Essential Fish Habitat and Potential Adverse Effects

Bibliography

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Background & Scope

NOAA Fisheries' Greater Atlantic Regional Fisheries Office (GARFO) is conducting research on the known population scale and ecosystem-level adverse effects of legacy and emerging contaminants on climate vulnerable, threatened, or endangered species of fish. This literature search was conducted to support that research. The literature presented here is organized by the species of concern in each article. Section 7 has articles that cover multiple species of fish, and Section 8 includes articles that were otherwise not able to be categorized. The literature contained in this bibliography was published between 2007 and 2023, and the search was performed between June and July 2023.

Sources Reviewed

Along with a web search for relevant grey literature materials the following databases were used to identify sources: Aquatic Science and Fisheries Abstracts, Dimensions, Lens.org, Clarivate Analytics' Web of Science: Science Citation Index Expanded, Wiley Online Library, ProQuest's Earth-Atmospheric & Aquatic Science Database, Science Direct, BioOne Complete, and Google Scholar. Only English language materials were considered.

Section 1: Alewife (Alosa psuedoharengus)

Able, K. W., Grothues, T. M., Shaw, M. J., VanMorter, S. M., Sullivan, M. C., & Ambrose, D. D. (2020). Alewife (Alosa pseudoharengus) spawning and nursery areas in a sentinel estuary: spatial and temporal patterns. *Environmental Biology of Fishes,* 103(11), 1419-1436. https://doi.org/10.1007/s10641-020-01032-0

Spatial and temporal distribution of anadromous alewife (Alosa pseudoharengusWilson) spawning and nursery habitats were determined by sampling in the Mullica River - Great Bay watershed (New Jersey, USA) in a combination of long- and short-term observational and quantitative studies. Reproduction was confirmed by examination of developing gonads, visual observations of spawning, and egg collections. Spawning typically lasted 2-4 days in discrete waves in freshwater tributaries from late March to late April. Nursery habitats for larvae and young-of-the-year alewife included low-salinity tributaries near the freshwater-saltwater interface and high salinity waters through early fall before departure to the ocean in late fall. Predation on eggs by fish predators, especially American eel (Anguilla rostrataLesueur), occurred below a dam. This predation was also observed in the laboratory on eggs and larvae. These findings point out that this dam provided for enhanced predation on alewife early life history stages, and may cause an ecological hotspot for predation-prey interactions for this anadromous species and its catadromous predator.

Bowlby, H. D. (2016). *Quantitative recovery planning: understanding how human activities in watersheds can influence population dynamics and genetic structuring of diadromous fishes.* (Ph.D.), Memorial University, Retrieved from https://research.library.mun.ca/12529/

Developing quantitative relationships that link human-induced environmental change with changes in population dynamics for species of conservation concern is hindered by: (1) a limited understanding of the cumulative effect (and relative importance) of population regulation, spatial dynamics, and demographic processes, (2) issues with detectability for species-environment interactions owing to data characteristics and (3) the cumulative or confounding nature of multiple threats. Taking a single-species approach based on endangered Atlantic salmon, I have partially addressed these challenges in my four research chapters. In chapter two, I characterized the conditions under which metapopulation structure would be expected to benefit a population assemblage and found that straying can reduce abundance and heighten extinction risk when productivity is low. For species of conservation concern, I would expect that remediation actions designed to influence demographic rates (e.g. mortality rates) would be more beneficial than actions influencing spatial dynamics. In chapter three, I accounted for the effects of observation and measurement error when quantifying relationships between hydrological variation and survival. Beyond the potential to change our interpretation of ecological relationships, I was able to infer the types of threats affecting juveniles in specific watersheds. In chapter four, I used patterns of effective dispersal to surmise the behavioural mechanism leading to watershed choice among straying adult salmon as well as the relative importance of multiple concurrent threats. My conclusions contradict some current perceptions on threats and suggest new directions for future research. In chapter five, I was able to develop a spatial tool that could inform management decisions or identify priority areas for restoration efforts. However, I was unable to fully characterize how environmental variation influences habitat utilization, distribution patterns, or population-level responses to human activities at multiple spatial extents. The relationships I describe are among the first to be developed for endangered Atlantic salmon in Nova Scotia at a population level. Several of the analyses represent novel

applications to conservation questions and have the potential to be extended or more widely applied. Because freshwater fishes, including diadromous fishes, are collectively one of the most imperiled species groups in the world, such research represents a timely contribution to conservation biology.

Dalton, R. M., Sheppard, J. J., Finn, J. T., Jordaan, A., & Staudinger, M. D. (2022). Phenological Variation in Spring Migration Timing of Adult Alewife in Coastal Massachusetts. *Marine and Coastal Fisheries,* 14(2). https://doi.org/10.1002/mcf2.10198

The timing of biological events in plants and animals, such as migration and reproduction, is shifting due to climate change. Anadromous fishes are particularly susceptible to these shifts as they are subject to strong seasonal cycles when transitioning between marine and freshwater habitats to spawn. We used linear models to determine the extent of phenological shifts in adult Alewife Alosa pseudoharengus as they migrated from ocean to freshwater environments during spring to spawn at 12 sites along the northeastern USA. We also evaluated broadscale oceanic and atmospheric drivers that trigger their movements from offshore to inland habitats, including sea surface temperature, North Atlantic Oscillation index, and Gulf Stream index. Run timing metrics of initiation, median (an indicator of peak run timing), end, and duration were found to vary among sites. Although most sites showed negligible shifts towards earlier timing, statistically significant changes were detected in three systems. Overall, winter sea surface temperature, spring and fall transition dates, and annual run size were the strongest predictors of run initiation and median dates, while a combination of within-season and seasonal-lag effects influenced run end and duration timing. Disparate results observed across the 12 spawning runs suggest that regional environmental processes were not consistent drivers of phenology and local environmental and ecological conditions may be more important. Additional years of data to extend time series and monitoring of Alewife timing and movements in nearshore habitats may provide important information about staging behaviors just before adults transition between ocean and freshwater habitats.

Ezzard, A. D. (2017). *Early Life History Of Larval River Herring In A Coastal Watershed: Abundance, Growth, And Mortality.* (Master's), East Carolina University, Retrieved from https://thescholarship.ecu.edu/handle/10342/6540

River herring are two closely-related, anadromous fish species, Alewife (Alosa aestivalis) and Blueback Herring (A. pseudoharengus), which have been historically, commercially, and ecologically important along the North American Atlantic coast for hundreds of years. However, recent decades have been marked by their dramatic population declines and a collapse of the fishery. Historical records show that the coastal watershed of North Carolina's Chowan River was an epicenter for river herring harvest and spawning from pre-1700 through the late 1980s. I spatiotemporally characterized the early life history of river herring larvae in the Chowan River and its tributaries in the spring spawning season of 2011 by calculating larval abundance, growth, mortality, and diet relative to water quality and chemistry. Results show that the Chowan River and its tributaries supported relatively high numbers of river herring larvae in 2011 compared to an early 1980s study, with mean catches per unit effort (CPUEs) ranging from 52.87 + 71.68 larvae/100 m3 to 1583.53 + 2698.18 larvae/100 m3 compared to a similar and neighboring riverine system - the Roanoke River - with mean CPUEs ranging from 4.1 + 20.9 larvae/100 m3 in 2008 to 30.8 + 149.8 larvae/100 m3 from a study in 2009. A concurrent study to my research indicated that

larval river herring diets are very similar between the adjacent systems, consisting primarily of copepods and rotifers in both the lower Chowan and the lower Roanoke River. Also, analyses of abundance, growth rates, and mortality rates suggest that density-dependent mechanisms likely control larval river herring trends throughout the Chowan system. Although all nursery habitats are worthy of research and conservation efforts, the Chowan River has continually proved to be a regional epicenter for successful reproduction and early life history of river herring and, therefore, merits special attention as a Strategic Habitat Area (SHA) by the State of North Carolina.

Ketola, H. G., Rinchard, J., O'Gorman, R., Begnoche, L. J., Bishop, D. L., & Greulich, A. W. (2009). Thiamine Content of Eggs and Lengths of Coho Salmon (Oncorhynchus kisutch) in Relation to Abundance of Alewife (Alosa pseudoharengus) in Eastern Lake Ontario, 2003 to 2006. *Journal of Freshwater Ecology,* 24(2), 247-254. https://doi.org/10.1080/02705060.2009.9664289

Early mortality syndrome in fry of Great Lakes salmonines is linked to reduced levels of thiamine in eggs, which reflects maternal consumption of forage fishes such as alewife (Alosa pseudoharengus) that contain thiaminase, an enzyme that destroys thiamine. We assessed annual variations in abundance and condition of alewives and thiamine status of coho salmon (Oncorhynchus kisutch) in Lake Ontario. We analyzed total thiamine in eggs of 20 coho salmon collected annually between 2003 and 2006 at the Salmon River Hatchery on the Salmon River, New York. Alewife abundance was assessed annually in southern and eastern Lake Ontario with bottom trawls during late April and early May. Mean thiamine concentration in eggs varied annually, with those collected in 2003 (2.5 nmol/g) being significantly higher than those collected in 2004 to 2006 (1.5 to 1.7 nmol/g). Although we did not test survival of fry, if reported threshold levels of thiamine for preventing mortality of Lake Michigan coho salmon fry apply, then many or most Lake Ontario coho salmon produced fry were likely to incur thiamine-deficiency mortality, especially during years 2004 to 2006. Comparison to indices of annual abundance of alewife in Lake Ontario with thiamine concentration in coho salmon eggs failed to show any significant Correlations ($P > 0.05$). However, total length of female spawning coho salmon was positively correlated ($P < 0.05$) with increasing condition and estimated energy content of adult alewives in the previous spring. These results suggest that growth of coho salmon in Lake Ontario was first limited by energy intake, whereas the amount of thiamine provided by alewives was sufficient for growth (in length) but not for producing thiamine-adequate eggs.

Mather, M. E., Frank, H. J., Smith, J. M., Cormier, R. D., Muth, R. M., & Finn, J. T. (2012). Assessing Freshwater Habitat of Adult Anadromous Alewives Using Multiple Approaches. *Marine and Coastal Fisheries,* 4(1), 188-200. https://doi.org/10.1080/19425120.2012.675980

After centuries of disturbance, environmental professionals now recognize the need to restore coastal watersheds for native fish and protect the larger ecosystems on which fish and other aquatic biota depend. Anadromous fish species are an important component of coastal ecosystems that are often adversely affected by human activities. Restoring native anadromous fish species is a common focus of both fish and coastal watershed restoration. Yet restoration efforts have met with uneven success, often due to lack of knowledge about habitat availability and use. Using habitat surveys and radio tracking of adult anadromous alewives Alosa pseudoharengus during their spring spawning migration, we illustrate amethod for quantifying habitat using multiple approaches and for relatingmobile fish distribution to

habitat. In the Ipswich River, Massachusetts, measuring habitat units and physical conditions at transects (width, depth, and velocity) provided an ecological basis for the interpretation of landscape patterns of fish distribution. Mapping habitat units allowed us to efficiently census habitat relevant to alewives for the entire 20.6 river kilometers of interest. Our transect data reinforced the results of the habitat unit survey and provided useful, high-resolution ecological data for restoration efforts. Tagged alewives spent little time in riffle-run habitats and substantial time in pools, although the locations of pool occupancy varied. The insights we provide here can be used to (1) identify preferred habitats into which anadromous fish can be reintroduced in order to maximize fish survival and reproduction and (2) pinpoint habitat types in urgent need of protection or restoration.

Nelson, G. A., Gahagan, B. I., Armstrong, M. P., Jordaan, A., & Bowden, A. (2020). A life cycle simulation model for exploring causes of population change in Alewife (Alosa pseudoharengus). *Ecological Modelling,* 422. https://doi.org/10.1016/j.ecolmodel.2020.109004

Over the last two decades, major changes in abundance and population characteristics of Alewife (Alosa pseudoharengus), an anadromous herring species, have been observed along the US Atlantic coast. Loss of spawning habitat, bycatch mortality in the directed pelagic fisheries, increased predation mortality by rebounding predators such as Striped Bass, changes in water flow and temperature affecting recruitment success, changes in ocean thermal habitat and direct and indirect effects of changes in zooplankton community have been expounded by different researchers as putative hypotheses for population changes in Alewife. Unfortunately, long-term, concurrently-measured time series of regional factors and direct measures of biological processes needed to elucidate underlying causes are severely lacking for Alewife. Therefore, we developed, calibrated and validated a mechanistic, spatially-explicit, full life-cycle simulation model that can be used to explore population responses of Alewife to various exogeneous drivers. Daily processes such as spawning, recruitment, mortality, exploitation, predation and movements are generated by using empirically-derived deterministic and stochastic relationships and time-series of environmental data linked to specific life stages. We demonstrate the use of the model as an investigative tool by simulating three hypotheses and comparing model results to observed trends in Alewife populations from southern New England.

Overton, A. S., Jones, N. A., & Rulifson, R. (2012). Spatial and Temporal Variability in Instantaneous Growth, Mortality, and Recruitment of Larval River Herring in Tar-Pamlico River, North Carolina. *Marine and Coastal Fisheries,* 4(1), 218-227. https://doi.org/10.1080/19425120.2012.675976

We estimated the variation in the instantaneous rates of growth and mortality between cohorts of larval alewife Alosa pseudoharengus and blueback herring A. aestivalis in the Tar-Pamlico River, Pamlico Sound, North Carolina. The age of larvae captured by push net was estimated by counting the daily rings on sagittal otoliths. Weight-at-age and abundance-at-age data were used to generate instantaneous daily growth (G) and mortality rates (M) for 7-d cohorts. The instantaneous daily growth rate was relatively constant between cohorts, ranging from 0.103 to 0.277 for alewives and from 0.105 to 0.200 for blueback herring. The instantaneous daily mortality rate was more variable between cohorts, ranging from 0.064 to 0.270 for alewives and from 0.100 to 0.251 for blueback herring. All but one blueback herring cohort had an M/G value exceeding 1.0, indicating that these cohorts were losing biomass during the early larval stage. For alewives, M/G values were more variable, with 50% of the cohorts

having values less than 1.0. The effect of habitat was consistent between species, with M/G values being higher and closer to 1.0 at sites in tributary creeks and backwater areas of Tar River. The overall M/G values were 0.57 for alewives and 1.60 for blueback herring from both backwater and main-channel sites, indicating that the environmental conditions in the Tar-Pamlico River are more favorable for alewives.

