From Headwater to Headland: Improving smolt survival in rivers and estuaries

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Based on a conference organised by the Atlantic Salmon Trust and The Tweed Foundation in Berwick-upon-Tweed
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Foreword

Over recent decades it has become increasingly clear that the North Atlantic is changing and changing fast. As a result of these changes salmon survival at sea has become highly variable and in many cases has dropped by more than two thirds. Indeed in some rivers survival from smolt to adult salmon has dipped below 5%. Losing 95% of salmon on their journey to and from the ocean is unprecedented. Sea trout too face a range of challenges and in some areas sea trout numbers have been decimated and individual populations are struggling to survive.

A key message from the 2011 NASCO Salmon Summit in La Rochelle was that in these circumstances it was vital to ensure that the maximum number of healthy wild smolts migrate to sea from our rivers. A great deal of work has been done to improve spawning and juvenile habitats and boost the numbers of smolts that begin their downstream migration. There has been less focus, though, on that migration itself. It was to address this gap that the Atlantic Salmon Trust and The Tweed Foundation organised this smolt conference. Our aim was to offer a platform to researchers working on the biology of both salmon and sea trout smolts to present their latest findings and to advise managers on strategies which could help to boost overall smolt survival.

In recent years it has become increasingly clear that losses in freshwater can be significant and that reducing these may be one of the most effective ways of boosting the number of smolts that leave our rivers. We also need to make sure that emigrating smolts are in the best possible condition; factors such as delays to migration and pollution can reduce their fitness, and so their ability to make the transition to salt water and to survive the perils of their ocean migration. Losses in the tidal stretches of rivers and in estuaries, too, must not be ignored; indeed, since marine survival is usually calculated from the point smolts can be counted in the lower river, such losses could be contributing to the overall fall in survival rates. This is why the conference sought to address the problems confronting smolts throughout the first stage of their migration, from the headwaters of our salmon and sea trout rivers to the headlands of the estuaries they flow into. Once the transition has been made to silver coated smolts and once the smolt shoals gather to make their downstream migration, the density dependent factors compensating for loses of fry or parr no longer apply; every silver smolt is precious, whether it is lost from a high mountain burn or on entry to salt water, and every loss will directly reduce the number of adults returning to spawn.

The conference made clear that man's influence on the overall survival of salmon and sea trout smolts can be profound. The NASCO SALSEA Programme clearly outlined the effects of climate change on the North Atlantic and on salmon survival at sea. However other factors such as predation, barriers, impacts from pesticides and other contaminants are all amenable to direct management actions. In the past we may have believed that we had the luxury of time to deal with these issues but given the array of challenges currently facing our smolts, taking urgent management action is no longer a choice - it is an imperative.

We believe that this conference marked a milestone in our understanding of smolts and smoltification. We are grateful to all of our contributors, who provided a wide range of fascinating and important scientific findings to our conference and who helped us grow in our understanding of this vitally important phase in the lives of salmon and sea trout.

Sarah Bayley Slater *CEO, Atlantic Salmon Trust*
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Further Information: Copies of the presentations and access to a full video recording of the conference are available on both the AST (http://www.atlanticsalmontrust.org/) *and The Tweed Foundation* (http://www.tweedfoundation.org.uk/) *websites.*

The Atlantic Salmon Trust and the Tweed Foundation wish to gratefully acknowledge the generous support of the Smolt Conference sponsors

Setting the Scene "The Journey, from Headwaters to Headlands"

A key objective of salmon and sea trout fisheries management should be to maximise the production of healthy, wild smolts. The aim of the Headwater to Headlands Conference, organised by the Atlantic Salmon Trust and The Tweed Foundation, was to explore what this meant in practice, reviewing the current state of scientific knowledge about salmon and sea trout smolts and considering the implications of this for management, both in freshwater and in estuaries and coastal waters. It also sought to identify those areas where managers and others need to know more, if they are to increase smolt numbers.

The conference themes focused on the journey a smolt makes from its headwater stream in the freshwater environment to the coastal zone. The journey from freshwater to seawater is a critical life stage for Atlantic salmon and sea trout. It is fraught with many perils along the way, from the challenging physiological demands to anthropogenic pressures in the form of land use activity, habitat conditions experienced and obstacles to migration. Each smolt which successfully migrates downstream to the marine environment exhibits remarkable navigation skills, tenacity and a fair share of luck.

This summary report starts with a brief description of the biological background to the smoltification process in salmonids and of the factors affecting the smolt's journey from freshwater to the marine environment. It then discusses the four topics covered by the conference sessions, drawing on the papers presented at it:

- Influences in freshwater
- Migration in rivers
- Survival in the lower river, estuary and coastal waters
- The impact of predation

A final over-arching section reviews the outcomes of the conference in relation to future research and management needs.

Biological background

Smoltification in salmonids

Before the journey begins juvenile Atlantic salmon must undergo a process involving a number of preparatory morphological, biochemical, physiological and behavioural changes that pre-adapt them for life in a high salinity marine environment (Thorpe *et al.* 1998; Thorstad *et al.* 2012). During smoltification, the salmon parr lose their territorial behaviour, show negative rheo-taxis and begin schooling. Morphologically, bodies become slimmer and dark blue with silver sides which aids with camouflage and migration in the pelagic marine environment. The majority of the changes are adaptions for the physiological challenges posed by seawater entry, especially the need to control entry and the osmotic stress encountered when they move from fully freshwater to the high salinity, marine environment. The timing or initiation of the smolting process is dependent on individual fish and its environment (temperature, food availability). In general, the smoltification process is synchronised with photoperiod (increase in day length) and water temperature and water flow (McCormick *et al.* 1998). It is generally accepted that juveniles need to reach a "threshold size" (usually >/=10cm) before they smolt and migrate in response to the environmental cues.

Migration timing and behaviour

Migration is defined as the synchronised movements of species, they occur at specific, predictable stages of the life cycle and involve a large proportion of the population (Lucas & Baras 2000). The benefits of migrations are balanced with costs, and an understanding of the factors that limit migratory success is needed to ensure appropriate strategies for management and conservation of both salmon and sea trout. The benefits of migrating to exploit a new feeding ground are balanced with a wide variety of costs that include increased energetic requirements, stressful environmental conditions, and exposure to novel predators. Factors that affect the severity of these costs are varied, specific to both the individual (quality of smolt from a specific river) and the landscapes experienced (catchment specific effects), and can act strongly on the specific population as they migrate. External factors which influence migration are: 1) environmental conditions (which can affect the physiology of the migrant), 2) the physical structure of the landscape (e.g. barriers, dams, habitat) and 3) biotic components (e.g. predators). Environmental conditions (such as temperature or water flow dynamics) are usually sub lethal. However cumulative or carryover effects on physiology can impact long-term fitness and survival as the smolts move into the marine environment to feed (Moore *et al.* 2008).

The environmental factors cueing downstream migrations are mainly water discharge and water temperature (Moore *et al.* 2008). Smolt migration may be initiated exclusively by water temperature, while in other rivers an increased water discharge during the spring may be more important (Jonsson and Ruud-Hansen 1985). Temperature experienced by the juvenile salmon over time may also determine the timing of downstream migration (Zydlewski *et al.* 2005;). In addition, social cues, such as presence of other migrants in the river, may also stimulate migration. The downstream migration of smolts within freshwater is an active process; smolts actively swim downstream often within the middle section of the river channel and near the surface where the water velocity is highest and where they can avoid areas of reduced flows (Davidsen *et al.* 2005; Svendsen *et al.* 2007). Fish tend to migrate at night during the early part of the season when the water temperature is below approximately 12°C. However, towards the end of the season when temperatures are generally higher, smolts migrate during both the day and night (Ibbotson *et al.* 2006; Thorstad *et al.* 2012).

The change in migratory behaviour from nocturnal migration to movement during both the day and night is often reflected in a significant seasonal change in the residency time of the smolts within the river. Fish that initiate their migration later in the season spend less time in the river before entering coastal waters. As a result, smolts from a river system may migrate through an estuary and enter the sea over a limited number of days (Moore *et al.* 1995). This period may represent the optimal time or window of opportunity for entry into the marine environment which is critical to their subsequent survival and return as adults (Hansen *et al.* 1989; Hvidsten *et al.* 2009). It is believed that smolts initiate their downstream migration when environmental cues in the river predict favourable ocean conditions (Hvidsten *et al.* 2009). However, what is considered most important is that the smolts enter the marine environment during a narrow "window of opportunity" when conditions in the sea are at their optimum in terms of water temperature and prey suitability, which allows survival to be maximised (McCormick *et al.* 1998).

