (e.g. extreme water temperatures, marine mortality induced by climate change)
9. Invasives (non-native invasive flora and fauna)
10. Stocking (stocking of Atlantic salmon having negative impact on population)
11. Predators (predation during any stage of lifecycle; e.g. cormorants, pike, trout, seals, dolphins, otters)
12. Other (incl. noise pollution, light pollution, shipping, etc.

Table 2. The five options in DBERAAS to assess the impact of the stressors and their definitions.

•Very strong impact. A recognised stressor having a sustained and very significant impact on key life stages or habitats which affects the entire population, and whose impact - if removed - is likely to result in a full population recovery within the context of the prevailing climatic conditions. • Strong impact. A recognised stressor having a sustained and significant impact on key life stages or habitats which affects the entire population, and whose impact - if removed - is likely to result in a substantial recovery within the context of the prevailing climatic conditions. • Moderate impact. A recognised stressor having an intermittent or moderate impact on non-key stages or habitats on a localised scale, and whose impact - if removed - is likely to result in some increase in the abundance of the population within the context of the prevailing climatic conditions. • Low impact. A recognised stressor having an occasional or low impact on non-key stages or habitats on a localised scale, and whose impact - if removed - is not likely to result in a detectable increase on the abundance of the population within the context of the prevailing climatic conditions.

Table 3.The 11 recovery/rebuilding actions listed in DBERAAS.

1. Stocking (introduction of hatchery origin Atlantic salmon)
2. Improved connectivity (e.g. fish passes, weir removal)
3. Habitat restoration (e.g. riparian vegetation, gravel beds)
4. Improved water quality (e.g. water treatment plants)
5. Reduction fishing mortality (e.g. legal actions, quotas, anti-poaching measures)
6. Diseases/parasite control (e.g. furunculosis, gyrodactylus, UDN)

7. Predator control (e.g. culling of predators)
8. Invasive species control (e.g. culling/removal of invasive flora or fauna, legislation)
9. Farmed fish escapes removal
10. Flow management (e.g. reduction in water abstraction, stricter control of hydro-regulation)
11. Others (e.g. reduction in shipping traffic, removing sources of light or noise pollution, etc.)

Table 4. DBERAAS population recovery benefits categories and definitions.

- **Very High benefit.** An action having a sustained and very substantial benefit on key life stages or habitats, which affects the entire population, and which helps achieve full population recovery within the context of prevailing climatic conditions
- **High benefit.** An action having a sustained and substantial benefit on key life stages or habitats, which affects the entire population, and which helps achieve a substantial population recovery within the context of prevailing climatic conditions
- **Moderate benefit.** An action having an intermittent or moderate benefit on non-key life stages or habitats, which affects parts of the population, and which helps achieve a moderate population recovery within the context of prevailing climatic conditions
- **Low benefit.** An action having an intermittent or small benefit on non-key life stages or habitats, which affects parts of the population, and which helps achieve some population recovery within the context of prevailing climatic conditions
- **Nil benefit.** An action having no detectable benefit on this population within the context of prevailing climatic conditions
- **No action.** This action was not taken on this particular river

Table 5. DBERAAS population status category options for database entry and definitions.

- **Full Population**. According to adult monitoring/catch data, juvenile abundance measures, other stock status indicators or expert opinion suggest, greater than 100% of Conservation Limit (CL) has been met.
- **Substantial Population**. According to adult monitoring/catch data, juvenile abundance measures, other stock status indicators or expert opinion suggest, 75% and 100% of CL has been met.
- **Moderate Population**. According to adult monitoring/catch data, juvenile abundance measures, other stock status indicators or expert opinion suggest, 50% and 75% of CL has been met.
- **Low Population**. According to adult monitoring/catch data, juvenile abundance measures, other stock status indicators or expert opinion, between 25% and 50% of CL has been met.

- **Very Low Population**. According to adult monitoring/catch data, juvenile abundance measures, other stock status indicators or expert opinion, 25% or less of CL has been met.

- **Extirpated**. According to adult monitoring/catch data, juvenile abundance measures, other stock status indicators or expert opinion this population has been extirpated.

- **Unknown**. Population status unknown.

Table 6. DBERAAS program goal categories and definitions.

- **Re-establish.** Recovery actions are being implemented to re-establish a population that has been shown to be extirpated. Once a population is re-established, it would then be considered within the 'Recovery' category.

- **Recovery.** Recovery actions are being implemented to recover a population that is at low abundance, may or may not be dependent on hatchery inputs and may or may not be threatened with extinction if current population trends continue into the future. Once a population is recovered, it would then be considered within the Rebuild category.

- **Rebuild.** Recovery actions are being implemented to increase the abundance of a self sustaining population of salmon to meet or exceed its CL.

As a guideline, a program considered within the Rebuild category should be at >25% of CL.

- **Fishery.** Recovery actions are implemented to provided **recreational and/or commercial fishing** opportunities. There is no expectation of increased natural reproduction as a result of the actions being implemented (e.g. ranching programs).

Table 7. Ranked stressors based on the combined scores of the 'very high impact' and 'high impact' categories in DBERAAS.

Stressor		% score	rank
Stressor 8	Climate Change	46	1
Stressor 2	Barriers	26	2
Stressor 6	Habitat Degradation	22	3
Stressor 1	Pollution	14	4
Stressor 3	Water Regulation	12	5
Stressor 12	Other	9	6
Stressor 4	Exploitation	7	7
Stressor 11	Predators	2	8
Stressor 10	Stocking	1	9
Stressor 5	Aquaculture	0	10
Stressor 7	Diseases/Parasites	0	10
Stressor 9	Invasives	0	10

Table 8. Ranked recovery and restorations actions based on the combined scores of the 'very high effect' and 'high effects' categories in DBERAAS.

Action		% score	rank
Action 2	Improved connectivity	34	1
Action 4	Improved water quality (including liming)	23	2
Action 3	Habitat restoration	14	3
Action 9	Flow management	11	4
Action 1	Stocking	10	5
Action 5	Reduction fishing mortality	4	6
Action 6	Predator control	4	6
Action 7	Invasive species control	0	7
Action 8	Farmed fish removal	0	7
Action 10	Parasite/disease control	0	7
Action 11	Other	0	7

Table 9. Overview table case studies.

River	Jurisdiction	Goal	Main stressors		Principal restoration actions		Goal achieved?	Evaluation
			1	2	1	2		
Dennys	USA, Maine	Annual returns of 60–120 fish	Climate change / marine survival		Stocking programme		No	Poor survival of stocked fish in estuarine / nearshore areas. Compounded by low marine survival.
Mandalselva	Norway	Re-establish sustainable population above CL	Acidification	Hydroelectric power schemes	Water quality improvement - liming	Stocking programme	Yes, largely. CL achieved in 6 of last 8 years	Recovery not fully sustainable yet as still dependent on liming
Tuloma	Russian Federation	Maintain population at historic level	Hydroelectric power schemes - barriers		Installation of fish passage facilities		Yes	Numbers of ascending salmon maintained at historic levels
West	Canada, Scotia Fundy	Increase freshwater survival and hence production of salmon	Acidification	Climate change / marine survival	Water quality improvement - liming	Habitat improvements	No	Freshwater environment improved with some evidence of better smolt survival. However, adult returns not monitored and thought to remain low
Tyne	UK (England & Wales)	Restore self-sustaining population	Water quality in estuary		Progressive improvements in water quality	Stocking programme	Yes	Dominant process was the improvement in water quality enabling natural recovery. Stocking programme is thought to have accelerated and stabilised stock recovery in its early stages when water quality improvements were still inconsistent
Gave of Pau	France	Re-establish a self-sustaining population of 1000–2000 adults per year	Barriers / river connectivity	Exploitation	Fish passage improvements - fishways	Stocking programme	No	Some improvement in adult returns, but well below target level. Project has so far failed to establish a self-sustaining breeding population

Shannon, Erne, Lee & Liffey	Ireland	Restore self-sustaining populations	Hydroelectric power schemes - barriers	Climate change / marine survival	Improve connectivity	Stocking programme	No - rivers far below CL	Extensive stocking programmes over the last 13 years, particularly for rivers with major HEP stations have made little real contribution to the productivity of these rivers or to the goal of restoring self-sustaining salmon runs.
Rhine	Netherlands, Germany, Luxemburg, France, Switzerland	Restore self-sustaining population	Pollution / water quality / water regulation	Barriers	Water quality improvement	Stocking programme	No	Water quality and spawning habitats in a number of tributaries shown to be suitable. Adult returns achieved and some evidence of natural spawning. However, numbers of returns currently falling and self-sustaining population not yet achieved
Garonne	France	Restore self-sustaining population	Barriers / river connectivity	Water regulation	Improve connectivity	Stocking programme	No	The project has so far failed to establish a self-sustaining breeding population. Numbers of returning adults are currently similar to those at the beginning of the programme. Various possible reasons for this, including reduced marine survival.
Testeboån	Sweden - Baltic Sea	Restore self-sustaining population	Hydroelectric power schemes - barriers	Habitat degradation	Stocking programme	Improve connectivity	Yes	The reintroduction programme has been very successful. Even though the salmon population has not yet reached the MSY-based management objective, the restoration efforts have resulted in the re-establishment of a self-sustaining wild salmon population

Tornionjoki	Finland - Baltic Sea	Increase spawners numbers. Improve population status	Over-exploitation		Control of exploitation (1990s on)	Stocking programme (1977–2002)	Yes	Population has recovered. Key factor was the introduction of restrictions on the sea fishery; this was associated with the simultaneous occurrence of relatively favourable natural conditions for marine survival. Stocking has had only minor, and perhaps even non-existent, impact on stock recovery.
Thames	UK (England & Wales)	Restore self-sustaining population	Pollution / water quality	Barriers / river connectivity	Stocking programme	Improve connectivity	No / Partial	Failed to achieve self-sustaining stock over anticipated timescales, although a number of project goals were achieved. In particular, the project raised the profile of the river and of fish migration and water quality requirements, and led to improvements.

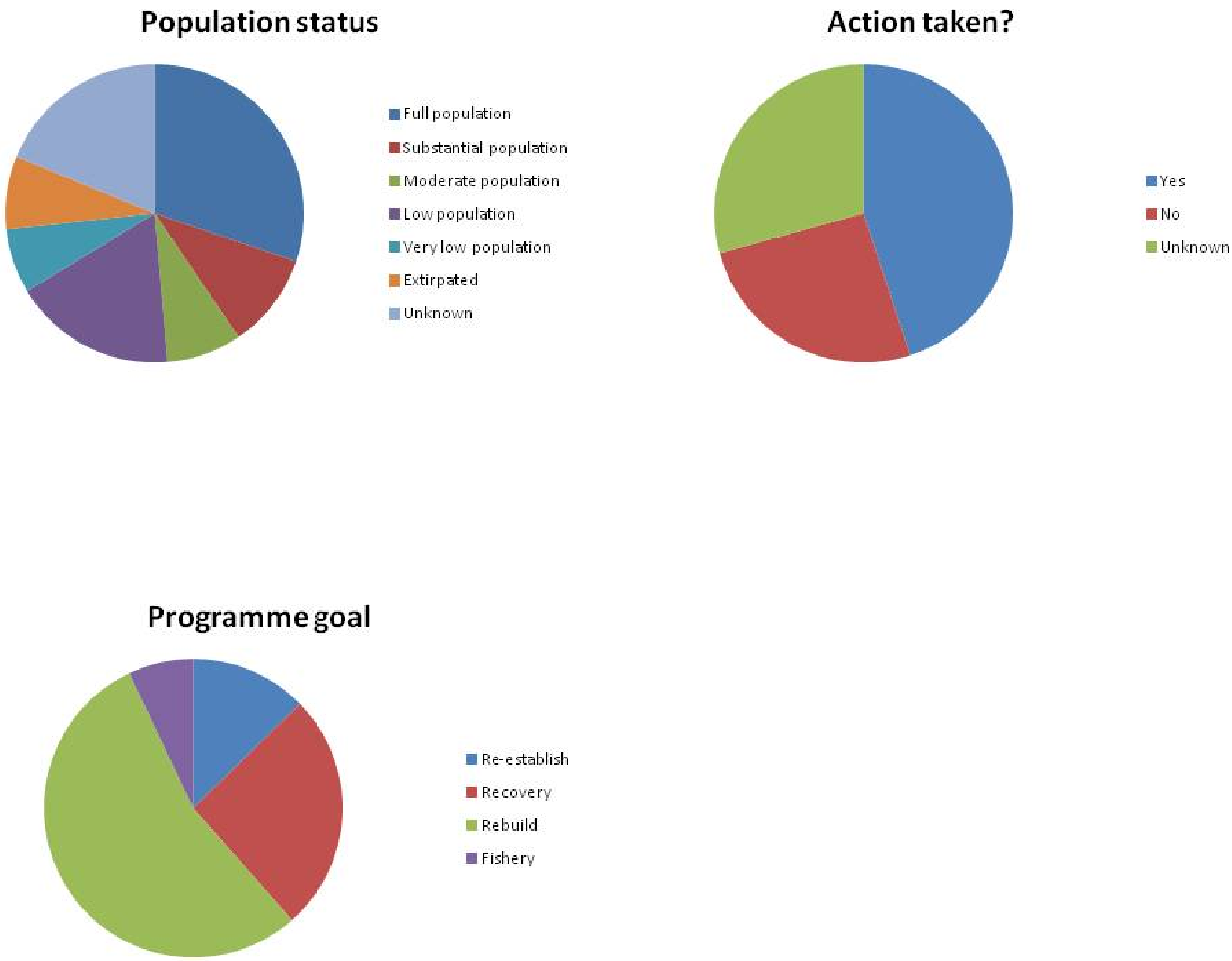
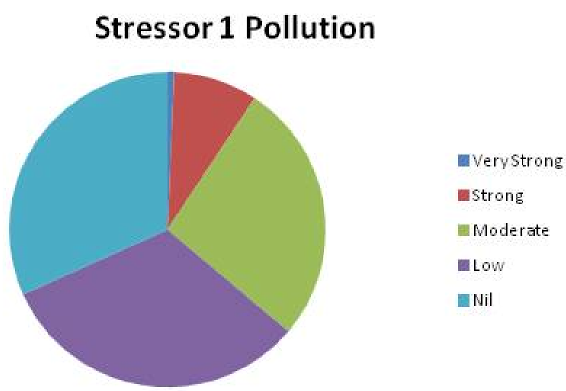
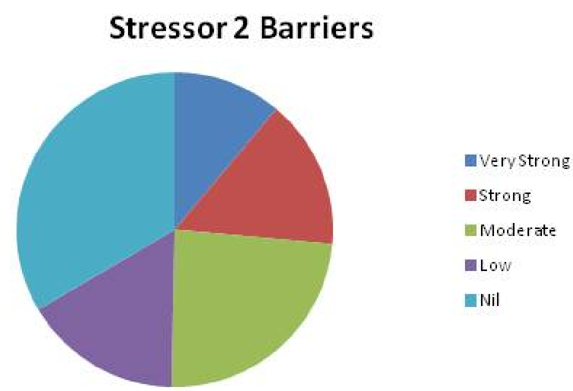
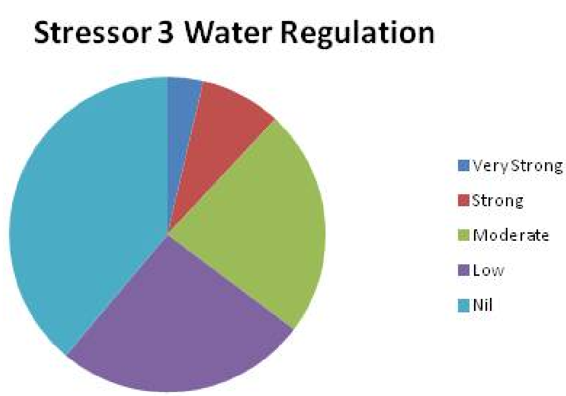
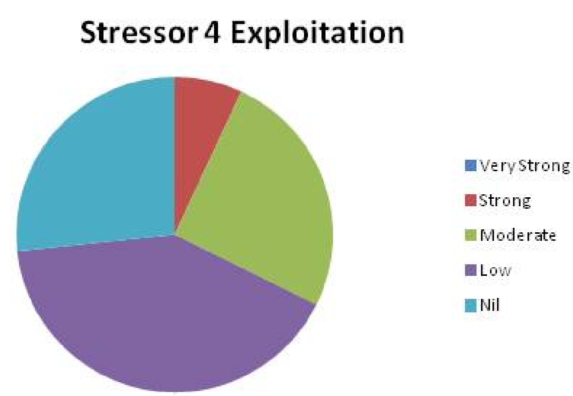


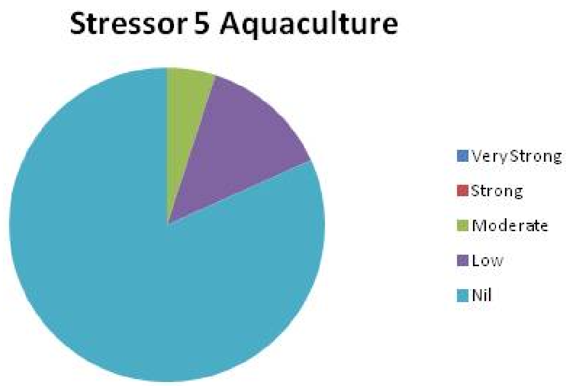
Figure 1. Pie charts of DBERAAS entries for the categories 'Population status', 'Action taken?', and 'Programme goal'.

