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Keynote Abstracts

Using telemetry to explore, understand, and manage salmonids

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Abstract: Telemetry is one of the fastest growing methods used in fishery management today and not without reason. A growing suite of methods is used over a continuum of scales in freshwater and marine environments to address a wide range of fisheries management issues. Methods range from hand-operated systems that are used to identify the locations of a limited number of fish every few hours to automatic systems that monitor the position of many individuals in three dimensions in near real-time. In fisheries that extend over large areas, remote methods such as archival tags or pop-up satellite transmitters, and large networks of acoustic arrays are also used. Telemetry is, nevertheless, only a tool and cannot address all problems or answer all the questions. As with all studies, it is necessary to identify the specific biological problem and address it with the most appropriate methods. Taking that into account, telemetry can often be the key to collecting fundamental data relating to field-based questions. In Denmark, we have used telemetry as one of the primary methods for many fisheries management related problems for more than two decades. Telemetry studies often reveal many previously unknown behavioural characteristics as well as overturning many dogmas within fisheries science. This knowledge is crucial for helping to build biologically realistic models and helps future management options. Studies of virtually all larger freshwater fish species including salmon, trout, pike, pikeperch, perch, roach and eel have benefited significantly from the application of a variety of methods of telemetry, including radio-, acoustic-, PIT, and satellite telemetry. I will give an overview of the contributions telemetry has made to fisheries science, with particular focus on management of salmonids in Denmark. The outcomes of these studies demonstrate the huge impact the advent of telemetry has had on the management of these fish, as well as the societal benefits that improved knowledge of fish behaviour can bring.

Can individual variation enable salmon to survive and succeed in a changing world?

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Abstract: Thermal tolerance can vary widely across individuals of the same species. Our research has examined how thermal tolerance differs across populations, over the life history, and between sexes in Pacific salmon. We take advantage of this variation to investigate the underlying mechanisms that determine thermal tolerance. Our most recent work has focused on understanding why migrating, sexually maturing adult female salmon have reduced survival at high temperature compared to males. During migration, both males and females undergo major morphological changes. While swimming upstream, both sexes develop their secondary sexual characteristics and grow their gonads. By the time they reach the spawning grounds, females support a much greater egg mass (~17% of body mass) compared to male testes (~3% of body mass). We examined several hypotheses: 1) males have a superior aerobic scope and swim performance at high temperature compared to females; 2) females have impaired oxygen delivery to their hearts; 3) females have prolonged recovery from anaerobic metabolism at high temperature. By using intraspecific comparisons, this research offers valuable insight into the factors that limit ecological thermal tolerance.

Migration biology in the Anthropocene

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Abstract: Migrations are inherently challenging for fish. Yet, humans can make migrations even more challenging through the erection of dams, deployment of nets and hooks, introduction of invasive species and degradation of water quality. It is now acknowledged that we are in the "Anthropocene" emphasizing the extent to which humans have decimated biodiversity and altered the environment. What does the Anthropocene mean for migratory fish? What adaptation strategies are needed for management of migratory fish in the Anthropocene? In this presentation I will tackle these and other questions as I explore the migration biology of fish in the Anthropocene.

Beyond genetics: phenotypic and developmental approaches to better understanding adaptive divergence in salmonids

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Abstract: A major challenge of evolutionary biology is to understand how biological diversity is generated, maintained, and altered. Even in emblematic taxa such as salmonids, we know relatively little how phenotypic variation arises and is sorted by natural selection. The recent literature outlines the importance of integrating the fields of ecology, evolution and development to grasp a better understanding of how phenotypic variation is formed within and among species. Using examples of Northern freshwater fishes, and especially the Arctic charr, we will discuss how developmental, physiological and behavioural approaches can be combined and provide new insights on adaptive divergence of fishes. Such integrated approach may be necessary to make effective restoration and conservation plans of fish populations.

Delegate Abstracts

The physiology of a large-effect puberty gene in Atlantic salmon (*Salmo salar*)

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Key words: genetics, Vgll3, physiology, maturation

Abstract: Recent genomic analysis of Atlantic salmon (*Salmo salar*) populations have found a single genomic region explaining 40% of variation in sea age at maturity. The main candidate gene in this region is Vgll3, a gene with a seemingly high degree of functional conservation, being associated with both human pubertal traits as well as adiposity in mice. Gaining knowledge on the function on this gene would then not only be helpful for the conservation and management on wild salmon population, but could also teach us something about common mechanisms in vertebrate growth and maturation. The presented experiment is a part of the effort in linking genotype to phenotype in this life history trait. Using a large laboratory Atlantic salmon population of 5000 individuals, we are following the development of these fish up to maturation (3 to 4 years) under the influence of two temperature- and two nutrition treatments. Along the way we are measuring key physiological traits, making use of metabolomic profiling, gene expression measurements, and metabolic rate measurements. In this presentation, I will highlight some recent findings on the mechanisms of the vgll3 gene, and how my own project is working on taking the step from the genetics to the physiology of salmon maturation.

The impact of barriers on Scottish Atlantic salmon distribution and migration

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Key words: barriers, eDNA, fisheries management, Scotland

Abstract: Wild Atlantic salmon are in dramatic decline across their entire range. In Scotland, recent findings from The Missing Salmon Project show that 50% of salmon are lost before they even reach the sea. In the Ness system in particular, this figure is as high as 91%. Numerous barriers such as hydropower dams and canals exist in the Ness system, whereby their occurrence has been attributed towards the decline of Scottish Atlantic salmon. The Caledonian canal was estimated to account for approximately 25% of lost salmon in the Ness system, yet whether these salmon are able to complete their migration is unknown. As part of the EU-funded AMBER project (Adaptive Management of Barriers in European Rivers), this study uses environmental DNA (eDNA) to understand how barriers in Scotland affect both the distribution and migration of Scottish salmon. A time series of eDNA was collected in the Caledonian canal during the period of smolt migration to specifically ask whether smolts were able to complete their migration out to sea. To test for the impact of barriers on salmon distribution, we used localities heavily impacted by barriers (e.g. dams) to test for the presence/absence of salmon both upstream and downstream of the barrier. Preliminary results suggest eDNA to be a promising tool in facilitating our understanding of the impacts that barriers have on salmon distribution and migration. Such methods could be applied across the Atlantic to aid adaptive management and help alleviate pressures on declining salmon populations.