Riley, K. L. P. (2012). *Recruitment of Estuarine-Dependent Alosines to Roanoke River and Albemarle Sound, North Carolina.* (Ph.D.), East Carolina University, Retrieved from https://thescholarship.ecu.edu/handle/10342/3867

The deleterious effects of dams on alosine populations are widely documented in many rivers along the Atlantic coast. Alterations to the natural hydrologic regime can disrupt spawning egg dispersal and recruitment of larvae to nursery habitats. The goal of this study was to investigate the ecological processes that influence recruitment of river herring (blueback herring Alosa aestivalis and alewife A. pseudoharengus) to nursery habitats within lower Roanoke River and Albemarle Sound North Carolina. It was hypothesized that variability in abiotic conditions and fluctuations in food abundance could structure nursery habitat and severely restrict recruitment. Ichthyoplankton and zooplankton samples were collected concurrently March through June 2008-09 at 19 stations within three areas: River Delta and Sound. Significant spatial and temporal differences were observed for river herring abundances. Abundances (number/100m^3 ± SD) were significantly higher in 2009 (30.8 ± 149.8) than in 2008 (4.1 ± 20.9). Across both years abundances within the River (21.0 ± 127.6) were significantly higher than those in Delta (7.4 ± 35.4) and Sound (4.6 ± 24.8). Yolk-sac larvae were prevalent throughout samples (32%); however larvae collected were predominantly preflexion stage (66%). Fish ages ranged from 4 to 19 days after hatch. Growth rates were similar for blueback herring (0.29 ± 0.16 mm/d) and alewife (0.30 ± 0.14 mm/d). Growth estimates were indicative of habitat quality and suggested riverine habitats supported the highest growth rates. Mortality estimates for blueback herring (0.76 ± 0.23 per day) were significantly higher than mortality estimates for alewife (0.64 ± 0.17 per day). High mortality for both years was probably related to larval dispersal and advective loss. Larvae do not appear to be food limited in this system as indicated by diet analyses and the spatiotemporal overlap between river herring and zooplankton. Decreasing zooplankton abundance was correlated with larval abundance and suggests foraging by larval alosines could negatively alter the structure of the zooplankton community. Diets varied little with early ontogeny and the smallest taxa (copepod nauplii and rotifers) accounted for over 85% of the diet. Because of a high-level of dietary overlap intraspecific and interspecific competition is substantial for anadromous alosines. The result of long-term data analysis (1984 - 2009) for larval and juvenile river herring confirms Roanoke-Albemarle stocks are in decline. Larval fish abundance was negatively affected by spring river flow (r^2 = 0.62). High flows (> 300 m^3/s) resulted in larval advection from Roanoke River. Spring river flow was positively correlated with juvenile abundance (r = 0.95) and best recruitment of juveniles occurs in years with moderate spring river flow (141 - 311 m^3/s).

Section 2: American Sturgeon (Acipenser oxyrhynchus oxyrhynchus)

Roy, N. K., Candelmo, A., DellaTorre, M., Chambers, R. C., Nádas, A., & Wirgin, I. (2018). Characterization of AHR2 and CYP1A expression in Atlantic sturgeon and shortnose sturgeon treated with coplanar PCBs and TCDD. *Aquatic Toxicology,* 197, 19-31. https://doi.org/10.1016/j.aquatox.2018.01.017

Atlantic sturgeon and shortnose sturgeon co-occur in many estuaries along the Atlantic Coast of North America. Both species are protected under the U.S. Endangered Species Act and internationally on the IUCN Red list and by CITES. Early life-stages of both sturgeons may be exposed to persistent aromatic hydrocarbon contaminants such as PCBs and PCDD/Fs which are at high levels in the sediments of impacted spawning rivers. Our objective was to compare the PCBs and TCDD sensitivities of both species with those of other fishes and to determine if environmental concentrations of these contaminants approach those that induce toxicity to their young life-stages under controlled laboratory conditions. Because our previous studies suggested that young life-stages of North American sturgeons are among the more sensitive of fishes to coplanar PCB and TCDD-induced toxicities, we were interested in identifying the molecular bases of this vulnerability. It is known that activation of the aryl hydrocarbon receptor 2 (AHR2) in fishes mediates most toxicities to these contaminants and transcriptional activation of xenobiotic metabolizing enzymes such as cytochrome P4501A (CYP1A). Previous studies demonstrated that structural and functional variations in AHRs are the bases for differing sensitivities of several vertebrate taxa to aromatic hydrocarbons. Therefore, in this study we characterized AHR2 and its expression in both sturgeons as an initial step in understanding the mechanistic bases of their sensitivities to these contaminants. We also used CYP1A expression as an endpoint to develop Toxicity Equivalency Factors (TEFs) for these sturgeons. We found that critical amino acid residues in the ligand binding domain of AHR2 in both sturgeons were identical to those of the aromatic hydrocarbon-sensitive white sturgeon, and differed from the less sensitive lake sturgeon. AHR2 expression was induced by TCDD (up to 6-fold) and by three of four tested coplanar PCB congeners (3–5-fold) in Atlantic sturgeon, but less so in shortnose sturgeon. We found that expression of AHR2 and CYP1A mRNA significantly covaried after exposure to TCDD and PCB77, PCB81, PCB126, but not PCB169 in both sturgeons. We also determined TEFs for the four coplanar PCBs in shortnose sturgeon based on comparison of CYP1A mRNA expression across all doses. Surprisingly, the TEFs for all four coplanar PCBs in shortnose sturgeon were much higher (6.4–162 times) than previously adopted for fishes by the WHO.

Roy, N. K., Walker, N., Chambers, R. C., & Wirgin, I. (2011). Characterization and expression of cytochrome P4501A in Atlantic sturgeon and shortnose sturgeon experimentally exposed to coplanar PCB 126 and TCDD. *Aquatic Toxicology,* 104(1-2), 23-31. https://doi.org/10.1016/j.aquatox.2011.03.009

The AHR pathway activates transcription of CYP1A and mediates most toxic responses from exposure to halogenated aromatic hydrocarbon contaminants such as PCBs and PCDD/Fs. Therefore, expression of CYP1A is predictive of most higher level toxic responses from these chemicals. To date, no study had developed an assay to quantify CYP1A expression in any sturgeon species. We addressed this deficiency by partially characterizing CYP1A in Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus) and shortnose sturgeon (Acipenser brevirostrum) and then used derived sturgeon sequences to develop reverse transcriptase (RT)-PCR assays to quantify CYP1A mRNA expression in TCDD and PCB126 treated early

life-stages of both species. Phylogenetic analysis of CYP1A, CYP1B, CYP1C and CYP3A deduced amino acid sequences from other fishes and sturgeons revealed that our putative Atlantic sturgeon and shortnose sturgeon CYP1A sequences most closely clustered with previously derived CYP1A sequences. We then used semi-quantitative and real-time RT-PCR to measure CYP1A mRNA levels in newly hatched Atlantic sturgeon and shortnose sturgeon larvae that were exposed to graded doses of waterborne PCB126 (0.01-1000 parts per billion (ppb)) and TCDD (0.001-10 ppb). We initially observed significant induction of CYP1A mRNA compared to vehicle control at the lowest doses of PCB126 and TCDD used, 0.01 ppb and 0.001 ppb, respectively. Significant induction was observed at all doses of both chemicals although lower expression was seen at the highest doses. We also compared CYP1A expression among tissues of i.p. injected shortnose sturgeon and found significant inducibility in heart, intestine, and liver, but not in blood, gill, or pectoral fin clips. For the first time, our results indicate that young life-stages of sturgeons are sensitive to AHR ligands at environmentally relevant concentrations, however, it is yet to be determined if induction of CYP1A can be used as a biomarker in environmental biomonitoring.

Section 3: Atlantic Salmon (Salmo salar)

Addo, L., Hajiesmaeili, M., Piccolo, J. J., & Watz, J. (2023). Growth and mortality of sympatric Atlantic salmon and brown trout fry in fluctuating and stable flows. *Ecology of Freshwater Fish,* 32(2), 282-290. https://doi.org/10.1111/eff.12685

Sub-daily fluctuations in streamflow may have adverse effects on the biota downstream of dams in hydropeaking-regulated rivers. Although the stranding of salmonid fry is one documented effect of hydropeaking, little is known about the species-specific behavioural and subsequent growth effects of sub-daily flow fluctuations. We investigated the effects of sub-daily flow fluctuation on growth, mortality and behaviour of sympatric Atlantic salmon (Salmo salar) and brown trout (S. trutta) fry (29-34 mm) in a laboratory experiment. The fluctuating flow treatment negatively affected growth and increased mortality for trout but not for salmon. The level of aggressive behaviour was similar in the fluctuating- and stable-flow treatments. Within the fluctuating flow treatment, there was a trend that more fishes were visibly active above the substrate during low than high flow. These findings suggest that hydropeaking-induced flow fluctuations may affect fry of different salmonid species in different ways and that brown trout fry may be more vulnerable to hydropeaking effects than Atlantic salmon fry. It can therefore be important to consider the possibility of divergent reactions by different fish species under hydropeaking situations and to incorporate species-specific strategies to conserve culturally and economically relevant riverine fish species.

Assuncao, M. G. L., Ives, M., Davison, P. M., Barber, J. L., Moore, A., & Law, R. J. (2020). Persistent contaminants in adipose fins of returning adult salmonids to the river Tees (UK). *Marine Pollution Bulletin,* 153. https://doi.org/10.1016/j.marpolbul.2020.110945

We report on concentrations of polybrominated diphenylethers (PBDEs), polychlorinated biphenyls (PCBs), dichlorodiphenyldichloroethylene (p,p'-DDE) and hexachlorobenzene (HCB) measured in the adipose fins of returning adult Atlantic salmon (Salmo salar) and sea trout (Salmo trutta) to the river Tees in the Northeast of England. Overall, higher concentrations of these contaminants were found in sea trout samples, where detected congeners reflected the more widely used commercial formulations, in particular for the PBDEs. Our results suggest that these fish could be bioaccumulating persistent organic pollutants via diet during their migratory routes (North Sea and the Norwegian Sea) and, in addition, some level of re-mobilisation of these compounds could still be occurring in the UK eastern coastal areas. The use of adipose fin of returning salmonids could be further developed as a non-lethal approach to assess whether persistent contaminants are being accumulated during the juvenile to adult phase of salmonids originating from UK rivers.

Bacon, P. J., MacLean, J. C., Malcolm, I. A., & Gurney, W. S. C. (2012). Ova fecundity in Scottish Atlantic salmon Salmo salar: predictions, selective forces and causal mechanisms. *Journal of Fish Biology,* 81(3), 921-938. https://doi.org/10.1111/j.1095-8649.2012.03311.x

Ova fecundities of Scottish Atlantic salmon Salmo salar, predicted from log10 regression of ova numbers and female fork length (LF), differed widely between upland and lowland stocks within the same river, whereas sea-age, river and year factors had insignificant effects on fecundity once LF was accounted for.

For upland fish, the relationship between log10 LF and log10 ova mass (MO) was stable between two datasets collected 40 years apart. Although upland and lowland females both produced comparable log10MO(log10LF)-1, lowland females partitioned this into 45% more, but smaller ova, whereas upland females produced fewer, but larger, eggs. The possible causes and implications of this are discussed for evolutionary perspectives (lifetime production), population structure (local tributary v. large catchments; environmental effects), population dynamics and stability (density-dependent control mechanisms) and fisheries management (stockrecruitment; short and long-term stock sustainability).

Baisez, A., Bach, J.-M., Leon, C., Parouty, T., Terrade, R., Hoffmann, M., & Laffaille, P. (2011). Migration delays and mortality of adult Atlantic salmon (Salmo salar) en route to spawning grounds on the River Allier, France. *Endangered Species Research,* 15(3), 265-270. https://doi.org/10.3354/esr00384

During summer periods when water temperatures are high, Atlantic salmon Salmo salar are forced to halt their migration. This phenomenon was observed in our study in the River Allier in France. Between 200 and 1200 S. salar have come to spawn in the River Allier every year for the last 2 decades, but the population has suffered a severe decline. In 2009, 30 individuals were radio tracked; of these, 11 died during the summer period, while the other 19 resumed their migration in the fall. This mortality level was higher amongst the S. salar that arrived towards the end of the migration period, i.e. those individuals that tended to spend the summer in the lower, warmer stretch of the river. In view of the continuing rise in freshwater temperatures, measures are urgently needed to reduce the impact of increased temperatures on fish in the River Allier. This could be achieved by (1) promoting summer delays further upstream by making it easier for fish to pass through dams and (2) by protecting the spawning adults, particularly in the locations of summer halt. This study is consistent with a growing body of literature that suggests that climate change could have devastating effects on the upstream migration phase of anadromous salmonids.

Beaugrand, G., & Reid, P. C. (2012). Relationships between North Atlantic salmon, plankton, and hydroclimatic change in the Northeast Atlantic. *ICES Journal of Marine Science,* 69(9), 1549-1562. https://doi.org/10.1093/icesjms/fss153

The abundance of wild salmon (Salmo salar) in the North Atlantic has declined markedly since the late 1980s as a result of increased marine mortality that coincided with a marked rise in sea temperature in oceanic foraging areas. There is substantial evidence to show that temperature governs the growth, survival, and maturation of salmon during their marine migrations through either direct or indirect effects. In an earlier study (2003), long-term changes in three trophic levels (salmon, zooplankton, and phytoplankton) were shown to be correlated significantly with sea surface temperature (SST) and northern hemisphere temperature (NHT). A sequence of trophic changes ending with a stepwise decline in the total nominal catch of North Atlantic salmon (regime shift in similar to 1986/1987) was superimposed on a trend to a warmer dynamic regime. Here, the earlier study is updated with catch and abundance data to 2010, confirming earlier results and detecting a new abrupt shift in similar to 1996/1997. Although correlations between changes in salmon, plankton, and temperature are reinforced, the significance of the correlations is reduced because the temporal autocorrelation of time-

series substantially increased due to a monotonic trend in the time-series, probably related to global warming. This effect may complicate future detection of effects of climate change on natural systems.