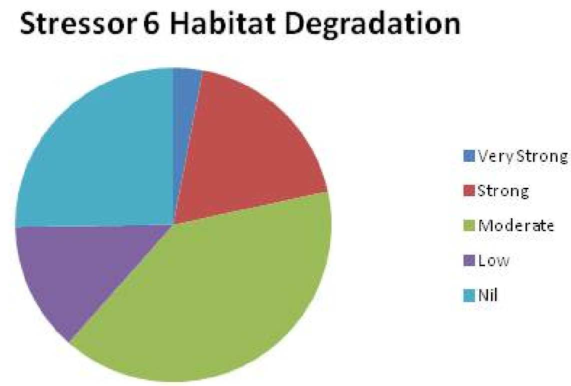

Stressor 1 Pollution
Very Strong
Strong
Moderate
Low
Nil

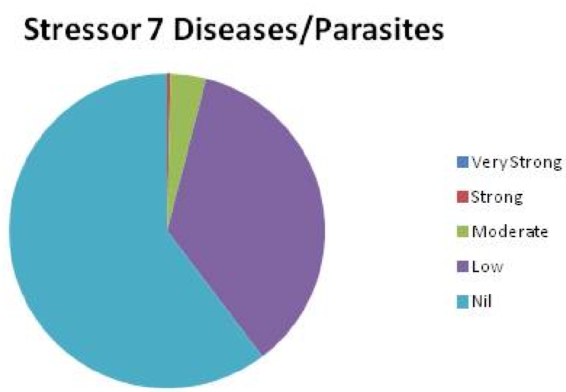

Stressor 2 Barriers
Very Strong
Strong
Moderate
Low
Nil

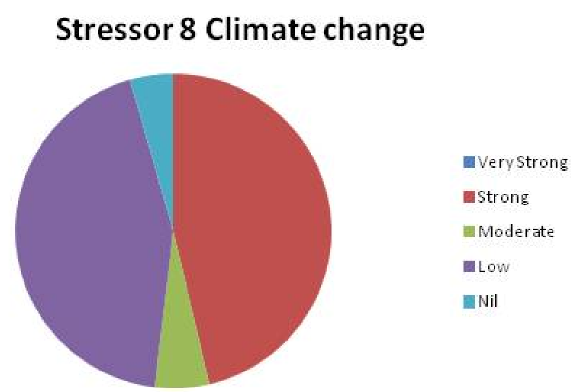

Stressor 3 Water Regulation
Very Strong
Strong
Moderate
Low
Nil


Stressor 4 Exploitation
Very Strong
Strong
Moderate
Low
Nil


Stressor 5 Aquaculture
Very Strong
Strong
Moderate
Low
Nil


Stressor 6 Habitat Degradation
Very Strong
Strong
Moderate
Low
Nil


Stressor 7 Diseases/Parasites
Very Strong
Strong
Moderate
Low
Nil


Stressor 8 Climate change
Very Strong
Strong
Moderate
Low
Nil

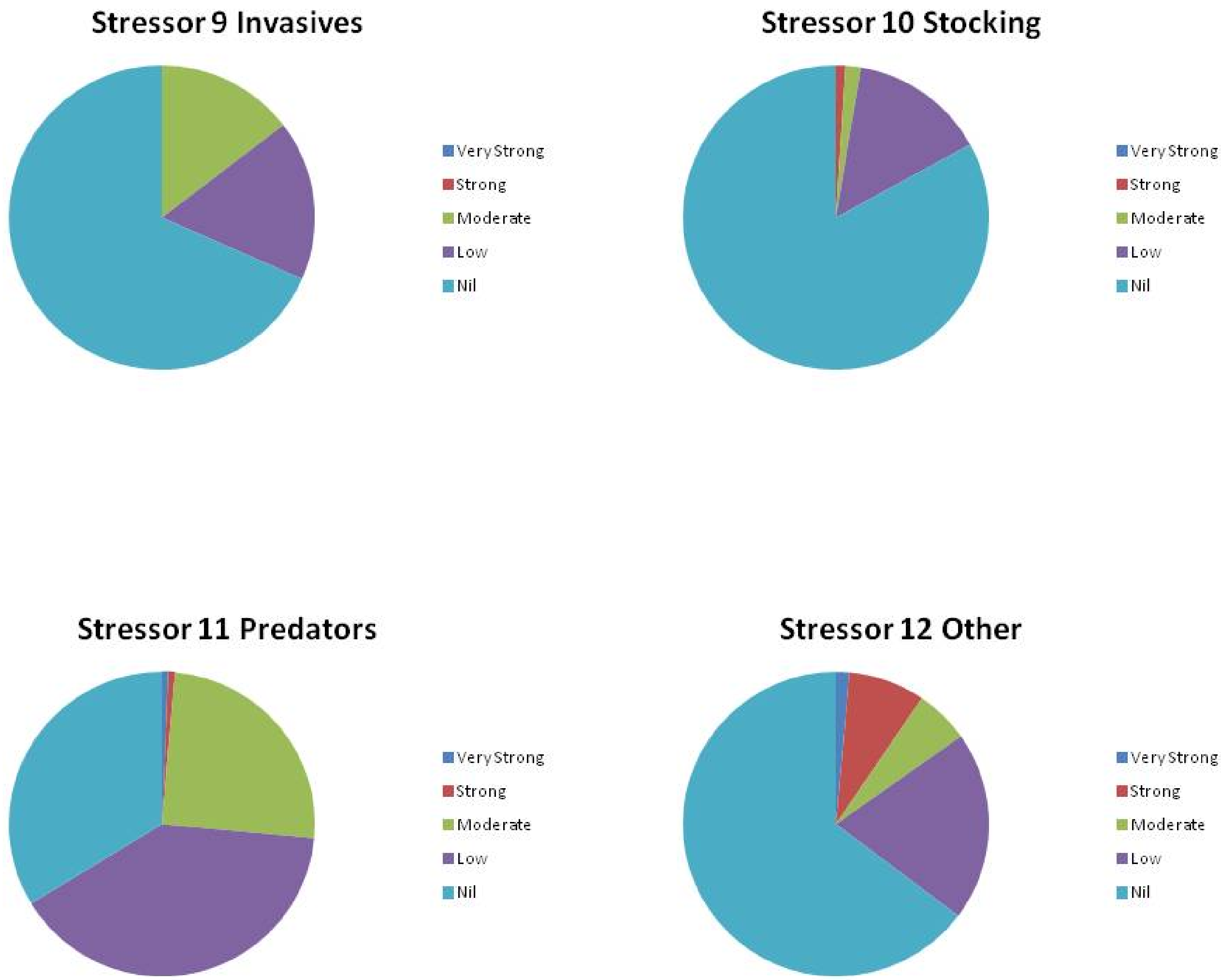
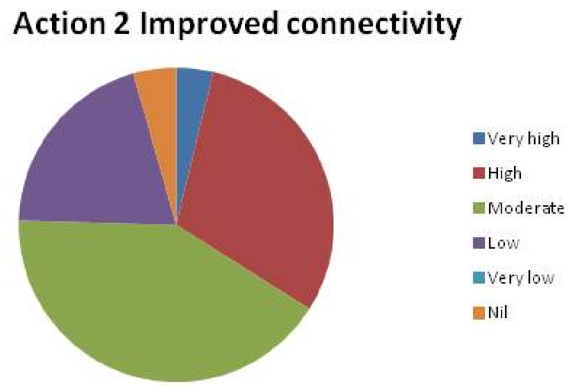
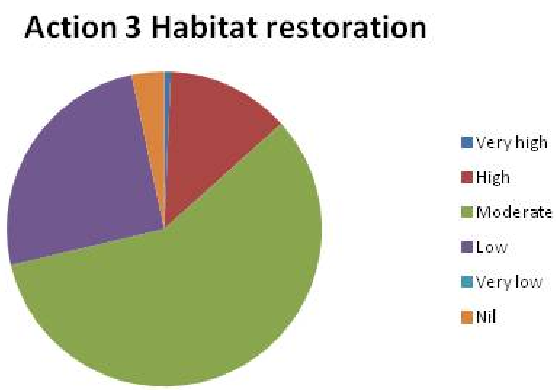
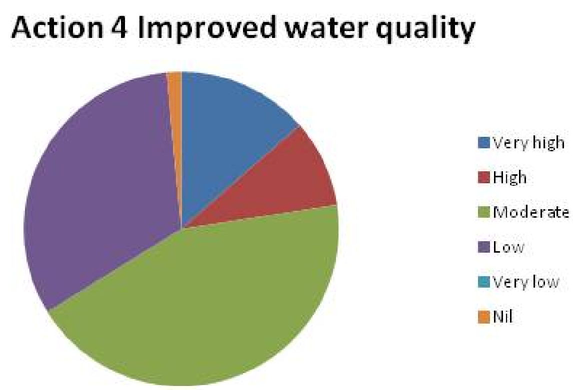


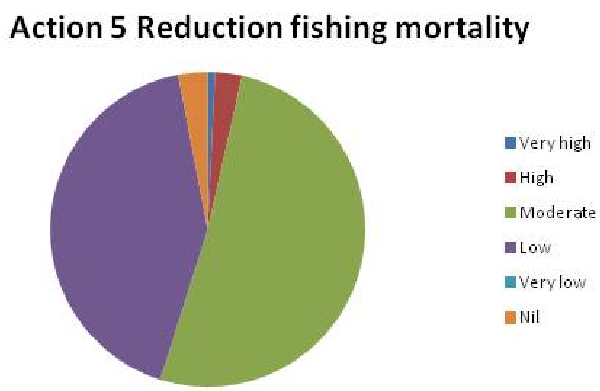
Figure 2. Pie charts of DBERAAS entries for the 12 Stressor categories.

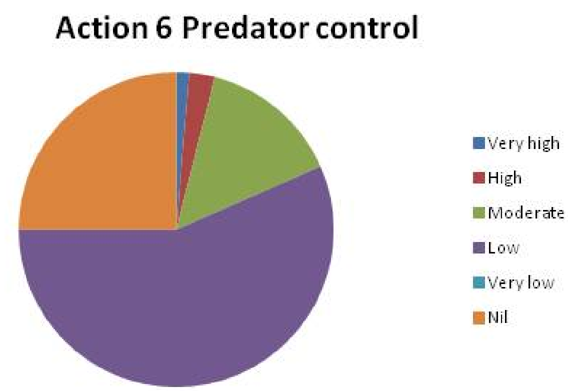

Action 1 Stocking
Very high
High
Moderate
Low
Very low
Nil

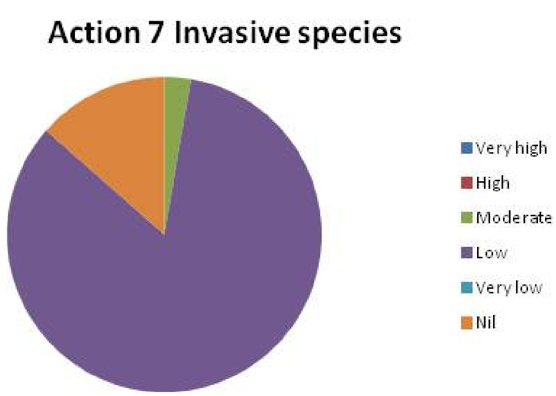

Action 2 Improved connectivity
Very high
High
Moderate
Low
Very low
Nil

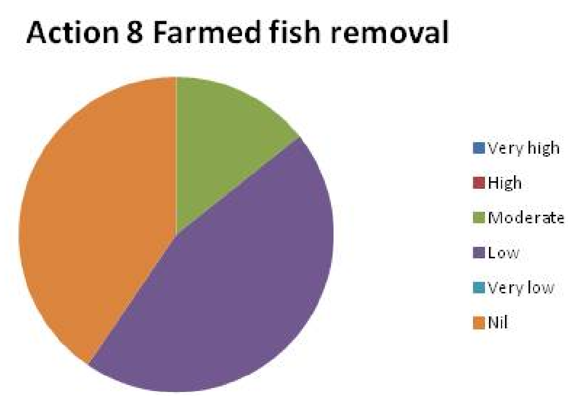

Action 3 Habitat restoration
Very high
High
Moderate
Low
Very low
Nil

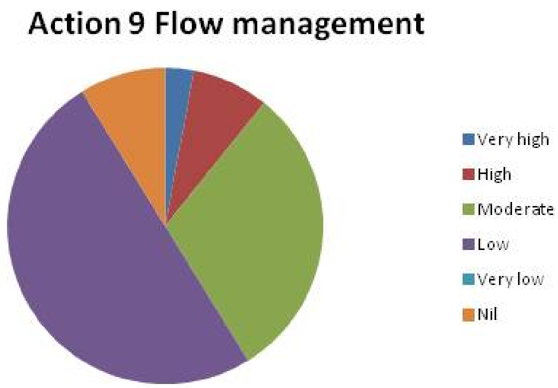

Action 4 Improved water quality
Very high
High
Moderate
Low
Very low
Nil

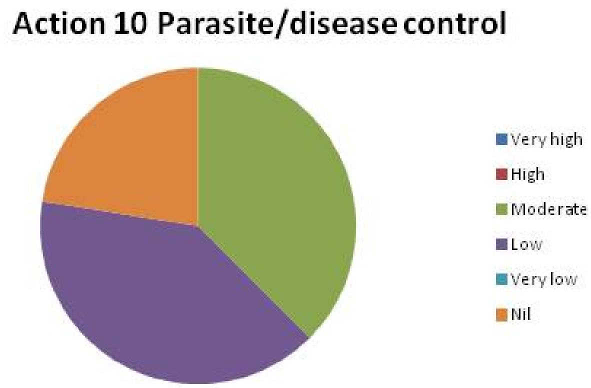

Action 5 Reduction fishing mortality
Very high
High
Moderate
Low
Very low
Nil


Action 6 Predator control
Very high
High
Moderate
Low
Very low
Nil


Action 7 Invasive species
Very high
High
Moderate
Low
Very low
Nil


Action 8 Farmed fish removal
Very high
High
Moderate
Low
Very low
Nil





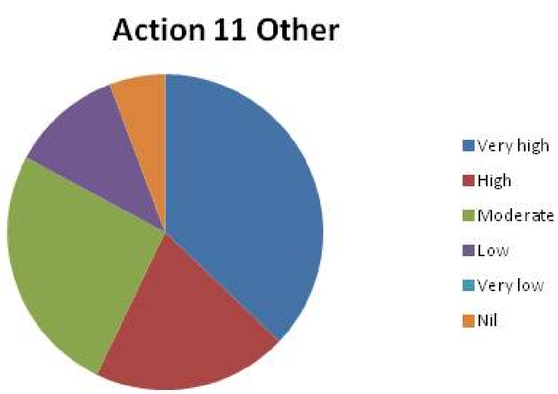


Figure 3. Pie charts of DBERAAS entries for the 11 Action categories.

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6 Cooperation

- WGNAS
- WGBAST
- WGRECORDS
- NASCO

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Annex 2: WGERAAS self-evaluation

1) Working Group on Effectiveness of Recovery Actions for Atlantic Salmon (WGERAAS).

2) Year of appointment: 2013

3) Dennis Ensing (UK)

4) Meetings:

18–22/02/2013 AFBINI Headquarters, Belfast, UK. Participants: 23

12–16/05/2014 ICES HQ, Copenhagen, Denmark. Participants: 7

10–12/11/2015 ICES HQ, Copenhagen, Denmark. Participants: 3

WG Evaluation

5) **Main outcomes**:

-Report and presentation to ICES Working Group North Atlantic Salmon (WGNAS) 2013

-Report and presentation to ICES WGNAS 2014

-Report and presentation to ICES WGNAS 2015

-Report and presentation to ICES WGNAS 2016

-Report and presentation to ICES WGNAS 2017

-Report and presentation to ICES Working Group on the Science Requirements to Support Conservation, Restoration and Management of Diadromous Species (WGRECORDS), 2014.

-Report and presentation to ICES WRECORDS 2015

-Report and presentation to ICES WRECORDS 2016

-Update included in WGNAS presentation North Atlantic Salmon Conservation Organisation annual meeting 2016

-Update included in WGNAS presentation North Atlantic Salmon Conservation Organisation annual meeting 2017

-Presentation on WGERAAS at Atlantic Salmon Federation Workshop on Atlantic Salmon Recovery, Chamcook, NB, Canada, 18–19/09/2013

-'Database on Effectiveness of Recovery Actions for Atlantic Salmon' (DBERAAS), one of the outputs of the WG, will be made available to NASCO in 2017. The WG recommends this database be electronically hosted by North Atlantic Salmon Conservation Organisation (NASCO) or another party.

6) Not yet as of 01/07/2017. The WG will report its advice in a final report to WGNAS in April 2018. WGNAS will, based on this advice, advice NASCO in June 2018.

7)

-Associated and Advisory Partner in 2013 EU Atlantic Area Programme bid 'SALAWARE' Safeguarding our Atlantic Salmon Cultural Heritage – Europe's Oldest Natural Legacy. Bid unsuccessful in acquiring funding.

-Associated and Advisory Partner in 2014 EU COST Action Programme bid 'SALNET' (A Network for the Promotion and Safeguarding of our Atlantic Salmon Heritage). Bid unsuccessful in acquiring funding.

-Representation and presentation on WGERAAS at Atlantic Salmon Federation Workshop on Atlantic Salmon Recovery, Chamcook, NB, Canada, 18–19/09/2013

8) Data to populate the database DBERAAS was not received from many countries, in spite of frequent requests for data at the various meetings of WGERAAS and WGNAS between 2013 and 2016. There appeared to be a reluctance to provide data by representatives from several nations without an official request to provide data by either NASCO or ICES.

Future plans

9) The WG does not request an extension

The recommendations for the final chapter ('Recommendations') of the report.

Annex 3: WGERAAS case studies

Case Study 01: Dennys River, USA

Helcom or NASCO River ID number: NASCO 130

River Catchment size (km²): ~342

Starting and end year of project: 2001–2007

Situation before restoration: Estimates of returning Atlantic salmon to the Dennys River in the late 1960s through early 1980s were between 50 and 500 adults annually (Beland 1996). In the years immediately preceding this study, returns were at 10 fish or below per year (USASAC 2014).

Main stressors on population: Very strong: Climate change (i.e. marine survival), Moderate: Pollution, Aquaculture, Habitat Degradation, Invasives, Predators.

Actions taken: stocking of 50K 1+ Dennys River strain smolts annually, 2001–2005.

Metrics used to evaluate success: adult counts.

Assessment before project: adult monitoring.

Project Aims: Annual returns of 60–120 fish as predicted from contemporary returns rates for other Maine smolt stocking programs.

Actions taken in more detail:

- A variety of other restoration activities have been undertaken on the Dennys River including improving connectivity, a variety of habitat restoration projects, improvements to water quality to address cultural oligotrophication
- Annual stocking of juveniles from the mid 1990-present (USASAC 2014):
    - Approximately 50K Dennys River strain 1+ smolts (2001 onwards)
    - Approximately 29K Dennys River strain parr
    - Approximately 142K Dennys River strain fry

Assessment during project:

- Annual counts of returning adults
- Ultrasonic telemetry monitoring of 1+ hatchery smolt migration through freshwater, estuarine and nearshore environs

Adjustments to goals during project: The goals of the projected were not adjusted during the effort as the approved restoration plan outlined a five-year stocking effort of 50K 1+ smolts annually.

Project success: The project was not successful. Total adult returns to the Dennys River from 2002–2007 were 22 fish (Figure 1, USASAC 2014). Of these, 18 were from the smolt stocking and 4 were from fry stocking or natural rearing. In a single year, 2005, there were zero returns to the Dennys River. Expected returns based on contemporary returns rates for other Maine smolt stocking programs were 300–600 total adult returns (60–120 per year).

Project evaluation: The smolt stocking effort was not successful in increasing adult returns to the Dennys River by the predicted amount. Concurrent ultrasonic telemetry investigations revealed that high proportions of the tagged smolts were not successfully making it to the open ocean environment (Figure 2). It was estimated that approximately between 35–90% of the smolts died before reaching the open ocean with the majority of the mortalities occurring with the estuarine and nearshore zones.

Although the causal mechanisms for the lack of adult returns from the smolt stocking program have not been identified, a number of factors may have contributed to the poor performance of the stocked smolts. The broodstock for the hatchery population are Dennys River origin fish, but this population's adaptive ability may be compromised due to recent population bottlenecks, introgression from aquaculture escapees and/or broodstock selection biases. Environmental challenges related to the Denny's river being a small coastal river, the highly energetic estuarine and nearshore environments, the changing seasonal cues due to earlier snowmelt and runoff (Dudley and Hodgkins 2002) and decreases in marine productivity for many North American Stocks (Mills *et al.* 2013) as well as shifting predator-prey dynamics as a consequence of past natural resource management actions and changing climate may have also contributed.