Smolt Production and Survival: Influences in Freshwater

Session 1: Key Questions

- *There is considerable evidence that chemical pollution, even at very low levels, can affect smolt condition and their ability to adapt to salt water. How significant are these impacts?*
- *What is likely to be the impact of climate change on smolt numbers? Will earlier smolt runs reduce feeding opportunities for post-smolts at sea? Is there likely to be a reduction in the age of smolting, and if so how will this affect survival?*

The pressures on the freshwater ecosystem are wide and varied and the effects these can have on smolts and post-smolt migration success is significant. Freshwater influences include environmental factors (i.e. climate change) and anthropogenic impacts (i.e. chemical pollution, barriers). Much of the focus on declining salmon populations has been on increased mortality during the marine phase of the life cycle. However marine mortality does not operate independently of factors operating in freshwater and the biological characteristics of smolts migrating to sea. Damage and delay to smolts as they negotiate in-river renewable energy schemes may also have consequences for their subsequent survival in the sea. Over recent decades climate change, resulting in modifications to river temperatures and flows, has resulted in smolts migrating at a younger age and at a smaller size. Over the same period smolt run timing across the geographic range has been earlier, at an average rate of almost 3 days per decade. This has given rise to growing concern about smolts potentially missing the optimum environmental migration "window', the timing of which may also be changing. Given that managers have very limited ability to influence the broad scale factors modifying salmon survival at sea, it is vital that freshwater habitats are managed, to both maximise the smolt output and to minimize the impact of factors acting in freshwater that may compromise salmon once they migrate to sea.

Contaminants - chemical exposure

Andy Moore (Cefas) presented findings on the role the freshwater environment can have on regulating smolt behaviour and subsequent survival in the sea. Physiological adaptation associated with the parr / smolt transformation to saltwater begins in the freshwater environment. Contaminants such as Atrazine have been shown to have significant effects on smolts and their marine survival, emphasising the importance of understanding the impacts of exposure to contaminants on numbers of returning adult salmon (Figure 1). The significant effects of atrazine highlight the importance of understanding the potential impacts of other contaminants. These data also show the need to improve our understanding of the impact of contaminants on important spawning tributaries, and to explore the efficacy of buffer zones as a means of reducing these impacts.

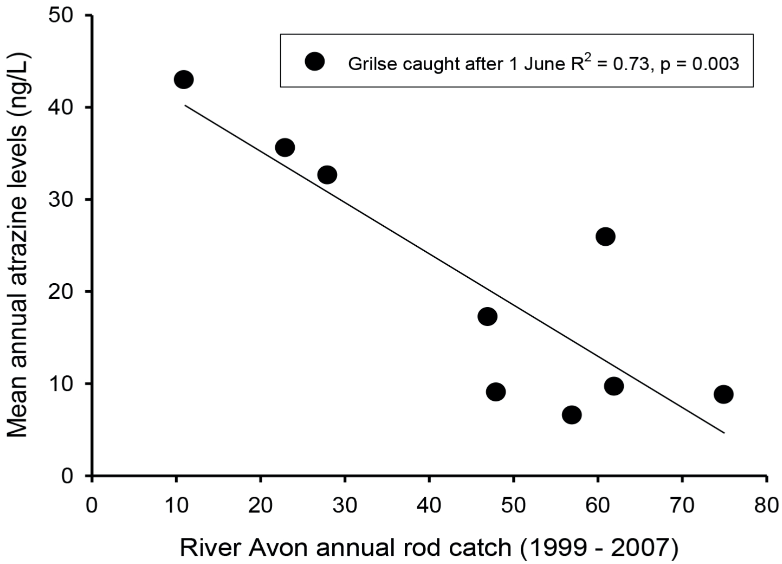

Figure 1: Salmon rod catch – 1 year after exposure to atrazine in freshwater (Moore et al. 2013)

Smolt length and age - Climate Change

Moore went on to describe how average smolt age is declining in northern European stocks and that this is believed to be principally driven by temperature as well as other factors such as density and prey availability. These findings were also supported by Elvira de Eyto (Marine Institute, Ireland), who reported results from the Burrishoole catchment relating to growth of juvenile salmonids in freshwater and how their growth is principally driven by seasonal and annual variations in temperature. Future climate projections indicate that water temperatures will be significantly warmer in the coming decades and the consequences of this are manifold (ICES, 2017). Data were presented on a large number of juvenile salmon length observations from headwater streams in the Burrishoole catchment over two decades. Spatial variation was examined in the lengths of juvenile fish caught throughout the entire river catchment at a single point in time (end of summer) over a 20-year period. These data were used to model observed growth trajectories in respect of the growing degree day (GDD), temperature metric. Projections of river temperatures until the end of the century were then used to model juvenile salmonid freshwater growth into the coming decades. The results indicated that salmon are reaching the critical threshold that initiates smoltification earlier (as much as three months in advance). She suggested two possible outcomes: if parr did not smoltify significantly earlier in the year, better growth would lead to larger, 2+ smolts (14-16 cm) which could potentially lead to better marine survival, less predation on smolts and more eggs in returning adults. On the other hand earlier migration (9-10cm), could lead to poorer marine survival, more predation and fewer eggs in returning adults.

Stephen Gregory (GWCT) continued with the theme of smolt length and presented preliminary findings on links between smolt length and subsequent marine survival. He hypothesized that larger smolts will be better able to avoid such threats by merit of their size and probable better swimming ability, thus predicting that larger smolts will have a higher probability of returning to their natal river as adults. He plans to further test this prediction with data from the River Frome, where, using Pit Tags, individual salmon have been tracked emigrating as smolts and returning as adults since 2006. Any effect of smolt length on their survival could have important implications, since River Frome parr are reducing in size, as has been observed on other rivers across Europe (Gregory *et al*., 2017), which could have a knock-on effect on marine survival.

Modelling freshwater smolt production

Alan Walker (Cefas) presented the ReMES model for estimating smolt production for a river basin according to user-defined reach mapping of length and wetted area, along with fry and/or parr densities from surveys. The model is based on simulations developed for estimating eel production. The ability to quantify smolt production throughout a river basin is a key step in determining the relative importance of spatially discrete impacts and prioritising management measures to improve the situation. Most traditional methods assess smolt production at fixed locations, typically as far downstream as possible, but cannot inform spatial disaggregation. ReMES applies parameter estimates of juvenile growth, mortality rates due to natural and anthropogenic factors and smoltification probabilities based on fish size and age and local productivity. The model presents annual smolt production in numbers or in biomass and can be parameterised to test climate change scenarios and various management strategies. He highlighted the importance of understanding the varying nuances of the salmon life cycle (growth rates, age at smolting, habitat requirements etc) and being able to incorporate these correctly into the model, so not to overestimate smolt production from a river basin. Areas of development include trialling the model in more rivers and including reach specific estimates, to attain a better understanding of the input parameters.

One such important input parameter for models is that of sex ratios and data on this critical topic in relation to sea trout was presented by Andy King (University of Exeter). Knowledge of the sex ratio is essential for effective management, for the development of biological reference points and for the development of models for estimating overall smolt production. He stressed the importance of adding a sex ratio component to models and explained how such models could be used to assess sex biased mortality.

Smolt Migration in Rivers

Session 2: Key Questions

- *There is growing evidence that climate change is affecting smolt migration, with smaller smolts migrating earlier and a mismatch between river and sea temperatures. How significant are these changes?*
- *What is the effect on smolt condition of delays to migration due to barriers and /or low flows?*

A central theme for Session 2 was the importance of the timing of the seaward migration of smolts and the "window of opportunity" that exists for their journey downstream to coastal zones.

The downstream migration is often initiated by increasing river discharge and/or water temperature. Reduced river flows are likely to inhibit or delay the emigration of smolts and their entry into coastal waters, in the more southern populations (Jonsson & Jonsson 2009). Any delay in downstream migration may result in reduced survival within the sea and lower numbers of returning adults. Smolts not entering the marine environment during the optimal period for emigration have exhibited lower return rates than fish entering during what is considered to be the window of opportunity (Hansen *et al.* 1989). In regions where there is a marked decrease in the spring river flows, the smolt run can become more dispersed over time and the shoals of fish become smaller. In both instances, this is likely to result in an increase in predation in freshwater, the estuary, and coastal zone.

Increased water temperatures during the freshwater stage of the smolt migration can often lead to the loss of osmoregulatory capacity; the fish undergo a partial de-smoltification process which reduces survival if they migrate into saline conditions (Duston *et al.* 1991; Stefansson *et al.* 1998; McCormick *et al.* 2005; Handeland *et al.* 2004). Therefore, there is concern that any delay in the movement of fish into the ocean, coupled with exposure to increased temperatures, will have a significant impact on the survival of the smolts and the numbers of returning fish. This is of concern when delays occur because of structures such as weirs, hydropower schemes and within the impoundments.