Minimising adverse effects of conservation: ecological effects of restoration of salmon carcasses to upland streams

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Key words: *Salmo salar,* nutrients, oligotrophic, population dynamics, phosphorus

Abstract: This PhD project will focus on the restoration of salmon carcass nutrients to upland streams. Declining populations of Atlantic salmon (*Salmo salar*) have resulted in a decreased contribution of marine-derived nutrients to fresh waters, as fewer adults return to breed and deposit nutrients from carcasses and waste products. Previous research demonstrated that increasing nutrient levels at the spawning grounds of Atlantic salmon results in increases in food supply through greater invertebrate abundance and biomass, resulting in an increased growth rate and genetic diversity of juvenile salmon. The first year of this project will compare the efficacy of two methods of nutrient supplementation using fish feed pellets as carcass analogues. Reaches of streams in northern Scotland will be designated as control (upstream) and experimental (downstream) sections. Experimental sections will be supplied with either bagged pellets or the same mass of scatted pellets, at a dose thought to be equivalent to historical natural salmon carcass densities. Wild salmon families have been conceived and will be stocked as eggs in equal number in the streams in March 2020, at the time of the nutrient manipulations. In July 2020 invertebrates will be sampled by electrobugging, and electrofishing will be conducted. Juveniles will be measured, and fin-clips taken for family identification. Algal sampling will take place at 50m intervals along streams to assess nutrient transport and persistence. This project ultimately aims to derive safe levels of nutrient input to increase the size and number of juvenile salmon, whilst reducing the potential for eutrophication to occur.

Ecology and physiology of sea trout during their spawning migration

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Key words: blood physiology, energetics, migration, PIT telemetry, *Salmo trutta*

Abstract: Sea trout (*Salmo trutta*) is one of the most widely studied species of fish. Yet, our understanding of what drives their behaviour and life history strategies remains limited because individuals vary so greatly. Here, we combine telemetry and physiological measurements to investigate the drivers of migration, particularly during the spawning season. We investigate behaviour and decisions linked to migration timing and its repeatability. We further explore whether physiological status (e.g., energetic resources or stress indicators) is linked to reproductive investment and to subsequent survival out of river.

Depth use and progression speed of Atlantic salmon post-smolt

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Key words: smolt, migration, telemetry

Abstract: Depth use and progression speed of wild Atlantic salmon smolts migrating through fjords in western Norway was measured with a passive acoustic telemetry array. Wild salmon smolt were found to predominantly use the top six meters of the water column on their journey through the fjord. Progression speed increased later in the migration period, at least partially due to higher temperatures. Understanding space use of migrating salmon smolts is important to managing risks ensuing from aquaculture in this area, especially with regards to the estimation of sea lice induced mortality.

Temporal variation and genetic variance of life-history traits in the Imsa Atlantic salmon population

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Key words heritability, life-history, animal model, pedigree, genomics, Atlantic salmon

Abstract: Atlantic salmon life-history traits and abundance have quickly changed over the last decades in many populations worldwide. Understanding the causes driving these changes and predicting future responses in a changing environment require deepening our knowledge about the trait's genetic architecture, additive genetic variance and their influence on fitness. Recent advances in genomics coupled with historical samples collection have opened opportunities to estimate such components. Here, we used 42 years of smolt and adult samples from the Imsa river in Norway to genotype individuals at 60k or 175 genetic markers in order to reconstruct a pedigree and estimate individual reproductive success. We use Animal models to estimate the genetic variance of migration date, sea age and weight, as well as their genetic correlations with reproductive success. Results from these models will be interpreted in parallel with observed temporal variation in trait means.

Can't pass, won't pass: the importance of displacing river-resident fish when quantifying fish pass performance

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Key words: telemetry, fish passage, displacement

Abstract: Anthropogenic fragmentation of longitudinal connectivity in rivers has had negative impacts on riverine fish species globally. Vast numbers of fish passes have been constructed to reverse these impacts, often at considerable expense, but their efficiency is rarely quantified. Further, it is hence inherently difficult to perform pass assessments for river-resident fish that are not obligated to perform an upstream migration; it is not known if fish cannot pass due to behavioural or physiological reasons or do not pass due to a lack of motivation. Passive Integrated Transponder telemetry was used to compare movements of displaced and non-displaced river-resident brown trout through a low-cost baffle fish pass. Trout are known to perform a homing movement when displaced, and thus displaced fish were assumed motivated to move while non-displaced fish were not. Significantly higher proportion of displaced fish approached and entered the pass in comparison to non-displaced fish, and thus overall passage efficiency was also significantly higher. The size of non-displaced and displaced fish that approached the weir did not differ but the size of displaced fish that entered the pass were significantly larger than displaced fish that approached but did not enter. It was concluded that majority of non-displaced fish did not pass due to lack of motivation whereas smaller displaced fish did not pass due to physiological capability. It was recommended that fish should be displaced during fish pass assessments for river-resident species to ensure reliable fish pass efficiency estimates are gathered while potentially reducing sample size, study duration and costs.

Demogenetic modelling: a tool to predict and understand the dynamic of intraspecific diversity in brown trout (*Salmo trutta*)

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Key words: demogenetic, intraspecific diversity, reproductive isolation, hybridization, introgression, management

Abstract: Intraspecific diversity management is a major issue as it holds a patrimonial value and represents a resilience mechanism for populations. Brown trout present a high intraspecific diversity with five distinct genetic lineages. In France, the Atlantic (ATL) and the Mediterranean (MED) lineages had evolved in allopatry for approximately a million years. However, since a century, traditional management practices have led to the introduction of domestic ATL trout in the Mediterranean area, which has caused massive hybridization and, consequently, introgression of MED alleles by ATL ones. To understand and predict the outcome of this process, we developed an individual-based demogenetic model that simulates the evolutionary mechanisms – and their genetic basis – influencing intraspecific diversity, as well as management practices and environmental conditions. The model is spatially explicit and represents real hydrographic networks, within which reproduction, growth, competition, dispersal and survival processes are simulated. Management practices can also be simulated (fishing, restocking, connectivity, populations transfer). The model integrates previous results showing that mate choice is heterogamous and that embryonic post-zygotic survival depends on a genotype-by-temperature effect. Our simulations confirm that these processes play an essential role in introgression dynamics, and that their interactions with management practices may potentially drive intraspecific diversity in unwanted directions. We argue that diversity management should be context specific with regard to environment and include eco-evolutionary processes. Our model therefore represents an innovative decision-making tool for managers.