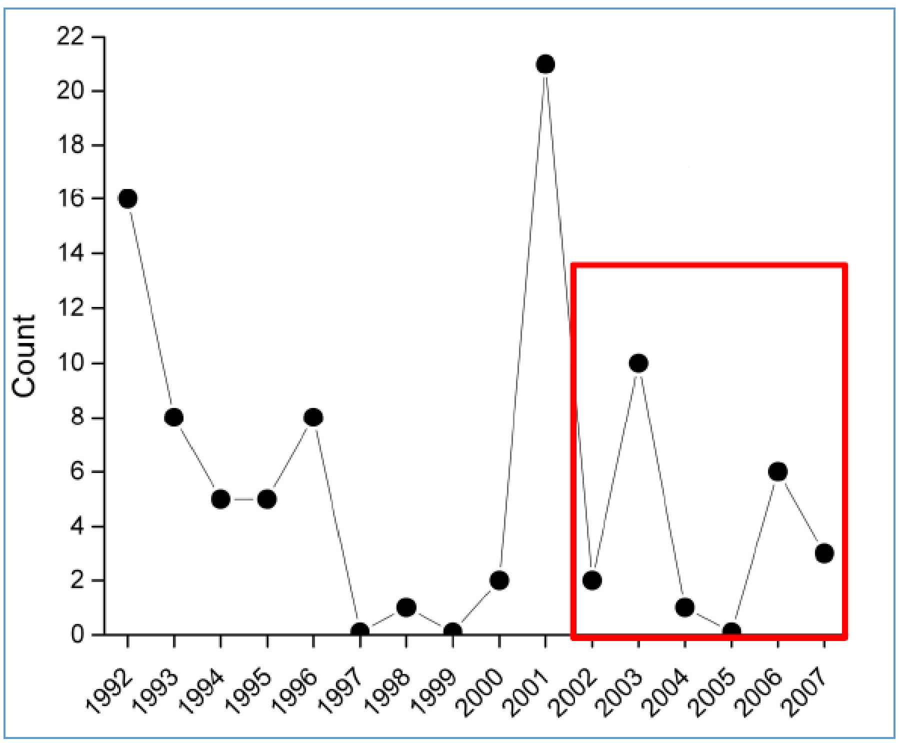


Figure 1. Adult returns to the Dennys River, 1992–2007. Of the 22 returns recorded from 2002–2007, 18 originated from the smolt stocking program.

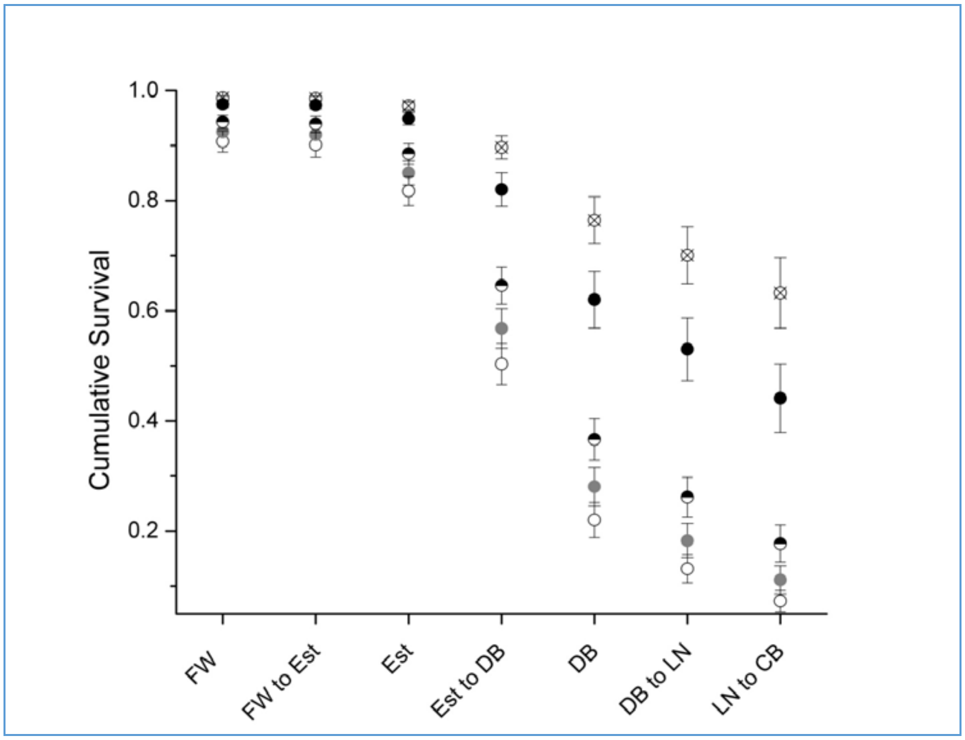


Figure 2. Cumulative survival 2001–2005 (2001 – solid circle, 2002 – open circle with X, 2003 – grey, 2004 – open circle and 2005 half solid black half open circle) through freshwater (FW and FW to Est), estuarine (Est and Est to DB) and nearshore (DB, DB to LN, LN to CB) environments.

Case study 02: River Mandalselva, Norway

Helcom or NASCO River ID number: NASCO 4845

River Catchment size (km²): ~1.880

Starting and end year of project: 1997 – present

Situation before restoration: stock lost due to acidification.

Main stressors on population: Pollution (acidification: low pHs and high concentrations of inorganic aluminium), barriers (hydroelectric power generation).

Actions taken: Water quality improvement (liming), stocking.

Metrics used to evaluate success: mean juvenile salmon densities.

Assessment before project: Assessment of stock status (electro-fishing for juvenile salmon) and water quality. River Mandalselva is also severely affected by hydroelectric power generation by the creation of obstacles to adult migration through stretches of low water flow and passage through dams, reduced rearing areas for younger fish, fluctuating water levels, and the descent of smolts through tunnels in which turbines have been installed.

Project aims: Re-establish a self-sustaining Atlantic salmon population above CL.

Actions taken in more detail:

- Substantial improvement of water quality in the whole catchment by full-scale liming since 1997
- Stocking in the period 1996–2005 with ova: 689 500; fry: 702 913; smolts: 31 123

Assessment during project:

- Annual assessment of mean juvenile salmon densities by electro-fishing at 18 sites over 8 years

Adjustments to goals during project: none

Project success: the benefit of recovery action is high (Fig. 1), CL was exceeded in the last 6 of 8 years, showing a substantial recovery. In recent years, major reductions in fossil fuel emissions have improved water quality in previously acidified waters (Skjelkvåle *et al.,* 2003; 2005). However, water quality in unlimed reaches is still inadequate for the survival of smolts of Atlantic salmon (see Kroglund *et al*., 2008). River Mandalselva (like other rivers in southern Norway) therefore still need to be limed to sustain healthy populations of Atlantic salmon and probably will continue to be needed for many years to come. The benefit of the recovery action can therefore also seen to be moderate as it is not truly sustained.

Project evaluation: Parr densities remained low during the first 3–5 years after the start of liming. For formerly lost and reduced salmon stocks, 3 and 5 years of liming, respectively, was needed to obtain a significant increase in parr densities (both $p < 0.05$). Annual rod catches of adult salmon increased significantly after liming started, reaching about 45 t after 10 years of treatment in 13 rivers including river Mandalselva. This is 11%–12% of the current total catch of Atlantic salmon in all Norwegian rivers. It was concluded that liming thus makes an important contribution to the restoration of salmon in formerly acidified rivers (Hesthagen *et al.*, 2011).

Case study 03: Tuloma River, Russian Federation

Helcom or NASCO River ID number: NASCO 51

River Catchment size (km^2): ~21140

Starting and end year of project: 1936 –present

Situation before restoration: With construction of the Lower Tuloma Dam in 1936 at the tidal extent of the river, and the larger Upper Tuloma Dam in 1965, both for hydroelectric power generation, salmon migration routes were interrupted. A fish ladder in the Lower Tuloma Dam provides passage over the dam, however, no salmon can ascend over the Upper Tuloma Dam. The Upper Tuloma Dam was constructed with a Borland lift fish pass, which was closed after five years of operation due to low numbers of salmon using it. The Padun Falls in the largest spawning tributary below the Upper Tuloma Dam was an obstacle for migrating salmon.

Main stressors on population: Barriers.

Actions taken: Maintained good connectivity in the lower part of the river by making the Lower Tuloma Dam passable for salmon, improved connectivity by construction the Pecha fish pass on the Pecha River which offers the largest spawning and nursery grounds for salmon below the Upper Tuloma Dam.

Metrics used to evaluate success: adult counts.

Assessment before project: feasibility study, adequate nursery habitat available in the Pecha River, problems with the impassable Upper Tuloma Dam.

Project Aims: to maintain the Atlantic salmon population in the Tuloma River system at the historical level.

Actions taken in more detail:

- The Lower Tuloma fish pass. The Lower Tuloma Dam was completed in 1936 and was located at the head of the Kola bay (Figure 1). About 50 km of the former main stem of the Tuloma River has become a part the Lower Tuloma Reservoir. The height of the Lower Tuloma Dam ranges tidally from 16 m to 20 m. A fish ladder was constructed at the same time as the dam and had a fish trap at its upstream exit
- The Upper Tuloma fish pass. The Upper Tuloma Dam was completed in 1965 and was located just above the Lower Tuloma Reservoir (Figure 1). The dam height is 63 m with the reservoir surface level varying by 5.5 m under normal operating conditions. A Borland lift fish pass was constructed at the same time as the dam, but it was closed after 5 years due to low numbers of ascending fish
- The Pecha River fish pass. The Padun Falls is located in the Pecha River about 1 km upstream of the Lower Tuloma Reservoir, and has a head drop of around 3.5 m depending upon the river conditions. A fish pass was constructed here at the same time as the Upper Tuloma Dam however it did not function as effectively as expected and was replaced by the efficient Pecha fish pass in 1991

Assessment during project:

- Annual counts of returning adults at the Lower Tuloma fish pass
- Electrofishing surveys to establish juvenile densities in the Pecha River

Adjustments to goals during project: The project objective has been to maintain a salmon population in the Tuloma River system at the historical level through natural reproduction in the spawning tributaries below the Upper Tuloma Dam. An additional goal of bringing Atlantic salmon above the Upper Tuloma Dam has been formulated recently. This could be achieved by transportation of adult fish trapped at the Lower Tuloma fish pass via road to the Upper Tuloma reservoir.

Project success: The project has succeeded in maintaining the Atlantic salmon population in the River Tuloma at the historical level. The numbers of adult salmon ascending the river in 1965–2012 have been at the same level as before the construction of the Upper Tuloma Dam in 1965 (Figure 2). There have been no long-term upward or downward trends in adult returns over the period.

Project evaluation: The project has reached its initial goals. Current issues are: continuing operation of the Lower Tuloma fish pass, adjustment in the spillway at the Lower Tuloma Dam. Additional issue is: bringing adult fish above the Upper Tuloma Dam.

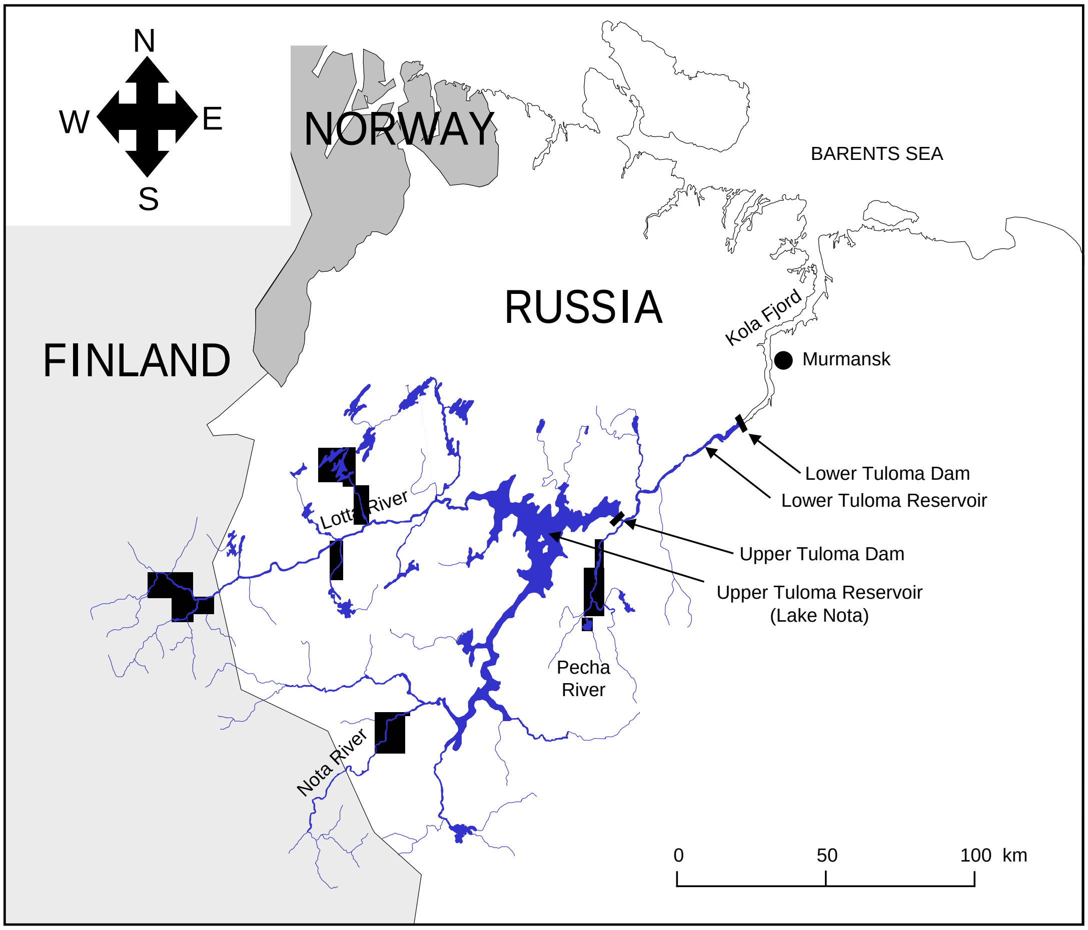


Figure 1. Tuloma River System (Tuloma River Project. Technical Feasibility of Migration Routes. 2000. Report No. 1014. EU Tacis Programme).

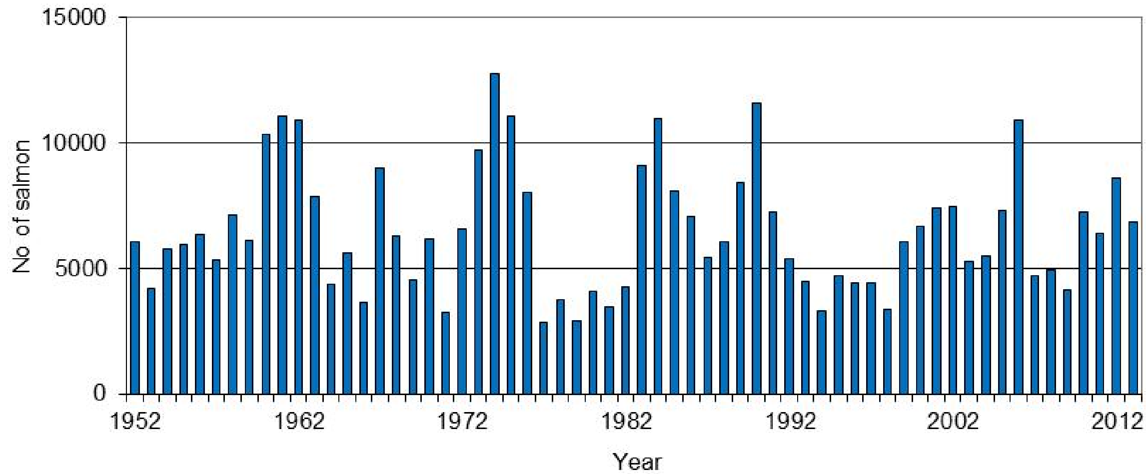


Figure 2. Number of adult salmon assended the Lower Tuloma fish pass in 1952–2012. (ICES North Atlantic Salmon Working Group Working Paper 2014/15).

Case study 04: West River, Canada

Helcom or NASCO River ID number: NASCO 2692

River Catchment size (km^2): ~262

Starting and end year of project: 2005 – present

Situation before restoration: Abundance of Atlantic salmon populations in the Southern Upland region of Nova Scotia has been in decline for more than two decades. A recent Recovery Potential Assessment for the Southern Upland (DFO 2013) noted that river acidification has significantly contributed to reduced abundance or extirpation of populations from many rivers in the region during the last century. The Southern Upland Atlantic Salmon RPA identified acidification, altered hydrology, invasive fish species, habitat fragmentation due to dams and culverts and illegal fishing and poaching as the freshwater threats with the highest overall level of concern, and salmonid aquaculture and marine ecosystem changes as the threats with the highest overall level of concern in the estuarine and marine environment (Bowlby *et al.* 2014).

The West River, Sheet Harbour is one of approximately 25 known rivers within the Southern Upland region to have a remnant population of Atlantic salmon. Juvenile densities are low (Halfyard 2007, Bowlby et. al. 2013) and well below reference values thought to reflect freshwater productivity of healthy populations. The river has been shown to be acidified to the point which is detrimental to salmon and is also subject to a number of other stressors such as habitat degradation and barrier construction associated with historical logging.

Main stressors on population: Pollution (acidification), climate change (marine survival).

Actions taken: Improved water quality (Acid mitigation program; i.e. liming).

Metrics used to evaluate success: Water chemistry, primary/secondary productivity, and juvenile and smolt Atlantic salmon abundance estimates.

Assessment before project: Water chemistry, primary/secondary productivity, and juvenile salmon monitoring.

Project Aims: The primary goal was to increase the freshwater survival, and consequently production, of Atlantic salmon (Halfyard 2007). Other goals were to increase the likelihood of population persistence, to monitor efficacy of lime dosing and associated biological response, and to demonstrate the efficacy of using lime dosing as part of a larger conservation effort (NSSA 2013).

Actions taken in more detail: Installation of a Kemira Kemwater lime doser ~30 km from the head of tide to provide automated dose to control the pH of river water at a pH of approximately 5.5 (Halfyard 2007). A pH above 5.5 has been shown to significantly reduce acid-related mortality in Atlantic salmon (Lacroix and Knox 2005).

A number of other restoration activities were ongoing within the watershed including:

- Watershed habitat planning, mapping and enhancement
- Supportive rearing
- Kelt reconditioning
- Smolt and sea trout research

Assessment during project: water chemistry, primary/secondary productivity, juvenile and smolt salmon monitoring.

Adjustments to goals during project: unknown.

Project success: No adult salmon abundance monitoring was conducted in conjunction with the project, so an assessment of adult return rates is not possible. The project was successful at improving water chemistry, and monitoring suggests a biological response for invertebrates and smolt production (Halfyard 2007, NSSA 2013).

Project evaluation: Adult salmon monitoring was not conducted for this project, so it is not possible to determine whether there was a significant response in adult returns associated with these mitigation initiatives. However, the population is thought to remain at low abundance.

The West River Sheet Harbour Acid Mitigation Program resulted in improvements in the freshwater environment. The primary goal of the West River, Sheet Harbour, Acid Rain Mitigation Project is to increase the freshwater survival, and consequently production, of Atlantic salmon (Halfyard 2007). The analysis of monitoring results indicate that the acid rain mitigation project coupled with other initiatives, such as supportive rearing and kelt reconditioning, provides some evidence of a positive biological response in smolt production when compared to the control site and to other smolt trends within Atlantic Canada and the USA (NSSA 2013).

During the recent RPA for Southern Upland Atlantic Salmon, population viability analyses for two of the larger populations remaining in the Southern Upland indicated that relatively small increases in either freshwater productivity or at-sea survival are expected to decrease extinction probabilities (Gibson and Bowlby 2013). It was further noted that larger changes in at-sea survival are required to restore populations to levels above conservation requirements.

Not all stressors (or at least all the major stressors) for the West River Sheet Harbour salmon population were addressed via this recovery action or other ongoing recovery actions. For any recovery effort to be successful at restoring populations above conservation requirements all stressors to the population should be identified and the magnitude of their effect on the productivity of the salmon population should be understood. At a minimum, the duration of time since this recovery project began coupled with low marine survival were not sufficient to allow increases in juvenile production to result in an adult population size that meets or exceeds the conservation requirement. A more complete understanding of the factors driving marine mortality will a) further allow researchers and managers to accurately set and communicate objectives and goals for recovery efforts and b) further allow for evaluation of recovery to reduce the stressor's impact on the salmon population's productivity.

Case study 05: River Tyne, UK (England & Wales)

Helcom or NASCO River ID number: NASCO 448

River Catchment size (km^2): 2936 km^2

Starting and end year of project: not specific project start date, water quality improvements in 1960s with closure of industrial plant and hatchery started in 1979.