Bernthal, F. R., Armstrong, J. D., Nislow, K. H., & Metcalfe, N. B. (2022). Nutrient limitation in Atlantic salmon rivers and streams: Causes, consequences, and management strategies. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 32(6), 1073-1091. https://doi.org/10.1002/aqc.3811

Freshwater catchments can experience nutrient deficits that result in reduced primary and secondary productivity. The most commonly limiting nutrients are nitrogen and phosphorus, either separately or together. This review considers the impact of increasing nutrient limitation in temperate basin stream and river systems, focusing on upland areas that currently or previously supported wild Atlantic salmon (Salmo salar) populations. Anthropogenic changes to land use and increases in river barriers have altered upland nutrient dynamics, with particular impacts on salmon and other migratory fish species which may be net importers of nutrients to upland streams. Declining salmon populations may further reduce nutrient sources, reducing ecosystem and fisheries productivity below desired levels. Experimental manipulations of nutrient levels have examined the impacts of this cultural oligotrophication. There is evidence that growth and biomass of juvenile salmon can be increased via appropriate additions of nutrients, offering potential as a conservation tool. However, further research is required to understand the long-term effects of these additions on salmon populations and stream ecosystems, and to assess the vulnerability of downstream habitats to eutrophication as a result. Although purposeful nutrient addition with the aim of enhancing and conserving salmonid populations may be justified in some cases, it should be undertaken in an adaptive management framework. In addition, nutrient addition should be linked to nutrient retention and processing, and integrated into large-scale habitat restoration and recovery efforts. Both the scientific and the management community should recognize that the ecological costs and benefits associated with adding nutrients to salmon streams may change in a non-stationary world.

Bernthal, F. R., Seaman, B. W., Rush, E., Armstrong, J. D., McLennan, D., Nislow, K. H., & Metcalfe, N. B. (2022). High summer temperatures are associated with poorer performance of underyearling Atlantic salmon (Salmo salar) in upland streams. *Journal of Fish Biology,* 102(2), 537-541. https://doi.org/10.1111/jfb.15282

Future warming scenarios are predicted to result in an increased frequency of high, and potentially stressful, temperatures in aquatic ecosystems. Here we examined whether the performance of wild underyearling Atlantic salmon (Salmo salar) in Scottish streams stocked with identical egg densities was influenced by thermal stress. Biomass and density declined with degree hours exceeding 23°C, indicating apparent mortality or emigration as a possible result of exposure to high temperatures. These results strengthen the need for further action such as riparian tree planting to reduce stream summer temperatures.

Borggaard, D., Dick, D. M., Star, J., Alexander, M. A., Bernier, M., Collins, M. J., . . . Staudinger, M. D. (2019). Atlantic Salmon (Salmo salar) Climate Scenario Planning Pilot Report. *Greater Atlantic Region Policy Series,* 19(5). Retrieved from https://www.greateratlantic.fisheries.noaa.gov/policyseries/index.php/GARPS/article/view/15

Scenario planning is a structured process that embraces uncertainty and explores plausible alternative future conditions under different assumptions to help manage risk and prioritize actions (Schwartz 1996, Peterson et al. 2003). It has been used by a variety of organizations to explore and help prepare for the future, it lends itself well to exploring the uncertainty surrounding changing environmental conditions, and it is widely applicable to natural resource management issues. For example, the conservation and management of protected resources can be particularly challenging when the rate and magnitude of climate-related changes, and the response of species to those changes, are uncertain (NMFS 2016). The structured process of scenario planning can help resource managers navigate through potentially paralyzing uncertainties, manage risk, and evaluate/prioritize management actions associated with adapting to, and managing for, climate change (Moore et al. 2013). For these reasons a scenario planning initiative was piloted by NOAA Fisheries to explore what the agency can do to improve remnant U.S. Atlantic salmon (Salmo salar) population resilience to changing conditions in riverine, estuarine, and marine environments across its current range. Project objectives included: 1) to better understand the challenges of managing Atlantic salmon in a changing climate; 2) to generate and discuss potential management actions and research activities that can be undertaken or encouraged to increase our understanding of the drivers of salmon productivity and resilience; 3) to increase collaborations and coordination related to the species recovery; and 4) to explore how scenario planning can be used to support decisions. Outcomes from this initiative included the identification of high priority research and management actions to further collaborations and efforts to recover this species. High priority actions were those that could be undertaken in the near-term using current resources and in consideration of potential future conditions. Such actions were identified for range-wide (U.S. headwaters to Greenland), watershed, estuarine (transition), and marine habitats. Examples of actions by habitat included: synthesize and refine range-wide life stage specific quantitative thresholds for temperature, flow, etc.; assess watershed habitat productivity; assess forage fish and survival connection and options for marine migration monitoring; and reduce dam-associated indirect estuarine mortality rate. This report summarizes the first use of scenario planning by NOAA Fisheries. The report also documents an important example of the application of scenario planning to marine environments and may serve as a useful reference for other case studies.

Bowlby, H. D. (2016). *Quantitative recovery planning: understanding how human activities in watersheds can influence population dynamics and genetic structuring of diadromous fishes.* (Ph.D.), Memorial University, Retrieved from https://research.library.mun.ca/12529/

Developing quantitative relationships that link human-induced environmental change with changes in population dynamics for species of conservation concern is hindered by: (1) a limited understanding of the cumulative effect (and relative importance) of population regulation, spatial dynamics, and demographic processes, (2) issues with detectability for species-environment interactions owing to data characteristics and (3) the cumulative or confounding nature of multiple threats. Taking a single-species approach based on endangered Atlantic salmon, I have partially addressed these challenges in my four research chapters. In chapter two, I characterized the conditions under which metapopulation structure would be expected to benefit a population assemblage and found that straying can reduce abundance

and heighten extinction risk when productivity is low. For species of conservation concern, I would expect that remediation actions designed to influence demographic rates (e.g. mortality rates) would be more beneficial than actions influencing spatial dynamics. In chapter three, I accounted for the effects of observation and measurement error when quantifying relationships between hydrological variation and survival. Beyond the potential to change our interpretation of ecological relationships, I was able to infer the types of threats affecting juveniles in specific watersheds. In chapter four, I used patterns of effective dispersal to surmise the behavioural mechanism leading to watershed choice among straying adult salmon as well as the relative importance of multiple concurrent threats. My conclusions contradict some current perceptions on threats and suggest new directions for future research. In chapter five, I was able to develop a spatial tool that could inform management decisions or identify priority areas for restoration efforts. However, I was unable to fully characterize how environmental variation influences habitat utilization, distribution patterns, or population-level responses to human activities at multiple spatial extents. The relationships I describe are among the first to be developed for endangered Atlantic salmon in Nova Scotia at a population level. Several of the analyses represent novel applications to conservation questions and have the potential to be extended or more widely applied. Because freshwater fishes, including diadromous fishes, are collectively one of the most imperiled species groups in the world, such research represents a timely contribution to conservation biology.

Braden, L. M., Sutherland, B. J. G., Koop, B. F., & Jones, S. R. M. (2017). Enhanced transcriptomic responses in the Pacific salmon louse *Lepeophtheirus salmonis oncorhynchi* to the non-native Atlantic Salmon *Salmo salar* suggests increased parasite fitness. *BMC Genomics,* 18. https://doi.org/10.1186/s12864-017-3520-1

Background: Outcomes of infections with the salmon louse Lepeophtheirus salmonis vary considerably among its natural hosts (Salmo, Oncorhynchus spp.). Host-parasite interactions range from weak to strong host responses accompanied by high to low parasite abundances, respectively. Parasite behavioral studies indicate that the louse prefers the host Atlantic Salmon (Salmo salar), which is characterized by a weak immune response, and that this results in enhanced parasite reproduction and growth rates. Furthermore, parasite-derived immunosuppressive molecules (e.g., proteases) have been detected at higher amounts in response to the mucus of Atlantic Salmon relative to Coho Salmon (Oncorhynchus kisutch). However, the host-specific responses of the salmon louse have not been well characterized in either of the genetically distinct sub-species that occur in the Atlantic and Pacific Oceans. Results: We assessed and compared the transcriptomic feeding response of the Pacific salmon louse (L. salmonis oncorhynchi,) while parasitizing the highly susceptible Atlantic Salmon and Sockeye Salmon (Oncorhynchus nerka) or themore resistant Coho Salmon (Oncorhynchus kisutch) using a 38 K oligonucleotide microarray. The response of the louse was enhanced both in the number of overexpressed genes and in the magnitude of expression while feeding on the non-native Atlantic Salmon, compared to either Coho or Sockeye Salmon. For example, putative virulence factors (e.g., cathepsin L, trypsin, carboxypeptidase B), metabolic enzymes (e.g., cytochrome B, cytochrome C), protein synthesis enzymes (e.g., ribosomal protein P2, 60S ribosomal protein L7), and reproduction-related genes (e.g., estrogen sulfotransferase) were overexpressed in Atlantic-fed lice, indicating heightened parasite fitness with this host species. In contrast, responses in Coho-or Sockeye-fed lice were more similar to those of parasites deprived of a host. To test for host acclimation by the parasite, we performed a reciprocal host transfer experiment and determined that the exaggerated response to Atlantic Salmon was independent of the initial host species, confirming our conclusion that the Pacific salmon louse exhibits an enhanced response to Atlantic Salmon. Conclusions: This study characterized

global transcriptomic responses of Pacific salmon lice during infection of susceptible and resistant hosts. Similar parasite responses during infection of Coho or Sockeye Salmon, despite differences in natural immunity to infection between these host species, indicate that host susceptibility status alone does not drive the parasite response. We identified an enhanced louse response after feeding on Atlantic Salmon, characterized by up-regulation of virulence factors, energy metabolism and reproductive-associated transcripts. In contrast, the responses of lice infecting Coho or Sockeye Salmon were weaker, with reduced expression of virulence factors. These observations indicate that the response of the louse is independent of host susceptibility and suggest that co-evolutionary host-parasite relationships may influence contemporary host-parasite interactions. This research improves our understanding of the susceptibility of Atlantic Salmon and may assist in the development of novel control measures against the salmon louse.

Broderick, C. J. (2012). *Climate Change and Atlantic salmon (Salmo salar): Changes in Flow and Freshwater Habitat in the Burrishoole Catchment.* (Ph.D.), Maynooth University, Retrieved from http://eprints.maynoothuniversity.ie/3996/

Climate change is anticipated to impact the flow regime of riverine systems with resultant consequences for the freshwater habitat of Atlantic salmon (Salmo salar) and the long-term sustainability of their population numbers. The Burrishoole catchment, a relatively small but productive salmon catchment (~90 km2) located on Ireland's west coast, is used as a case study to investigate this. A series of high resolution climate scenarios were employed to examine potential changes in the climate and hydrology of this catchment. The climate scenarios used represent different combinations of greenhouse gas emission scenarios, driving GCMs and statistical/dynamical downscaling models; in addition, three different rainfall-runoff models (HBV, HYSIM and TOPMODEL) were employed – integrating across both structural and parameter uncertainty. By considering multiple model pathways this study attempts to sample across the uncertainties encountered at each stage in the process of translating prescribed anthropogenic forcings into local scale responses in the catchment system. The hydrological projections were examined in the context of the habitat and flow requirements of Atlantic salmon at key stages in their life-cycle (e.g. spawning, migration). Model projections suggest that the catchment is likely to become warmer, with wetter winters and drier summers occurring. The results of the hydrological modelling suggest that this will be accompanied by an increase in the seasonality of its flow regime - manifest in an increase in low (Q95) summer and high (Q05) winter flows. If realised, these changes are likely to impact salmon through a reduction in the availability of preferred habitat, a loss in connectivity across the catchment system and a disruption to the evolved synchrony between the occurrence of optimal in-stream conditions and the time at which certain life history events occur. Each of these factors is likely to impact the processes of migration, reproduction and recruitment - each of which is critical for the long-term viability of healthy, self-sustaining wild stocks in the catchment. Based on the projected flow data it is likely that the carrying capacity and productivity of the catchment may be reduced. In addition, by affecting those life stages which are already subject to significant mortality losses (e.g. fry emergence, smolt migration), changes in climate may result in population collapse - particularly if successive year-classes are affected. The results of the hydrological modelling highlight the sensitivity of smaller spatey catchments to changes in climate. Given that the Burrishoole system is typical of many catchment systems found along Ireland's western seaboard, the results highlight a vulnerability to climate change which is present more generally across the region.

Cairns, D. K., MacFarlane, R. E., Guignion, D. L., & Dupuis, T. (2012). *The status of Atlantic salmon (Salmo salar) on Prince Edward Island (SFA 17) in 2011.* Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/347279.pdf

Prince Edward Island, Salmon Fishing Area 17, is part of the southern Gulf - Gaspe Designatable Unit which COSEWIC assessed as Special Concern in 2010. Rivers containing salmon fell to 28 in 2000-2002 and to 22 in 2007-2008, with salmon presence detected in one additional river in 2011. Atlantic salmon on PEI are negatively affected by sedimentation, blockages to upstream passage due to artificial and beaver dams, excessive water temperatures and low dissolved oxygen levels caused by some dams, pesticide inputs, and competition with rainbow trout. Fishing mortality from aboriginal fishery harvests and from angling is currently low and probably has little impact on salmon populations. Major sources of uncertainty in this assessment include low sample sizes in angler card surveys, use of historic rather than current data on biological characteristics, and use of a redd:spawner ratio measured at only one site in one year.

Casas-Mulet, R., Alfredsen, K., Brabrand, A., & Saltveit, S. J. (2016). Hydropower operations in groundwater-influenced rivers: implications for Atlantic salmon, *Salmo salar*, early life stage development and survival. *Fisheries Management and Ecology,* 23(2), 144-151. https://doi.org/10.1111/fme.12165

During their early life stages (egg maturation, hatching, alevin development), between late autumn and early spring, young Atlantic salmon are exposed to surface-groundwater interactions in the hyporheic zone and may depend on influx of subsurface water during periods of regulated low discharge for survival. Two studies, one in a seasonally regulated river and one in a river exposed to hydropeaking, displayed unexpectedly high survival of eggs in surface de-watered areas because of the influx of oxygen-rich subsurface water. Field observations of newly hatched alevins in these two rivers showed them to be more sensitive (i.e. suffered higher mortality from) to surface de-watering than were eggs. Exposure to dry conditions in drawdown areas was highlighted as the main cause for alevin mortality. Therefore, shorter periods of surface de-watering in the river with hydropeaking resulted in higher alevin survival than the seasonally regulated river when still permanently drained after egg hatching. Greater consideration should be given to all early life-history stages when implementing discharge release strategies, and the extent of groundwater influence and the potential for flexible hydropower operations should be taken into account.