Hierarchical Bayesian state space model for estimating location of DST-tagged Atlantic salmon

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Key words: SSM, particle filter, geolocation, diurnal vertical behaviour

Abstract: Marine survival has been decreasing in most Atlantic salmon stocks in the last decades. Identifying feeding areas and migration routes is essential to identify likely causes of this pattern. Archival tagging of salmon kelts have given valuable information on migration and predation of salmon at sea. However limited information is available on smolt/post-smolt migration. We developed a method for locating Icelandic hatchery smolts using temperature and diel dives (see Gudjonsson et al 2015). Although useful the methods had a few drawbacks that can be improved. Advantages in black-box Bayesian software has made more algorithm available for non-statisticians. Particle filters are for example intriguing for state-space models given the high auto-correlation of parameters. The objective of this project is to develop a model that simultaneously estimates; location, depth behavioural pattern and parameters describing depth behaviour in a single framework from temperature and depth DST-data. It will hopefully result in better location estimates, estimates of behavioural patterns and not less importantly the uncertainty of location and other parameters. The rationale behind the model will be introduced and preliminary results if available.

Reviewing the implications of climate change for the migration phenology of Atlantic salmon

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Key words: migration, phenology, climate change

Abstract: Global climate change is increasing temperatures of air and water across the world and altering seasonal weather patterns. The onset of spring is generally occurring earlier and the conditions associated with autumn arriving later. Largely the phenological flagship species have been birds with ~78% of migration timing papers focussed on them. Harder to observe but of great recreational, cultural and economic importance are migratory salmonids. Salmonids carry out two distinctive migration phases, downstream smolt migration and upstream spawning migration, with a downstream post-spawning migration less common. Salmonid downstream migration timing has been linked to survival and growth. Migration timing needs to be linked to key events like prey densities or flow events that allow upstream migration, with migration timing changing, as well as the timing of events like prey density peaks and flood timing, there is a chance for mismatch. This review will synthesise a range of salmon migration timing studies, looking into which salmonids are adapting to climate change and how? What might the limitations of adaptation be and how might these interact with other anthropogenic factors? What evidence is there that salmonid migration timing is becoming disconnected from peak prey abundance and causing trophic mismatches? It will also cover a discussion on temporal data and what is needed to effectively assess this question going forwards, and what can we all do to work towards that aim.

Genetic load affects female sexual ornaments and offspring performance in whitefish

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Key words: inbreeding coefficient, sexual ornaments, kinship, genetic load

Abstract: Whitefish are among the few lek-mating species where males and females display breeding ornaments. We tested whether these ornaments reveal genetic load, and whether maternal and/or paternal genetic load and kinship affects embryo performance. We sampled 31 whitefish from a natural population, measured their breeding tubercles with a 3D scanner, used 16,633 SNPs to estimate individual inbreeding coefficients (*F)* as measure of inbreeding and segregation loads ("genetic load"), and collected their gametes for full-factorial *in vitro* fertilisations to produce 5,616 embryos that were singly raised and that represented 234 families. We found that larger breeding tubercles revealed lower *F*. This correlation was stronger in females than in males, despite males having larger tubercles. We found significant dam and sire effects on embryo development rate. Maternal *F* did not correlate with egg size but affected offspring growth. Paternal *F* did not significantly affect offspring growth. With our breeding design, sire effects on offspring could only be genetic. We therefore conclude that variation in parental *F* did not cause significant genetic effects on offspring performance. We further conclude that the information context of breeding tubercles is sex specific, and that parental genetic load affects offspring performance mainly through reduced quality of egg contents

Hydropower-induced selection in anadromous salmonid fishes

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Key words: hydropower, fish personality, behaviour, smolt, migration, mitigation measures, selection

Abstract: Anthropogenic activities affect fish populations worldwide. River dams have profound impacts on ecosystems by changing habitats and hindering migration. Hydropower is regarded as one of the most serious threats to anadromous salmonids. It induces direct size-related mortality for turbine migrating smolts and sublethal injuries that make smolts more vulnerable to predation in the downstream river stretches. A range of mitigation measures have been installed at hydroelectric power plants to safely guide smolts downstream. However, not all individuals in a population use these measures. Thus, the migration route choice appears crucial for individual fitness. Accordingly, we observed two different smolt migratory strategies; One part of the population spent little time in the forebay before migrating through the turbine tunnel, while others ceased their migration and stayed in the forebay until a favourable bypass route were available. Later, we documented that bypass migrants had a higher locomotor activity in a behavioural profiling arena than turbine migrants. In addition, compared to hydropower-naive smolts, bypass migrants had higher probability of making the bypass route choice when faced with the same choice a few days later. Taken together, these results suggest size- and behaviour-dependent selection processes at hydroelectric power plants. Optimal site-specific mitigation measures at hydropower plants are, thus, crucial for preserving sustainable populations of anadromous fish, maintaining behavioural diversity and population genetic variation.

Does rearing environment affect fluctuating asymmetry in body morphology of landlocked salmon (*Salmo salar m. sebago*) juveniles?

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Key words: morphology, landlocked salmon, conservation, restoring

Abstract: The natural breeding areas of landlocked salmon (*Salmo salar* m. *sebago*) population in Finland was destroyed in 1950s to 1970s due to logging and damming their natal rivers. Ever since the drastic change in the environment the population has been dependent on hatchery implements. At the smallest the broodstock used to establish the hatchery stocks was down to less than 10 individuals in four consecutive years in the early 90s. After more than 40 years of hatchery dependent breeding we were interested on *how much plasticity is left in the population* and *how different rearing methods effect the morphology* of the landlocked salmon. To be able to successfully re-establish once lost population with low genetic diversity the importance of plasticity emphasizes. We compared one-summer-old landlocked salmon morphology and symmetry in three different hatchery rearing backgrounds and semi-wild background. All of the fish originated from the same family groups. The first group was reared in standard hatchery conditions. In the enriched method the water level, direction and velocity varied during rearing. In semi-natural conditions the fish were reared in outdoor stream-ponds, where they foraged natural prey. Semi-wild fish were stocked in river as fry and electro fished in late August prior the experiment. We photographed the fish from both sides, and conducted within- and between individual comparisons of both sides. Preliminary results indicate that natural conditions produce more symmetrical fish who have slender bodies with notably longer fins than their hatchery conspecifics.