Situation before restoration: Historically, the River Tyne supported substantial runs of salmon and sea trout. However, during the first half of the 20th century there was a dramatic decline in numbers of fish due mainly to a reduction in estuarine water quality as a result of industrial and urban sewage pollution. Records continue to show catches of a few hundred salmon in most years through the 1930s, but after World War II virtually no fish were reported. Zero catches were recorded in 1951 and 1959.

Main stressors on population: Pollution, exploitation, habitat degradation.

Actions taken: Improvements water quality, stocking.

Metrics used to evaluate success: Rod catch data, routine juvenile monitoring surveys. A specific investigation to evaluate the contribution of hatchery-reared fish to the recovery was based on an analysis of tag returns from a major coded wire microtagging programme (1983–2000).

Assessment before project: Catch data.

Project Aims: Recovery of salmon stock.

Actions taken in more detail:

- 160 000 0+ and 1+ salmon parr stocked annually, numbers stocked have often exceeded this level with up to 600 000 parr being stocked in some years (Milner *et al.*, 2004, 2008); the majority of the stocked fish were 0+ parr.

- Between 1983 and 2000, batches of the stocked salmon parr were marked with coded wire microtags (CWTs). Only 1+ parr were tagged.

Assessment during project:

Detailed assessment of CWT recoveries was achieved through both active screening of catches and voluntary returns. Rod catches and juvenile survey data are also available.

Adjustments to goals during project: Not applicable.

Project success: The River Tyne stock has recovered rapidly with an average rod catch over the last 10 years of almost 4000 salmon (3968); (Figure 1). The River Tyne is also one of relatively few rivers in UK (England & Wales) which currently exceeds its conservation limits (CL) on a regular basis and which is classified as 'Not at Risk' against the management objective of meeting the CL in four years out of five, on average. As such, the recovery of the Tyne stock can be considered a success.

In terms of the salmon stocking programme, the first returns of adult fish from hatchery-reared parr were in 1980. Hatchery returns peaked between 1984 and 1987, when these were estimated to contribute up to 274 fish (best estimate; range 128–566) to the rod catch annually and 2084 fish (best estimate; range 975–4,515) to the spawning escapement. Percentage returns of stocked parr to the coast and to the river declined since the start of the programme, due to reductions in marine survival. Estimates of the long term (1980–2000) weighted returns to the coast and river were 0.6% (range 0.5–0.8%) and 0.3% (range 0.1–0.6%) respectively (Figure 2). Over the same time the weighted contributions to the Tyne rod catch was estimated at 6% (range 3–14%); later estimates (post-1995) were lower.

In the early years of the stocking programme, contributions of hatchery fish to the run and escapement were higher because the natural recovery was in its early stages. Best estimates of annual % hatchery contribution to the rod catch ranged between 22 and 42% between 1983 and 1986 (Figure 3). These estimates are based on first returns; it has not been possible to assess potential contribution of stocked fish to later generations.

Project evaluation: The Tyne recovery has been a success. However, natural recovery was the dominant process following the clean-up of the estuary, thereby removing this barrier to smolt and adult migration. The contribution from stocking is thought to have accelerated and stabilised stock recovery in its early stages when water quality improvements were still inconsistent.

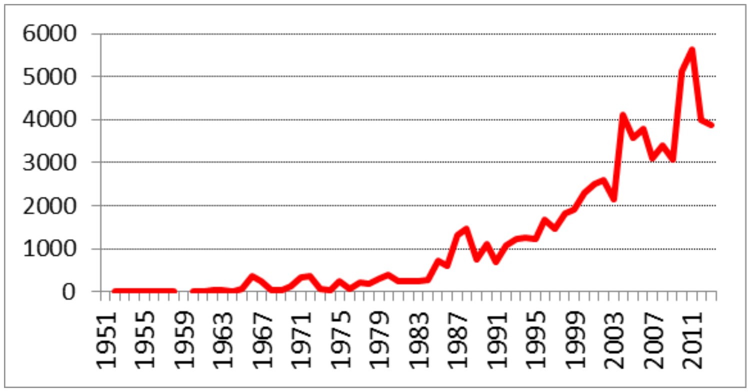


Figure 1. Declared rod catch of salmon on the River Tyne, 1951–2013.

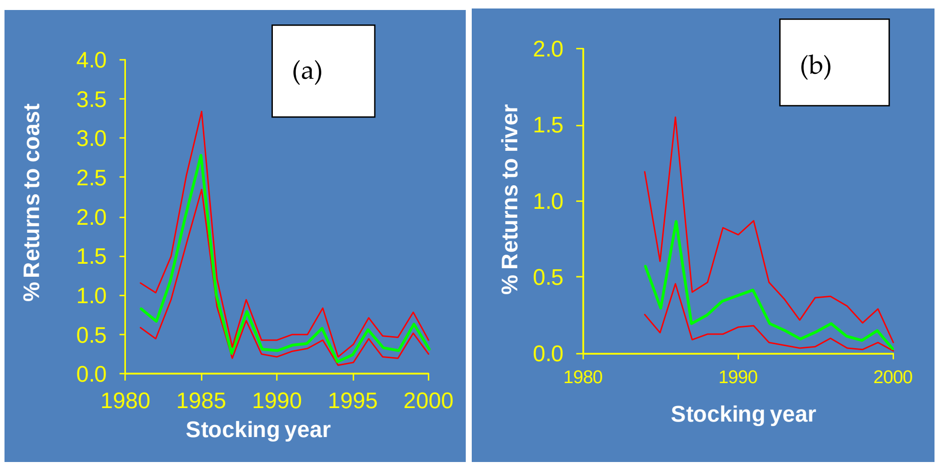


Figure 2. Estimated return rates of stocked hatchery-origin Tyne salmon to: (a) the coast (pre coastal fishery), and (b) the river (pre-rod fishery). Upper, middle and lower lines are MAX, BEST and MIN estimates, respectively [see Milner *et al.*, 2004; 2008 for further details].

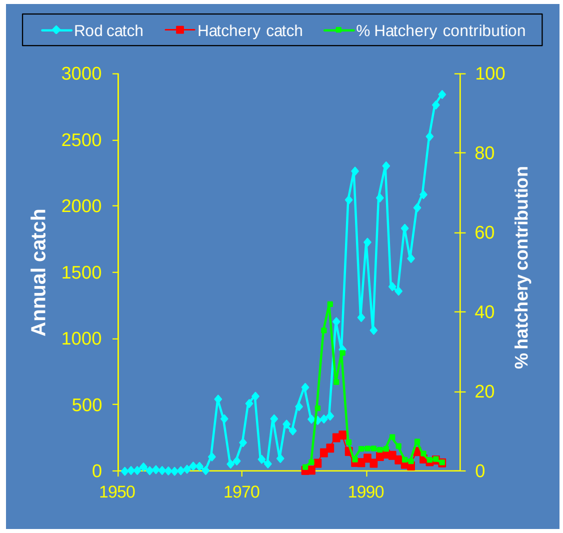


Figure 3. Annual Tyne salmon rod catch [corrected for underreporting – see Milner *et al.*, 2004; 2008], estimates of hatchery derived salmon in the rod catch and the % hatchery contribution.

Case study 06: River Gave of Pau, France

NASCO River ID : NASCO 780

River Catchment size (km²): 2710

Starting and end year of project: 1983 –present. A priority since 2004.

Situation before restoration: Strong decrease in 1917 after building of 2 dams in lower part of the river. Second important regression in 1958 due to the building of Artix-Pardies dam, without fishway and totally no-passable by fish: no more access to the main spawning area. Loss of functionality in lower stretches during the second half of 20th century. Previous barriers in lower part (downstream of Orthez) have never extirpated the population. The population has alsways been exploited.

Main stressors on population: Barriers, Exploitation, Pollution.

- Barriers: N =55 (29 hydroelectric power plants, storage and run-of-the-river stations), cumulative head around 125 m. 37 barrages on main river, cum. head of 105 m (of which 15 downstream the best production areas), others on tributaries Few fish reach the best spawning grounds (upstream of Nay, 1010 km up the confluence with river Adour). Issues with flow fluctuations and lack of attractive water in by-passed stretches leading to delay in migration
- Exploitation: essentially by net in estuary and coast exerted on mixed stock composed by Nives, Oloron and pau populations Pau)

- Habitat degradation: gravel extraction in salmon habitat in the 1950s, stopped in the 1980s. Main river is classified as a "heavily modified water body"
- Pollution: issues with industrial discharge in lower part and domestic waste in middle and upper reaches

Actions taken: Improved connectivity, stocking.

- Connectivity restoration: 42 fishways built mainly in 1980s and 1990s on main stem and one tributary, giving theoretically free access to all the main stem from the mid 1990s onwards at an estimated cost of 12 Millions €. Many by-pass facilities exist but some of which have low efficiency. In practical terms the high numbers of dams and several poor facilities for fish passage are still a problem
- Stocking: fair effort since middle of years 2000, with 500 000 fish yearly (coming from wild strains and F1) . 0.15 M€ per year these last years

Metrics used to evaluate success: juvenile counts, adult counts, monitoring of exploitation, passage, and fry survival.

Assessment before project: No real feasibility study undertaken. Many barriers exist on the river but of limited size (compared with rivers Garonne or Dordogne for example). Good quantity nursery habitat available and a healthy potential donor population in the geographically close river Gave d'Oloron.

Project Aims: Re-establish a self-sustaining salmon population of 1000–2000 returning adults per year (which is the estimated potential level of the population, once all obstacles removed).

Actions taken in more detail:

- Making weirs passable, facilitating access to middle part of river by constructing 42 fishways potentially making more than 200 km accessible. Many by-pass facilities however are not efficient
- Installation of video-counter at the ninth obstacle (Artix) to monitor upstream fish movements
- Stocking of juveniles : mainly since 2004, with Gave d'Oloron stock.
- Juvenile abundance surveys

Assessment during project:

- Fish passage: the 15 lower dams allow passage for only 35% of expected run (telemetry studies by ONEMA during 5 years)
- Exploitation: catch supposed to be around 35% of stock
- Reproduction: redd counting from 2011 : low natural reproduction is observed
- Survival of released fish 5 to 10 times better with late releases than with early ones ('late' refers to after snow melt flow)

- Stocking efficiency study comparing wild and hatchery origin adult fish by otolith Sr: Ca methodology (Fig 1 showing returning adult numbers and stocked fish per stage)
- Stocking
  - o Fed fry mainly, coming from local spawners from early 90s (discontinued stocking non-native strains as was done previously)
  - o 40 000 fish annually before 2004, more than 500 000 after 2003
  - o Early stocking in april and may, on main river and tributary Ouzom; late release since 2 years
- Returns:
  - o Clear increase: 100–200 fish before 2005 ; 350–600 fish from 2005 to 2012
  - o Mainly 1SW fish before 2006 but 30% of returning adults are MSW after 2006.
  - o Possible explanation: increased stocking from 2004, limited but increasing natural spawning contribution as a result of recent improvement of fish passage on two weirs in lower part of the river (Casteltarbe (2000) and Baigts (2001)).
  - o Return rate (rough proxi) : 0, 057% to 0, 57 per 1000 stocked juveniles. More accurate return rate estimations will be available from 2014.

Adjustments to goals during project: No real change of goal except small increase of initial aim of 1500–2500 fish per year, which is the potential level of the population, once all obstacles removed . Achievable if: 1) free passage is fully restored without delay, and 2) exploitation is reduced.

Project success: The project has so far failed to establish a self-sustaining breeding population, but it probably was impossible to achieve in the period and the current effort.

Project evaluation: No attainment of goal. Among causes :

- Impact of dams preventing two-thirds of runs to reach spawning grounds and killing at least 20% of smolt production ; 30 to 40% of good quality spawning habitat is only available today (against 70 and 65% on rivers Oloron and Nive)
- Over-exploitation during this rebuilding phase. A third of run is harvested
- Unsuccessful stocking : lack of genetic diversity and sub-optimal timing of release

Possible improvements :

- Stocking :
  - o improve genetic quality: increase the number of wild spawners in the broodstock (currently under review)

  - delay fish release after spates and snow melt to improve fry survival
- Fish passage
  - replace old fishways and build new ones with increased flow. Ten fishways will facilitate 80% of returning adult fish to reach good habitats
  - equip all hydroelectricity plants with good by-pass structures and flows to reduce mortality by one third.
- Counting adult fish
  - plan to build a video-counting facility, furher downstream of current counter, on the fourth dam.

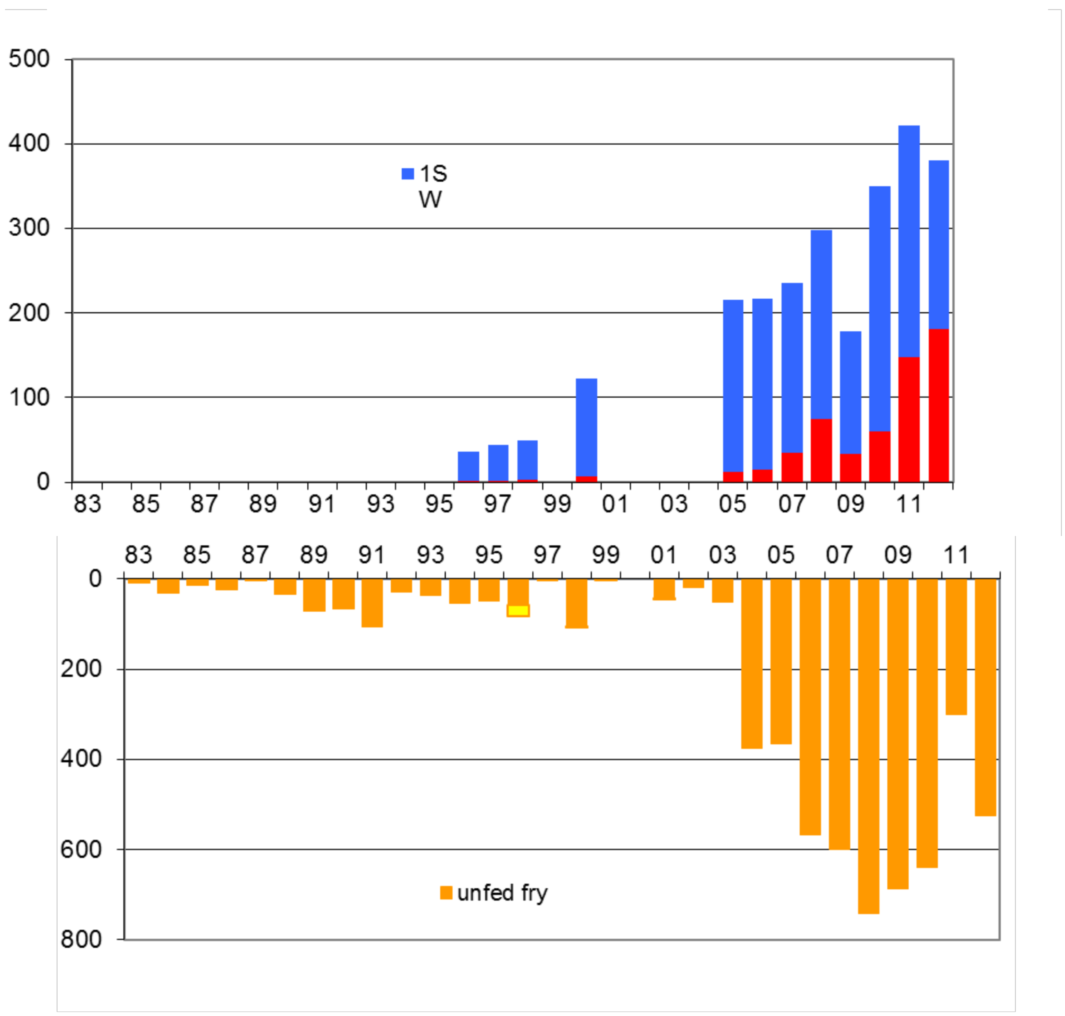


Figure 1. River Gave de Pau fry stocking (bottom) and adult returns (top). The stocking graph is shifted to the right by 2 years.

Case study 07: River Shannon, Erne, Lee and Liffey, Ireland

River Catchment size (km²): Shannon 30 896, Erne 6 457, Lee 1 923, and Liffey 2 308

Starting and end year of project: Dams built between 1925 and 1960s. Hatcheries built between 1958 and 1970s. The River Shannon rises in the mountains of Cavan, and extends south for almost 160 miles where it enters the Sea at Limerick. The river flows through three large lakes or loughs i.e. Lough Allen, Lough Ree and Lough Derg. While the harnessing of the river for hydro power did not significantly affect the environment for fish life in the upper reaches, it created **an obvious entry and exit problem for salmon.** Upstream passage was facilitated by the installation of fish lifts or ladders. Dams also present problems for juvenile fish travelling downstream. Similar connectivity issues related to hydropower developments apply on the Erne, Lee and Liffey. To compensate for this, **fish hatcheries were built to produce juveniles for restocking each year.** This case study examines the outcome of more recent stocking efforts from 1994 to 2007.

Situation before restoration: Prior to 1929, the salmon stock on these rivers was large with significant commercial fisheries operating. Some were particularly noted for the presence of very large multi-sea winter salmon. With the introduction of a hydroelectric power station the return of salmon declined dramatically in most instances.

Main stressors on population: Barriers, climate change, exploitation.

Actions taken: Improved connectivity, stocking.

Metrics used to evaluate success: Assessment of adult returns from restocking activities related to Conservation limit requirement in numbers of adult salmon (Table 1). The magnitude of the potential returns estimated from these releases has been compared to the individual Conservation Limits for these rivers to gauge, at least in numerical terms the possible contribution these stocking activities might have on the wild stocks. The issue of quality of the returning fish and their ability to perform as well on spawning beds or in survival through subsequent life-history stages compared to wild stocks is not dealt with here.

Assessment before project: Catch data.

Project Aims: Recovery of salmon stock.

Actions taken in more detail: In 1994, the Fisheries Research Centre (and subsequently the Marine Institute from 1996) began collecting records of all of the stocking activities in Ireland in an effort to establish the scale of restocking programmes i.e. the number and size of the rivers being stocked, the numbers and source of any wild fish being removed for broodstock purposes and the possible impacts and effects on wild salmon stocks. Under this programme, (ESOPS, Enhancement Stocks – Origin, Progress and Status) all hatchery operators have been requested to supply details of the broodstock captured, eggs produced, and all locations, dates and numbers of progeny at each life stage released into the wild. In this way a comprehensive overview of the stocking activities in Ireland has been produced since 1995.

In order to quantify the returning adults from the various stocking strategies using different life-history stages of Atlantic salmon in Ireland, conversion factors for the survival of eyed ova, unfed fry, fry and parr to the smolt stage are required. These have derived from de Eyto *et al.*, 2007, McGinnity, 1997 and McGinnity (pers. comm). Subsequently, conversion of smolts to adults is based on returns from the Irish National Coded Wire Tagging and Tag Recovery Programme (Ó Maoiléidigh *et al.,* 2001). A distinction is made when converting smolts from plantings to adult returns and smolts reared entirely in the hatchery to adult returns. In the former, the survival rates generated in the National CWT programme for "wild" Irish smolts is used which would be considerably higher in most instances than hatchery reared smolts. Similarly, the exploitation rates used for adults derived from the returns of planted smolts is also based on the wild exploitation index on the assumption that the planted progeny will have spent more time in the wild and will subsequently behave more like true wild salmon. This will result in higher overall returns of planted hatchery progeny (eyed ova to parr) than assuming survivals and exploitation rates derived for smolts reared entirely in the hatchery.

The main objective of most restocking programmes in Ireland has generally been to restore depleted salmon stocks. While often significant returns of salmon have been generated from these programmes, the difficulty has been in gauging the long term success of the strategy. This was essentially due to the lack of an acceptable population "benchmark" with which to measure the outcome of the restocking projects.