Eric Verspoor (University of Highlands and Islands) in his presentation outlined the importance of local adaptation in smolt migration and how this is often an unrecognized factor in smolt and post-smolt mortality. The descent of Atlantic salmon populations to the ocean involves migrations varying from <2km to >1,000km. The types of habitat involved ranges from systems dominated by fast flowing fluvial habitat to the slower flowing waters of lakes. To survive and return to spawn, populations must integrate freshwater migration timing needs with those of post-smolt marine migrations. Different populations can begin migration in rivers separated by thousands of kilometres and cover a few hundred to many thousand kilometres to the Norwegian, Barents, and Labrador Seas and the coastal waters of Greenland. Seasonal differences in migration initiation and seawater entry with latitude are known. However, the extent of variation in smolt migration behaviour among and within river stocks and its potential adaptive basis, remains unclear.

Verspoor went on to question the meaning of the term '*local adaption'*. Studies were beginning to suggest that many populations have differing specific migration pathways; it had been shown, for example that different populations from the same river may migrate to different feeding locations (Byron & Burke 2014). This raised a number of questions: if where a salmon smolt migrated to feed was related to rates of mortality (assuming different feeding areas/ different predation pressures/ a variation in the abundance of prey), could mortality rates be predicted from oceanic oscillations (e.g. North Atlantic Oscillation (NAO), or Atlantic Multi-decadal Oscillation (AMO)). Changes in the strength of these oscillations might negatively or positively impact smolt survival in a given year? Such effects would add significant complexity to our understanding of smolt migration and subsequent returning adult numbers. Existing knowledge of salmon smolt migration biology makes a compelling case for heritable variation among populations and that this is locally adaptive. If so, stocking of non-native fish, river habitat change, interbreeding with farm escapes, and global warming all have the potential to reduce local adaptation and increase both smolt and post-smolt mortality. In Verspoor's view, there needs to be a paradigm shift in thinking on salmon freshwater migration biology.

Data presented from the Loire-Allier stock by Mich Fleming (Conservatoire National du Saumon Sauvage, France) developed the theme of run timing and increasing environmental mismatch. Loire Allier salmon have the longest freshwater migration of any extant stock in Western Europe, with a journey of some 900km. They are increasingly threatened by altered river conditions, exacerbated by physical alterations to the river. To guide the conservation and management of this ancient salmon stock in the face of climate change and other impacts, studies were undertaken of its specific migratory adaptations in respect of the timing of smolt migration and seawater adaptation, and of the effect of environmental change. This work showed that salmon populations in the Loire Allier have specifically adapted to meet the challenge of long river migrations. However alterations to the physical habitat can significantly delay smolt migration; dams, for example, create lake habitat which the riverine smolts are not adapted to. As a result of these delays, late migrants will simply not arrive at the correct time in the estuary when temperatures will be below the critical threshold for smolts. The Loire Allier salmon provide a unique insight into the expected smolt migration responses to climate change and this study highlights the importance of maintaining, protecting and restoring natural river continuity in salmon rivers across Europe.

Richard Kennedy (AFBI) presented results from a series of long-term studies, starting in 1974, of smolt migration from the River Bush in Co. Antrim, Northern Ireland. These described the migration patterns, timing and biological characteristics of wild Atlantic salmon smolts and showed that while smolt runs have recently increased towards historic levels of abundance, there was also significant evidence for earlier running smolts. The results indicated that earlier migration was closely linked to river temperature patterns (Figure 2).

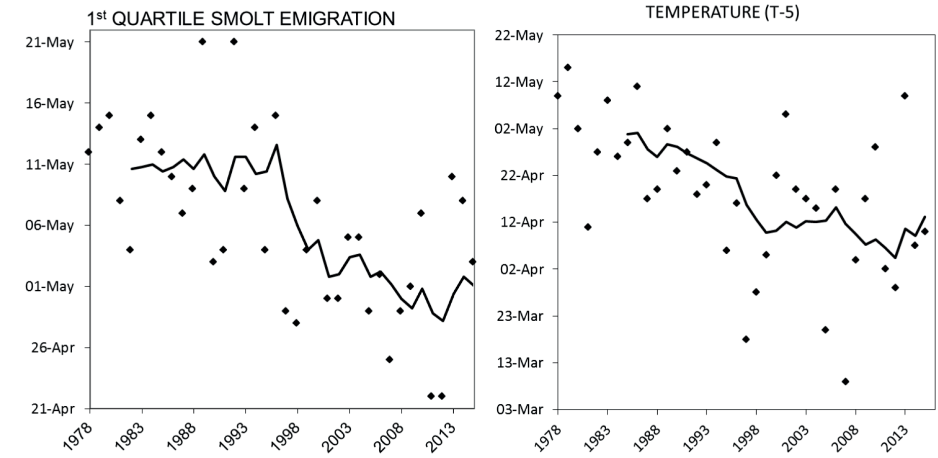

Figure 2: Date of emigration of 25% of the annual smolt run compared to T5 temperature (river 5 days above 10C). This highlights the correlation between warming water and earlier smolt runs.

Distinct seasonal patterns were evident for biological characteristics of Bush smolts, with mean age and length decreasing throughout the emigration period. These results mirrored findings from Session 1 papers. Kennedy showed that adult return rates from River Bush 2+ smolts were much higher than for 1+ fish. These findings complemented data presented from the River Frome smolts (Gregory et al. 2017) and provide support for the argument that larger smolts may survive better than smaller smolts. Historical work conducted in the 1980s indicated high levels of in-river predation on Bush smolts by piscivorous birds (Kennedy & Greer, 1988). A pilot study undertaken in 2014 used acoustic telemetry to examine the movement, timing and survival of Bush smolts through different sections of the river and into inshore coastal waters. Attention was focused on the movement across the transitional zone, 25% of total losses were observed in the freshwater zones, with loses of 28% in the marine zone. Critically, Kennedy outlined the thermal mismatch that earlier running fish are encountering. Smolts are experiencing increasingly warmer conditions in the river but relatively cooler conditions in the sea. This leads to a thermal mismatch between river temperature and marine temperatures, particularly for earlier running smolts, which could potentially put them at a disadvantage (Figure 3.)

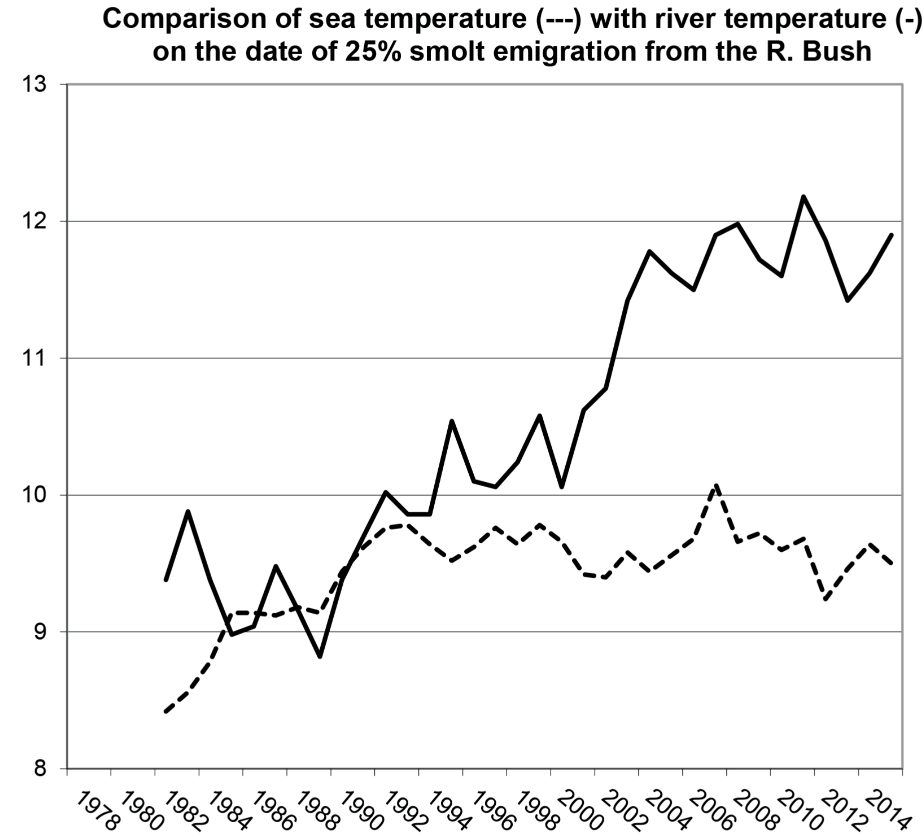

Figure 3: Comparison of sea temperature (y-axis °C) (---) with river temperature (-) on the date (x –axis) of 25% smolt emigration from the R. Bush [5 yr. rolling mean]

Although increasing smolt runs in the River Bush show positive signs, the marine survival remains low, highlighting once again the need to understand what is happening to post-smolts in the ocean.