Muscle tissue lipids in Atlantic salmon juveniles

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Key words: lipids, Atlantic salmon, vgll3

Abstract: A recent GWAS study identified a strong association between a single genomic region near the transcription co-factor *vgll3* gene, and age at maturity in Atlantic salmon. *Vgll3* negatively regulates adipocyte differentiation in mice and has also been associated with pubertal timing in humans. However, direct functional evidence linking *vgll3* with age-at-maturity is yet to be demonstrated. That said, individual lipid reserves have been shown in a number of species to play a key role in determining age at maturity – a life-history trait tightly linked to fitness in many species – and result from the interplay between genetics and the environment. Therefore, the aim of this study was to investigate links between *vgll3* and adiposity during early development in salmon using a lipidomics approach. To do so, juvenile salmon with different *vgll3* genotypes were reared on two different lipid/protein ratio feeds during autumn 2017 under common-garden conditions. Size taken at two different time points allowed for the determination of individual growth and the final sampling time point included sampling of muscle tissue from 49 individuals. Tissue-specific lipid compositions and concentrations have been determined by thin layer chromatography. Initial results show the presence of most major lipid classes in the salmon lipidome with male juveniles having a higher concentration of storage lipids than females. Comparison of lipid profiles between individuals with differing genotypes is complete with no differences. Overall, the results of this study contribute to understanding how the environment effects the early lipid reserves and their composition in juvenile Atlantic salmon.

A lousy problem: fish lice infections in UK freshwaters

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Key words: fish lice, *Argulus*, rainbow trout, infection, parasite, angling

Abstract: Angling as a sport and hobby is an important economic resource, supporting rural communities and proving cultural benefits. In the UK trout fisheries support 5000-6000 jobs, with freshwaters the main source of fishing licence sales (93% of 2017 rod licence sales, worth £20.3 million). However due to narrow profit margins fisheries are often at risk, with any persistent loss of stock, fishery performance or reputation threatening economic viability and potentially leading to closure. Over the past decade, parasitic freshwater fish lice (genus *Argulus*) have dramatically increased in notoriety. In trout fisheries alone there is an estimated loss of £5 million annually due to louse infections, which decrease fish catchability and condition ultimately leading to fish mortality. With limitations surrounding the application and resistance of chemotherapeutics, stock management options are the primary means of parasite control for many fisheries, although these approaches can be limited, expensive and ineffective. The absence of successful control measures has also fuelled illegal use of environmentally damaging chemicals in efforts to reduce financial losses.
To help address these issues, we need to: 1) understand why freshwater fish lice have increased in notoriety and remained persistent in the UK, and 2) review current management approaches and evaluate new, novel control methods as an alternative to chemical use. This presentation will provide an overview of current progress in understanding UK infections in Stillwater trout fisheries via distribution of a questionnaire, alongside results from laboratory parasite studies which are being used to develop improved control methods.

The effect of genes associated with maturation on sperm trait variation in mature male Atlantic salmon parr

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Key words: Sexual selection, sperm competition, maturation, reproduction

Abstract: Sperm traits are strong predictors of fertilisation success in Atlantic salmon and therefore are important for reproduction in this species. As an external fertilising species, Atlantic salmon sperm is adapted to compete against other males' sperm for fertilisations. In particular, ejaculates of mature parr are more competitive than anadromous males, showing higher sperm cell density and velocity. The *vgll3* and *akap11* loci are both strongly associated with sea age at maturity in Atlantic salmon, while *akap11* is also directly involved in sperm motility. We aim to test whether different genotypes of the *vgll3* and *akap11* locus influence variation in sperm traits and whether these effects are modulated by environmental temperature and diet. Here, we use fresh ejaculates from approximately 300 captivity-bred two-year-old Atlantic salmon parr raised under two temperature treatments (2°C difference) and two feeding treatments (high fat versus low fat) in a full factorial design. We measure the sperm traits (1) sperm density, (2) straight line velocity (3) curvilinear velocity and (4) longevity using Computer Assisted Sperm Analysis. Additionally, we aim to analyse differential gene expression of *vgll3* and *akap11* within ejaculates to see how expression profiles in sperm vary with respect to the genotypes in these genes. This study will deepen our understanding of how sperm traits vary with respect to environmental conditions and genetic background.

The marine life of sea trout (*Salmo trutta*)

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Key words: salmonid, sea trout, telemetry, behaviour, marine, migrations, temperature, depth

Abstract: Brown trout (*Salmo trutta*) is a highly adaptable salmonid, capable of inhabiting a variety of aquatic habitats. In recent years, studies with biotelemetry have uncovered aspects of the marine behaviour of sea-run individuals (sea trout) suggesting that the adaptability of brown trout extends into the marine environments. We used a combination of acoustic telemetry and data storage tags to investigate the migratory behaviour and temperature and depth preferences of Danish sea trout. The trout exhibited a characteristic diel behavioural pattern with repetitive dives during daytime and residency at the surface during night-time. The fish adjusted their vertical position in the water column in ways that enabled them to maintain a body temperature within the scope reported as optimal for growth in the species (12-17° C) for the majority of the marine period. Horizontal migrations farther than 100 km away from the natal river occurred in 98 % of tagged individuals. Migration speeds were up to 86 km d^{-1} in fjord systems and 58 km d^{-1} in the open sea. The migrations enabled the fish to escape predator-fields and optimize their metabolic scope available for growth by optimizing the experienced temperatures and salinities. The observed behaviours were notably different from those observed with similar methods in sea trout from other regions, thus suggesting that local adaptations may occur in the species. The results therefore improve our understanding of factors shaping the marine migration strategies of salmonids.