Casas-Mulet, R., Saltveit, S. J., & Alfredsen, K. T. (2016). Hydrological and thermal effects of hydropeaking on early life stages of salmonids: A modelling approach for implementing mitigation strategies. *Science of The Total Environment,* 573, 1660-1672. https://doi.org/10.1016/j.scitotenv.2016.09.208

Alterations in hydrological and thermal regimes can potentially affect salmonid early life stages development and survival. The dewatering of salmon spawning redds due to hydropeaking can lead to mortality in early life stages, with higher impact on the alevins as they have lower tolerance to dewatering than the eggs. Flow-related mitigation measures can reduce early life stage mortality. We present a set of modelling tools to assess impacts and mitigation options to minimise the risk of mortality in early life stages in hydropeaking rivers. We successfully modelled long-term hydrological

and thermal alterations and consequences for development rates. We estimated the risk of early life stages mortality and assessed the cost-effectiveness of implementing three release-related mitigation options (A,B,C). The economic cost of mitigation was low and ranged between 0.7% and 2.6% of the annual hydropower production. Options reducing the flow during spawning (B and C) in addition to only release minimum flows during development (A) were considered more effective for egg and alevin survival. Options B and C were however constraint by water availability in the system for certain years, and therefore only option A was always feasible. The set of modelling tools used in this study were satisfactory and their applications can be useful especially in systems where little field data is available. Targeted measures built on well-informed modelling tools can be tested on their effectiveness to mitigate dewatering effects vs. the hydropower system capacity to release or conserve water for power production. Environmental flow releases targeting specific ecological objectives can provide better cost-effective options than conventional operational rules complying with general legislation.

Chaput, G. (2012). Overview of the status of Atlantic salmon (Salmo salar) in the North Atlantic and trends in marine mortality. *ICES Journal of Marine Science,* 69(9), 1538-1548. https://doi.org/10.1093/icesjms/fss013

Chaput, G. 2012. Overview of the status of Atlantic salmon (Salmo salar) in the North Atlantic and trends in marine mortality. - ICES Journal of Marine Science, 69: 1538-1548.Since the early 1980s, the ICES Working Group on North Atlantic Salmon has collated and interpreted catch data, exchanged information on research initiatives, and provided advice to managers in support of conservation efforts for Atlantic salmon. During the past three decades, the annual production of anadromous Atlantic salmon from more than 2000 rivers draining into the North Atlantic has been less than 10 million adult-sized salmon. This represents a minor component, by number and biomass, of the pelagic ecosystem in the North Atlantic Ocean. Ideally, Atlantic salmon would be assessed and managed based on river-specific stock units, the scale that best corresponds to the spawner to recruitment dynamic. In reality, comparatively few river-specific assessments are available for either the Northwest or the Northeast Atlantic. The marine survival of Atlantic salmon is low and, based on return rates of smolts to adults from monitored rivers, has declined since the mid- to late 1980s. Abundance has declined more severely for the multi-sea-winter components, and especially in the southern areas of the species' range. Common patterns in abundance, inferred at the level of stock complex in the North Atlantic, suggest that broad-scale factors are affecting productivity and abundance and that they are acting throughout the salmon's time at sea.

Corey, E., Linnansaari, T., Dugdale, S. J., Bergeron, N., Gendron, J. F., Lapointe, M., & Cunjak, R. A. (2020). Comparing the behavioural thermoregulation response to heat stress by Atlantic salmon parr (Salmo salar) in two rivers. *Ecology of Freshwater Fish,* 29(1). https://doi.org/10.1111/eff.12487

Climate change is expected to increase the frequency and magnitude of extreme thermal events in rivers. The Little Southwest Miramichi River (LSWM) and the Ouelle River (OR) are two Atlantic salmon (Salmo salar) rivers located in eastern Canada, where in recent years, water temperatures have exceeded known thermal limits (similar to 23 degrees C). Once temperature surpasses this threshold, juvenile salmon exploit thermal heterogeneity to behaviourally thermoregulate, forming aggregations in coolwater refuges. This study aimed to determine whether the behavioural thermoregulation response

is universal across rivers, arising from common thermal cues. We detailed the temperature and discharge patterns of two geographically distinct rivers from 2010 to 2012 and compared these with aggregation onset temperature. PIT telemetry and snorkelling were used to confirm the presence of aggregations. Mean daily maximum temperature in 2010 was significantly greater in the OR versus the LSWM (p = 0.005), but not in other years (p = 0.090-0.353). Aggregations occurred on 14 and 9 occasions in the OR and LSWM respectively. Temperature at onset of aggregation was significantly greater in the OR (Tonset = 28.3 degrees C) than in the LSWM (Tonset = 27.3 degrees C; p = 0.049). Logistic regression models varied by river and were able to predict the probability of aggregation based on the preceding number of hours >23 degrees C (R-2 = 0.61 & 0.65; P-50 = 27.4 degrees C & 28.9 degrees C; in the OR and LSWM respectively). These results imply the preceding local thermal regime may influence behaviour and indicate a degree of phenotypic plasticity, illustrating a need for localised management strategies.

Cote, J., Roussel, J. M., Cam, S., Bal, G., & Evanno, G. (2012). Population differences in response to hypoxic stress in Atlantic salmon. *Journal of Evolutionary Biology,* 25(12), 2596-2606. https://doi.org/10.1111/jeb.12007

Understanding whether populations can adapt to new environmental conditions is a major issue in conservation and evolutionary biology. Aquatic organisms are increasingly exposed to environmental changes linked with human activities in river catchments. For instance, the clogging of bottom substratum by fine sediments is observed in many rivers and usually leads to a decrease in dissolved oxygen concentrations in gravel beds. Such hypoxic stress can alter the development and even be lethal for Atlantic salmon (Salmo salar) embryos that spend their early life into gravel beds. In this study, we used a common garden experiment to compare the responses to hypoxic stress of four genetically differentiated and environmentally contrasted populations. We used factorial crossing designs to measure additive genetic variation of early life-history traits in each population. Embryos were reared under normoxic and hypoxic conditions, and we measured their survival, incubation time and length at the end of embryonic development. Under hypoxic conditions, embryos had a lower survival and hatched later than in normoxic conditions. We found different hypoxia reaction norms among populations, but almost no population effect in both treatments. We also detected significant sire x treatment interactions in most populations and a tendency for heritability values to be lower under stressful conditions. Overall, these results reveal a high degree of phenotypic plasticity in salmon populations that nevertheless differ in their adaptive potential to hypoxia given the distinct reaction norms observed between and within populations.

Couillard, C. M., Courtenay, S. C., & Macdonald, R. W. (2008). Chemical-environment interactions affecting the risk of impacts on aquatic organisms: A review with a Canadian perspective - interactions affecting vulnerability. *Environmental Reviews,* 16, 19-44. https://doi.org/10.1139/a07-008

Environmental change can increase the vulnerability of aquatic species to toxic chemicals by challenging an organism's aptitude to respond to chemicals or to repair toxic injury or by modifying animal behaviours like migration or predation. On the other hand, xenobiotics may affect the capacity of aquatic species to adapt to environmental challenges that come with change (e.g., pathogens,

temperature). Across Canada we have identified a number of circumstances where chemicals and environmental variability have likely worked together to affect vulnerability of aquatic organisms. For example in the Maritimes, exposure to municipal wastewater or bleached kraft pulp mill effluent altered immune function in bivalves and increased their risk of developing haemocytic neoplasia, a disease known to cause high mortality. Northwest Atlantic cod stocks have experienced large-scale changes in environment and exhibit marked seasonal cycles in energy reserves. The risk associated with subsequent redistribution of persistent chemicals in the body together with nutritional deficiency is presently under evaluation since it could affect the recovery of these endangered stocks. In the Great Lakes, the introduction of an invasive fish species, the alewife, modified the diet of salmonids, which led to a deficiency of the vitamin thiamine in eggs causing early mortality. Contaminants may interact with thiamine deficiency and thus critically impair recruitment of salmonids. Viewing the risks presented by toxic chemicals from the point of view of species vulnerability, offers managers opportunities to mitigate such risks, for example, through habitat, ocean and fisheries management. Further research is needed to develop biomarkers of vulnerability, identify most vulnerable life stages and populations, to understand the interactions between global environmental changes, nutritional status, pathogens and toxic chemicals, and to develop integrated approaches to manage vulnerability of aquatic ecosystems to toxic chemicals.

Couillard, C. M., Macdonald, R. W., Courtenay, S. C., & Palace, V. P. (2008). Chemical-environment interactions affecting the risk of impacts on aquatic organisms: A review with a Canadian perspective - interactions affecting exposure. *Environmental Reviews,* 16, 1-17. https://doi.org/10.1139/a07-007

As a consequence of human activity, the variability and range of environmental conditions is increasing. We review how the interactions between toxic chemicals and environmental change may affect exposure of aquatic organisms to stressful conditions and therefore alter the risk of deleterious impacts. Even in the absence of new inputs of contaminants, changing environmental conditions alters the transport, transformation and distribution of contaminants and their bioavailability. Conversely, some toxic chemicals modify the exposure of aquatic species to other stressors by affecting species distribution, behaviour or habitat. Across Canada there are a number of specific examples where interactions between contaminants and environmental change are probably harming aquatic species. In the Arctic, change in foraging brought on by change in ice regime, is a plausible mechanism to explain the marked recent increase in mercury concentrations in Beaufort Sea beluga whales. On the Pacific coast, chemical exposure by itself or in combination with other environmental factors, is a leading suspect for altered migration timing of some salmon stocks in the Fraser River leading to massive pre-spawning mortality. In the North Atlantic, short-term exposure of Atlantic salmon to endocrine-disrupting substances in their freshwater natal environments later leads to detectable effects at the time of their migration to saltwater. In Alberta, biotic and abiotic characteristics of the habitat dramatically affect exposure pathways and the risk of toxic effects of selenium in early life stages of trout. A better understanding of the interactions between toxic chemicals and environmental factors is a fundamental requirement for efficient management and protection of aquatic ecosystems.

Cunjak, R. A., Linnansaari, T., & Caissie, D. (2013). The complex interaction of ecology and hydrology in a small catchment: a salmon's perspective. *Hydrological Processes,* 27(5), 741-749. https://doi.org/10.1002/hyp.9640

For the past 22years, we have monitored hydro-meteorological conditions and fish population dynamics in Catamaran Brook, a 52km2 catchment in the Miramichi River system of New Brunswick, Canada. Given the long-term nature of the multidisciplinary dataset, we are able to provide an overview of the complex interaction between streamflow and fish population dynamics drawing on previously published material as well as new data analyses. For autumn-spawning fishes like the Atlantic salmon, access to headwater reaches was directly related to streamflow during late October (when they ascend spawning tributaries), as well as the propensity of beaver dams in the stream (also a function of streamflow). Winter streamflow was positively correlated with egg survival, except when rain-on-snow conditions induced severe ice break-up events that likely caused the highest mortalities on record for salmon and other fishes. Juvenile recruitment was significantly influenced by density-dependent processes of growth and competition but further mediated by density-independent factors like winter flow. In spring, fry emergence was largely temperature-driven, although peaks in fry drift were sometimes synchronized with secondary discharge peaks and temperature. Tributaries like Catamaran Brook provide thermal refugia for coolwater fishes like salmon and trout during the summer when wide, shallow main-stem Atlantic rivers experience low discharge and high water temperatures that induce physiological and behavioural stress (i.e. >23 degrees C). These phenomena are discussed in detail, especially in terms of how they may be compromised by future changes in hydrologic conditions resulting from predicted climate change scenarios.

Dugdale, S. J., Franssen, J., Corey, E., Bergeron, N. E., Lapointe, M., & Cunjak, R. A. (2016). Main stem movement of Atlantic salmon parr in response to high river temperature. *Ecology of Freshwater Fish,* 25(3), 429-445. https://doi.org/10.1111/eff.12224

Atlantic salmon become thermally stressed when water temperatures exceed 23 degrees C. To alleviate this stress, they behaviourally thermoregulate by moving to patches of cold water, often forming large aggregations. These patches are known as thermal refuges. Given the consensus that climate change will increase temperatures in Atlantic salmon catchments, thermal refuges will become increasingly important in minimising summer mortalities. While the behaviour of salmonids within thermal refuges is fairly well understood, less is known about their main stem movement in search of thermal refuges or its thermal and temporal cues. We detail the results of a PIT telemetry study to investigate the main stem movement behaviour of thermally stressed Atlantic salmon parr in a temperature-impacted river. PIT antennas placed around two thermal refuges and at the upstream and downstream limits of their surrounding reach were used to record the movement of salmonids during a heatwave. We observed parr movement at the upstream and downstream antennas 135min prior to the occurrence of the midpoint of aggregations in the thermal refuges, indicating that Atlantic salmon parr make reach-scale movements in search of cool water prior to aggregating. Logistic regression showed that the number of degree hours >28 degrees C predicted the occurrence of main stem movement with a good degree of accuracy, indicating that this temperature represents a fundamental threshold causing Atlantic salmon parr to move towards cool water. Such data could be instrumental in allowing river managers to place limits on human activity within rivers, allowing salmon populations time to recover following heat stress events.

Elvidge, C. K. (2013). *Evaluating the effects of sub-lethal acidification on wild populations of juvenile Atlantic salmon.* (Ph.D.), Concordia University, Montreal, Quebec, Canada. Retrieved from https://spectrum.library.concordia.ca/id/eprint/977754/

One of the many environmentally deleterious effects of industrialization is the acidification of freshwater, which results in part from precipitative inputs of anthropogenic pollutants. Considerable effort has been allocated to the study and remediation of severely acidified aquatic systems, with the effects of weak levels of acidification (pH 6 – pH 7) on biological communities having received less attention. One effect that has been studied is the chemical mediation of predator-prey interactions in freshwater and marine fishes. Following mechanical damage to the epidermis, as would likely occur during a predation event, many taxa release chemical alarm cues which elicit antipredator responses from conspecifics and other opportunistic receivers subject to similar levels of predation risk and potentially enhance the survival of alarm cue receivers during subsequent interactions with predators. Under weakly acidic conditions (pH < 6.6), these chemical alarm cues are rendered non-functional and do not elicit alarm responses from conspecific or heterospecific receivers. Weak acidification effectively deprives prey fishes of one source of chemosensory information on ambient risk levels. Here, I describe a series of field experiments designed to evaluate the effects of this environmentally-mediated loss of information on wild populations of juvenile Atlantic salmon (Salmo salar) in four acidic and five neutral streams in the Miramichi River system, New Brunswick, Canada. Acid-impacted Atlantic salmon in these experiments demonstrated a loss of response to conspecific and heterospecific chemical alarm cues, as well as significantly greater responses to remaining (visual) threat cues than salmon under neutral conditions. Fish in neutral streams appeared to demonstrate additive responses to multiple risky cues consistent with dynamic threat-sensitivity and the sensory complementation hypothesis, whereas fish in acidic streams demonstrated non-threat-sensitive responses consistent with the absence of sensory complementation and greater value being assigned to information received through visual cues. Contrary to predictions, juvenile salmon do not appear to suffer increased mortality through predation as a result of this loss of information, nor do they experience negative growth effects resulting from temporal trade-offs between antipredator and foraging behaviours. Rather, acid-impacted Atlantic salmon demonstrated behavioural compensation through increased preference for complex habitats which offer greater abundance of physical refugia and limit line-of-sight for visually foraging predators, effectively mitigating the increased risk of predation associated with limited information.