Barriers to migration

Barriers such as dams and low head weirs play a major role in the fragmentation of rivers and have major impacts on fish populations by preventing or restricting movement. Barriers potentially delay smolt migration, exposing fish to higher levels of predation and increasing the risk that they will miss the optimal window for reaching the sea. The recent drive towards renewable energies has caused a marked increase in applications for small-scale hydropower schemes increasing the number of barriers in our rivers; these structures can delay migration, and can also expose smolts to possible injury from passage through the turbines.

Peter Walker (RSK Environment) gave an overview of issues facing downstream migrating smolts, outlining the different types of obstacles and threats that they encounter. While options for aiding safe downstream passage of smolts existed, he was concerned that in some cases these were not adequate. He went on to highlight the pros and cons of these different options.

Joel-Rees Jones (NRW) presented the results of a study on a sluice gate system, on the River Dee in North Wales, where 94 smolts (67 wild, 27 hatchery) were tagged and tracked by fixed receiver. Of these, 91.5% successfully reached and passed by the sluice gates. Of the smolts that reached the sluices, 6.6% failed to successfully migrate downstream through the sluices and 3.2% took over 4 days to pass on downstream. Smolts migrated more quickly in higher flows. Smolts travelled at lower speeds through the sluices, suggesting migration may have been somewhat delayed by the sluice gates.

Rasmus Lauridsen (GWCT) outlined the results of a study into the impact of a hydropower scheme on the River Frome. The scheme in question was equipped with a "*fish friendly*" Archimedes screw. Transitional behaviour was observed in and around the turbine. A high probability of survival was observed. No significant differences were observed in transition time or in marine survival between fish which passed through the turbine and those that avoided the turbine. While the study showed that this hydropower scheme appeared to have a minimal impact on smolt survival, Moore had earlier presented data showing that 8 -18% of salmon smolts moving though turbines exhibited signs of damage. This raises concerns over how well smolts which have suffered significant scale loss will adapt to the physiological pressures of saltwater.

Population Structure and Sea Trout Migration in Scandinavia

Sigurd Stefansson was scheduled to open Session 3 with a keynote address: *Drivers for smolt survival in estuaries and coastal waters*. As he was not able to attend the conference, Johann Hojesjo (University of Gothenburg) stepped in at short notice with a paper on migration behaviour, genetics and habitat-based stock assessment of sea trout stocks in the Baltic, which addressed a number of the themes covered by the conference.

Population structure of sea trout along the Swedish coast had been assessed using Single-Nucleotide Polymorphisms (SNPs) and preliminary results revealed a certain degree of local adaptation. However, trout originating from rivers entering the same fjord were more closely related than fish from rivers discharging into other fjords. Genetic clusters encompassing regions were observed, suggesting a degree of straying among the sea trout populations in a particular fjord. Tracking data on migratory patterns and survival of smolts on their outward migration through lower river estuaries and coastal waters suggest that both discharge and temperature govern the initiation of downstream migration but that their effect may depend on the level of precipitation. Migration was mainly nocturnal and a significant number of individuals were not observed. Both smolts and kelts showed similar mortality, which was higher in years with lower rainfall, probably due to increased predation as a result of reduced flows, leading to lower turbidity and migratory delays. Once again this result highlights the importance of identifying habitat fragmentation, as ultimately this may alter the discharge and temperature and therefore affect the triggers for migration.

He then discussed the habitat-based stock assessment of sea trout stocks that was being developed in Sweden. If this was to successfully model production, a number of important inputs were needed. These included: biological reference points; quantitative habitat classification; information from electrofishing at representative habitats; information on winter and migration mortality, on degrees of smoltification and on carrying capacity of streams (i.e. region specific reference data). Habitat-based modelling could potentially act as a guide on which sections of habitat to restore and how these could be improved, providing vital information for managers.

Smolt survival in the lower river, estuary and coastal water

Session 3: Key Questions

- *What do we know about smolt behaviour, and survival, once they reach the lower estuary and about early marine migration?*
- *How can we assess losses in estuaries and coastal waters and establish their causes?*

Smolt migration into the marine environment

Several papers presented at the conference, and much of the discussion, dealt with aspects of tracking smolts and acoustic telemetry projects. This section covers the key findings from the tracking studies and the discussion points raised.

Very little is known of salmon smolt migratory tactics and migration success as they enter the marine habitat or of the factors which influence their subsequent survival and dispersal throughout the ocean. This is primarily due to the difficulties in locating and capturing individuals during this transit period. Mortality in the early marine stages of migration is thought to be high. Reported mortality rates greater than 5% km^{-1} are not uncommon in estuaries, with averages of approximately 1% km^{-1} in the early marine phase of migration (Thorstad *et al.* 2012). However, the reported mortality rate of smolts is highly variable and transfer of average mortality rates derived from one site to another should be done with caution. Currently work is underway to better understand the mortality and migration success of smolts in estuarine and marine environments. Smolt distribution at sea has previously been inferred from the recapture of fish in surface trawls within the Atlantic Ocean (NASCO, 2011). There is a keen interest in determining the offshore movements of fish as they enter the open ocean. The technology of choice which allows researchers to study fish movements in these open ocean environments is acoustic telemetry. Acoustic telemetry requires a transmitter, attached to an individual, which transmits an acoustic signal to a receiver comprising a hydrophone and a data logger where information is recorded and stored. Acoustic tags are uniquely coded, and can determine and transmit information to the receiver on environmental parameters (e.g. depth, temperature etc.) which are being experienced by a fish within range of a hydrophone. Telemetric information can be used to inform the position of the individual at a specific time and provide data on the environmental and physiological parameters of the fish (Thorstad *et al.* 2013). By strategically deploying an array of receivers throughout the study area it is possible to monitor the behaviour and survival of the fish in question. Alternatively, it is also possible to actively track fish with a mobile hydrophone beyond the range of a fixed receiver array.

Angus Lothian (University of Durham) presented findings on salmon smolt migration from freshwater through to the coastal zone on the River Deveron. This research yielded key insights into the early marine behaviour of smolts. Smolts captured from the River Deveron were tagged with acoustic transmitters and tracked through the river and the immediate Moray Firth. Overall survival of smolts in the Deveron was 40%, with a higher mortality in the river than in the early marine stage (Figure 4.)

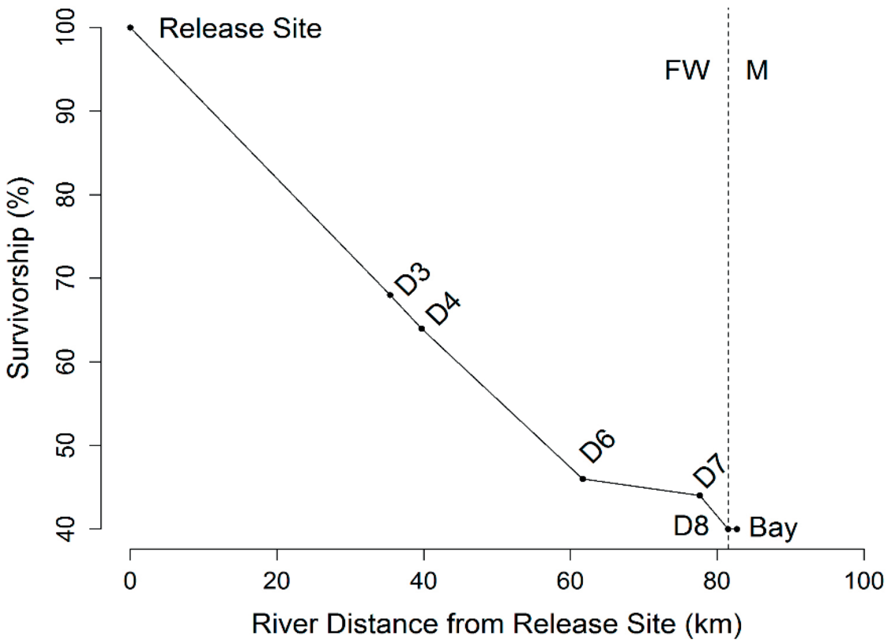

Figure 4: Survivorship of smolts on the river Devron (Lothian et al. 2017)

River Deveron smolts had a greater swimming speed in the marine environment than in the river (marine = 37.37 ±28.20 km day $^{-1}$; river = 5.03 ± 1.73 km day $^{-1}$). The main smolt trajectory leaving the river was northerly towards the mouth of the Moray Firth and was mainly undertaken in the hours of darkness. Marine pathways did not follow geographical features and could be influenced by water currents.