Genetic and phenotypic diversity of Icelandic brown trout populations

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Key words: brown trout, populations, ddRADseq, diversity, conservation

Abstract: Brown trout colonized Iceland soon after the end of the last Ice Age, *ca.* 10,000 years ago and populations of some watersheds became isolated early in post glacial history after the formation of impassable waterfalls. Several of these populations have been affected by intense geological events, and more recently, by human activities (*e.g.* building of dams). We hypothesized that (a) populations thought to have been isolated for millennia are genetically distinct due to genetic drift and (b) there is an association between morphology and type of habitat (*i.e.* lacustrine vs riverine). We sampled over 40 water bodies around Iceland and using ddRADseq data we identified *ca.* 2,500 SNP loci that were used to visualize genetic differences. We also assessed morphological differences using geometric morphometrics on photographs of specimens. Our results showed that headwater populations were very genetically distinct, and anadromous populations seemed to be more related to our outgroup (coming from Scotland) than to these headwater fish. Furthermore, the genetic relatedness of the populations reflected to some extent the geographical location, especially when considering only anadromous populations. There was a strong association between the type of environment and morphological features, with fish that inhabit streams displaying a more fusiform and a downward pointing jaw, while lake residents had a wider body and an upward pointing jaw. Given the current socio-economic importance of trout for Iceland (*e.g.* angling) assessing the genetic and phenotypic diversity could be used for conservation purposes, triggering an intervention when diversity thresholds are reached.

The importance of understanding the role of environmental factors on Atlantic salmon population dynamics and life stages at the northern outskirt of its distribution

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Key words: Atlantic salmon, temperature, Iceland, population dynamics, food web, growth rate, migration, life stages, mortality

Abstract: Atlantic salmon (*Salmo salar*) plays an important ecological role and contribute to the economy in Iceland, thus, it is important to understand the impact of environmental stressors and habitat quality on the population to better manage and sustain the population in the future. The populations of Atlantic salmon in rivers in northeast Icelandic represent the species distribution at its northern outskirts. My previous study on comparing salmonid populations in different rivers along a latitudinal gradient showed that temperature and water level significantly influences growth rates and population dynamics. Temperature also positively correlates with metabolism of salmon. Salmonid populations located in higher latitudes had a higher abundance which could be due to more algae and invertebrates with an overall higher biomass. Therefore, further research on individual populations is needed, which is the aim of the doctorate study. The study will be focused on the River Vesturdalsa in Northeast Iceland, which is one of the MFRI´s key study rivers for the last 40 years. We will be using an ecosystem-based approach to investigate and measure the impact of sustaining and growing the salmon population. The effect of temporal and spatial changes in temperature, food availability and density on growth will be investigated through analysing long-term data time series. Extensive habitat mapping and individual based tagging (PIT-tags) will be conducted to identify the areas within the river that salmon inhabits at different life stages. Finally, the impacts of management efforts on the population will be discussed.

Consequences of dispersal on Atlantic salmon metapopulation persistence and dynamics of local populations

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Key words: dispersal, metapopulation, persistence, Atlantic salmon, individual based model

Abstract: Spatial dispersal is a ubiquitous trait in organisms. It is central in the theory of metapopulations, with potential consequences on their stability and persistence, as well as on local population dynamics. Although dispersal and metapopulation functioning have been suggested for salmonid, the consequences of dispersal are still underappreciated, likely because assessing dispersal in nature is challenging. We used a demo-genetic individual-based model mimicking an Atlantic salmon metapopulation connected by a distance dispersal kernel. Our model depicts a complex relationship between dispersal and the metapopulation portfolio effect. In particular, we show that low dispersal rates favor metapopulation stability, via the demographic rescue of small populations and stabilizing effects of dispersal. However, higher dispersal rates tend to synchronize populations, leading to antirescue effects. We also show density-dependent effects of dispersal on local populations, especially in sink ones, with consequences on life-history strategies and especially age at maturation, mainly via phenotypic plasticity. Altogether, we suggest that the spatial structure of Atlantic salmon populations should be considered in management and conservation strategies because the dynamics of local populations rely on the whole metapopulation functioning via spatial dispersal.

Bubbles to help the lost traveller: Non-physical structures ability to guide migrating salmon past hydropower plants

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Key words: Salmon migration, hydropower, guidance structures, telemetry

Abstract: One solution to combine hydropower with wild Atlantic salmon (*Salmo salar*) is to build fishways around the hydropower plant to allow a safe passage. A key difficulty is guiding the salmon to the entrance of these fishways. The most common method to guide salmon during downstream migration is a physical structure, e.g. a rack, which aside from guiding fish also will catch debris brought along with the current. Removing debris leads to a high maintenance demand for a physical guiding structure to be functional. As an alternative to physical structures for guiding fish, this study evaluates the ability of non-physical structures to guide downstream migrating salmon in a preferred direction. The tested treatments are sound, light, and air bubbles. Here, we evaluate these treatments ability to guide Atlantic salmon smolts in a controlled laboratory setting. We also scale up the most promising treatment to full-scale in a large river. Our laboratory results showed that a barrier of bubbles (no sound or light treatment) significantly reduced passages in the target zone with over 80% compared to the control. No significant effects were observed for the other treatments. In the full-scale study, we evaluated the bubble treatment with a 50-meter-long bubble barrier in Ume River, northern Sweden. Eighty salmon smolt was tracked with high-resolution acoustic telemetry and we observed a significant repelling effect of the bubbles also in the full-scale experiment, with a 90% reduction of passages through the barrier.

Boldly going: Does personality relate to fishway passage performance in trout?

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Key words: personality, behaviour, passage performance, nature-like bypass, low head barriers

Abstract: River habitats are highly fragmented due to cross-river constructions such as weirs. In efforts to restore habitat connectivity, fishways are increasingly employed to enable free movement of aquatic fauna. However, fishways are not always effective in achieving this and it remains uncertain what factors play a role in an individual's likelihood of succeeding in passage. Recent theoretical work suggests that bolder individuals may have increased chances of passage success, but there is limited empirical work that investigates this, and no work that relates personality to the behaviours exhibited during passage attempts. This study aimed to carry out boldness assays of brown trout (*Salmo trutta*) juveniles (n=78) under natural conditions within a river, and relate those boldness scores to both the passage success and the behaviours exhibited during passage attempts at a nature-like bypass. Boldness did not relate to passage success, but did marginally relate to the number of attempts an individual made before succeeding in passage - shy individuals attempted passage more times than bold individuals. This study furthers our understanding of how fish interact with fishways. It also highlights that fish passage studies need to take both passage success and the behaviour exhibited during passage attempts into consideration to obtain a more complete view of the utility of fishways and the impact of partial-barriers to fish movement.