Feeney, R., Trueman, C. N., Gargan, P. G., Roche, W. K., & Shephard, S. (2022). Body condition of returning Atlantic salmon *Salmo salar L*. correlates with scale delta C-13 and delta N-15 content deposited at the last marine foraging location. *Journal of Fish Biology*. https://doi.org/10.1111/jfb.14968

Patterns of feeding and growth of Atlantic salmon Salmo salar L. in the marine environment are critical to understanding how observed declines in recruitment may reflect warming or other oceanic drivers. The isotopic composition of scales can provide insight into differences in marine feeding location and possibly temperature regime. The authors used archived scale samples to measure delta C-13 and delta N-15 deposited in the scales of one sea-winter (1SW) salmon during their last season of growth at sea before they returned to five Irish rivers. delta C-13 values were related statistically to observed salmon body condition (Fulton's K), and fish with higher delta C-13 values tended to show significantly better condition. In contrast, delta N-15 values were negatively related to body condition. There was no important effect on condition of length at smolt migration, and the effect of duration of marine

residence varied among rivers. It is likely that delta C-13 values partly reflected ambient ocean temperature and recent marine feeding environment before return migration, such that the observed relationship between higher delta C-13 values and increased body condition may express an advantage for adult fish feeding in warmer, potentially closer, waters. If greater body condition influences fitness, then a changing temperature regime in the Northeast Atlantic may drive shifts in salmon survival and reproduction. This study provides evidence that there is spatial and trophic variation at sea between salmon from rivers of origin that are located relatively close to each other, with potential consequences for body condition and, consequently, fitness and life history; this suggests that salmon populations from geographically proximate rivers within regions may exhibit differential responses to ocean-scale climatic changes across the Northeast Atlantic.

Finstad, B., Kroglund, F., Bjørn, P. A., Nilsen, R., Pettersen, K., Rosseland, B. O., . . . Ebbesson, L. O. E. (2012). Salmon lice-induced mortality of Atlantic salmon postsmolts experiencing episodic acidification and recovery in freshwater. *Aquaculture,* 362, 193-199. https://doi.org/10.1016/j.aquaculture.2010.10.037

Acid rain has reduced several salmonid stocks in Norway and salmon lice have been identified as a major population regulation factor. The combination of these two factors has also been seen to reduce postsmolt survival. In the present study, we have addressed the effects of an episodic exposure to acidic water and later recovery in good freshwater quality (Acid/Recovery groups) followed by salmon lice infestation in seawater in more detail. The ecological perspective of this can be directly addressed to changes over the last decades from chronic acidification over Norway and Europe, to more episodic spring acidification of rivers prior to or during downstream migration of smolts. The results showed that salmon lice-induced mortality increased in all episodic Acid/Rec groups. However, the group given the longest recovery period experienced the lowest mortality compared to the other treatment groups. A period of recovery after acid exposure may eventually restore the fish back to normal physiological level, but in the present experiment a period of 14days of recovery after a 2day exposure to acid water was too short to fully restore the fish back to normal levels. Even short-time episodic acidification followed by recovery during springtime and the vulnerable smoltification process, may therefore have negative and often unnoticed effects in wild salmonids until the postsmolts meet other stressors in the marine phase such as salmon lice and other fish diseases.

Finstad, B., Kroglund, F., Strand, R., Stefansson, S. O., Bjorn, P. A., Rosseland, B. O., . . . Salbu, B. (2007). Salmon lice or suboptimal water quality - Reasons for reduced postsmolt survival? *Aquaculture,* 273(2-3), 374-383. https://doi.org/10.1016/j.aquaculture.2007.10.019

Salmon populations on the western coast of Norway may experience both moderately acidified rivers and salmon lice (Lepeophtheirus salmonis Kroyer) attacks. The present study addresses the question of interactive effects of acidification and salmon lice infestation on postsmolt survival. Three groups each of approximately 1500 one-year old Atlantic salmon smolts of the Imsa strain, South-Western Norway, were exposed to one of three suboptimal water qualities (high acid, moderate acid and episodic acid) and experienced acidic water (pH 5.6-5.9 and 7-45 mu g Ali/l) with different exposure duration (3 to 10 days). A fourth group exposed to pH> 6.6 and < 9 mu g Ali/l acted as control (reference group). After freshwater exposure, smolts (n = 150) from each group were moved into tanks containing brackish

water (16 parts per thousand) and after 8 h they were given full strength seawater (33 parts per thousand) and given 1 day of recovery before being infected with salmon lice copepodids. Four non-infected groups (n = 100) from the same exposures acted as controls. Over a 42 day period, postsmolts were regularly inspected and sampled for mortality, lice density and physiological status in seawater. The lice per smolt density were highest in the episodic acid group, followed by the high acid, moderate acid and the reference groups. Mortality was low in the four non-infected control groups, and significantly elevated in the lice infected groups (high acid > moderate acid > episodic acid > reference). Plasma chloride levels were within the normal range in the non-infected groups, while fish in the infected high acid and moderate acid groups had elevated plasma chloride levels. High gill aluminium was seen in the three exposure groups in freshwater. Year to year variations in acidification pressure and salmon lice densities can singularly and in combination explain some of the year to year variations in postsmolt survival and hence the variations in Atlantic salmon year-class strength in Norwegian rivers.

Foldvik, A., Holthe, E., Bremset, G., & Solem, O. (2022). Effects of Episodic Exposure to High-pH Water on Survival of Atlantic Salmon Eggs and Juveniles: Results from Laboratory and Field Studies. *Environmental Toxicology and Chemistry,* 41(3), 771-780. https://doi.org/10.1002/etc.5282

Although effects of acidification on salmonid fish are well studied and documented, effects of episodic high pH have rarely received attention. In the present study, we investigated effects of high-pH events on Atlantic salmon (Salmo salar) using both field and laboratory data. Effects of an episodic high-pH event on juvenile densities in a Norwegian river were studied using data from several electrofishing surveys conducted both before and after the event. Effects of high pH on survival of eggs were studied by exposing eggs to a range of high-pH treatments for different durations. Juvenile densities from the field study showed that the high-pH event had little or no effect on the cohort that had been exposed to pH 9.7-10.3 during the egg stage. This finding was in accordance with the laboratory experiment that showed no excess mortality on eggs until pH was >12. The high-pH event occurred in March during low winter flows, and densities of older juveniles in May were significantly lower in the affected area compared to controls upstream. In June and September the difference was not significant, but there was a clear spatial trend indicating that the event had a negative effect on densities of older juvenile salmon. Environ Toxicol Chem 2022;00:1-10.

Friedland, K. D., Manning, J. P., & Link, J. S. (2009). *Thermal Phenological Factors Affecting the Survival of Atlantic Salmon in the Gulf of Maine.* Paper presented at the Gulf of Maine Symposium: Advancing Ecosystem Research for the Future of the Gulf. Retrieved from https://publications.gc.ca/site/eng/9.620094/publication.html

The marine survival of Atlantic salmon Salmo salar stocks in the Gulf of Maine area has declined as sea surface temperature in the coastal ocean has increased; in part, this change in recruitment can be attributed to a phenological mismatch between the timing of smolt migrations and initial conditions postsmolts find during their early marine phase. Salmon juvenile migrations to the ocean are released by photoperiod and spring transitional freshwater temperatures, neither of which have changed significantly in recent decades, thus actuating the migrations at nearly the same time each year. However, ocean water temperatures have increased during the spring transition period, suggesting that smolts have entered the ocean under varying physical and biological conditions. The phenological effect

observed in the Gulf of Maine is consistent with the relationship observed for the North American stock complex. In light of recent findings related to the growth of postsmolts, the contrast in recruitment for North American salmon, and Gulf of Maine stocks in particular, appears to be the result of mortality that occurs during the first months at sea. This mortality covaries with the thermal changes in the coastal ocean, which we suspect is associated with variation in the predator field.

Friedland, K. D., Shank, B. V., Todd, C. D., McGinnity, P., & Nye, J. A. (2014). Differential response of continental stock complexes of Atlantic salmon (Salmo salar) to the Atlantic Multidecadal Oscillation. *Journal of Marine Systems,* 133, 77-87. https://doi.org/10.1016/j.jmarsys.2013.03.003

Atlantic salmon, Salmo salar, in the North Atlantic are managed as a set of population complexes distributed in North America and Europe. In recent years, these complexes have experienced reduced marine survival and many populations within the complexes are at risk, especially those at the southern ends of the species amphi-Atlantic range. Atlantic salmon is an anadromous fish dividing its life history between residence in freshwater and the marine environment. The freshwater portion of the life history includes spawning and the rearing of juveniles where in-river production has tended to be relatively stable, whereas the first year at sea, termed the post-smolt year, is characterized by more variable rates of mortality. Although their habitats are widely separated geographically along the North Atlantic seaboards, strong recruitment coherence exists between North American and European stock complexes. This recruitment coherence is correlated with ocean temperature variation associated with the Atlantic Multidecadal Oscillation (AMO). The North Atlantic Oscillation (NAO) appears to be relatively unimportant as a driver of salmon abundance. The mechanism determining the link between AMO-related thermal variation and abundance appears to differ fundamentally for the two continental stock groupings. Whereas ocean climate variability during the first springtime months of juvenile salmon migration to sea appears to be important to the survival of North American stocks, summer climate variation appears to be central to adult recruitment variation for European stocks. This contrast in seasonal effects appears to be related to the varying roles of predation pressure and size-related mortality on the continental stock complexes. The anticipated warming due to global climate change will impose thermal conditions on salmon populations outside historical context and challenge the ability of many populations to persist.

Gillard, G., Harvey, T. N., Gjuvsland, A., Jin, Y., Thomassen, M., Lien, S., . . . Sandve, S. R. (2018). Life-stage-associated remodelling of lipid metabolism regulation in Atlantic salmon. *Molecular Ecology,* 27(5), 1200-1213. https://doi.org/10.1111/mec.14533

Atlantic salmon migrates from rivers to sea to feed, grow and develop gonads before returning to spawn in freshwater. The transition to marine habitats is associated with dramatic changes in the environment, including water salinity, exposure to pathogens and shift in dietary lipid availability. Many changes in physiology and metabolism occur across this life-stage transition, but little is known about the molecular nature of these changes. Here, we use a long-term feeding experiment to study transcriptional regulation of lipid metabolism in Atlantic salmon gut and liver in both fresh- and saltwater. We find that lipid metabolism becomes significantly less plastic to differences in dietary lipid composition when salmon transitions to saltwater and experiences increased dietary lipid availability. Expression of genes

in liver relating to lipogenesis and lipid transport decreases overall and becomes less responsive to diet, while genes for lipid uptake in gut become more highly expressed. Finally, analyses of evolutionary consequences of the salmonid-specific whole-genome duplication on lipid metabolism reveal several pathways with significantly different ($p < .05$) duplicate retention or duplicate regulatory conservation. We also find a limited number of cases where the whole-genome duplication has resulted in an increased gene dosage. In conclusion, we find variable and pathway-specific effects of the salmonid genome duplication on lipid metabolism genes. A clear life-stage-associated shift in lipid metabolism regulation is evident, and we hypothesize this to be, at least partly, driven by nondietary factors such as the preparatory remodelling of gene regulation and physiology prior to sea migration.

Gillson, J. P., Basic, T., Davison, P. I., Riley, W. D., Talks, L., Walker, A. M., & Russell, I. C. (2022). A review of marine stressors impacting Atlantic salmon Salmo salar, with an assessment of the major threats to English stocks. *Reviews in Fish Biology and Fisheries,* 32(3), 879-919. https://doi.org/10.1007/s11160-022-09714-x

Atlantic salmon Salmo salar is a socio-economically important anadromous fish species that has suffered synchronous population declines around the North Atlantic over the last five decades. Reduced marine survival has been implicated as a key driver of the declines, yet the relative importance of different stressors causing mortality at sea is not well understood. This review presents a synopsis of the principal stressors impacting Atlantic salmon in estuarine and marine environments. It also applies a semi-quantitative 2-D classification system to assess the relative effects of these stressors on English salmon stocks and their likely development over the next decade. Climate change and predation were identified as the biggest threats at present and over the next decade. Poor water quality and bycatch were classified as relatively high impact stressors, but with a lower likelihood of becoming more prevalent in the future due to available mitigation measures. Other, less influential, stressors included tidal barrages, artificial light at night, impingement in power-station cooling waters and thermal discharges, pile-driving noise pollution, invasive non-native species, electromagnetic fields, salmon mariculture, and tidal lagoons. Salmon fisheries exploitation was not regarded as an important stressor currently because effective exploitation rate controls have been implemented to substantially reduce fishing pressure. Future research priorities include addressing knowledge gaps on expanding stressor impacts from climate change, predation, renewable energy developments, and artificial light at night. Local management actions directed towards improving freshwater and estuarine habitats to maximise ecosystem resilience to stressors and minimise their cumulative impacts are recommended.