Lorraine Hawkins (River Dee Trust) presented the results of a similar smolt tracking study on the River Dee. Dee smolts were tracked through the lower Dee and the busy inner harbour at Aberdeen. 50 salmon smolts were tagged, which represented the complete size range from the system. Size – dependant, in-river mortality was significant, yet surprisingly migration through the inner harbour was quick, with no losses. Migration was most closely aligned to river flows and was predominantly nocturnal, although more daytime migration occurred latter on in the run. These results were similar to those from the Deveron, with these two contrasting systems exhibiting remarkably similar freshwater mortality estimates (River Deveron = 0.77% km^{-1} and River Dee = 0.78% km^{-1}).

Niall Gauld (MSS) presented results from three acoustic telemetry studies investigating the initial marine migration of salmon and sea trout on the west coast of Scotland. The studies in question comprised:

- Applecross - smolt tracking
- Inner Loch Linnhe - salmon and sea trout smolt tracking
- Smolt movement around the Isle of Mull

Applecross smolt tracking

The detection rate of smolts in the initial marine phase was high, with 90% of smolts detected on the sea pool receivers and just over half of these detected leaving Applecross Bay. Subsequent detections along the coast were low, with evidence that the efficiencies of the different arrays varied considerably. High variability of migration speeds was observed.

Inner Loch Linnhe salmon and sea trout smolt tracking

Few studies have directly compared the movements and behaviour of salmon and sea trout smolts as they emigrate from rivers during the early phases of their lives at sea. Information on how the fish use the inshore environment is a prerequisite for understanding, and potentially mitigating against possible negative impacts that may occur due to human activities in these areas.

This study provided the first comparative information on salmon and sea trout smolts behaviour from the same loch in Scotland. There were no significant differences in terms of when the smolts left the rivers. Once in the sea, the majority of sea trout smolts stayed in the local area, while salmon smolts migrated rapidly from the loch.

Smolt movement around the Isle of Mull

The initial results from this study showed that movement speeds of smolts were highly variable, with smolts tending to move faster during an ebbing tide. Route choice was split for smolts from the River Lochy between the Firth of Lorne and the Sound of Mull, with a small preference for the former. In contrast only a small proportion of detected River Awe fish migrated up the Sound of Mull, with most fish travelling down the Firth of Lorne.

Matt Newton (AST) presented findings on estuarine and marine migration of salmon smolts in the Moray Firth, Scotland. The nearshore and offshore behaviour of emigrating smolts remains relatively unknown. A large acoustic array was established, in collaboration with Marine Scotland, to monitor the movement and mortality of smolts through an estuary

(Cromarty firth) and open ocean (Moray Firth) (Figure 5).

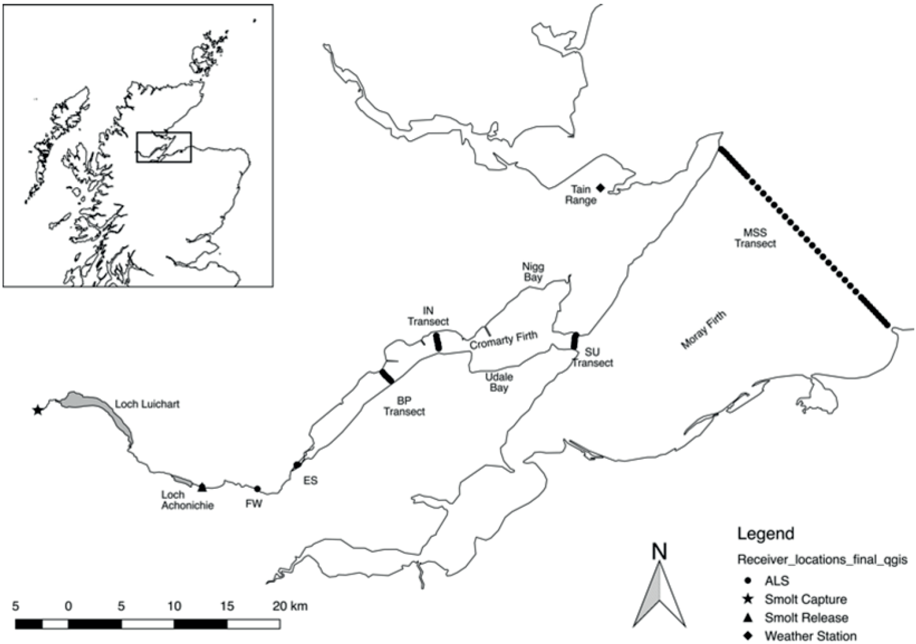

Figure 5: Acoustic array in the Moray Firth

This collaborative study tracked fish in the marine environment where their movement was unconstrained by a land narrowing. The results showed that smolt swimming was not aligned with tidal currents and that passive particle tracking failed to provide a good tool for predicting smolt migration routes. Mortality rates within the study (Table 1) were relatively low when compared with other studies. Atlantic salmon smolt mortality has been shown to range between 0.3 – 5% km^{-1} in fresh water, 0.6-36% km^{-1} in estuaries and 0.8 – 3.4% km^{-1} in the marine environment (Thorstad et al. 2012). Mortality may occur for a variety of reasons during smolt migration, but the most commonly cited are a lack of physiological preparedness (for transition between fresh and marine water) and predation.

Table 1: Mean and Standard deviations of rate of movement and the duration for fish moving between each transect. * denotes upstream movement from IN to BP. This is not an outward migration movement.

Movement Location	Mean ROM $m.s^{-1}$	S.D. ROM $m.s^{-1}$	Mean Duration (Hours)	S.D. Duration (Hours)	Mortality % per km
Release (FR)	0.08	0.09	90.69	127.11	3.14
FW → ES	0.26	0.38	46.32	54.76	1.55
ES → BP	0.13	0.15	52.79	43.77	0.37
BP → IN	0.53	0.34	6.63	15.02	0.21
IN → BP	0.62	0.13	2.50	0.68	0.00
IN → SU	0.29	0.30	25.45	22.04	0.37
SU → MSS	0.27	0.14	37.39	20.84	1.18

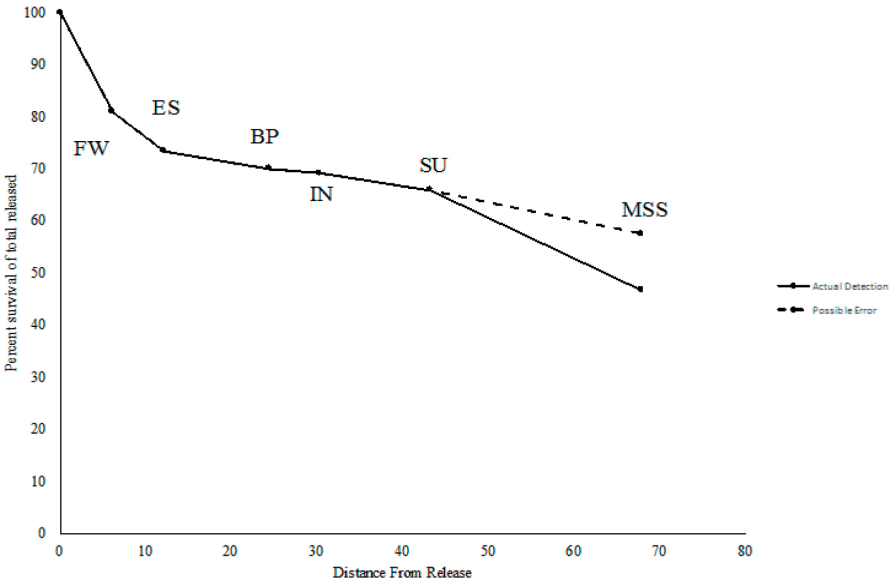

Figure 6: Survival curve for fish within the study. Transect locations are identified by black dots and labelled.

Should a lack of physiological preparedness be responsible for mortality, survival is expected to be positively correlated with day of year, as later migrating smolts are more physiologically prepared for migration in the marine environment (Stich *et al.,* 2015). However, the data from this study supported the hypothesis that mortality was caused by predation. Fish have been shown to learn about the location of food socially, along with the ability to learn novel food types (Brown and Laland, 2001, 2002). As a new resource becomes available (e.g. migrating smolts) it is at first minimally exploited (high prey survival), as predators take time to adjust and improve foraging efficiency. As time passes, predators learn and increase their foraging efficiency in relation to that resource, leading to low prey survival. Migration in numbers as employed by migrating smolts decreases predation risk (Furey et al. 2016), thus a positive relationship between "*within-group-survival*", early migration and increased-group-size, strongly supports the view that predation is the primary cause of mortality in this study.