Molecular differences behind the reduced cardiovascular capacity of migrating char and trout to face high temperatures compared to resident conspecifics

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Key words: heat shock response, arrhythmia, migration, salmonids

Abstract: Climate change could have extremely detrimental effects on spawning migrating salmonids since their upstream migration occurs during the warmest time of the year. Besides facing warm temperatures, the fish need capacity to pass through rapids to reach spawning grounds. To get clarity how well the fish can respond to climate change during migration we compared the maximum cardiovascular capacities and thermal tolerances between upstream migrating and resident Arctic char (*Salvelinus alpinus*) and brown trout (*Salmo trutta*) in Northern Norway (67.1°N). The migrating char and trout got cardiac arrhythmias at 14.9±0.7°C and 16.5±0.9°C, respectively while the river temperature was around 12.3°C i.e. only 2°C lower than the temperature where the major part of the migrating fish got arrhythmias. Interestingly the resident char and trout got arrhythmias at 21.2±0.9°C and 22.0±0.9°C, respectively. Moreover, maximum heart rate was lower in migrating than resident fish ($p<0.001$). When focusing on the heat shock response we found that the expression of the HSP70 was higher in migrating fish compared to the resident conspecific, moreover, the expression of the HSPs was different between the two species. Higher heat shock response might suggest a condition of stress in migrating fish, and different thermal adaptation between species. These results are valuable when addressing riverine conservation policies.

Impact of anthropogenic structures on fish swimming kinematics and passage

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Key words: small-scale hydropower, hydrokinetic turbines, natural flood management, acoustic Doppler velocimetry, turbulence-fish behaviour interactions, motion tracking

Abstract: Rivers are an invaluable natural resource for drinking water extraction, recreational purpose and energy generation. As such they have been subject to the construction of numerous anthropogenic structures and now only 1% of the UK's rivers remain free flowing. Currently, new manmade structures are mostly added to river systems in order to harness sustainable energy and mitigate flooding. But these obstructions alter the ecosystem influencing fish habitat selection and swimming performance often delaying or preventing migration. Near field effects concern essentially changes in the turbulent regime of the flow with regions of high vorticity, turbulent kinetic energy and Reynolds stresses. Such changes can be beneficial or detrimental to fish. Small-scale laboratory experiments undertaken in open channel flumes in the Hydro-Environmental Research Centre's laboratory at Cardiff University, UK, aim to investigate the impact of porous log jams used for natural flood management and vertical axis turbines on habitat usage and swimming kinematics of rainbow trout (*Oncorhynchus mykiss*). Near-wake hydrodynamics are measured and visualised using acoustic Doppler velocimetry, particle image velocimetry and flow visualisation. Habitat usage and fish swimming kinematics are monitored using camera recording and motion tracking algorithms. Our experimental observations identified correlations between turbulent wake hydrodynamics and fish behaviour, providing new insights on fish behaviour and habitat adaptation in relation to power extraction and flood mitigation schemes. These findings will help to foster the development and installation of vertical axis turbines and natural flood management interventions.

Ovarian fluids improve competitiveness of sperm of more colourful lake char

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Key words: ovarian fluid, carotenoid, sperm competition, salmonid, competitive fertilization

Abstract: Ovarian fluids of externally fertilizing fish have repeatedly been hypothesized to support sperm velocity of some males over others, thereby providing a possible mechanism of cryptic female choice. To test this, we collected sperm and eggs from wild-caught lake char (*Salvelinus umbla*). Sperm of two males each were allowed to compete in water with or without ovarian fluid for fertilization of eggs of different females. In total, 40 different replicated mating scenarios were tested, and 1,464 (>99%) of the resulting embryos were genetically assigned to their father using microsatellites. In parallel, sperm characteristics of the competitors were measured in water with or without ovarian fluids, and male colouration was quantified from standardized photos. Yellower males had faster sperm that reacted better to ovarian fluids and thereby reached higher fertilization rates that paler males. We conclude that ovarian fluids give sperm of more colourful males a competitive advantage. This improved competitiveness could reveal cryptic female choice (e.g. a preference for yellower males) or variation in male reproductive strategies (males investing differently in sperm characteristics).

The effects of stress on adult Atlantic salmon prior to spawning on the viability of their offspring

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Key words: catch-and-release, conservation, behaviour, physiology, survival, growth, intergenerational effects

Abstract: Conservation regulations often require anglers to release adult Atlantic salmon (*Salmo salar*) that they have captured. Yet, almost nothing is known about whether this highly stressful event has any long term adverse intergenerational effects, or how this conservation initiative will actually affect the species on the long run. The greatest effects are likely to occur near spawning, therefore such data are important for the better reinforcement of the developing regulations. This study examines how adult pre-spawning stress can affect the survival, growth, behaviour, physiology and vulnerability to disease of the next generation. Adult salmon were caught on their upstream spawning migration using a permanent fish trap on the river Blackwater, and were then exposed to one of four treatments, which comprised of exercise (to simulate capture during angling) followed by air exposure of different durations. The effects on the next generation were then quantified by studying the survival and growth rate of the offspring at successive developmental stages. Furthermore, their standard metabolic rate (SMR), maximum metabolic rate (MMR) and aerobic scope (AS) were also estimated to evaluate whether stress experienced by parents had an effect on offspring metabolism. Additional experiments also investigated fry boldness, dominance and exploratory behaviour of a novel environment. Lastly, a short fungal (*Saprolegnia* spp.) outbreak in the stream system provided an opportunity to explore whether pre-spawn parental stress can affect the vulnerability of fry to disease. The results of this experiment will provide an insight into any intergenerational effects induced by catch-and-release angling of the adult pre-spawned salmon.