Gregory, S. D., Bewes, V. E., Davey, A. J. H., Roberts, D. E., Gough, P., & Davidson, I. C. (2020). Environmental conditions modify density-dependent salmonid recruitment: Insights into the 2016 recruitment crash in Wales. *Freshwater Biology,* 65(12), 2135-2153. https://doi.org/10.1111/fwb.13609

Understanding the effects of density-dependent and density-independent factors on recruitment is often inhibited by difficulties quantifying their relative contributions in highly variable recruitment data. Use of data-driven statistical methods with data that include one or more extreme recruitment events could help overcome these difficulties. Juvenile Atlantic salmon and trout abundances in Wales have declined over the last 2 decades, and 2016 was a notably poor recruitment year in rivers around

southern Europe, including England and Wales. The 2016 recruitment crash coincided with extreme winter weather conditions, leading to speculation that unusually warm temperatures and high flows adversely affect salmonid recruitment and caused the 2016 crash, although this remains untested. We developed data-driven statistical models to: (1) describe juvenile salmonid recruitment from density-dependent and density-independent factors; and (2) assess whether the density-independent factors probably contributed to the 2016 salmon recruitment crash. We compiled salmon and trout young-of-year juvenile abundances from electrofishing surveys, egg deposition estimates and river flow and air temperature data from 2001-2017 for seven Welsh rivers, broadly representative of rivers around Wales. We used river flow and air temperature data to derive ecologically and behaviourally meaningful density-independent explanatory variables. Salmonid recruitment in Wales was best described using density-dependent and density-independent factors, especially for salmon: after accounting for a concave relationship with egg deposition, salmon juvenile abundance was reduced under (1) warmer spawning temperatures that might inhibit spawning, and (2) higher flood frequencies during pre-emergence and emergence that might washout eggs or alevins. Results were less clear for trout, perhaps because they are behaviourally more plastic. Our findings provide empirical support for general and predictable effects of temperature and flow during spawning and emergence on salmonid-especially salmon-recruitment in Wales. Furthermore, we suggest that the 2016 salmon recruitment crash was caused-in part-by particularly inclement spawning and emergence conditions, which could be more common under future climate change. Our findings suggest that future salmonid stock assessment models could include the effects of density-independent variables on recruitment to improve their predictive power.

Greig, S., Sear, D., & Carling, P. (2007). A field-based assessment of oxygen supply to incubating Atlantic salmon (Salmo salar) embryos. *Hydrological Processes,* 21(22), 3087-3100. https://doi.org/10.1002/hyp.6635

Oxygen fluxes through artificially created salmon redds within four UK rivers were quantified and assessed against survival to hatching of Atlantic salmon embryos. All sites recorded high spatial variability in survival. Minimum survival to hatching was zero at all sites. Maximum survival to hatching ranged from 35% to 91%. Mean survival to hatching ranged from 8.7% to 71 %. Intra- and inter-site variations in rates of oxygen supply were observed. Generally, interstitial dissolved oxygen concentrations declined over the incubation period from a maximum recorded directly after redd creation, although localized fluctuations were recorded. Similarly, interstitial flow velocities declined over the incubation period from a maximum directly after redd creation to a minimum at hatching. With respect to the causes of embryo mortalities, oxygen supply was shown to be a stronger determinant of survival than interstitial oxygen concentration or interstitial flow velocity. To improve delineation of potential causes of embryo mortalities in the field, the statistical analysis was integrated within mass transfer theory of the processes controlling respiration to determine the likely mechanisms inhibiting respiration. Based on this analysis, mortalities were assessed to have resulted from periods of lethal oxygen concentrations, from periods of interstitial flow velocities that were insufficient to remove metabolic waste, or from combinations of oxygen concentration and interstitial flow that did not support respiratory requirements. A set of oxygen-supply-related thresholds for assessing incubation habitat quality are proposed.

Hansson, M. C., Persson, M. E., Larsson, P., & von Schantz, T. (2009). Polychlorinated biphenyl (PCB) load, lipid reserves and biotransformation activity in migrating Atlantic salmon from River Morrum, Sweden. *Environmental Pollution,* 157(12), 3396-3403. https://doi.org/10.1016/j.envpol.2009.06.026

Atlantic salmon accumulate high levels of contaminants such as polychlorinated biphenyls (PCBs) in their lipids during the adult growth phase spent at sea. The lipids are later utilized during migration for swimming and biological adaptations. We hypothesize that migrating salmons' biotransformation processes are affected by the high levels of built-up PCBs compared to salmon that in a pre-migrational stage. For these analyses we sampled adult Atlantic salmon during migration in the Swedish River Morrum and measured the 21 most common PCB congeners (Sigma PCB) and lipid levels in muscle tissue, aryl hydrocarbon receptor (AHR2) and cytochrome P4501A1(CYP1A1) transcript levels as well as ethoxyresorufin-O-deethylase activity (EROD) in liver. We also determined which AHR2 genotypes the salmon carried. We show that EROD activity is correlated to CYP1A1 level but not to Sigma PCB concentration. Sigma PCB concentration does not predict levels of neither the AHR2 nor CYP1A1 genes. We find no associations between specific AHR2 transcription levels and AHR2 genotypes or a correlation between AHR2 and CYP1A1 transcription levels, which is in direct contrast to pre-migrational adult salmon from the Baltic Sea. When we compare River Morrum to salmon we have previously sampled in the Baltic Sea we show that migrating salmon have significantly lower lipid levels in their muscles; higher muscle concentrations of Sigma PCB on a lipid basis; and significantly lower CYP1A1 and EROD levels compared to salmon from the Baltic Sea. Also, transcript levels of three out of four AHR2 genes are significantly different. In conclusion, migrating Swedish Atlantic salmon carry higher concentrations of PCBs in their lipids compared to salmon in the Baltic Sea, but have lower activation of biotransformation genes and enzymes. Our results indicate that accumulated pollutants from the Baltic Sea are deactivated inside the migrating salmon's lipid tissues and increase in concentration when migration is initiated thereby limiting their impact on biotransformation processes.

Havn, T. B., Uglem, I., Solem, O., Cooke, S. J., Whoriskey, F. G., & Thorstad, E. B. (2015). The effect of catch-and-release angling at high water temperatures on behaviour and survival of Atlantic salmon *Salmo salar* during spawning migration. *Journal of Fish Biology,* 87(2), 342-359. https://doi.org/10.1111/jfb.12722

In this study, behaviour and survival following catch-and-release (C&R) angling was investigated in wild Atlantic salmon Salmo salar (n = 75) angled on sport fishing gear in the River Otra in southern Norway at water temperatures of 163-211 degrees C. Salmo salar were tagged externally with radio transmitters and immediately released back into the river to simulate a realistic C&R situation. The majority of S. salar (91%) survived C&R. Most S. salar that were present in the River Otra during the spawning period 3-4 months later were located at known spawning grounds. Downstream movements (median furthest position: 05km, range: 01-110km) during the first 4days after release were recorded for 72% of S. salar, presumably stress-induced fallback associated with C&R. Individuals that fell back spent a median of 15days before commencing their first upstream movement after release, and 34days before they returned to or were located above their release site. Mortality appeared to be somewhat elevated at the higher end of the temperature range (14% at 18-21 degrees C), although sample sizes were low. In conclusion, C&R at water temperatures up to 18 degrees C had small behavioural consequences and was associated with low mortality (7%). Nevertheless, low levels of mortality occur due to C&R angling and these losses should be accounted for by management authorities in rivers where C&R is practised.

Refinement of best practices for C&R may help to reduce mortality, particularly at warmer temperatures.

Hawkins, A. (2021). Factors affecting Atlantic Salmon Populations Adversely; Using the River Dee, Scotland, as an Example. *Journal of Earth Science and Climatic Change*, 1-22. https://doi.org/10.46715/jescc2021.07.1000113

The stocks of the Atlantic salmon (Salmo salar) have declined in the sea and in many rivers in North America and Europe in recent years and are experiencing a crisis. Despite their high degree of legal protection, the quality of their aquatic environments within rivers and in the sea, including local coastal waters, appears to be deteriorating. Salmon survival, has declined both within the sea and within rivers. The status of the Atlantic salmon stocks is considered here, together with the adverse effects of different sources, and those steps that may need to be taken to improve the condition of the salmon. This paper is intended to assist management bodies in taking steps to resolve the problems that exist for salmon, both within rivers and in the sea. It makes particular use of information available from the River Dee in Scotland.

Hedger, R. D., Naesje, T. F., Fiske, P., Ugedal, O., Finstad, A. G., & Thorstad, E. B. (2013). Ice-dependent winter survival of juvenile Atlantic salmon. *Ecology and Evolution,* 3(3), 523-535. https://doi.org/10.1002/ece3.481

Changes in snow and ice conditions are some of the most distinctive impacts of global warming in cold temperate and Arctic regions, altering the environment during a critical period for survival for most animals. Laboratories studies have suggested that reduced ice cover may reduce the survival of stream dwelling fishes in Northern environments. This, however, has not been empirically investigated in natural populations in large rivers. Here, we examine how the winter survival of juvenile Atlantic salmon in a large natural river, the River Alta (Norway, 70 degree N), is affected by the presence or absence of surface ice. Apparent survival rates for size classes corresponding to parr and presmolts were estimated using capture-mark-recapture and Cormack-Jolly-Seber models for an ice-covered and an ice-free site. Apparent survival (Phi) in the ice-covered site was greater than in the ice-free site, but did not depend on size class (0.64 for both parr and presmolt). In contrast, apparent survival in the ice-free site was lower for larger individuals (0.33) than smaller individuals (0.45). The over-winter decline in storage energy was greater for the ice-free site than the ice-covered site, suggesting that environmental conditions in the ice-free site caused a strong depletion in energy reserves likely affecting survival. Our findings highlight the importance of surface ice for the winter survival of juvenile fish, thus, underpinning that climate change, by reducing ice cover, may have a negative effect on the survival of fish adapted to ice-covered habitats during winter. Reductions in ice-cover may cause increased Atlantic salmon juvenile mortality, particularly for larger individuals. This is likely to be the result of greater decline in energy stores in ice-free conditions. Likely effects of climate change in cold temperate and Arctic regions include reduced ice cover, and consequently increased juvenile winter mortality, and a change in the juvenile age distribution to being composed of younger individuals.

Heggenes, J., Alfredsen, K., Bustos, A. A., Huusko, A., & Stickler, M. (2018). Be cool: A review of hydro-physical changes and fish responses in winter in hydropower-regulated northern streams. *Environmental Biology of Fishes,* 101(1), 1-21. https://doi.org/10.1007/s10641-017-0677-z

Winter is an ecologically challenging season for ectothermic cold-water fish in natural streams because of reduced flow and freezing. Hydropower regulation in many northern rivers increase winter stream flow and temperatures, and reduce ice formation and surface ice cover. From a background review of knowledge about e.g. Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) winter survival strategies, we explore responses to hydropower impacts as a basis for adaptive management, mitigating strategies, and future research. Winter intensity and duration, hydrologic conditions and channel characteristics drive complex ice processes which become more complex and pervasive in smaller, high-gradient streams. Stream ice formation may be divided into the dynamic period 'freeze-up' in early winter with sub-surface ice, more stable 'mid-winter' with surface ice, and the ecologically challenging 'ice break-up' in winter-spring with potential mechanical ice runs and scouring. The characteristics of periods vary depending on climate and hydropower regulation. In reaches downstream of power-plant outlets water temperature may increase and reduce surface ice formation. The mid-winter period destabilize or become absent. In bypass reaches flows decrease and facilitate freezing and ice production. Knowledge about longitudinal water temperature changes is limited. Hydro-peaked systems may aggravate high-low flow effects. A basic winter survival strategy in salmon and trout is energy storage, but also reduced metabolism, tolerance and starvation effected by quiescence. Energy storage may depend on local conditions, but there is little indication of adaptation to local thermal climates. Intraspecific phenotypic plasticity is important. The main behavioural strategy is risk-reducing sheltering in the substratum or deep areas, and nocturnal activity. Local movements between daytime refuges and nighttime slow-current activity areas are usually limited to meters. Larger fish may move more and aggregate in restricted suitable deep-slow refuge habitats such as pools and deep glides. Fish cope with ordinary thermal ice phenomena, and do not appear to become trapped in ice. Surface ice may reduce fish metabolism, but other factors, e.g. availability of substrate shelter, may override this effect. Mechanical ice break-ups and less surface ice may reduce survival. An adaptive mitigating strategy may be higher regulated flows in winter which increase rearing and/or resting habitat and survival, but studies are few and knowledge is limited. However, higher regulated flows also affect temperature regime. Low flows increase ice formation, reduce and fragment available habitat, and may reduce egg and fish survival. Influx of ground water may mitigate these impacts, as will stabilize minimum flows. Sudden drops in regulated water discharge should be avoided. Fish may strand, in particular at low temperatures in the daytime when fish are less mobile and seek shelter. The challenging winter season is understudied, and important management considerations and future research areas for better adaptive management are suggested.

Hellstrom, G., Klaminder, J., Finn, F., Persson, L., Alanara, A., Jonsson, M., . . . Brodin, T. (2016). GABAergic anxiolytic drug in water increases migration behaviour in salmon. *Nature Communications,* 7. https://doi.org/10.1038/ncomms13460

Migration is an important life-history event in a wide range of taxa, yet many migrations are influenced by anthropogenic change. Although migration dynamics are extensively studied, the potential effects of environmental contaminants on migratory physiology are poorly understood. In this study we show that an anxiolytic drug in water can promote downward migratory behaviour of Atlantic salmon (Salmo salar) in both laboratory setting and in a natural river tributary. Exposing salmon smolt to a dilute

concentration of a GABAA receptor agonist (oxazepam) increased migration intensity compared with untreated smolt. These results implicate that salmon migration may be affected by human-induced changes in water chemical properties, such as acidification and pharmaceutical residues in wastewater effluent, via alterations in the GABAA receptor function.

Hrachowitz, M., Soulsby, C., Imholt, C., Malcolm, I. A., & Tetzlaff, D. (2010). Thermal regimes in a large upland salmon river: a simple model to identify the influence of landscape controls and climate change on maximum temperatures. *Hydrological Processes,* 24(23), 3374-3391. https://doi.org/10.1002/hyp.7756

Temperature observations at 25 sites in the 2000 km(2) Dee catchment in NE Scotland were used, in conjunction with geographic information system (GIS) analysis, to identify dominant landscape controls on mean monthly maximum stream temperatures. Maximum winter stream temperatures are mainly controlled by elevation, catchment area and hill shading, whereas the maximum temperatures in summer are driven by more complex interactions, which include the influence of riparian forest cover and distance to coast. Multiple linear regression was used to estimate the catchment-wide distribution of mean weekly maximum stream temperatures for the hottest week of the 2-year observation period. The results suggested the streams most sensitive to high temperatures are small upland streams at exposed locations without any forest cover and relatively far inland, while lowland streams with riparian forest cover at locations closer to the coast exhibit a moderated thermal regime. Under current conditions, all streams provide a suitable thermal habitat for both, Atlantic salmon and brown trout. Using two climate change scenarios assuming 2.5 and 4 degrees C air temperature increases, respectively, temperature-sensitive zones of the stream network were identified, which could potentially have an adverse effect on the thermal habitat of Atlantic salmon and brown trout. Analysis showed that the extension of riparian forests into headwater streams has the potential to moderate changes in temperature under climate change.