Changes in swimming depth have also been strongly related to temperature and salinity (Plantalech Manel-La et al. 2009), and light conditions (Davidsen et al. 2008). Migrating salmonids smolts have been found to swim in the brackish upper 1−3 m when they first enter the marine environment (Plantalech-Manella et al. 2009), but swim deeper in the water column once they leave shallower near-shore areas (Davidsen et al. 2008). It is hypothesised that smolts are found deeper in the water column in daylight to avoid avian predators (Reddin and Short, 1991), and that the higher variability in depth during daylight is due to fish actively foraging, since they rely on visual cues to identify prey (Davidsen et al. 2008; Hedger et al. 2008).

Although the direct drivers of smolt movement remain unknown, and fish do not appear to be driven directly by tidal currents, the large spatial scale of detections presented by Newton paves the way for future modelling research into the paths and vectors of smolts in the marine environment. It is likely that smolt movements are influenced to some extent, by marine currents, and potentially by salinity plumes or even magnetic fields, but such analyses of the underlying mechanisms need further research if we are to fully understand the marine migration behaviour of salmon smolts in the marine zone.

Predation of migrating smolts

Session 4: Key Questions

- *What is the impact of predation in freshwater on smolt numbers and how can this be assessed and what can be done to reduce it?*
- *To what extent do physical factors within rivers (barriers, channel straightening, reduced flows etc) increase predation levels, and how can these be altered to reduce predation?*
- *How best can we assess the impact of different predators (birds, fish and mammals), and how do different physical factors affect these? How practical, and effective, is action against predators?*

The Impact of Predation

Niels Jepsen (DTU-Aqua) provided an overview of smolt predation issues by cormorants in Denmark. Following on from a significant increase in the cormorant population across Europe in the 1990s, a number of studies have been undertaken to assess the survival of migrating salmon and sea trout smolts in Danish rivers, impoundments, lakes and estuaries.

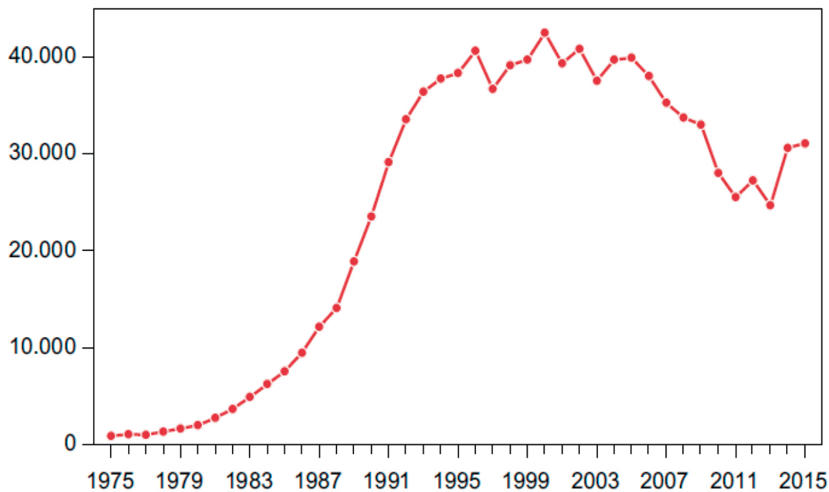

Figure 7: Cormorant population size (thousands) over time in Denmark

Studies were carried out using radio and acoustic telemetry, PIT tags, Coded Wire/CW tags and Pellet analysis. Both wild and hatchery reared smolts were tagged. The first of these studies was published in 1998 and since then many papers and reports have shown that predation from cormorants is a very important factor regulating overall salmon and sea trout abundance in Danish rivers. In one example presented, of 74 tagged salmon smolts, 8 were detected as lost in the river (4 from pike, 4 from birds) and 17 tags were found in cormorant colonies sites, giving a predation rate from cormorants of 42 %.

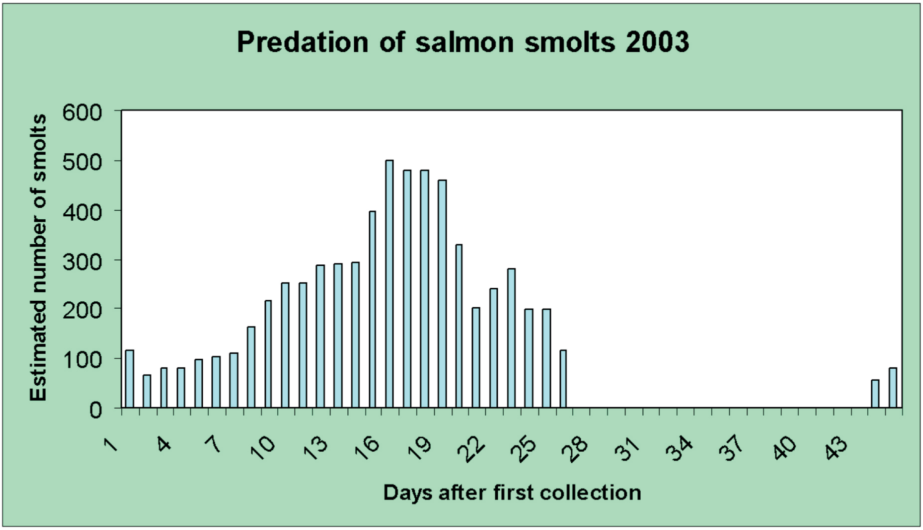

Figure 8: Estimated number of predated smolts during a typical run window.

Research in Ringkøbing Fjord found from telemetry work that 40-50% of salmon smolts which were tagged, were recovered from a neighbouring cormorant colony. Coded wire (CW) tagging revealed 25% of the available tagged salmon smolts were eaten during the 3-week smolt migration period. It was estimated, based on pellet analysis, that during one season in total some 30,000 salmon smolts, 1.4 million flounders and 38,000 eels were eaten by cormorants.

Both wild and hatchery smolts seemed very vulnerable to predation during the transition from running water to stillwater habitats and thus easy prey for cormorants. Predation rates of 40-60% were commonly found during the few weeks of smolt out-migration. Smolts were found to be vulnerable at a number of points:

- Transition from running to stillwater
- Impoundments (lakes, reservoir)
- Estuaries

- Coast
- Obstacles (dams, weirs, barrages)

There was increasing evidence that predation from cormorants was now the main regulating factor for many fish stocks, including salmon, in Denmark. At present many measures are being taken in an attempt to reduce this unsustainable level of predation, by shooting cormorants during the smolt period but also along rivers during wintertime.

Predation - Case study examples

Jake Davoile & Richard Bamforth (Angling Trust) described the actions undertaken by the Angling Trust (UK) to reduce predation by piscivorous birds. This coordinated programme gave existing license holders the chance to work cooperatively and enabled the development of strategies to combat predation and protect fish stocks. Such strategies include a co-ordinated plan for lethal control to condition the birds and enhance scaring. There had also been an improvement in the non-lethal techniques which were deployed to complement lethal control. Efforts are concentrated at known hotspots and pinch points, such as weirs and dams. A reporting procedure is now in place and communication links between fisheries keep all fishery managers informed of the current situation.

Joanie Carrier (INRS, Canada) presented a paper on double-crested cormorant populations in the Gulf of St. Lawrence, Canada. Numbers of these birds had been increasing since the end of the 1970's and, in coastal regions they were now very abundant. The size of the colony was estimated using aerial photos in 2014 (905 breeding pairs) and 2015 (1147 breeding pairs). To determine cormorant diet, regurgitated pellets were collected during the six weeks smolt migration period in 2014 (n=441 pellets). Prey identification and enumeration was based on a sub-sample (n=360) in which fish otoliths were paired. The dominant species found over 15 taxonomic groups found were winter flounder and rainbow smelt. The anecdotal presence of Atlantic salmon otoliths in the pellets shows that smolts are not likely to be an important prey species contributing to the Bonamy Rocks cormorant diet. This may be a result of the high abundance of other prey species available in the estuary and the small window of time over which the smolts pass the colony.