Assessment during project: Detailed assessment of CWT recoveries was achieved through a National Coded Wire Tagging and Tag Recovery Programme. Both active screening of catches, broodstock and voluntary returns information were available.

Adjustments to goals during project: Not applicable.

Project success: There are four rivers which have been harnessed for hydro-electrical power generation. Of these the highest estimated return of hatchery fish relative to the Conservation Limit is to the River Lee, with over 10% of the required Conservation Limit being generated (Fig. 9). However, despite consistent restocking this river is estimated to be only meeting 2.2% of its Conservation Limit (based on the runs of wild fish past the fish counter) suggesting that the overall contribution of the hatchery fish is probably much less. Early restocking programmes for the river Erne are likely to have generated up to 40% on average of the returns required to meet the Conservation Limit. However, more recent contributions are estimated to be much lower (less than 5%) and the river is far below its Conservation Limit (only 9.5% of Conservation Limit being attained at the time based on upstream counts). The decline in potential returns is linked to decreasing marine survival. Both the Liffey and Shannon are only generating a small fraction of the Conservation Limit in numbers of salmon (Fig. 1).

Project evaluation: In general the results suggest that the contribution being made by hatchery reared intervention (in this instance simply in terms of adult numbers being generated) is minimal for rivers with hydro dams as these are still significantly below conservation limits. The objective of establishing self-sustaining runs of salmon in the first instance and the further objective of meeting the required Conservation Limit are unlikely to be fulfilled with the a restocking strategy alone. In fact may limit the re-establishment of small quasi-wild populations which could have established following extensive restocking in earlier years.

On the basis of the present results, it is concluded that extensive stocking programmes undertaken in Ireland over the last thirteen years, particularly for rivers with major hydro-power generating stations have made little real contribution to the productivity of these rivers or to the goals of restoring self-sustaining salmon runs.

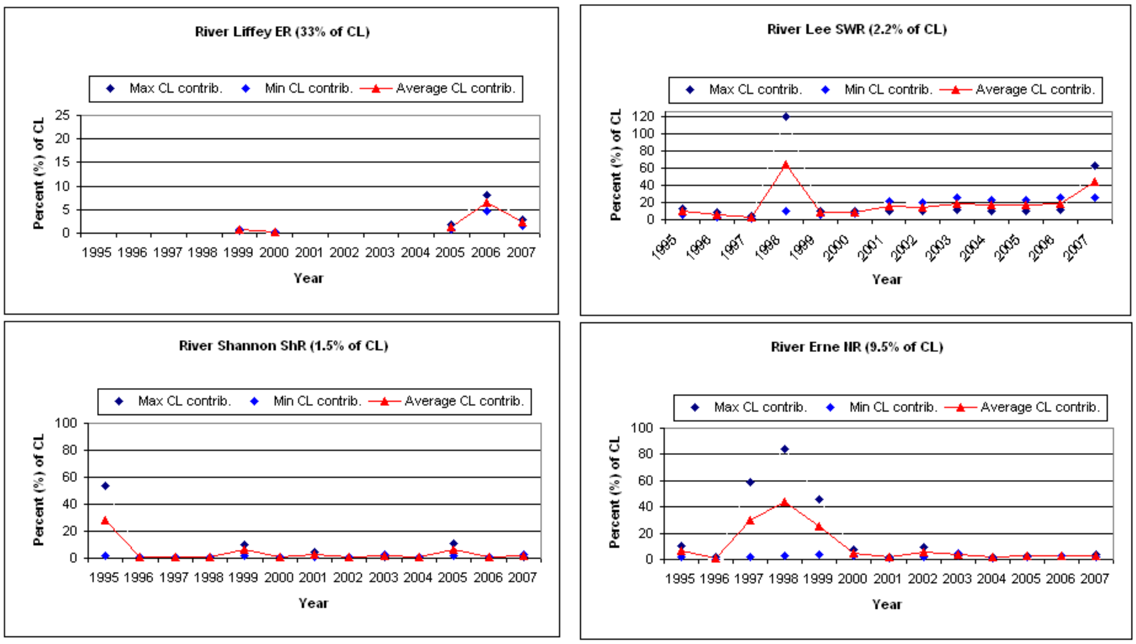


Figure 1. Estimated potential returns of hatchery-reared Atlantic salmon relative to Conservation Limit requirements – Rivers currently below CL and with hydroelectric installations.

River	Wetted Area U/S Dams	Total CL	1SW CL	2SW CL	Average Count
Shannon	30,895,619	49,524	45,909	3,729	707
Erne	6,457,264	16,554	15,345	1,247	1445
Liffey	2,308,361	4,391	4,062	329	1157
Lee	1,923,476	2,789	2,585	210	57

Table 1. Stocks above large rivers impounded for hydroelectric schemes in the Republic of Ireland for case study 07. Counts are average counts for the most recent 5 years with the exception of the Liffey (Islandbridge) which is the most recent 4 years.

Case study 08: River Rhine (Netherlands, Germany, Luxemburg, France, Switzerland)

Helcom or NASCO River ID number: NASCO 284, 784

River Catchment size (km2): ~185.300

Starting and end year of project: 1987 – present (ongoing)

Situation before restoration: One of the world's largest Salmon populations (> 1 Mio. returners / year in 19th century) extirpated since ~1960 (Fig 2).

Main stressors on population: Pollution, barriers, water regulation, habitat degradation, exploitation, climate change, predation, others (shipping).

Actions taken: Water quality improvement, stocking, improved connectivity, reduction of fishing mortality.

Metrics used to evaluate success: adult counts, grilse-MSW-ratio; some regions: also juvenile counts, redd counts.

Assessment before project: feasibility studies (pilot projects); cartography of adequate nursery habitat available in selected tributaries and upper river, potential problems with lack of spawning habitat in some tributaries, impassable weirs in the Upper Rhine and most tributaries.

Project aims: Re-establish a self-sustaining Atlantic salmon population in river Rhine by the year 2020 (formerly year 2000).

Actions taken in more detail:

- Substantial improvement of water quality in the whole catchment (nutrients, heavy metals, residual pollution like PCB etc., micropollutants)
- Making several weirs in tributaries passable, making access to tributaries in the upper part of the main stream (fish-passes Iffezheim and Gambsheim allow access to tributaries up to Strassbourg, fish-pass Strassbourg is under construction and will operate 2015, construction of fish-pass Gerstheim will begin 2015), improvement of existing fish passes in tributaries and in the High Rhine.
- Monitoring intensified; video observations and traps at fish-passes Iffezheim and Gambsheim (river Rhine), Koblenz (river Moselle), Siegburg (river Sieg) & Kostheim (river Main) to monitor ascending adults
- Stocking of juveniles: approx. 40 Mio. since 1994; 251 950 ova, 7 558 370 YOY and 311 060 farm reared smolts (mostly age 1) between 2009–2013 (Fig 1).
- Some stocking material is gained from brood-stocks partly consisting of fish caught as 'naturally spawned' fry and/or stripped returners.
- Reduction of fishing mortality by implementation of fishing regulations (full protection of the species in the whole Rhine river basin, ban zones on "hot spots"), but lack of saturation anti-poaching measures

Assessment during project:

- Annual counts of returning adults (traps, video-observations, electro-fishing, telemetry and other methods) and estimations (partial counts) of migrating smolts
- Electro-fishing surveys to establish juvenile densities (stocked and wild fish)
- Redd counts
- Genetic studies (brood-stock, returners)

Adjustments to goals during project: The time span of the project was extended (year 2000 to 2020) taking into account that the re-introduction of an extinct species and especially the main action to promote it – the restoration of connectivity – is a complex and protracted task. The goal of establishing a self-sustaining breeding population can only be achieved once marine survival improves significantly and factors concerning survival of smolts and adults in the migration corridor (river and/or estuary and/or coastline) are further identified and reduced (e.g. poaching, predation, barrier in the Delta-Rhine).

Project success: The re-introduction of Atlantic salmon in river Rhine proved that water quality and spawning habitats in numeral tributaries are suitable for the species. The selected strains used for stocking (Ätran in the Lower and Middle Rhine, Allier in the Upper and High Rhine) basically manage to make their way from the North Sea to their home waters. Salmon use the installed fish passes and benefit from improved patency in program waters (481 barrage weirs were altered between 2000 and 2013). Accessible habitat is used for spawning in most program waters. However, the project has so far failed to establish a self-sustaining breeding population of Atlantic salmon in the River Rhine system. Numbers of recorded returning adults experienced a peak when two monitoring-facilities (Iffezheim at the Upper Rhine and Buisdorf near Siegburg at river Sieg, Lower Rhine) started to operate in the year 2000 (Figure 3). Another high followed in the year 2007 – the year after the Irish drift net fisheries where closed. Since then the number of recorded adults has declined from ~800 (in 2007) to ~300 (in 2013) individuals. The apparent downward trend in the last six years is attributed to decreasing marine survival, poaching (including by-catch), predation (e.g. cormorants), and probably navigation. Redds and 'naturally spawned' fry have been encountered annually throughout more than 12 years of the project in some tributaries, but numbers are also decreasing significantly. It is expected that at least some returning adults originate from natural reproduction already.

Project evaluation: As stated before, very low marine survival and factors within the migration corridor (poaching, predation, probably navigation) are generally seen as the main causes for the projects not reaching its initial goals. Additional issues preventing achievement of projects goals are: installation of new hydro power plants in program waters, passage problems with some obstructions particularly in low-flow conditions. With current marine survival levels etc. the goal of establishing a self-sustaining breeding population of Atlantic salmon until 2020 does not appear to be within reach and might be 'readjusted'.

Case study 09: River Garonne, South West France

Helcom or NASCO River ID number: NASCO 780

River Catchment size (km^2): 55 846. However, access restricted to only 30% of the catchment after 1950–60, following the construction of large dams in the upper river.

Starting and end year of project: 1985 – present

Situation before restoration: Salmon declined in the second part of the nineteenth century following the construction of the Bazacle dam at Toulouse and the continuation of fishing. Mid-19th century industrial development contributed to the elimination of the last salmon from the river. Some restocking trials took place in the mid-19th century and again after the Second World War. The dam linked with the Golfech nuclear power plant downstream of Toulouse prevented migration of fish in the early 1970s. A subsequent restoration programme was initiated in the late 1980s with the re-opening of the Golfech and Toulouse dams to fish migration.

Main stressors on population: Barriers, water regulation, habitat degradation, pollution, over-exploitation

Barriers: There are 95 obstructions on the nine rivers / tributaries of relevance to salmon. This includes 45 hydroelectric plants with a cumulative head of around 200 meters: three on the main stem of the Garonne (downstream production areas), 20 on the upper Garonne, and others on different tributaries (10 on the Ariège, 10 on the Neste and 1 on the Pique); (Figure 1).

Water Regulation: There are particular problems due to abstraction in summer, including water storage in many reservoirs in the Upper-Pyrenees and diversion of water for irrigation (e.g. Neste and St Martory canals).

Habitat degradation: Key issues include lack of gravel caused by extraction in the lower and middle parts of the river and sediment retention due to dams built in upstream areas.

Pollution: There are few problems in the upper Garonne basin. However, there are greater concerns in downstream areas and in the estuary, with pollution by sewage downstream of large towns (Toulouse, Bordeaux), agricultural run-off and some industrial discharges (e.g. heavy metals from factories on the Lot tributary).

Over-exploitation: Prior to 2000, by-catches occurred in the net fisheries in the estuary and on the coast; this is considered less of an issue now due to an imposed moratorium on catches to protect shad. Some fish were previously also intercepted in fisheries elsewhere (in the mid-1980s, some 40 micotagged fish were reported caught by nets on the west coast of Ireland).

Actions taken: Connectivity restoration, stocking with monitoring of adults and survival of stocked fish, improved management / governance.

Connectivity restoration: 34 fishways have been built over a period of 80 - 90 years on the main stem and principal tributaries at an estimated cost of up to 15 million €. In the initial stages, by-pass facilities on some fishways were poorly developed (average mortality of 20%).

As an alternative strategy, since 1999, some fish have been trapped and trucked over 60 km from upstream of Toulouse (Carbonne) to spawning and rearing areas in the upper Garonne (Pointis), with a similar programme to transport smolts moving downstream (Figure 2). This enables adult fish to by-pass 18 dams and smolts to by-pass 21 turbine systems, although other downstream migration problems persist.

Stocking: Stocking has taken place since the early 1990s, with 460 000 fish stocked annually since 2000. Broodstock were originally sourced from native stocks in Loire-Allier and Adour-Gaves, but later relied on captive broodstock from fish returning to the Garonne. The cost of the stocking has been estimated at 0.3 million € per year in the most recent years.

Monitoring: Since 1993, there has been year-round video-counting of adult returns in the fishways of 2 dams (Golfech and Toulouse), and, since 1999, additional information has been derived from trapping adults at Carbonne power plant, smolts at the Pointis power plant, and monitoring of natural spawning levels. Smolt production from stocked fry is assessed in the upper Garonne to evaluate run sizes and habitat productivity. Juvenile abundance is monitored by electrofishing surveys since 1990 at a yearly cost of 0.25 million €.

Metrics used to evaluate success: Juvenile counts, adult counts, juvenile survival rate, smolt to adult return rate.

Assessment before project: There was only a limited feasibility study before restoration work started. This indicated the availability of 20 000 functional units (100 m^2) of nursery habitat (10 000 units on the main stem of the Garonne and 10 000 in the Ariège basin). While there were a number of impassable weirs on both the main stem and Ariege tributary, there was a strong belief that engineering solutions could be applied to restore free upstream passage and minimise problems during downstream passage.

Project Aims: Re-establish a self-sustaining salmon population on the River Garonne.

Actions taken in more detail:

- Many weirs have been made passable providing access to upstream sections of the river (34 fishways installed and 120 km made available), with an associated 'trap and truck' initiative.
- In recent years, additional improvements to fish by-pass facilities on tributaries (6 on the River Ariège, 2 on the River Neste) at a cost of around 6 million €.
- Installation of video counting facilities in the first (Golfech) and second (Bazacle, Toulouse) dams and trapping since 1999 at Carbonne dam to monitor ascending adults.
- Installation of facilities to monitor smolt runs since 2000 at two trap and truck stations (Camon and Pointis) on the River Garonne.
- Monitoring of juvenile abundance by electric fishing operations since 1990.
- Stocking of juveniles: Since 1995, Bergerac hatchery produces juveniles (F1) from returning adults (F0) trapped in Golfech and Tuilières fish facilities (this latter being on the Dordogne River) and Pont Crouzet hatchery produces juveniles (F2). Genetic analysis of adults show native wild origins.

Assessment during project:

- Annual counts of adults and smolts.
- Electrofishing surveys to assess juvenile abundance and survival of released fish.

Results: Figure 3 shows returning adult numbers and stocked fish per stage (X1000).

Juvenile counts indicate low levels of natural spawning, but fair abundance of released fish (up to 30 0+ parr per unit) and an estimated survival rate of around 7% from fed fry to smolt (70% of smolts are 1 year old).

Adult returns, based on monitoring at Golfech since 1993, have ranged from 50 to 600 fish, with an average of 120 fish per year. Prior to 2003, almost 80% of adult returns were grilse, but returns have had a high proportion of MSW fish since this time. The average return rate (smolt to adult) is low at 0.5%, with the best rate of 1.1 % recorded for a batch of released fry marked as smolts during subsequent trapping. For assessment purposes, released fry are only assumed to contribute to smolt runs in the following spring.

Adjustments to goals during project: There has been no overall change in the project objectives, but considerable effort has been focused on improving downstream migration conditions. This has included:

- Work to improve upstream passage on the two lower dams (Golfech and Bazacle);
- Building and improving by-pass facilities on the Ariège tributary;
- Safeguarding downstream runs through by-passing dams and related problems of turbine mortality through enhanced trap and truck operations on the upper-Garonne (e.g. replacing spaced bar screens ahead of turbines and the use of two successive trapping facilities to save 90% of the smolt runs);
- Transporting adult fish trapped in the Golfech fish-lift directly to spawning grounds in the Ariège tributary, to confirm its potential for natural spawning. There is no stocking at this site and assessment is made by redd surveys, monitoring of juvenile fish and genetic studies. There is no smolt trap and truck programme on the River Ariège
- Investigating the adult losses between Golfech and Toulouse. These are considered surprisingly high given improvement of the fishways in Toulouse (attraction water) and based on the assessments at the fish lift and the efficiency of the fishways. Various possible causes have been considered, including reduction in water quality and increased predation by Wels catfish, which are increasing in abundance with warming water.

Project success: The project has so far failed to establish a self-sustaining breeding population of salmon. Numbers of returning adults are currently similar to those at the beginning of the programme, but the age structure is inversed, with mostly MSW salmon in the current returns. Some redds and 'naturally spawned' fry are encountered annually, with 5–10% of spawners assessed as arising from natural spawning (based on a genetic assignment study). It is unclear whether the MSW increase is some habitat effect or is a result of prevailing environmental conditions.

There is concern that increased temperatures, low flows and reduced oxygen levels may be preventing grilse from entering the river during the summer months, possibly linked with climate change.

Project evaluation:

As yet, the project goals have not been attained. Possible causes for this are:

- The continuing impact of the two lower dams, despite these being equipped with apparently good fishways;
- Low flows in late spring / early summer preventing grilse runs;
- Spawning and juvenile habitat less functional than expected (e.g. lack of coarse sediment and negative effect of floods leaving spawning grounds covered in fine sediment);

- Too much exploitation of returning fish in national and international waters: earlier interception by nets on the coast of Ireland before the closure of this fishery and in mixed fisheries in Gironde (no control and evaluation of salmon catch);
- Low marine survival since the mid-1990s due to modification of the marine habitat with climate change. This coincided with the middle of the restoration effort.

Issues that remain:

- Is restoration achievable? And, if so, at what level?
- Is it possible to restore free passage conditions sustainably?
- Do salmon have the ability to survive in much modified rivers?

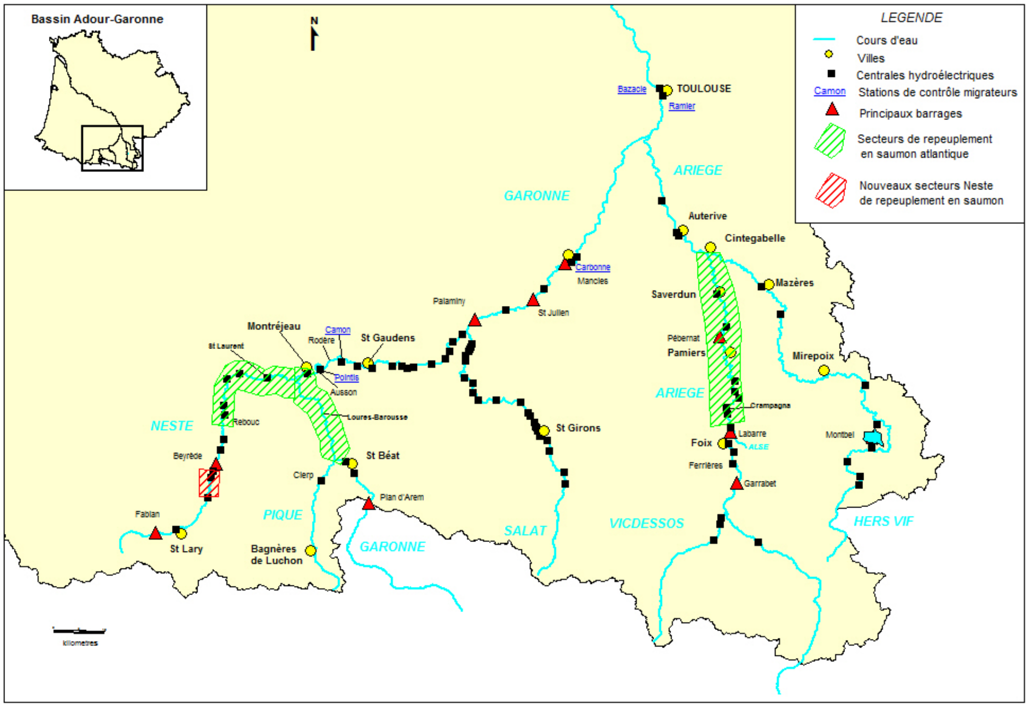


Figure 1. Dams, stocking areas and fish traps in the upper Garonne basin (Legend: river, towns, hydroelectric plants, fish control facilities, main dams, stocking areas, new stocking area).