Izzo, L. K., & Zydlewski, J. (2017). Retrospective Analysis of Seasonal Ocean Growth Rates of Two Sea Winter Atlantic Salmon in Eastern Maine Using Historic Scales. *Marine and Coastal Fisheries,* 9(1), 357-372. https://doi.org/10.1080/19425120.2017.1334723

Substantial declines of anadromous Atlantic Salmon Salmo salar have occurred throughout its range, with many populations at the southern extent of the distribution currently extirpated or endangered. While both one sea winter (1SW) and two sea winter (2SW) spawner numbers for the North American stocks have declined since the 1950s, the decline has been most severe in 2SW spawners. The first months at sea are considered a period of high mortality. However, early ocean mortality alone cannot explain the more pronounced decline of 2SW spawners, suggesting that the second year at sea may be more critical than previously thought. Atlantic Salmon scales collected by anglers and the state agency from 1946 to 2013 from five rivers in eastern Maine were used to estimate smolt age and ocean age of returning adults. Additionally, seasonal growth rates of maiden 2SW spawners were estimated using intercirculi measurements and linear back-calculation methods. Generalized linear mixed models (Gaussian family, log link function) were used to investigate the influence of average sea surface temperature, accumulated thermal units, the Atlantic Multidecadal Oscillation (AMO) and North Atlantic Oscillation indices, smolt age, smolt length, postsmolt growth, and river of origin on growth rate during

the oceanic migration of North American Atlantic Salmon. Results suggest that different factors influence salmon growth throughout their oceanic migration, and previous growth can be a strong predictor of future size. Growth was negatively impacted by the phase of the AMO, which has been linked to salmon abundance trends, in early spring following the postsmolt period. This is likely when the 1SW and 2SW stock components separate, and our results suggest that this period may be of interest in future work examining the disproportionate decline in 2SW spawners.

Jackson, D., Cotter, D., ÓMaoiléidigh, N., O'Donohoe, P., White, J., Kane, F., . . . Cullen, A. (2011). Impact of early infestation with the salmon louse *Lepeophtheirus salmonis* on the subsequent survival of outwardly migrating Atlantic salmon smolts from a number of rivers on Ireland's south and west coasts. *Aquaculture,* 319(1-2), 37-40. https://doi.org/10.1016/j.aquaculture.2011.06.042

The potential impact of sea lice infestation on outwardly migrating Atlantic salmon smolts has been investigated by treating populations of ranched salmon, prior to release, with a prophylactic sea lice treatment conferring protection from sea lice infestation, for up to 9weeks. Established populations of ranched Atlantic salmon with well described rates of return were chosen to investigate the potential contribution of early infestation with the salmon louse, Lepeophtheirus salmonis to mortality in Atlantic salmon. Results of five releases from four locations are presented and compared with a time series of releases from Lough Furnace in Newport, County Mayo. The results of this study would suggest that infestation of outwardly migrating salmon smolts with the salmon louse (L. salmonis) was a minor component of the overall marine mortality in the stocks studied.

Jahnke, A., Mayer, P., Adolfsson-Erici, M., & McLachlan, M. S. (2011). Equilibrium sampling of environmental pollutants in fish: Comparison with lipid-normalized concentrations and homogenization effects on chemical activity. *Environmental Toxicology and Chemistry,* 30(7), 1515-1521. https://doi.org/10.1002/etc.534

Equilibrium sampling of organic pollutants into the silicone polydimethylsiloxane (PDMS) has recently been applied in biological tissues including fish. Pollutant concentrations in PDMS can then be multiplied with lipid/PDMS distribution coefficients (D(Lipid,PDMS)) to obtain concentrations in fish lipids. In the present study, PDMS thin films were used for equilibrium sampling of polychlorinated biphenyls (PCBs) in intact tissue of two eels and one salmon. A classical exhaustive extraction technique to determine lipid-normalized PCB concentrations, which assigns the body burden of the chemical to the lipid fraction of the fish, was additionally applied. Lipid-based PCB concentrations obtained by equilibrium sampling were 85 to 106% (Norwegian Atlantic salmon), 108 to 128% (Baltic Sea eel), and 51 to 83% (Finnish lake eel) of those determined using total extraction. This supports the validity of the equilibrium sampling technique, while at the same time confirming that the fugacity capacity of these lipid-rich tissues for PCBs was dominated by the lipid fraction. Equilibrium sampling was also applied to homogenates of the same fish tissues. The PCB concentrations in the PDMS were 1.2 to 2.0 times higher in the homogenates (statistically significant in 18 of 21 cases, $p < 0.05$), indicating that homogenization increased the chemical activity of the PCBs and decreased the fugacity capacity of the tissue. This observation has implications for equilibrium sampling and partition coefficients determined using tissue homogenates.

Jonsson, B., & Jonsson, N. (2009). A review of the likely effects of climate change on anadromous Atlantic salmon *Salmo salar* and brown trout *Salmo trutta*, with particular reference to water temperature and flow. *Journal of Fish Biology,* 75(10), 2381-2447. https://doi.org/10.1111/j.1095-8649.2009.02380.x

The present paper reviews the effects of water temperature and flow on migrations, embryonic development, hatching, emergence, growth and life-history traits in light of the ongoing climate change with emphasis on anadromous Atlantic salmon Salmo salar and brown trout Salmo trutta. The expected climate change in the Atlantic is for milder and wetter winters, with more precipitation falling as rain and less as snow, decrease in ice-covered periods and frequent periods with extreme weather. Overall, thermal limits for salmonids are species specific. Scope for activity and growth and optimal temperature for growth increase with temperature to an optimal point before constrain by the oxygen content of the water. The optimal temperature for growth decreases with increasing fish size and varies little among populations within species, whereas the growth efficiency may be locally adapted to the temperature conditions of the home stream during the growth season. Indirectly, temperature influences age and size at smolting through its effect on growth. Time of spawning, egg hatching and emergence of the larvae vary with temperature and selective effects on time of first feeding. Traits such as age at first maturity, longevity and fecundity decrease with increasing temperature whilst egg size increases with temperature. Water flow influences the accessibility of rivers for returning adults and speed of both upstream and downstream migration. Extremes in water flow and temperature can decrease recruitment and survival. There is reason to expect a northward movement of the thermal niche of anadromous salmonids with decreased production and population extinction in the southern part of the distribution areas, migrations earlier in the season, later spawning, younger age at smolting and sexual maturity and increased disease susceptibility and mortality. Future research challenges are summarized at the end of the paper.

Jonsson, B., & Jonsson, N. (2017). Fecundity and water flow influence the dynamics of Atlantic salmon. *Ecology of Freshwater Fish,* 26(3), 497-502. https://doi.org/10.1111/eff.12294

Populations are retained at reduced levels by resource competition and environmental stochasticity. In the Norwegian River Imsa, the relationship between fecundity of Atlantic salmon (Salmo salar) spawners and number of smolts per unit river area was investigated for cohorts spawned from 1976 to 2011. Annual number of smolts produced per unit area was best described by a multiplicative model and increased with the fecundity of the females as proxy for number of eggs deposited and the minimum water flow in August towards the end of the first growth season. Mean monthly water temperature, or water flow in any other month during the first year, had no significant effect on number of smolts produced. At sea, there was an almost linear relationship between number of emigrating smolts and returning adults, possibly because population abundance of Atlantic salmon is low relative to the carrying capacity in the ocean. Thus, both number of eggs spawned and minimum water flow in late summer influenced population abundance in the present river.

Jonsson, B., & Jonsson, N. (2018). Egg incubation temperature affects the timing of the Atlantic salmon *Salmo salar* homing migration. *Journal of Fish Biology,* 93(5), 1016-1020. https://doi.org/10.1111/jfb.13817

Here, we show that adult Atlantic salmon Salmo salar returned about 2 weeks later from the feeding areas in the North Atlantic Ocean to the Norwegian coast, through a phenotypically plastic mechanism, when they developed as embryos in c. 3 degrees C warmer water than the regular incubation temperature. This finding has relevance to changes in migration timing caused by climate change and for cultivation and release of S. salar.

Jonsson, B., & Jonsson, N. (2019). Phenotypic plasticity and epigenetics of fish: embryo temperature affects later-developing life-history traits. *Aquatic Biology,* 28, 21-32. https://doi.org/10.3354/ab00707

Temperature during embryonic development affects ecological traits and influences the ability to rapidly adapt to the prevailing conditions in changing environments. Here, we review examples of how these developmental effects are manifested in life-history traits from studies of various fish species, with examples of impacts on somatic growth, age at migration and maturation, allocation of resources to gonads and egg size. Temperature during embryogenesis appears important for some behavioural decisions, such as when maturing Atlantic salmon Salmo salar return home from the ocean for spawning in distant rivers during summer. In some species, early temperature influences sex determination. The temperature level during embryogenesis may preadapt the fish to maximize offspring production under the thermal conditions encountered at the embryo stage. This thermal influence is a phenotypically plastic response that triggers polyphenism in salmonids and may be a first step in speciation of North American darters (Percidae). The responses to early temperature appear to be regulated by epigenetic mechanisms, such as DNA methylation, histone modification and micro RNAs.

Jonsson, B., Jonsson, N., & Finstad, A. G. (2014). Linking embryonic temperature with adult reproductive investment in Atlantic salmon *Salmo salar*. *Marine Ecology Progress Series,* 515, 217-226. https://doi.org/10.3354/meps11006

The expression of fitness-related traits, such as egg and gonad size, often varies among habitats and exhibits clinal variation along climatic and latitudinal gradients. However, the mechanisms allowing such variations are obscure and have been ascribed to both phenotypic plasticity and genetic adaptation. We experimentally tested whether variation in egg and gonad size of a poikilotherm vertebrate is influenced by the temperature individuals experienced during embryogenesis, possibly as an epigenetic effect. Atlantic salmon Salmo salar eggs were incubated under 3 embryonic thermal regimes: cold, mixed and warm treatments. The cold group received ambient river water (mean +/- SD: 2.6 +/- 0.4 degrees C) and the warm group received water at 4.6 degrees C above ambient temperature, the expected temperature in the river towards the end of this century, from fertilization until exogenous feeding commenced. The mixed group received ambient river water until hatching, whereupon the larvae received heated water until exogenous feeding commenced. When exogenous feeding was initiated, all fish were reared under identical, natural thermal conditions. At adulthood, fish that developed from warm-incubated eggs were largest, had the highest mass-length relationship and developed larger eggs and higher gonad mass relative to their own body size. There was no similar effect of thermal environment during larval

development. The treatment did not affect age of maturity or fecundity. Thus, thermal conditions during embryo genesis affected the expression of adult life-history traits, a mechanism by which fish may rapidly change the size of their propagules to the anticipated thermal offspring environment. This is a novel result explaining variation in these core life-history traits.

Kanerva, M., Vehmas, A., Nikinmaa, M., & Vuori, K. A. (2014). Spatial Variation in Transcript and Protein Abundance of Atlantic Salmon during Feeding Migration in the Baltic Sea. *Environmental Science & Technology,* 48(23), 13969-13977. https://doi.org/10.1021/es502956g

The fitness and reproductive output of fishes can be affected by environmental disturbances. In this study, transcriptomics and label-free proteomics were combined to investigate Atlantic salmon (Salmo salar) sampled from three different field locations within the Baltic Sea (Baltic Main Basin (BMB), Gulf of Finland (GoF), and Bothnian Sea (BS)) during marine migration. The expression of several stress related mRNAs and proteins of xenobiotic metabolism, oxidative stress, DNA damage, and cell death were increased in salmon from GoF compared to salmon from BMB or BS. Respiratory electron chain and ATP synthesis related gene ontology-categories were upregulated in GoF salmon, whereas those associated with RNA processing and synthesis, translation, and protein folding decreased. Differences were seen also in metabolism and immune function related gene expression. Comparisons of the transcriptomic and proteomic profiles between salmon from GoF and salmon from BMB or BS suggest environmental stressors, especially exposure to contaminants, as a main explanation for differences. Salmon feeding in GoF are thus "disturbed by hazardous substances". The results may also be applied in evaluating the conditions of pelagic ecosystems in the different parts of Baltic Sea.

Keinänen, M., Käkelä, R., Ritvanen, T., Pönni, J., Harjunpää, H., Myllylä, T., & Vuorinen, P. J. (2018). Fatty acid signatures connect thiamine deficiency with the diet of the Atlantic salmon (Salmo salar) feeding in the Baltic Sea. *Marine Biology,* 165(10), 161. https://doi.org/10.1007/s00227-018-3418-8

Thiamine (vitamin B1) deficiency in salmonids related to a lipid-rich fish diet causes offspring mortality in the yolk-sac fry phase. A low free thiamine (THIAM) concentration in eggs is an indication of this syndrome. Thiamine deficiency of salmon (Salmo salar) feeding in the Baltic Sea, called M74, was connected to the principal prey fish and feeding area using fatty acid (FA) signature analysis. The FAs of feeding salmon from two areas of the Baltic Sea, the Baltic Proper (57°10′ 19°30′) and the Bothnian Sea (61°30′ 20°00′) in 2004, reflected the principal prey species in these areas, sprat (Sprattus sprattus) and herring (Clupea harengus), respectively. Arachidonic acid (ARA, 20:4n-6) and 18:1n-7 indicated dietary herring, 18:1n-9 dietary sprat and 14:0 feeding in the Baltic Proper. The muscle FA profile of non-M74 female spawners of the River Simojoki in a year (1998) with a moderate M74 incidence and salmon of a non-M74 year (2004) reflected herring FAs, whereas the FAs in the M74 year and specifically in M74 females displayed characteristics of sprat. In the M74 year, the THIAM concentration had the strongest positive correlation with the proportion of muscle ARA, and the strongest negative correlations with 14:0 and the ratios 18:1n-9/ARA and 14:0/ARA. Thus, ARA along with 14:0 and these ratios were the most sensitive FA indicators of the dietary species and origin of the M74 syndrome. Despite the pre-spawning fasting, tissue FA signatures were consequently able to connect dietary sprat in the Baltic Proper with thiamine deficiency in Baltic salmon.