Jason Daniels (ASF, Canada) presented findings from the Miramichi River, Canada which has the largest run of Atlantic salmon in North America. However, the population has experienced multi-decadal declines in abundance, along with many populations of North American Atlantic salmon. The southern Gulf of St. Lawrence population of striped bass, a top predator in the estuarine environment is known to spawn only in the brackish region of the Northwest Miramichi River. This population of striped bass was nearly extirpated by the mid 1990's. Following management changes the population has rebounded from an estimate of 3,000 to 5,000 spawners in the mid 90's to 301,000 as of 2015. Given the overlap in timing of the striped bass aggregation and spawning in the Miramichi River and the emigration of salmon smolts from river to sea, concern has been raised over the potential impacts which striped bass may be having on the emigrating salmon smolts. To address this concern smolt and striped bass movement within the river system were monitored using acoustic telemetry.

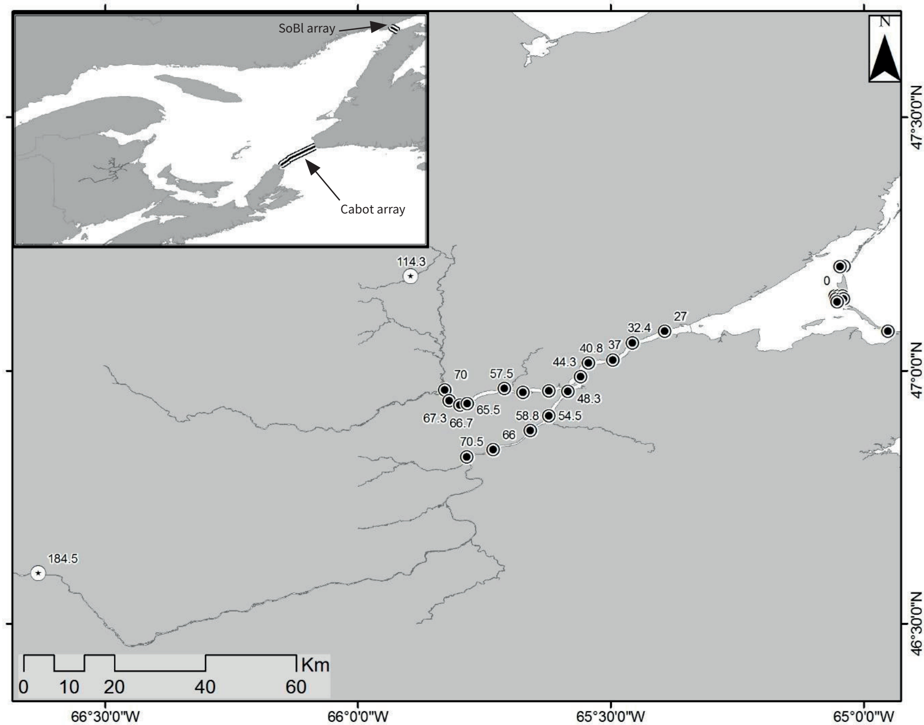

Figure 9: Map of the Miramichi River in New Brunswick, Canada. Receiver locations (black outlined circles) are denoted by their respective distance (km) up river with the zero km mark defined as the receiver array located at Miramichi Bay mouth. Smolt release locations (black outlined star) are located in both the Southwest and Northwest Miramichi Rivers. Inset map depicts the Gulf of St. Lawrence as well as receiver arrays (black outlined solid line) that span the two entrances/exits of the gulf, the Strait of Belle Isle (SoBI) array and the Cabot Strait (Cabot) array.

Models were developed to differentiate between movement patterns of smolts and striped bass. The model was used to estimate the proportion of smolts consumed by striped bass annually. Smolt consumption estimates range from 14.1% to 27.6% and 3.9% to 19.4% respectively.

This study raised interesting questions with regards to the conservation of salmon and that of the recovering striped bass population. Can anything be done to increase the survival of smolts moving downstream past the concentrations of striped bass; can predation control efforts be put in place to reduce the number of striped bass, which supports the economy through sport fishing.

Table II: Summary of smolts tagged by stock and by year. Model output is based on the number of smolts with detections in the study site. Model output is presented as the percent of smolts classified as consumed under both the binary classification as well as the scaled estimate which accounts for classification uncertainty.

Year	Miramichi River stock	No. released	Fork length (cm)	No. smolts with ≥1 detections	No. smolts detected at SoBI	% consumed smolts	
			Mean (range)			binary	scaled
2013	Northwest	40	14.0 (12.6,16.7)	36	2	16.7	24.0
	Southwest	65	14.6 (13.4,16.7)	41	5	17.1	17.7
2014	Northwest	50	13.6 (12.1,16.7)	40	5	20.0	24.5
	Southwest	80	14.2 (13.2,16.9)	50	7	8.0	10.0
2015	Northwest	80	14.2 (13.3,17.7)	70	17	6.7	13.7
	Southwest	80	14.2 (13.0,17.0)	59	11	1.9	4.8
2016	Northwest	60	14.1 (12.9,18.2)	50	8	18.0	19.4
	Southwest	59	14.0 (12.9,15.9)	28	8	10.7	10.4

The Way Forward: Future Research and Management Priorities

If we are to maximise the output of healthy salmon and sea trout smolts from our rivers, it is clear that we need to pay more attention to the actual process of smolt migration. It is also clear that marine mortality does not operate independently of factors affecting successful smolt migration in freshwater or independently of the biological quality / characteristics of smolts migrating to the sea. The condition of the smolts that survive the freshwater portion of their migration is of critical importance. This final part of the report summarises the main points that emerged from the conference, and suggests priorities for further research and for management action.

Freshwater Legacies - Influences of the freshwater environment on smolt quality

- *There is considerable evidence that chemical pollution, even at very low levels, can affect smolt condition, in particular, their ability to adapt to salt water.*

Contaminants derived from a range of sources, including agriculture, industry and household products, have been shown to adversely affect smolt quality, reducing the smolts ability to survive once they move into the marine environment. Dealing with the problem is made more difficult by the immense range of potential contaminants and by the fact that sub-lethal effects, at least in freshwater, may be caused by very small quantities of a specific contaminant. Such effects have been known for many years. However, work needs to continue, if possible at the population level, on identifying contaminants, on assessing their impact, both on smolt condition and on their ability to adapt to the marine environment. It is important to recognise that the potential impact on smolts of exposure to contaminants is taken into account when assessing water quality, as assessing impacts on parr alone is likely to underestimate the impact of sub-lethal effects on smolt survival and hence on the number of returning adults.

Priorities for further work

- Identify the impact of potential contaminants on smolt condition and on their ability to adapt to the marine environment.
- Assess the impact of contaminants at the population level.
- Continue to take the necessary measures to improve water quality for juvenile salmonids and reduce their exposure to contaminants, taking into account impacts on smolt condition and long-term survival.
- Assess levels of contaminants in important spawning tributaries and whether these are affecting smolt survival.

The Impacts of climate change on migration timing and smolt size

- *Warming freshwater is leading to faster growing, younger and smaller smolts.*
- *The migration patterns, timing and biological characteristics of wild Atlantic salmon smolts suggests there is a critical migration window.*
- *A thermal mismatch may occur when the earlier running fish are experiencing warmer conditions in the river but relatively cooler conditions in the sea.*
- *Late migrants will simply not arrive at the correct time in the estuary and when they do reach the estuary, temperatures will be above the critical threshold for smolts*

One of the consistent findings from the conference was that climate change is impacting directly on the migration patterns of salmonid smolts. This has two potential consequences: migrating smolts will be younger, smaller and less fit; smolts may reach the sea when conditions are less than optimal for their survival, with colder sea temperatures and reduced feeding opportunities. Both these effects are likely to reduce marine survival, as there is increasing evidence that smaller smolts display lower rates of marine survival. There is evidence from some of the key index monitoring sites that smolt age is dropping, with increasing numbers of smaller, 1+ smolts running to sea.

There was also evidence presented that different populations within a single river migrated to different feeding locations and undertook varying oceanic migrations. It was suggested that there is a compelling case for heritable variation among populations and that this is locally adaptive; if this is the case, adaptions in relation to the timing of smolt migration are likely to be linked to all aspects of their life at sea.

Priorities for further work

- Continue to monitor: seasonal water temperatures and flows, timing of smolt migration and the size / age of migrating smolts from a variety of catchment types.
- Integrate studies on the timing of smolt migration with oceanic migration patterns, feeding locations and timing of adult return.

Modelling smolt production in freshwater

- *Knowledge of smolt output from most rivers is very limited; alternative methods of assessing smolt production from a wide variety of river / lake types and differing habitat types are needed.*

Only on a number of index rivers are there reliable, long-term estimates of annual smolt production. Managers would greatly benefit from robust models that were capable of producing estimates of smolt production, based on specific inputs such as estimates of spawning areas, juvenile habitat and fry counts. Such models are under development at present but it is clear from preliminary work in this area, the range of different inputs that are required to produce an effective management model. Outputs from this approach may well support efforts to define more accurate BRPs not alone for salmon smolts but also for sea trout smolts. The description and understanding of life history variation between rivers and regions is a demanding research requirement.