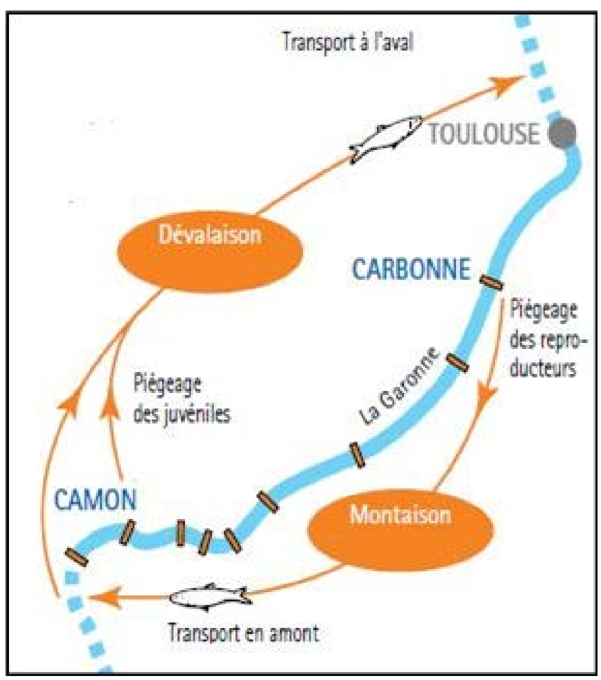


Figure 2. Catch and 'trap and truck' strategy on the upper Garonne river.

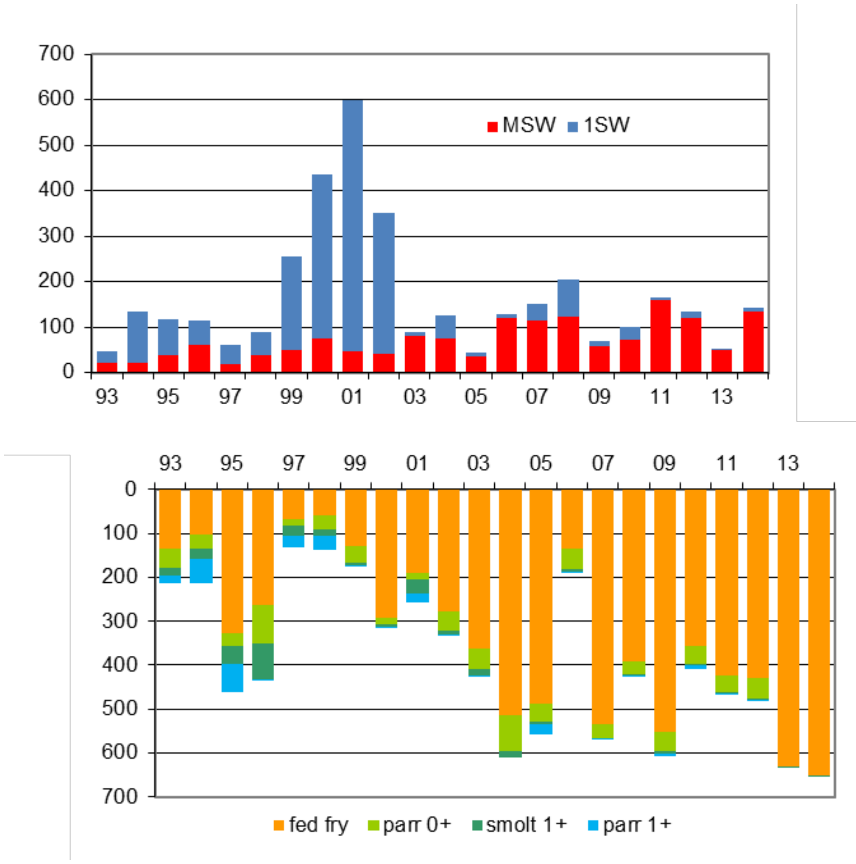


Figure 3. River Garonne - adult returns (top panel) and stocking details (bottom panel, X1000).

Case study 10: River Testeboån, Sweden, Baltic Sea

Helcom or NASCO River ID number: 1039

River Catchment size (km²): 1112

Starting and end year of project: 1991 – present

Situation before restoration: The salmon in the River Testeboån have suffered from human perturbations over a very long time, and the local population was finally extirpated in the 1960s mainly due to increased hydropower generation. In 1997, when the Salmon Action Plan was adopted in the Baltic Sea by the International Baltic Sea Fisheries Commission, the Testeboån was classified as a "potential salmon river" by ICES. In the 1990s, the River Testeboån was also selected for reintroduction efforts nationally.

Main stressors on population: The river has been affected by anthropogenic impacts for centuries, in earlier years by the iron industry and later by hydropower production. The river has also been used for transporting timber and many stretches have been subject to gravel abstraction. During the most recent decades, hydropower production has been the main stressor on the salmon population (Figures 1 and 2). Several migration barriers (dams) have hampered or prohibited salmon from reaching spawning and nursery areas, and increased hydropower generation finally resulted in the population being extirpated in the 1960s. Acidification has been a concern further upstream in the river system, but it is uncertain to what extent it has affected salmonid fish. During the reintroduction programme prior to 2010, high fishing pressure at sea also had a negative effect on the recovery of the salmon population.

Actions taken: Stocking of salmon eggs and fry, improved migration possibilities, restoration of river habitats, liming, reduced sea fishery.

Metrics used to evaluate success: The salmon population is monitored annually using electrofishing and in recent years also counting of ascending adults and out-migrating smolts. The function of fish ladders / fishways and water regulation regimes has been evaluated by means of visual inspection. The timing and survival of smolts during downstream migration has been evaluated using tagging studies.

Assessment before project: Water chemistry, habitat inventories and electrofishing to estimate abundance of salmon and trout.

Project Aims: To reintroduce a wild, self-sustaining salmon population in good status.

Actions taken in more detail: Reintroduction efforts started in 1991, when eyed salmon eggs from the nearby River Dalälven were stocked in the Testeboån. Between 1994 and 2006, stocking of mainly eyed eggs and fry was carried out on an annual basis. Stocking material during the whole period originated from the River Dalälven. Migration possibilities for fish have been improved successively at the power plant at Strömsbro, situated about 2 km from the river mouth, by means of new water regulations. This has helped attract fish to fishways and has made it possible for more ascending spawners to find their way upriver. In addition, survival during the smolt migration has been improved by closing the power plant, or decreasing the amount of water passing through the turbines, during the smolt migration period. In 2014, a permanent smolt diverter was installed in the inlet channel to the power plant at Strömsbro, to prevent smolts from passing the turbines. In 2005, the second power plant on the river, situated at Forsby about 5 km from the river mouth, was removed. This made 21 km of the river accessible for salmon and sea trout. Restoration work to restore salmon and trout habitats, by means of putting back stones and boulders, has been undertaken in other parts of the river. To address acidification issues, liming is undertaken in the upper parts of the catchment. The exploitation in the sea fishery has declined in recent years as a result of reduced quotas and nationally imposed changes in the geographical distribution of the fisheries to reduce mixed-stock fishing. These measures have facilitated recovery of the salmon population.

Assessment during project: The salmon population has been monitored using electrofishing and in some years also counting of ascending adults and out-migrating smolts. In 2013, the reintroduction programme was evaluated by ICES. The outcome of this evaluation was a decision that the Testeboån should be regarded as a wild, self-sustaining salmon river. Since then, the population status has been evaluated in relation to the MSY-based management objectives agreed for wild Baltic salmon populations, by comparing estimates of the current smolt production with expert opinions about the potential smolt production capacity (PSPC). The wild smolt production in recent years has varied, mainly as a result of varying possibilities for adult spawners to reach the spawning grounds, and is believed to be below 50% of the PSPC. Thus, according to ICES analyses, the river has not yet reached the MSY-based management objective (75% of PSPC).

Adjustments to goals during project: There have been no changes to the overall project aims and objectives.

Project success: The reintroduction programme has been very successful. Even though the salmon population has not yet reached the MSY-based management objective, the restoration efforts have resulted in the re-establishment of a self-sustaining wild salmon population.

Project evaluation: Despite the success of this reintroduction project, there is a need for ongoing improvements to enable further development of the salmon population. The function of the permanent smolt diverter at Strömsbro is unclear, and an evaluation may be carried out during 2016. The problems for adult salmon in finding their way upriver has not been solved completely, as water levels in summer, and the amount of water passing the power plant at Strömsbro, still affect upstream migration. A more sustainable solution, enabling more adult salmon to reach spawning areas, is probably necessary to secure a continued recovery of the salmon population in the Testeboån.

Figure 1. The River Testeboån downstream of the power plant at Strömsbro. The photo is taken from the dam construction (see Figure 2).

Figure 2. Construction of the smolt leader/diverter at Strömsbro. The steel rods prevent smolts from entering the inlet channel to the power plant. The photo is taken from the inlet channel. The dam construction with fishways for smolts and adults, a smolt trap and equipment for counting adults and registering PIT tags can be seen in the background.

Case study 11: River Tornionjoki/Torneälven, Finland/Sweden, Baltic Sea

Helcom or NASCO River ID number: HELCOM 899

River Catchment size (km²): 40 010

Starting and end year of project: 1980s – present

Situation before restoration: The River Tornionjoki is the most northerly of the river basins in the Baltic Sea catchment and is the largest producer of wild salmon in the Baltic Sea. It is also the largest unregulated river in Western Europe, with no migration obstacles, either natural or man-made, in the main river, and both the river habitat and water quality are considered to be in an almost pristine state. Salmon spawn widely throughout the catchment and parr occur in the swiftly flowing sections of the main river, in the headwaters and in the major tributaries from the lowermost riffles up to 400–500 km from the sea.

The highest catches recorded in the river were around 400 tonnes and these occurred 2 to 4 centuries ago when almost all fishing was confined to the river. Since that time, salmon fishing has spread gradually from the rivers to the Baltic Sea. Offshore fishing targeted at feeding salmon dominated catches during the second half of the 20th century; coastal fishing also expanded during this period. Consequently, in more recent times, salmon have been harvested by various fisheries along their whole migration route and the vast majority of the catch has been taken by sea fisheries.

The abundance of Tornionjoki salmon declined rapidly after World War II and the stock was especially weak throughout the entire 1980s, when it was considered to be on the verge of extinction. Annual smolt runs of wild Tornionjoki salmon were no more than 70 000 - 80 000 individuals in the late 1980s.

Main stressors on population: Over-exploitation due to consecutive fisheries operating along the salmon's whole migration route.

Actions taken: Hatchery supplementation programme (1977–2002) and restrictions on fishing activity (early 1990s on).

Metrics used to evaluate success: Population abundance of wild-origin and stocked salmon over time. Comparison of the development of the supplemented and non-supplemented salmon populations of the area, with similar fishing pressure over time.

Assessment before project: Population abundance and harvest estimates prior to years with enforced fishing restrictions (i.e. from 1980s). Parr densities (electrofishing) and river catches from years before hatchery supplementation started.

Project Aims: The primary goal of the fishing restrictions was to increase survival to spawning, with the ultimate goal of increasing wild reproduction. The objective of the supplementation programme was to increase juvenile and adult population abundance (wild and stocked), with the ultimate goal of increasing wild reproduction.

Actions taken in more detail:

Restriction of Fishing: Total allowable catches (TAC) were introduced in 1991 for Baltic Sea fisheries. TACs were reduced from 600 000–700 000 salmon during the early 1990s to 400 000–460 000 during 1996–2007. Further reductions in TAC were enforced in 2008–2013 and currently the TAC is around 100 000 salmon. In 1997, the International Baltic Sea Fisheries Commission, which manages sea fishing in the Baltic Sea, adopted a so-called Salmon Action Plan (SAP). The most important management goal of the SAP was to attain at least 50% of the estimated potential smolt production capacity in each wild salmon river by 2010. Reductions in TACs were made mainly in response to achieving this goal. Wild spawners, especially old females, tend to return to rivers earlier in the season than younger and reared salmon. To safeguard these fish, early-season closures of coastal fishing has been enforced in both Finland and Sweden since the 1980s. The closures were of relatively short duration until the mid-1990s, when the closure periods were extended substantially. These stricter restrictions have remained in force ever since. Restrictions on river fishing have also been strengthened in parallel with the restrictions on sea fishing.

Supplementary stocking: A joint Finnish-Swedish hatchery programme, using salmon of Tornionjoki origin, started in 1977. This annual supplementary stocking increased in volume throughout the 1980s and early 1990s and was at its highest level in the mid and late 1990s. Altogether, about 3 million eggs or fry, 8 million parr (mostly 1-year old) and 0.8 million smolts (mostly 2-year old) were released. Released parr and smolts were marked by removing the adipose fin before stocking. The stocking was discontinued in 2002, due to the recovery of the Tornionjoki stock. Only salmon native to the river were used for rearing; both wild-caught and captive broodstock were used for egg production.

Assessment during project: Reconstruction of population abundance dynamics from the late 1980s to the present, with separation of wild-origin and stocked stock components. This was based on the following input data: stocking statistics, electrofishing surveys, smolt trapping, tag-recapture data, catch and effort statistics by fishery, and catch samples. Observations of wild-reared proportions at smolt and spawner stages were included. Nearby salmon populations were also assessed using the same methodology, although the available input data differed in some cases.

Adjustments to goals during project:

Goal for the years before 1997: increase in wild abundance.

Goal for 1997–2010: to attain at least 50% of the estimated potential smolt production capacity by 2010.

Goal since 2010: to attain at least 75% of the estimated potential smolt production capacity (MSY proxy).

Project success:

The abundance of wild smolt runs stayed at the same level of magnitude (50 000–100 000 per year) in the 1980s. Recovery started in the late 1980s - early 1990s (70 000–200 000 per year), jumped to 600 000–800 000 per year at the turn of millennium, and has increased further since 2008 to the present 1.3 - 1.5 million smolts per year. The abundance of wild spawners has increased from 3000–4000 individuals in the early 1990s to 80 000 - 120 000 individuals in the period 2012 to 2015. The overall abundance of both wild and reared-origin (arising from both parr and smolt stocking) smolts and spawners, and their relative contributions to these runs, are shown in Figures 1 - 2.

The abundance of wild-origin Tornionjoki salmon has increased from 15-fold (smolts) to 30-fold (spawners), from the beginning of 1990s to present. This time period covers 3 to 4 wild salmon generations (the average lifespan of female Tornionjoki salmon is 6–7 years), which means that the average increase in abundance has been 4 to 10 fold per generation.

Reared-origin salmon accounted for up to about half of the total smolt runs in the late 1980s and in the 1990s (Figure 2). Survival of stocked 1-year old juveniles to smolt varied from about 10% to 25%. Based on the stocking statistics and abundance of wild salmon parr in the 1970s and early 1980s, the contribution of stocking to the population was similar or lower prior to 1987. Smolts of different groups showed synchronous variation and similar patterns of capture in net fisheries as wild salmon. Post-smolt survival of wild Tornionjoki smolts was on average two times higher than that of smolts stocked as parr and 2.5 times higher than that of stocked smolts. Average survival from smolt to spawners of wild salmon was 2.8 times higher than that of salmon stocked as parr and 3.3 times higher than that of salmon stocked as smolts (Romakkaniemi, 2008).

Total cumulative mortality of Tornionjoki salmon has decreased from about 95% in the late 1980s to about 40% in the 2010s (Figure 3). As a result, survival of maturing fish from fishing has increased over 10-fold (5% vs. 60%) during the time period. The corresponding survival to spawning has not increased as much because adult natural mortality affects final spawner numbers even if salmon are not exploited in fisheries.

Wild salmon stocks of northern Baltic rivers (including the Tornionjoki and the Simojoki) have shown similar overall patterns of stock recovery, regardless of whether these have been supplemented by stocking initiatives or not (Romakkaniemi *et al.*, 2003; Romakkaniemi, 2008).

Project evaluation:

The key factor behind the recovery of the Tornionjoki salmon stock was the introduction of restrictions on the sea fishery; this was associated with the simultaneous occurrence of relatively favourable natural conditions for survival (Romakkaniemi, 2003 and 2008). An ongoing reduction in fishing pressure has maintained the recovery of the stock at the present time.

The relative impact of decreased fishing pressure (over a 10-fold increase in survival from fishing from the 1980s to the 2010s) overshadowed and fully masked the presumed impact of supplementary stocking, which was not the key factor in the revival (about 1.2x increase in spawner abundance over 4 salmon generations: 1.2^4 ≈ twofold total effect). Only the increase in survival from fishing could have increased abundance with the documented speed. Moreover, the results of the comparison of the recovery of stocks with and without supplementary stocking confirms that stocking has had only minor, and perhaps even non-existent, impact on stock recovery.

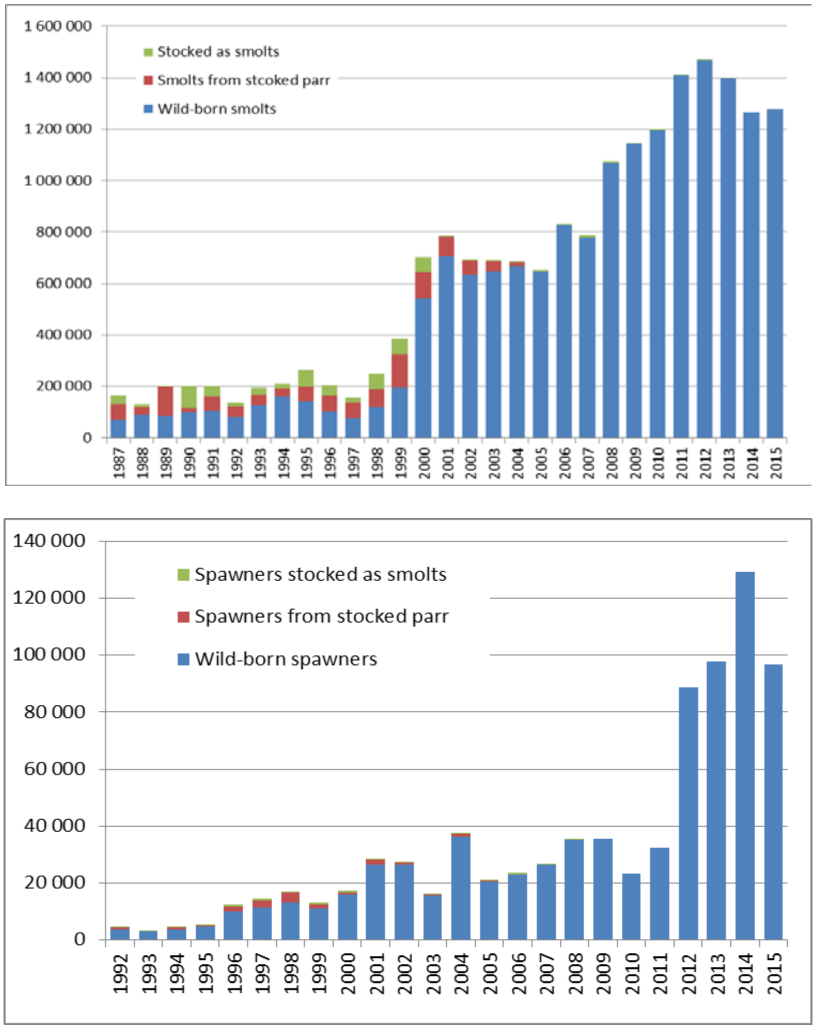


Figure 1. Estimated abundance (number of individuals, median values) of wild-origin and stocked salmon (originating from parr and smolt introductions) in the annual smolt run (upper panel, years 1987–2015) and spawning stock (lower panel, years 1992–2015) on the River Tornionjoki (ICES, 2015; Romakkaniemi, 2008).