A gut feeling: how has 12 generations of domestication impacted the Atlantic salmon (*Salmo salar*) gut microbiome?

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Key words: gut, microbiome, Atlantic salmon, aquaculture, common garden

Abstract: Domestication has long been part of agriculture, but up until the 19th century the process had only occurred in a handful of aquatic organisms. Despite the slow establishment of aquaculture, numerous aquatic systems are now undergoing rapid change in response to controlled anthropogenic pressures. Many hallmarks of domestication, such as growth, have been well characterised, but one relatively germinal area of interest that has not been well studied is the impact of domestication on host associated gut bacterial communities, also known as the gut microbiome. We examine interactions between genetic background of Atlantic salmon (*Salmo salar*) (wild, farmed and hybrid) post-smolt and the bacterial communities residing within the mid-gastro intestinal tract; with all fish being reared in common garden tanks. To assess bacterial diversity we used metabarcoding and the 16S ribosomal RNA gene variable region 1-2 marker. Amplicons from this process were indexed and sequenced using the high throughput Illumina MiSeq platform. Alpha and beta diversity metrics were used to give insight into the types of bacterial diversity between genetic backgrounds, which has implications for nutrition, immunity and overall physiological wellbeing of the salmon host.

Aerobic exercise training with optimal intensity increases cardiac thermal tolerance in juvenile rainbow trout

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Key words: aerobic exercise training, cardiac thermal tolerance, rainbow trout, cardiac performance

Abstract: For more than a century selective breeding has focused on farming purposes, e.g. fast growth, affecting simultaneously cardiorespiratory capacity of the fish negatively. Compromised cardiovascular capacities can lead to lower capacity of salmonids to face environmental stressors like heatwaves, events that are becoming more frequent with climate change. Thereby, farmed salmonids might be in danger in future. Previous studies have shown that aerobic training improves several aspects of cardiac performance of fish e.g. cardiac output, oxidative capacity and growth. This study provides new insights on how enhanced cardiac performance, induced by endurance swimming training, improves the capacity of fish to face heatwaves. We exposed juvenile rainbow trout to three different swimming programs: 1, 2 and 3 body lengths (control, medium, high speed) per second for 6 hours per day for 5 weeks. Thereafter, we measured maximal heart rate (fHmax) of fish at different temperatures and the thermal tolerance of the cardiovascular function by measuring the temperature where fish got arrhythmias (Tarr). Training with medium velocity increased the Tarr significantly as compared to controls, while high velocity training did not have significant effect on Tarr. In order to understand the physiological and cellular basis of the enhanced thermal tolerance with training we are currently analysing the fHmax and the metabolic energy supply capacity. These findings provide a valid training program that can increase the capacity of hatchery salmonids to face heatwaves and it can be applied directly in the aquaculture facilities to enhance fish production by reducing the mortality during heatwaves.

A sex-dependent genotype by growth interaction underlying age at maturity in Atlantic salmon

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Key words: age at maturity, Atlantic salmon, genetics, phenotypic plasticity

Abstract: Age at maturity is a critical life history trait that affects fitness traits such as survival, size at maturity and lifetime reproductive success. In Atlantic salmon, age at maturity represents a classic evolutionary trade-off between survival and reproduction; larger, later-maturing individuals have higher reproductive success, but they also have a higher risk of dying before first reproduction. In Atlantic salmon, 30-40% of the variation in age at maturity is explained by a genetic marker in the proximity of the *vgll3* gene, a gene that also links with growth, maturation and condition in mammals. Selection favours earlier maturation in males than females, and, interestingly, *vgll3* exhibits sex-dependent dominance, promoting earlier maturation in males than females. Growth conditions experienced early in life is expected to influence age at maturity, because the survival-reproduction trade-off may differ between slow- and fast-growing individuals. In this project, our aim is to understand how growth and genetics interact to influence age at maturity in male and female Atlantic salmon. We use life-history and genetic data obtained from salmon scales, to study 1) whether *vgll3* influence age at maturity via effects on growth, and 2) whether *vgll3* influence age at maturity through interactions with growth.

Assessment of Smolt-to-Adult Supplementation (SAS) strategy as a conservation tool in depressed Atlantic salmon (*Salmo salar*) populations

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Key words: Smolt–to-Adult Supplementation, SAS, Atlantic salmon, *Salmo salar*, smolt, broodstock, conservation, hatchery, experimental river, egg experiment, fecundity, fertility

Abstract: The Smolt–to-Adult Supplementation strategy (SAS) for Atlantic salmon (*Salmo salar*) is considered to be a possible conservation tool in areas where the populations of wild Atlantic salmon have declined below the defined conservation levels. The SAS management may have benefits in comparison to traditional, juvenile stocking methods based on broodstock collections. However, the SAS strategy may also have risks that are not thoroughly understood yet. The goal is to evaluate differences between adult wild Atlantic salmon and adult SAS Atlantic salmon in a natural experimental stream environment and to study the behaviour, performance (*i.e.*, growth, intercohort fitness) of the progeny from both groups. Over a timespan of three years 40 pairs of adult SAS and wild Atlantic salmon are released annually into a selected experimental stream (Northwest Millstream, Miramichi, Canada) and monitored throughout the spawning period. The reproduction success will be evaluated using electrofishing surveys to collect the progeny in the following years. The progeny found in the experimental stream will be identified via the use of genetic parental analyses to evaluate the reproduction success of the released adult individuals. The condition factor at different time points and the survival rates of the progeny are examined over time. Additionally, a laboratory experiment is set up to evaluate differences in egg size, fecundity and fertilization success of adult SAS and wild individuals as well as the as survival rate up to first feeding fry and phenotypical appearance of the progeny from both groups.