Priorities for further work

- Develop standardised, habitat –based, smolt production models for salmon and sea trout.

Barriers to migration

➢ *Man-made barriers to migration are one of the main factors delaying the downstream movement of smolts*

Most of the focus to date on barriers has been on their impact on upstream migration, and there is a need to examine more closely their impact on migrating smolts, both in terms of direct and indirect impacts. Not all barriers are problematic and in recent years valuable lessons have been learned on how best to mitigate the impacts of barriers on migrating smolts, particularly on smaller sea trout streams. Further work on the impact of barriers may be needed but the refinement of existing best practice guidelines would be very useful.

Priorities for further work

- Continue to carry out assessments of the ability of smolts to pass barriers on main stem rivers and on key tributaries and where necessary, take action to improve smolt passage

Smolt survival in the lower river, estuary and coastal waters

➢ *A greater understanding of smolt migration routes and behaviour is an urgent requirement if we are to understand and prioritise the causes of smolt mortality as they leave freshwater and enter the marine environment.*

Tracking studies are beginning to provide detailed information on smolt movements and migration pathways. Acoustic tagging technology is particularly promising, but other forms of telemetry, such as wireless tracking and data storage tags, remain a valuable source of data. Given the speed at which telemetric techniques are developing, project designs need to remain flexible and open to revision on a frequent basis.

There is an obvious need to extend these studies. However, information exchange workshops and conferences are urgently required to agree and update best practice and to assess the merits and disadvantages of the various approaches to tracking in lower river / near shore waters. Greater collaboration between researchers is required and a more open exchange of information on techniques and results. Given the costs of tracking infrastructures, such as acoustic arrays, there are clear benefits in developing multi-species projects, although it is important that these are well integrated at the design stage and capable of tracking all of the target species.

Priorities for further work

- Establish collaborative networks and arrange workshops / conferences to ensure close co-ordination of projects and the exchange of technical information on tracking techniques, the development of robust protocols and approaches to data analysis.
- Undertake further intensive tracking studies to identify smolt migration routes and improve our understanding of smolt and early post-smolt behaviour and the causes of smolt mortality.

The Impact of Predation

➢ *Research has shown that predators can at times have significant impacts on smolts, particularly when these are delayed as a result of manmade structures. This highlights the need for managers to identify predation bottlenecks and investigate appropriate and timely actions.*

Migrating smolts naturally attract predators, but their impact can be significantly increased by delays imposed by barriers to movement. In such cases the obvious first step is to take the necessary action to improve passage of smolts and reduce delays. However, this may not be possible or adequate, and direct action to reduce predation levels may be needed. While in situations such as those pertaining in certain areas of the UK predation by birds may be manageable, the situation in Denmark is quite different. Here predation by cormorants has reached unsustainable levels and the authorities have been forced to implement unprecedented predator control programmes. It has been found that due to the limited duration of the smolt migration period, effective predation reduction measures are far easier to impose. Predators normally take some time to adjust their behaviour to exploit a new food source and vigorous steps to discourage them at the start of the migration period significantly reduces overall levels of predation.

Priorities for further work

- Seek to improve our understanding of predator impacts and of how to influence predator behaviour.
- Develop co-ordinated programmes to reduce the impact of predation on migrating smolts, including deterrents, selective removal of predators and measures to reduce smolt exposure to predators.

Appendix 1: List of Speakers – Berwick Conference 2017

Chair: Ken Whelan, Atlantic Salmon Trust

Andy Moore, Cefas

The role of the freshwater environment on regulating smolt behaviour and survival in the sea

Elvira de Eyto, Marine Institute, Ireland

Growth of juvenile salmonids in the Burrishoole river system, western Ireland: implications of warming water temperatures for smolt age

Stephen Gregory, Salmon and Trout Research Centre, Game & Wildlife Conservation Trust

Length of Atlantic salmon smolt and their subsequent marine survival

Alan Walker, Cefas

ReMES: Reach-based model estimates of smolt production

Andy King, University of Exeter

The sex ratio of sea trout smolts: preliminary results from the rivers Tamar and Frome

Eric Vespoor, Rivers and Lochs Institute, University of Highlands and Island

Local adaptation in smolt migration: an unrecognized factor in smolt and post-smolt mortality?

Richard Kennedy, AFBI Northern Ireland

Long-term smolt emigration patterns on the River Bush and associations with climate change and predation

Mich Fleming, Conservatoire National du Saumon Sauvage, France

The smolt migration of Allier-Loire salmon: timing and increasing environmental mismatch

Peter Walker, RSK Environment

Running the gauntlet – a review of the perils of downstream migration for smolts and an overview of existing mitigation options

Joel Rees-Jones, Natural Resources Wales

The influence of sluice gate operation on the migratory behaviour of Atlantic salmon smolts

Rasmus Lauridsen, Salmon and Trout Research Centre, Game & Wildlife Conservation Trust

Medium term effect of low head hydropower schemes on Atlantic salmon smolt migration

Johann Hojeso, Department of Biology and Environmental Sciences, University of Gothenburg

Population structure and migratory patterns of Sea Trout in Scandinavia

Angus Lothian, University of Durham

Migration speed, mortality and pathways of Atlantic salmon smolts in a river and the early marine zone in Scotland

Lorraine Hawkins, River Dee Trust

Tracking Dee smolts: where are the risks during smolt migration

Matt Newton, University of Glasgow

Estuarine and Marine migration of Atlantic salmon smolts in Moray Firth, Scotland

Niall Gauld, Marine Scotland Science

The utility of acoustic telemetry to investigate the initial marine migration of salmon on the west coast of Scotland

Niels Jepsen, Section for Freshwater Fisheries Ecology, DTU-Aqua

The impact of Cormorant predation on smolt survival

Jake Davoile & Richard Bamforth, Fisheries Management Advisors, Angling Trust

Piscivorous bird predation: update from the Angling Trust

Joanie Carrier, Institut National de la Recherche Scientifique, Canada

Assessment of Smolt Predation by Double-Crested Cormorants in the Restigouche River Estuary

Jason Daniels, Atlantic Salmon Federation, Canada

Estimating proportional consumption of acoustically tagged Atlantic salmon smolts by striped bass in the Miramichi River

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Summary of Work of The Tweed Foundation

Established in 1983, The Tweed Foundation is a company with charitable status, that is independently financed, and which promotes and protects the native fish stocks of the Tweed through science-based management, environmental protection and improvement in the Tweed Fisheries District. It advances the understanding of Tweed's fish populations and the aquatic ecosystems that support these through its biological work plan - The Tweed & Eye Fisheries Management Plan - which was first published in 1990 and is reviewed every five years, with interim updates undertaken annually.

The Foundation also encourages the use, conservation and the management of fishery resources in recreational activities, particularly for young people through its 'TweedStart' programme for schools. It is at the forefront in bringing a professional, scientific approach to fisheries management and is engaged in an extensive programme of data collection and analyses, fish stock and environmental monitoring and habitat enhancement with the aim of protecting Tweed's valuable fish stocks and maximising the river's natural productivity.

The Tweed Foundation provides biological information to many other stakeholders and organisations, including the Scottish Government, as well as fulfilling an educational remit; its work contributes to the preservation of the Salmon rod fishery on the Tweed, which is worth £24m to the local economy.

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Summary of Work of the Atlantic Salmon Trust

Since 1967 the Atlantic Salmon Trust (AST) has supported research into key aspects of the lives of migratory salmonids. AST is the UK's only charity whose work is devoted exclusively to the conservation of wild Atlantic salmon and sea trout. The Trust facilitates research, partners research projects, organises scientific meetings, workshops and conferences. It communicates its findings to anglers, fishery managers, fishery owners and the public.

The role of the Trust is to demonstrate how both species can be conserved and managed to enable their value to society to be realised sustainably. The Trust's work concentrates on improving our knowledge of these fish, their habitats and their complex and fascinating life histories, and the threats to their survival. Until relatively recently this knowledge was confined mainly to the freshwater aspects of their life cycle, but the AST is now focusing on the migration and marine phase of their life cycle.

The abundance of Atlantic salmon, prior to any fisheries exploitation, has declined over the last forty years; from 8 – 10 million fish in early 1980s to 3 – 4 million fish at present (NASCO, 2016). At present AST's major concern is the dramatic decline in marine survival in the Atlantic which has fallen from over 15% in the 1980s to, at times, less than 5% in the last five years.

AST is now focusing a large part of its research activities on the coastal zone and wider ocean. Once considered the 'black box' in terms of knowledge, new scientific and technological advances are making research into this vast area possible.

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