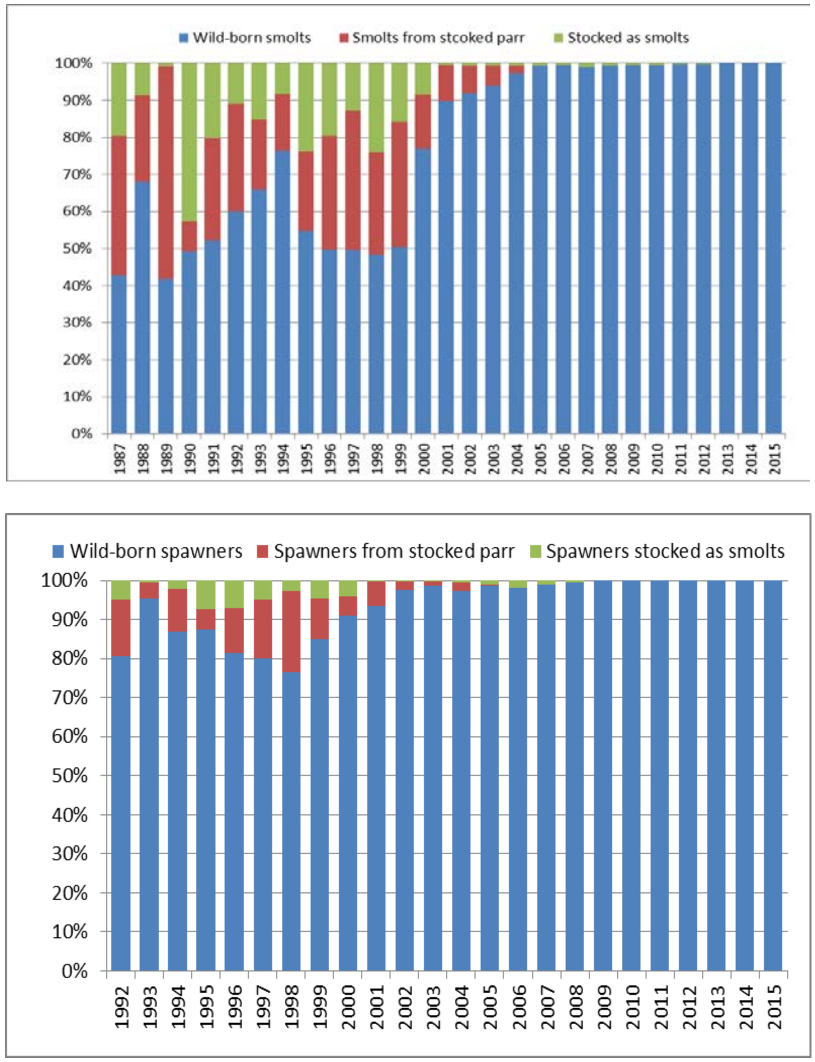


Figure 2. Estimated proportions of wild-origin and stocked salmon (originating from parr and smolt introductions) in the annual smolt run (upper panel, years 1987–2015) and spawning stock (lower panel, years 1992–2015) on the River Tornionjoki, based on the estimates from Figure 1 (ICES, 2015; Romakkaniemi, 2008).

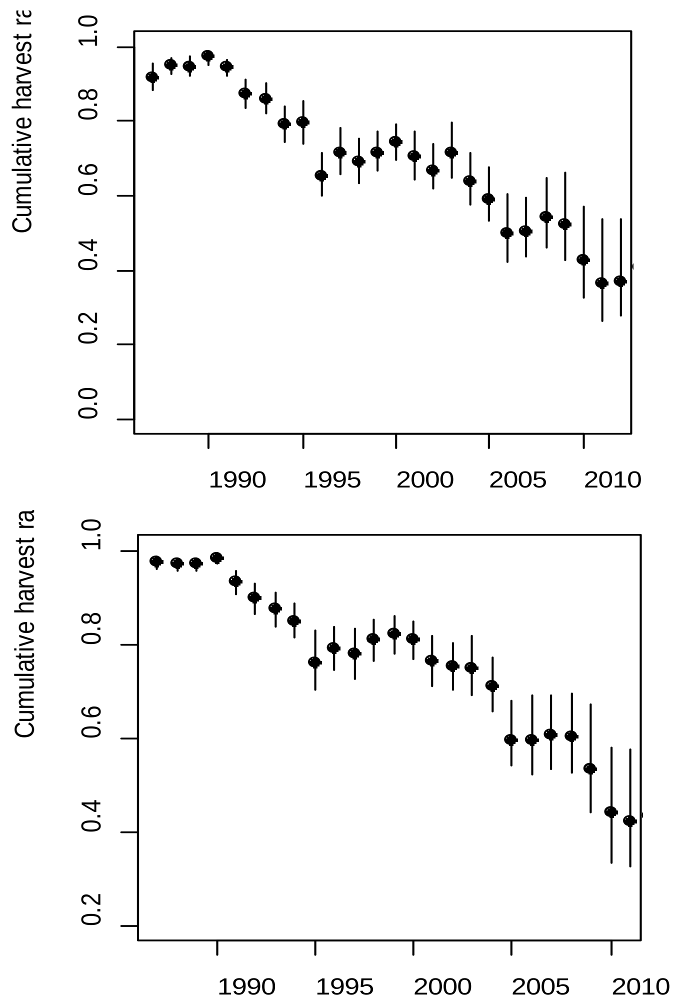


Figure 3. Total cumulative fishing mortality (presented as harvest rates, 1=100% mortality) across the life of Tornionjoki salmon maturing as 2SW (upper panel) and 3SW (lower panel) fish. The X-axis indicates the year of smolting (1987–2011) (ICES, 2015).

Case study 12: River Thames, United Kingdom (England)

Helcom or NASCO River ID number: NASCO 452

River Catchment size (km^2): 12 860

Starting and end year of project: 1979 – present

Situation before restoration: The River Thames is known to have supported a large run of salmon historically and a substantial fishery existed on the river until the early 19th Century. The industrial revolution and urbanization of London and other parts of the catchment resulted in increased levels of pollution and the construction of barriers, and salmon were last recorded in the 1830s. Some limited, and unsuccessful, efforts were made to restore salmon to the Thames prior to the 1970s. Following improvements in water quality through London, a salmon was recorded in the lower Thames, downstream of London, in 1974 and this helped stimulate interest in fresh initiatives to restore salmon to the river. The Thames Salmon Rehabilitation Scheme was established in 1979.

Main stressors on population: Pollution, multiple barriers, river flows / abstraction, exploitation.

Actions taken: Hatchery stocking started in the 1970s with an associated tagging programme; fish passes were constructed on many barriers and their performance evaluated; evaluation of spawning and juvenile habitat.

Metrics used to evaluate success: Monitoring of adult returns at trapping facility; catch records; tagging programme to evaluate success of stocking; habitat and juvenile surveys; genetic analysis.

Assessment before project: General monitoring of water quality and multi-species fishery surveys.

Project Aims: The Thames Salmon Rehabilitation Scheme set out initial aims extending over a period of more than two decades. These aims were split into a number of phases:

- Phase 1 (7 years) – Juvenile stocking programme. Provision of adult trap in lower river for the capture of adult salmon and the use of some returning adults as broodstock for the rearing programme.

- Phase 2 (5 years) - Maintenance of the juvenile rearing programme and work to facilitate natural spawning and rearing of salmon in the main river and tributaries. Undertake weir modifications to enable adult salmon to ascend a further 30km of the main river and permit access to some lower tributaries.

- Phase 3 (5 years) - Continuation of the artificial rearing programme. Undertake further weir modifications to allow access to a further 80 km of main river and additional tributaries, including the Kennet.

- Subsequent Phases (at least 5 years) - Reviews of Scheme. Refocusing of stocking programme to establish the most cost-effective methods and optimize survival rates. Particular focus on returning adults to the River Kennet, the tributary of the Thames with the largest amount of suitable breeding and nursery habitat. Completion of fish pass construction programme and assessing connectivity by radio tracking. Development of a Thames 'stock'. Assessment of the productive spawning habitat in the catchment.

The project objectives were subsequently reviewed and updated in line with Salmon Action Plan delivery in 2003/4 (see below).

Actions taken in more detail:

- Stocking programme commenced in the 1970s – fish from various sources were used. Initially, stocking relied mainly on Scottish hatchery lines, although occasional releases of fish from rivers in southern England were also made. Subsequent switch to utilise fish that were only subject to one generation of captive breeding from Irish sources, with increasing emphasis on using fish reared from adults returning to the Thames.

- A programme of fish pass construction to enable returning adults to negotiate the numerous weirs (e.g. 36 between the tidal limit and spawning/rearing habitat in the Kennet tributary).
- Ongoing improvements to water quality through improved treatment of waste, new interceptor sewers, etc.

Assessment during project: Monitoring of varying life stages as well as water quality and flows. Adult salmon returns were evaluated using a trapping facility a short distance upstream of the head of tide, combined with catch records. A coded wire tagging programme was instigated to evaluate the success of stocking and the impact of interception fisheries. Tracking studies were used to assess the efficacy of fish passes and river connectivity. Habitat surveys were conducted to evaluate the extent and suitability of spawning and rearing habitat. Juvenile surveys of appropriate areas and genetic analysis of returning fish were also undertaken.

Adjustments to goals during project:

The initial focus was primarily on achieving adult returns to the river. As fish pass construction advanced, the focus shifted to establishment of a self-sustaining run in the River Kennet, which was identified as the tributary with the most suitable spawning and rearing habitat.

As part of a process of developing river-specific Salmon Action Plans for all the principal salmon rivers in England and Wales, revised objectives were formulated to further progress the restoration of salmon to the Thames in 2004. Eight specific targets were identified, which included:

- Achieving an average of 250 adult salmon returns to the river each year;
- Demonstrating that adult salmon have successfully spawned and produced juveniles in the River Kennet;
- Fish passes to be open throughout the fish migration period and operate at greater than 95% efficiency;
- Ensuring the effective input of salmon water quality requirements in determining future water quality standards for the Thames tideway;
- Continuing the programme of work to evaluate the exploitation of salmon outside of the freshwater Thames.

More recently, in view of decreasing returns, ongoing water quality issues, funding pressures, and the general decline in the survival of Atlantic salmon at sea, the juvenile stocking programme was stopped. There is an ongoing aspiration to return salmon to the Thames, but the focus now is away from single species activities and more towards achieving general improvements in water quality and aquatic biodiversity consistent with meeting Water Framework Directive requirements. Evidence from other rivers in England and Wales indicates that if the habitat is suitable, natural recovery will occur.

Project success: In the early part of the programme, the numbers of adult salmon recorded in the river gradually rose, reaching a peak of 338 in 1993. However, in 1997 the numbers of adult salmon recorded in the Thames declined significantly, reaching a low in

2005 when no salmon were captured (Figure 1). Subsequent to this, stocking was discontinued.

Salmon habitat assessments indicated that two tributaries, the Kennet and Lambourn, contained large areas of salmon nursery habitat. Although areas of 'text-book' spawning habitat were limited and sedimentation was identified as a concern, it was considered that successful breeding and rearing was possible in these areas assuming fish had upstream access.

The efficacy of the fish passes on the Thames and Kennet was monitored by a radio tracking investigation over a number of years (1996–2004). Many weirs were found to have high passage efficiency rates, particularly those further upstream. However, there were issues with passes in the lower river and, based on the derived efficiencies, the cumulative effect suggested that only 9 salmon from every 100 entering the river would reach the Kennet.

Two major construction projects were agreed to resolve the long-standing problem of storm sewage discharges into the Thames Tideway. These will substantially reduce the level of untreated sewage overflowing into the river by capturing it from 34 sewer overflow points and transferring it to treatment works. One tunnel was due to be completed in 2014 and the other in 2020.

A number of the objectives established in the Salmon Action Plan process were achieved. However, the one that was repeatedly missed, and which was the main one many stakeholders cared about, was how many adult salmon were coming back each year. Thus, while the programme might not be considered a success, a number of the major issues identified at the outset in the SAP (e.g. water quality in the tideway, entrainment at water intakes, interception in fisheries outside freshwater) have been addressed, or are likely to be over the coming years.

Project evaluation:

The rehabilitation scheme failed to achieve the hoped for reintroduction of a self-sustaining stock of salmon in the River Thames over anticipated timescales, although a number of the project goals were achieved. In particular, the project raised the profile of the river and of fish migration and water quality requirements, and led to improvements that have benefited wildlife and river users. The project was a template for many other rehabilitation schemes around Britain

The juvenile stocking programme has now ceased and motivation for further restoration work has been reduced because the expectation of returning adults has also been reduced. Nonetheless, there is still the aspiration of returning salmon to the Thames, although the focus now is away from single species activities and more towards more general habitat and biodiversity improvements in line with meeting wider Water Framework Directive requirements. The expectation is that if the conditions are suitable the fish will return. This is supported by a recent genetic investigation (Griffiths *et al.*, 2011), which indicated that untagged salmon ascending the river in 2005–8 originated not from exogenous fish stocked into the Thames, but predominantly from other rivers in southern England. This highlighted the potential for natural processes of recolonisation to operate in rivers where salmon have become locally extirpated.

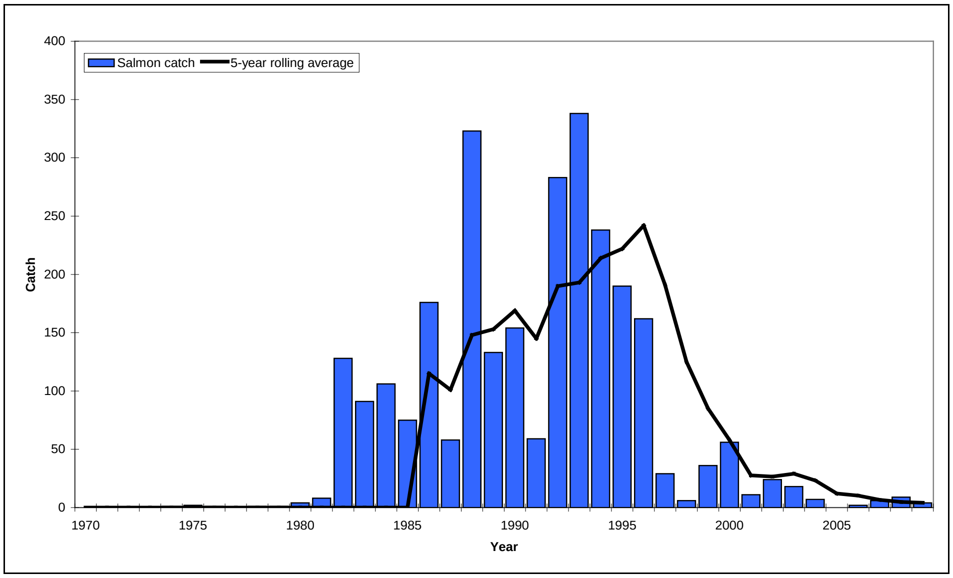


Figure 1. Adult salmon captures recorded in the River Thames, together with the 5-year average.

Annex 4: 'Conclusion' chapter from the report on the Atlantic Salmon Federation (ASF) hosted workshop 'What works? A Workshop on Wild Atlantic Salmon Recovery Programs'

St. Andrews, New Brunswick, Canada, 18–19 September 2013

Conclusions

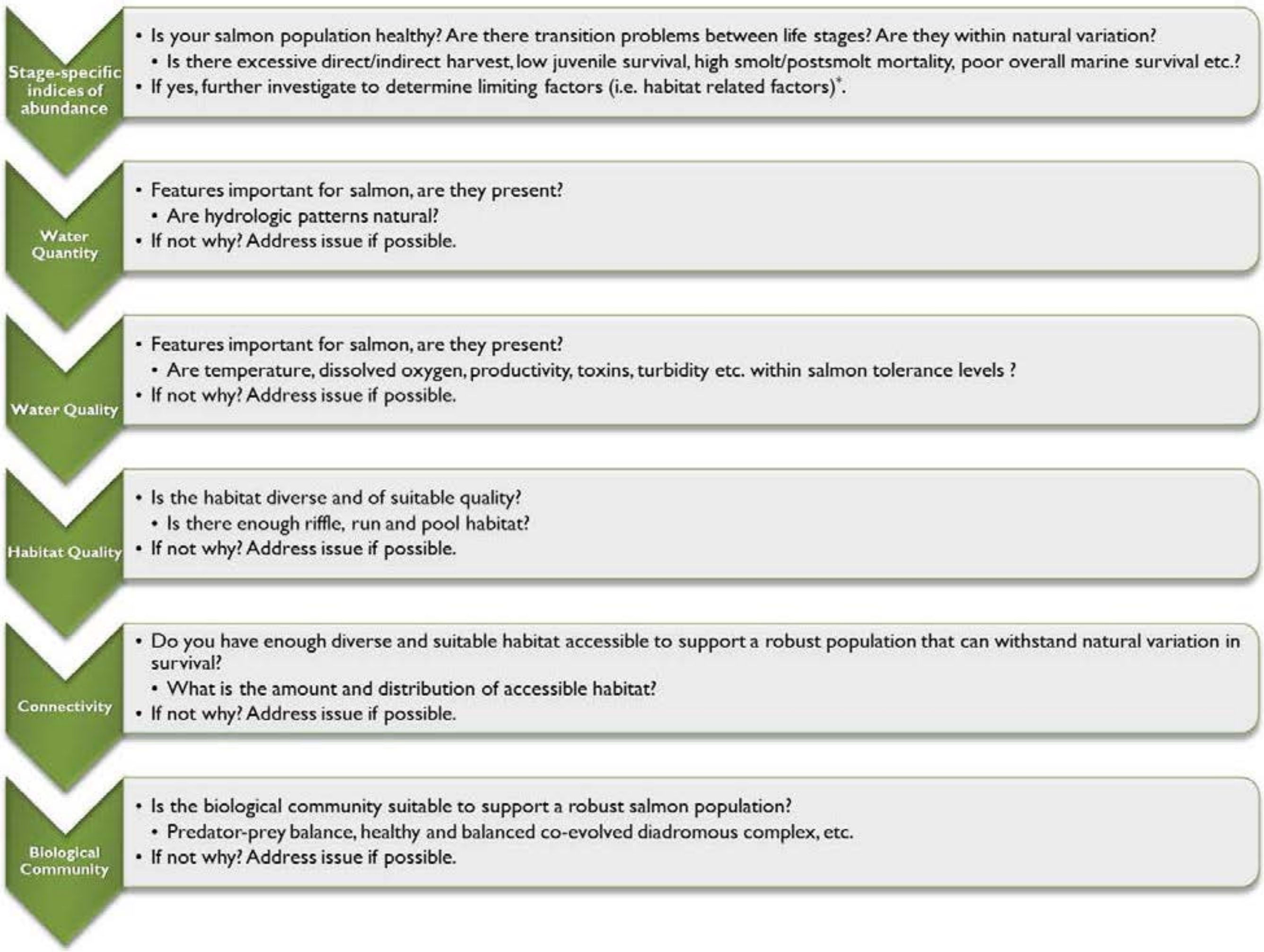
Developing a salmon restoration plan is a complicated undertaking. There are numerous factors that need to be considered from the state of the salmon resource in question, to the state of the riverine, estuarine, and marine environments as well as the societal and political factors. The complexities of these issues were clearly exemplified by the content of the presentations, posters and panel discussion associated with this workshop. There is not one clear universally agreed upon approach or menu that practitioners can apply to create a successful salmon restoration program. There are however, general guiding principles that we can recommend based on our experiences from this workshop.