Overwinter energy management strategies and survival of farmed Atlantic salmon offspring in the wild

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Key words: farmed, Atlantic salmon, overwinter survival, energy management, energy stores

Abstract: Farmed Atlantic salmon have undergone intense selective regimes that have led to changes in fitness-related traits associated with behaviour, morphology and physiology. Salmon regularly escape from farm- and captive- rearing facilities and can interbreed with wild individuals in adjacent rivers. Consequently, there is introgression of farmed alleles and co-selected traits into wild populations from escaping fish, which are likely to have deleterious effects on recipient wild population viability. Previous studies have shown that first winter survival of juvenile salmon is lower among the progeny and hybrid progeny of farmed parents relative to the offspring of wild parents. In natural salmon populations, lipid energy stores are reduced by the end of winter and can affect fish condition and individual survival. How energy stores are acquired, used and defended has been shown to play a role in over winter survival. In this study, we assess and present preliminary results of the relative seasonal energy management and overwinter survival of the progeny of farmed and wild salmon, including hybrid progeny, in a common garden experiment undertaken in the wild. The energy phenotypes of interest include body condition; dry weight; water content and lipid content. Our results would indicate that inherent energy budgeting among the progeny of farmed salmon is maladaptive and an important determinant of their poor performance in the wild.

Timing is everything: factors that affect Atlantic salmon smolt migration phenology

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Key words: Atlantic salmon, smolt, migration phenology

Abstract: Atlantic salmon ('salmon') stocks are declining throughout their native range. As an anadromous species, they undergo long migrations spanning fresh and saltwater, and improving our knowledge of aspects of their migrations could have important conservation implications. We use data from a long-term salmon monitoring project on a chalk stream in Southern England (River Frome), spanning fourteen years, to test the influence of migration phenology and environmental factors on salmon migration behaviour. Each autumn, 10 000 juvenile salmon are PIT-tagged and released to over-winter. A proportion are recaptured the following spring during their smolt run. Using the number of PIT-tagged individuals captured each day during the smolt run, we are investigating the factors affecting the probability of a fish moving downstream on a given day, including water temperature, flow, and photoperiod. Our results should assist managers and scientists in improving their understandings of the freshwater life history of salmon.

Archived scales of Atlantic salmon reveal a sex-specific maturation reaction norm related to growth at sea

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Key words Atlantic salmon, *Salmo salar*, life history strategies, marine growth, maturation probability, sex-specific effects, management

Abstract: We test the hypothesis that the recent decline in abundance of Atlantic salmon and concomitant changes in life history strategies may partly result from a response to a decline in the growth conditions available for salmon during marine migration. Major changes in the North Atlantic may have affected growth, survival and the timing of key life-history events such as age at maturity, a life history trait that is a key component of the fitness. Available literature suggests the existence of a sexspecific plastic reaction norm linking maturation with growth at sea, but the extent to which this mechanism can explain variations in age at maturity observed in wild populations remains unclear. Based on a historical collection of scales (1987-2017) from the Selune River, France, we showed that marine growth declined over the first summer, particularly since the 2000s, whereas growth remained stable over the rest of the marine sojourn in returning adults. A concomitant decline was observed in the proportion of fish maturing after one year at sea, especially in females. 74% of the temporal variability in this trait was explained by sex and variations in growth over the first summer at sea. Results support the hypothesis of a sex-specific reaction norm, with the individual probability to mature after one year at sea increasing when growth increases, and with females requiring higher growth than males to attain the maturation threshold.

Can the past explain the present? Using archived Atlantic salmon (*Salmo salar*) scales and stable isotopes to investigate long-term trends in marine resource use and migration

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Key words: compound-specific stable isotope analysis, Greenland, carbon, hydrogen, nitrogen, trophic ecology

Abstract: Marine survival of wild Atlantic salmon (*Salmo salar*) populations has declined precipitously over the last 50 years, associated with climate change induced changes to ocean temperature and prey abundance. Fewer adult salmon are returning to their natal rivers than ever before and those returning are smaller than previously recorded, however changes in their marine feeding over this time frame remain unexplored. A consumer's stable isotope ratios encode its trophic ecology; therefore, analysis of archived scales can infer long-term trends in resource use, trophic position, and foraging location of marine feeding Atlantic salmon. Scale growth representing the preceding summer at sea will be excised and analysed for bulk carbon, nitrogen, hydrogen, and oxygen stable isotopes, along with compound-specific carbon and nitrogen analysis. Using these data, I will investigate trends in resource use and trophic position of salmon returning to rivers in Greenland, Europe and Eastern Canada over a 50-year time scale. Secondly, two genetically distinct populations of wild salmon are found within the Bay of Fundy (BoF), in Eastern Canada: the inner BoF and outer BoF populations. Inner BoF salmon are thought to exhibit a localized migration strategy by staying in and around the Bay, whereas outer BoF salmon are thought to migrate to the Northwest Atlantic. Migration patterns of BoF salmon will be inferred by applying stable isotope data to marine isoscapes. The aim is to utilize stable isotopes as a tool to improve the understanding of Atlantic salmon migration, distribution, and resource use at sea.

Diversity of chars (*Salvelinus* spp.) in the Coppermine River near Kugluktuk, Nunavut

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Key words: *Salvelinus*, Indigenous fisheries, genetics, morphology, Arctic, community-partnered research, species at risk

Abstract: Climate change disproportionately affects Arctic ecosystems and represents a significant threat to the local Inuit, who depend on traditional foods including char (*Salvelinus* spp.) harvested from subsistence fisheries. In the Canadian Arctic, where importing food is prohibitively expensive, chars are of critical importance to food security due to their abundance and availability for year-round harvest. However, despite their importance, the genetics, ecology, and demography of these fishes – namely the closely related Arctic char (*Salvelinus alpinus*) and Dolly Varden char (*Salvelinus malma*) – remain understudied, making it difficult to anticipate the effects of climate change on species persistence. In the Hamlet of Kugluktuk in Nunavut, Canada, local fishers have recently reported physical variation in fish appearance; while the local subsistence fishery has traditionally supported solely Arctic char, these observations have led to the belief that Dolly Varden are also present in the system. I am using next-generation sequencing technologies to assess whether both Arctic char and Dolly Varden are present in the system, and the extent of past and contemporary species hybridization. I am also investigating whether char from the system exhibit quantifiable morphological and meristic variation, and whether this variation is consistent with results from genetic analyses. Preliminary results suggest that meristic data may be used to differentiate between the two species. Results from my project will help address questions raised by Inuit communities in the Canadian Arctic, and will contribute to evidence-based management decisions that are being taken to ensure long-term viability of char fisheries.

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