Suggested Approach

In a completely natural state, Atlantic salmon survival and productivity will vary over time. Significant decreases in adult abundance due to natural variation can be interpreted as a call for concern and action. However, it is important to consider population abundance trends over some specified time-frame. Short-term population fluctuations are expected and therefore, should not carry the same weight or level of concern as long-term population declines. Maintaining longterm monitoring programs allows for the detection of these types of population trends and allows the increases and decreases to be put into historical context. It is difficult for local, provincial/state and federal agencies to maintain the funding needed for these types of programs as they often do not compete well against other short-term projects and investigations. However, maintaining these programs is essential to the responsible management of any salmon population. In the absence of long-term monitoring, contemporary field data can provide information on population status. In the absence of any contemporary data, expert opinion may be the best information available, including that provided by local and traditional knowledge. This hierarchy highlights the importance of long-term monitoring data and underscores that it is never too late to start a monitoring program. Healthy and diverse freshwater, estuarine, and marine habitats are fundamental to having healthy wild salmon populations. These provide the key elements needed for salmon survival and productivity and the basis for life history complexity within a population. Life history complexity (e.g., multiple river ages, multiple sea ages, 'early' and 'late' returns, repeat spawners, etc.) enables the development of increased population complexity. Diverse populations and ecosystems are more resilient, thereby providing greater buffering against environmental variation. When stock diversity decreases it can lead to increased annual fluctuations in returning salmon and a higher probability of major population declines (Schindler *et al.* 2010). Long-term population declines and loss of life history and ecosystem diversity can often be caused by anthropogenic (i.e., human induced) impacts on aquatic communities (e.g., out of balance predator-prey relationships, declining co-evolved diadromous complex, excessive indirect or direct harvest etc.), habitat conditions (e.g., decrease water quality and quantity, decrease habitat quality and quantity etc.) and/or connectivity (limited access to the full suite of habitats types needed). Therefore, the first principles of any recovery program will need to be founded on habitat restoration and protection combined with sound management based on population monitoring. As referenced earlier, the process of developing a salmon restoration plan is complicated and there is no one template available that will fit all possible situations. The development of an effective restoration program for Atlantic salmon requires:

- An understanding of the problem
- A clear statement of desired outcomes
- An evaluation of available options
- A long-term commitment to the program

The following flow chart is intended to provide guidance on the steps that should be taken when assessing the status of the salmon population and habitat in the watershed, both of which are essential components for the development of an effective restoration plan.



***Gibson (this workshop, see Section 5) provided clear examples of how population modeling can allow scientists and managers to investigate 1) how the dynamics of the populations have changed, resulting in the population decline and 2) how populations would be expected to respond to specific recovery actions based on those dynamics. Understanding the impacts of threats to the population through these types of modeling effort are absolutely essential to effective and efficient restoration planning.**

Following the above process will aid managers in determining what root-cause problems are affecting the productivity of the salmon population(s) they are focused on so that suitable plans can be developed to address them.

Stocking

For many years, stocking has been used as the default method of countering low fish numbers. However, stocking has often resulted in unforeseen consequences (e.g., deleterious genetic changes resulting in loss of wild traits) and as such, must be very carefully considered before incorporating into a recovery plan. Otherwise, the "stock first" approach is knee-jerk and could eventually inflict more harm than it does good for the population under recovery. Hatcheries were originally thought of as a "techno" fix to the problem of declining salmon populations. Instead of analyzing and fixing the habitat problems and/or reducing the excess harvest of adult spawners, hatcheries were designed to simply increase the number of salmon available. This practice often simply disguised the problems limiting production. The flow chart above will focus the manager's attention on the task of identifying the limiting factors for the population. Unless the factors limiting the population are identified and mitigated, stocking will not achieve population recovery. Through continued research and innovation of hatchery and rearing practices, our understanding of how to effectively use and manage hatcheries is continually growing, but remains far from complete. There are significant ecological and genetic risks associated with the use of hatcheries. Salmon stocks were once viewed as interchangeable (i.e. transferrable from one region or watershed to another), which is in contrast to the contemporary knowledge of unique populations within and among rivers. Despite these concerns, the use of hatcheries to rear Atlantic salmon for stocking may be justified in some cases. A clear example for hatchery intervention is when populations are in danger of extirpation. In other situations stocking should only be considered after all available fishery management measures have been exhausted and a full understanding of the threats has been developed (see figure above) and actions have been undertaken to improve habitat quality and quantity, and fish passage. Simply put, stocking fish into poor habitat and/or areas with poor fish passage will likely yield few, if any, benefits toward recovery. If stocking is to be considered as part of the overall recovery plan, it is important to have an understanding of the goals and timelines for hatchery intervention. There are a number of guiding principles that should be considered for hatchery intervention:

- First, consult with population dynamics and genetic experts to fully understand the pros and cons of the proposed effort.
- If the objective of the program is recovery of wild populations then human intervention should be minimized so as not to interfere with natural smolt recruitment processes.
- The start and finish of a stocking program should be predetermined.

Spawning and Rearing

- Use local wild broodstock if available.
- Use a large number of randomly selected breeders (e.g., mix sizes of fish).
- Obtain a representative genetic composition to balance the demographic gains with genetic diversity (April, this workshop). Minimize time spent in the hatchery.
- Maximize wild or "wild-like" exposure.
- Alter artificial rearing environments to promote fish traits that may be more favorable in nature.
- Wild exposure of hatchery products can improve short (within generation) and long term (transgenerational) success of artificially reared fish.

Releases

- Need to identify and fix limiting factors that may impede survival at each life stage and plan releases accordingly.

- Carefully consider the most appropriate choice of life stage to be stocked, based on the tenet of minimizing hatchery involvement and maximizing wild exposure.
- Long term monitoring is essential to understanding long-term contribution of the stocked fish and therefore to measuring success (egg to at least F1 generation).

<u>And remember that:</u>

- Stocking should be considered a temporary tool.
- Stocking should not inhibit other restoration/recovery measures.
- Stocking, by itself, will not be sufficient to recover/restore populations.

Wrap-Up

The information presented at this workshop and above demonstrates the significant progress that has been made in our knowledge of wild Atlantic salmon recovery and restoration programs. In this workshop there were a series of presentations that described advantages and disadvantages of various hatchery techniques, stocking strategies, habitat restoration and fish passage improvement methods. The workshop presentations did not span the full range of human intervention but highlighted various approaches along the spectrum. Some techniques showed promise, but in all cases hatchery intervention alone did not result in recovery. For many years fisheries professionals have focused on monitoring for the primary purpose of assessing stock abundance. Stock restoration and enhancement techniques were often undertaken without a firm understanding of the full suite of threats in the watershed; the effect of these on the population; and the risks, limitations, and benefits associated with particular recovery actions. The lessons highlighted and demonstrated within this workshop show the benefit of, and our progress towards, moving away from this paradigm. The existing approach to resource management typically has not achieved long term conservation goals. Science based decisions have been compromised by short term government priorities and the needs of dominant stakeholders. This often leads to short term band aid approaches (e.g. stocking) rather than addressing long term management of habitat and harvest. These approaches need to change. More stakeholders (NGOS, recreational anglers, scientists, First Nations) need to become involved to create an active and committed decision making body to develop locally tailored solutions. The lessons highlighted within this workshop are not unique to salmon recovery initiatives. They are reflective of the general evolution towards an ecosystem approach to natural resource management and restoration. There are many other recent examples of ecosystem and holistic based natural resource management, which can be helpful guides when developing an Atlantic salmon management plan. For example, Palmer *et al.* (2005) proposed five criteria that could be used to measure the success of river restoration projects. These criteria help bring an ecological perspective to processes of river restoration. Given that salmon restoration and river restoration activities often overlap (Fleming, this workshop), the criteria proposed by Palmer *et al.* (2005) may provide a solid foundation for both evaluating the potential effects of proposed salmon restoration actions, as well as the outcomes of salmon restoration efforts post-implementation. The five criteria proposed by Palmer *et al.* (2005) are summarized below:

1. There should be a specific guiding image of the restoration effort under consideration that envisions a more dynamic and healthy state than currently exists.

2. The ecological condition of the system/population must be measurably improved.

3. The population should be more self-sustaining and resilient to external perturbations so minimal follow-up is needed.

4. No lasting harm should be inflicted.

5. Both pre- and post-assessment activities must be completed and data must be made publicly available.

This workshop focused on the science and management of Atlantic salmon, with particular emphasis on the biology and ecology of the species and new techniques in restoration. However, the successful restoration and management of the species will involve a full suite of additional considerations such as regional economics, the available resources (e.g. fiscal, standing stock, infrastructure, etc.), and political and societal views of the effort. The development of an effective management and or restoration plan for the species will require that all of these additional factors be taken into account. It is impossible for us to suggest a recovery plan that would meet the needs of your watershed and salmon population. The particulars of what you are dealing with within your watershed (e.g., population status, habitat status, politics and local engagement) will determine the best course of actions. We can, however, suggest a number of building blocks or principles that should form the foundation of any recovery plan. Below we present five guiding principles:

1. Team

a. The foundation of a recovery plan requires a solid and committed team to create a local decision making body.

b. A 'champion' (individual or organization) needs to be identified as project leader.

> i. Teams need a good leader, someone who has passion for the watershed, restoration tasks, and can leverage the strengths of each member to ensure the work identified as needed by the team is accomplished. Finding effective leaders is no simple task, but is essential to success.

c. The team should consist of a diverse group of stakeholders (e.g. NGOs, First Nations, recreational anglers, scientists, and watershed users), government officials (i.e. science and management) and policy makers (i.e. elected officials).

d. Partnering allows for the pooling of resources, increases funding options and allows for the addressing of critical questions at a broader level.

e. Team members must share knowledge, discuss options for best recovery strategies, and work together to plan and prioritize projects using science based decision processes that include and take into consideration local and traditional knowledge wherever possible.

f. The team must meet regularly to review progress (e.g., stock status reports, research projects, etc.) and determine best management options.

2. Holistic Approach

It is now generally recognized in conservation circles that any given population cannot be recovered in isolation of other co-existent native fish populations and ecosystem circumstances, nor is there much chance at recovery if the strategy is to address symptoms as opposed to root cause issues. As such, we suggest that any recovery strategy must take a holistic approach, taking into consideration the following:

a. Need to take a multi-species and ecosystem-wide approach if you want to achieve the best chance of salmon recovery (e.g., status of population in nearby rivers/watersheds, status of other native fish communities).

b. Must identify and understand the root cause(s) of limiting factors and how they relate to the entire ecosystem.

c. Coupling salmon restoration interests with those of the diadromous species complex will ensure that:

> i. The salmon's long-term interests are represented.
>
> ii. Actions taken will provide greater benefit to the entire ecosystem that supports wild Atlantic salmon.
>
> iii. There is a broader ecosystem recovery potential.
>
> iv. An expanded potential resource pool is available to support restoration efforts.

d. Practical, management plans should be developed for each watershed. A practical management plan accurately characterizes the status of the salmon resource as best as can be accomplished with combined scientific, local and traditional knowledge. It will also characterize the effects of individual threats allowing managers to identify and prioritize restoration actions on a watershed by watershed basis.

> i. Specific issues/threats are often not limited to a single tributary, but rather are occurring within the larger watershed. For example, conducting targeted stream bank restoration programs to address localized erosion issues often only serve as applying "band-aids" on issues that are symptomatic of larger scale issues that should be addressed.
>
> ii. This should not be considered an indictment of in-stream work. It can often provide important short-term benefits. However, the larger watershed level issues (i.e. the root causes) must be properly identified and addressed to support a long term solution so as to avoid or prevent similar problematic symptoms in the future.

e. Prioritizing actions should occur independently of fiscal concerns, and perhaps more importantly political concerns.

f. A multilevel approach is needed: (local, regional, national, international).

> i. Local groups should focus efforts in freshwater and estuarine areas, i.e. areas within their sphere of influence.
>
> ii. Larger efforts (e.g., marine mortality) must be taken on by larger entities, with the support of local groups.

g. The causes of marine mortality and an understanding of post-smolt to adult migration behavior and mortality (where, when, and how), including indirect bycatch and directed harvest, must be identified. Increase support to study marine mortality using the state of the art technologies.

h. Productivity limitations caused by low marine survival should not be considered a reason to prevent freshwater actions. One of the fundamental goals of any recovery effort should be to improve or maximize freshwater production of highly fit juvenile salmon to help offset the effects of high marine mortality.

3. Long-term commitment (funding and leadership)

a. Any recovery effort requires a long term commitment by the team involved.

b. Clear goals and timelines (e.g., start and end dates) must be defined for each phase of the project.

c. Performance measures must be established for each phase of the project.

d. Funding sources must be confirmed and reviewed periodically.

4. Monitoring and evaluation

a. Monitoring and evaluation must be fundamental components of any recovery program.

b. There must be a clear understanding of the project purpose, experimental design, and performance measures when designing a monitoring program so that the outcomes of the recovery effort can be understood and adjustments can be made as necessary.

c. Spatially and temporally representative monitoring of all restoration efforts is needed to assess effectiveness.

d. Thorough monitoring and evaluation of a recovery program can take multiple generations, extending well beyond the time frame of the recovery actions (it takes 4 to 8 years to complete a single salmon generation from egg to returning adult).

5. Outreach and communication

a. Recovery and management plans that are based on science and local/traditional knowledge must be communicated to policy makers and politicians.

b. The science and management information needs to be transferred to policy makers and politicians.

c. A collective vision (from the team) would help inform and influence decision makers (i.e. elected officials) and others (e.g., industry, philanthropist foundations who can influence policy and funding actions).

d. Documenting and sharing lessons learned from failed restoration programs is just as important as for successful programs to prevent future failures.

e. Ultimately, political will is needed to accomplish on the ground recovery actions, and this of course depends entirely on the presence of a strong team with strong leadership.

One final thought

There are no guarantees that a holistic recovery program that addresses multiple threats within a watershed in support of either a wild population, or a live gene banking program will be successful in recovering salmon. However, by ensuring that freshwater habitat is as productive as possible, it puts the watershed and its salmon population in a better position so that the chances of recovery are improved.

Annex 5: Summary of the output document 'To stock or not to stock' from the conference on salmon stocking organised by the Atlantic Salmon Trust and IBIS

EU Interreg funded collaboration between the Loughs Agency, University of Glasgow and Queen's University Belfast (IBIS 2013)

Glasgow, UK, 27–28 November 2013

A scientific consensus on salmon stocking

Kyle A Young, Colin Adams, Andy Ferguson, Carlos Garcia de Leaniz, Stephen Gephard, Neil Metcalfe, Phil McGinnity, Ted Potter, Tom Reed, Ian Russell, Jamie Stevens & Eric Verspoor

On 27–28 November in Glasgow UK, the Atlantic Salmon Trust supported a conference on Atlantic salmon (*Salmo salar*) stocking sponsored by IBIS, a European funded collaboration between the Loughs Agency, University of Glasgow and Queen's University Belfast (IBIS 2013). As an output from that conference, the organisers have published a document, 'To stock or not to stock', which summarises the advice on stocking from various salmon management organisations. In support of that document, this paper summarises what the authors believe accurately reflects the current scientific consensus on salmon stocking.

We have written this paper for fisheries policy makers and managers who may not be familiar with the relevant scientific terminology, concepts and evidence. It presents our consensus view of the current scientific understanding of stocking in a series of brief statements, using non-technical language as far as possible (see Definitions).

The following statements are informed not only by research on Atlantic salmon, but also by research on other ecologically similar salmonids. The statements are sufficiently general to often apply to the stocking of these species as well. We recognise that uncertainty remains around specific scientific questions related to stocking. The complexity of salmonid ecology and life histories, the diversity of habitats and stocking programmes, and the difficulty in studying long-lived organisms that spend the majority of their lives at sea, all contribute to this uncertainty. We do not believe, however, that current areas of uncertainty preclude stating the following evidence-based principles.

- Removing adult salmon from the natural environment, breeding them in captivity, and stocking their hatchery-reared offspring into the natural environment can, but does not always, increase the number of adults they contribute to the next generation. The net demographic outcome of stocking depends on the balance between the higher survival rates experienced by fish in captivity, and the subsequently lower survival rates of stocked fish relative to wild fish of the same age.

- Hatchery fish that survive to reproduce as adults in the natural environment, whether through mating with other hatchery fish or wild fish, typically produce fewer adults in subsequent generations than do wild fish, and this difference is more pronounced where permanent hatchery lines or non-native fish are used for stocking.

- Stocking may thus increase the number of adults in a population temporarily, but is likely to reduce the longer-term productivity of the population.

- Stocking poses a risk to wild salmon populations through a variety of ecological and evolutionary mechanisms, such as increased competition for food and interbreeding between hatchery and wild fish.

- The risk to wild populations is scale-dependent. The more hatchery fish that are stocked and the higher the ratio of hatchery to wild fish in the natural environment, the greater the risk to the wild population.

- The impact of stocking on the genetic make-up of a salmon population depends in part on the type of broodstock used. Some impacts can be minimised by using wild native broodstock (i.e. same population) bred and reared using best practice. However, even in this case genetic changes can occur due to the absence of sexual selection (i.e. crosses are artificially produced that would not happen in the wild), and relaxed selection in the hatchery environment, which may lead to domestication.

- Following the cessation of stocking, the integrity of a wild population is likely to recover over time. However, in some cases stocking may lead to permanent changes in the genetic composition of a population, which may affect population productivity.

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

- Where a population is at imminent risk of extinction, and all appropriate and possible fishery management and habitat restoration interventions have been realised, time-limited stocking may be appropriate to rescue the population. That is, when local extinction is imminent, the benefit of a short-term increase in adult abundance may outweigh the risk of long-term damage.

- Where the integrity of wild salmon is not a management priority, stocking may support fisheries by producing adults for capture or harvest. In such instances, however, some stocked fish will inevitably stray to neighbouring populations, which may have different management objectives. It is important to appreciate and assess this risk.

- The costs, benefits and impacts of a stocking programme on wild populations can only be assessed with well-planned monitoring programmes. Such monitoring is an important part of all stocking activities.

- Science alone does not determine the role of stocking in salmon management. Social, political and economic factors all influence fisheries management decisions.

Definitions

- **wild** refers to fish whose entire life, from the fertilisation of eggs to death, occurs in the natural environment in the absence of direct human intervention. Intervention in this context includes the direct and indirect effects of stocking, e.g. when hatchery fish survive to reproduce in the natural environment, their offspring are not wild. This definition does not strictly depend on habitat quality or stocking history. Wild salmon can be present in severely degraded 'non-wild' rivers and in rivers currently or historically subjected to stocking.

- **hatchery** refers to fish that have spent some portion of their life (from fertilisation) in captivity, without regard to the duration of time spent in, or the naturalness of, that captive environment.
- **stocking** refers to the act of placing hatchery eggs or fish in the natural environment.
- **population** refers to a group of interbreeding salmon which is to some degree genetically distinct from other such groups. For example, a river's salmon stock might contain multiple populations that spawn at different times or locations within the same catchment.
- **productivity** refers to a population's capacity to grow in size.
- **integrity** refers to the degree to which a wild salmon population interacts naturally with the environment and other species sharing aquatic ecosystems