Keinänen, M., Uddström, A., Mikkonen, J., Casini, M., Pönni, J., Myllylä, T., . . . Vuorinen, P. J. (2012). The thiamine deficiency syndrome M74, a reproductive disorder of Atlantic salmon (Salmo salar) feeding in the Baltic Sea, is related to the fat and thiamine content of prey fish. *ICES Journal of Marine Science,* 69(4), 516-528. https://doi.org/10.1093/icesjms/fss041

Keinänen, M., Uddström, A., Mikkonen, J., Casini, M., Pönni, J., Myllylä, T., Aro, E., and Vuorinen, P. J. 2012. The thiamine deficiency syndrome M74, a reproductive disorder of Atlantic salmon (Salmo salar) feeding in the Baltic Sea, is related to the fat and thiamine content of prey fish. – ICES Journal of Marine Science, 69: 516–528. This study clarifies how the diet of Baltic salmon leads to thiamine deficiency in eggs, and consequently to M74 mortality of yolk-sac fry. The main prey species, sprat (Sprattus sprattus) and herring (Clupea harengus membras), and their biomass in the Baltic Proper (BPr) and the Bothnian Sea, the two feeding grounds of salmon originating from the northern Gulf of Bothnia rivers, are compared. The thiamine concentration of both prey species is lowest in the youngest age groups. Because average fat content and energy density are greater in sprat than in herring, and greatest in youngest sprat, the supply of thiamine per unit energy is least in a diet containing many young sprat. Also, the greater is the supply of thiamine and fat from sprat in the southern BPr in the preceding year, the lower the concentration of thiamine in salmon eggs. Thiamine deficiency in eggs results from an unbalanced diet abundant in fatty prey fish, such as young sprat, from which the supply of thiamine is insufficient in proportion to the supply of energy and unsaturated fatty acids for salmon, which must undergo a long prespawning fasting period.

Kesler, M., Kangur, M., & Vetemaa, M. (2011). Natural re-establishment of Atlantic salmon reproduction and the fish community in the previously heavily polluted River Purtse, Baltic Sea. *Ecology of Freshwater Fish,* 20(3), 472-477. https://doi.org/10.1111/j.1600-0633.2010.00483.x

The River Purtse was historically a significant Atlantic salmon spawning river in the Gulf of Finland (Baltic Sea). After the establishment of oil shale mining and processing in the catchment area in the late 1920s, the salmon population went extinct. By the 1970s, the river was heavily polluted and the lower reaches lacked any fish fauna. However, since the 1990s, pollution from oil shale mines was greatly reduced and water quality started to improve. The first fish species to repopulate the polluted area were gudgeon and nine-spined stickleback. The first salmon parr from wild spawning were recorded in 2006. Up to 2009, a total of fifteen fish species have been recorded including trout and the sensitive bullhead. This study illustrates the natural recovery of the fish fauna following water quality improvement.

King, J. J. (2015). Ecology And Economics Of Fish Kills: Mortality And Recovery Of Brown Trout (Salmo Trutta L.) And Atlantic Salmon (Salmo Salar L.) In An Irish River. *Biology and Environment-Proceedings of the Royal Irish Academy*(3), 157-170. https://doi.org/10.3318/bioe.2015.16

There is a small international scientific literature, principally from North America, on recovery of fish communities following substantial fish kill events and a smaller literature on monetary assessment of losses in such events. A chemical discharge led to over 90% loss of brown trout (Salmo trutta L.) and Atlantic salmon (Salmo salar L.) age classes in 31km of the River Boyne catchment, a major Irish salmon-producing and angling fishery in July 1997. Subsequent investigations permitted a novel study that examined both the changes in the fish community composition over time and also a monetary assessment of losses. The population structure and density of 1 and older brown trout took four to five

years to recover. The population of 1+ salmon increased substantially during the recovery period, to levels threefold higher than those recorded prior to the pollution event. Financial loss assessment was examined through 'replacement cost' and through consequential loss models. An examination of the monetary modelling, in the light of the fish community recovery, showed there was an ecological justification for the potential loss model used. This approach to appraisal of loss is considered to have an international relevance, in the context of ecosystem processes and the 'polluter pays' principle.

Kroglund, F., Rosseland, B. O., Teien, H. C., Salbu, B., Kristensen, T., & Finstad, B. (2008). Water quality limits for Atlantic salmon (Salmo salar L.) exposed to short term reductions in pH and increased aluminum simulating episodes. *Hydrology and Earth System Sciences,* 12(2), 491-507. https://doi.org/10.5194/hess-12-491-2008

Acidification has caused the loss or reduction of numerous Atlantic salmon (Salmo salar L.) populations on both sides of the North Atlantic. Acid deposition peaked in the 1980's and resulted in both chronically and episodically acidified rivers. At present, water quality is improving in all affected rivers due to reduced acid deposition. However, spring snow melt, heavy rainfall and sea salt episodes can still cause short term drops in pH and elevated concentrations of bioavailable aluminum. Technical malfunction in lime dozers will cause short termed episodic spates in the limed rivers. The current situation has prompted a need for dose-response relationships based on short term exposures of Atlantic salmon to assess the potential population effects of episodic acidification. Water quality guidelines for salmon have been lacking, despite a large number of experiments, all demonstrating dose-response relationships between water chemistry and fish health. We have summarized results from 347 short-term (< 14 days) exposures of salmon parr and smolt performed between 1990 and 2003 in Norway. The experiments have been performed as bioassays, where fish have been exposed in tanks fed river water, in tanks where the river water quality has been manipulated (added H+ and Al) and as Carlin-tagged smolt releases after pre-exposure to moderately acidic waters. The results from the various bioassays are compared to water quality limits proposed on basis of the relationship between water quality and population status/health in Norwegian rivers. The focus of this article is placed on chemical-biological interactions that can be drawn across experiments and exposure protocols. We propose dose-response relationships for acid neutralizing capacity (ANC), pH, cationic Al and gill accumulated Al, versus mortality in freshwater, effects on hypo-osmoregulatory capacity in seawater challenge tests and on smolt to adult survival in release experiments. The "no effect" dose depends on the life history stage tested and on the sensitivity of the biomarkers. Parr are more tolerant than smolt. Concentrations of Al that have no significant impact on freshwater life history stages can still have major population effects if they occur prior to smolt migration. While smolt can survive in freshwater for a prolonged period of time (> 10 days) at an Al dose resulting in a gill Al concentration of up to 300 mu g Alg(-1) dw, a 3 day exposure resulting in a gill Al accumulation in the range of 25 to 60 mu g Alg(-1) dw reduces smolt to adult survival in a dose related manner by 20 to 50%. For smolt to adult survival, the biological significant response is delayed relative to the dose and occurs first after the fish enters the marine environment. In addition to exposure intensity and timing, exposure duration is important for the setting of critical limits.

Lavery, J. M. (2017). *Mortality and development of wild Atlantic salmon (Salmo salar) embryos associated with environmental conditions over winter in the Miramichi River basin.* (Master's), University of New Brunswick, Retrieved from https://unbscholar.lib.unb.ca/handle/1882/13740

No abstract available.

Li, M. L., Schartup, A. T., Valberg, A. P., Ewald, J. D., Krabbenhoft, D. P., Yin, R. S., . . . Sunderland, E. M. (2016). Environmental Origins of Methylmercury Accumulated in Subarctic Estuarine Fish Indicated by Mercury Stable Isotopes. *Environmental Science & Technology,* 50(21), 11559-11568. https://doi.org/10.1021/acs.est.6b03206

Methylmercury (MeHg) exposure can cause adverse reproductive and neurodevelopmental health effects. Estuarine fish may be exposed to MeHg produced in rivers and their watersheds, benthic sediment, and the marine water column, but the relative importance of each source is poorly understood. We measured stable isotopes of mercury (delta Hg-202, delta Hg-199, and delta Hg-201), carbon (delta C-13), and nitrogen (delta N-15) in fish with contrasting habitats from a large subarctic coastal ecosystem to better understand MeHg exposure sources. We identify two distinct food chains exposed to predominantly freshwater and marine MeHg sources but do not find evidence for a benthic marine MeHg signature. This is consistent with our previous research showing benthic sediment is a net sink for MeHg in the estuary. Marine fish display lower and less variable delta Hg-199 values (0.78 parts per thousand to 1.77 parts per thousand) than freshwater fish (0.72 parts per thousand to 3.14 parts per thousand) and higher delta Hg-202 values (marine: 0.1 parts per thousand to 0.57 parts per thousand; freshwater: -0.76 parts per thousand to 0.15 parts per thousand). We observe a shift in the Hg isotopic composition of juvenile and adult rainbow smelt (Osmerus mordax) when they transition between the freshwater and marine environment as their dominant foraging territory. The Hg isotopic composition of Atlantic salmon (Salmo salar) indicates they receive most of their MeHg from the marine environment despite a similar or longer duration spent in freshwater regions. We conclude that stable Hg isotopes effectively track fish MeHg exposure sources across different ontogenic stages.

Liebich, T., McCormick, S. D., Kircheis, D., Johnson, K., Regal, R., & Hrabik, T. (2011). Water chemistry and its effects on the physiology and survival of Atlantic salmon *Salmo salar* smolts. *Journal of Fish Biology,* 79(2), 502-519. https://doi.org/10.1111/j.1095-8649.2011.03046.x

The physiological effects of episodic pH fluctuations on Atlantic salmon Salmo salar smolts in eastern Maine, U.S.A., were investigated. During this study, S. salar smolts were exposed to ambient stream-water chemistry conditions at nine sites in four catchments for 3 and 6 day intervals during the spring S. salar smolt migration period. Plasma chloride, plasma glucose, gill aluminium and gill Na(+)- and K(+)-ATPase levels in S. salar smolts were assessed in relation to ambient stream-water chemistry during this migration period. Changes in both plasma chloride and plasma glucose levels of S. salar smolts were strongly correlated with stream pH, and S. salar smolt mortality occurred in one study site with ambient stream pH between 5.6 and 5.8 during the study period. The findings from this study suggest that physiological effects on S. salar smolts are strongly correlated with stream pH and that in rivers and streams with low dissolved organic carbon (DOC) concentrations the threshold for physiological effects and mortality probably occurs at a higher pH and shorter exposure period than in rivers with higher DOC. Additionally, whenever an acidification event in which pH drops below 5.9 coincides with S. salar

smolt migration in eastern Maine rivers, there is potential for a significant reduction in plasma ions of S. salar smolts.

Lothian, A. J., Newton, M., Barry, J., Walters, M., Miller, R. C., & Adams, C. E. (2018). Migration pathways, speed and mortality of Atlantic salmon (Salmo salar) smolts in a Scottish river and the near-shore coastal marine environment. *Ecology of Freshwater Fish,* 27(2), 549-558. https://doi.org/10.1111/eff.12369

Long-distance migration of Atlantic salmon (Salmo salar) is known to result in high levels of mortality. For a species experiencing global population decline, it is thus vital to better understand migration behaviour, both in the river and marine stages. Atlantic salmon smolts (n=50) were tracked using acoustic telemetry in the River Deveron, Scotland, and adjacent coastal area. Higher rates of mortality were observed in the river (0.77% per km) than the early marine stage of migration (0.0% per km). Mortality likely resulted from predation. Higher swim speeds were recorded in the early marine stage compared with the river (marine=7.37 +/- 28.20km/day; river=5.03 +/- 1.73km/day [mean +/- SD]), a potential predator avoidance behaviour. The majority of smolts leaving the river did so in darkness and on a flooding tide. Overall river and marine migration success were linked to nights of lower lunar brightness. Marine migration speed decreased with increasing environmental noise levels, a finding with implications for fisheries management. The migration pathway in the early marine environment did not follow obvious geographical features, such as the coastline. Thus, we suggest that early marine environment pathways are more influenced by complex water currents. These findings highlight factors that influence smolt migration survival and behaviour, areas on which future research should focus.

Lynn, T. J., Jeong, J. W., & Duffy, M. S. (2020). Bet hedging and cold-temperature termination of diapause in the life history of the Atlantic salmon ectoparasite *Argulus canadensis*. *Parasitology,* 147(14), 1774-1785. https://doi.org/10.1017/s0031182020001766

Argulus canadensis is a crustacean ectoparasite observed increasingly on wild migrating adult Atlantic salmon. We investigated temperature and salinity tolerance regarding development, survival and hatch of A. canadensis eggs to help understand spatiotemporal features of transmission. Argulus canadensis eggs differentiate to pharate embryos by 35 days buttheir hatch is protracted to similar to 7 months. Cold treatment > 75 days mimics overwintering and terminates egg diapause, with 84.6% (72.1-100%) metanauplius hatch induced > 13 degrees C and synchronized to 3-4 weeks. Inter- and intra-clutch variability and protracted hatch in the absence of cold-temperature termination of diapause is compatible with bet hedging. Whereas diapause likely promotes phenological synchrony for host colocalization, bet hedging could afford temporal plasticity to promote host encounter during environmental change. Our egg storage and hatch induction/synchronization methodologies can be exploited for empirical investigations. Salinity tolerance reveals both significantly higher embryonic development (94.4 +/- 3.5% vs 61.7 +/- 24.6%) and metanauplius hatch (53.3 +/- 7.5% vs 10.1 +/- 8.2%) for eggs in freshwater than at 17 ppt. Unhatched embryos were alive in freshwater by the end of the trial (213 days) but were dead/dying at 17 ppt. Eggs did not develop at 34 ppt. Salinity tolerance of A. canadensis eggs supports riverine transmission to adult Atlantic salmon during return to freshwater for mating each year.

MacKenzie, K. M. (2010). *The marine life of Atlantic salmon: evidence from the chemistry of scales.* (Ph.D.), University of Southampton, Retrieved from https://eprints.soton.ac.uk/191971/

This research provides a new method to identify likely marine feeding grounds for migratory pelagic species that are problematic to directly study at sea. The method is based on stable isotope compositions of tissues that may be sampled without harming the target animals, and can be conducted retrospectively from tissue archives. The wild Atlantic salmon has been in steep decline throughout its native range over the past four decades, largely due to increases in marine mortality. This research investigated potential causes of this decline using stable isotope analysis of archived scale samples, taken from returning adult salmon over the past few decades. Investigations of UK scale holdings identified the River Frome and Northeast Coast Driftnet Fishery archives as the most available and useful, giving good spatial contrast and temporal coverage. After developing sampling and analytical protocols, carbon and nitrogen isotopic composition was measured in grilse (one-sea winter) and multi-sea winter (MSW) salmon scale samples taken from both archives over 23 and 14 years. Analyses were performed on the last marine growth season, giving a retrospective record of marine conditions experienced by each fish. Both isotopes are influenced by baseline environmental conditions, and climatic effects are found to exert strong controls on numbers of fish returning to both the Northeast Coast and River Frome populations. Trophic level and/or baseline nitrate effects are also found to influence returning abundance to these populations, although more strongly in the Frome. Yearly d13C values were correlated with median yearly sea surface temperature values for each degree of latitude and longitude across the North Atlantic, and maps produced of the correlation strengths. These maps suggest likely feeding grounds for each cohort within each population, with the River Frome grilse and MSW salmon respectively feeding near the shelf breaks of northeast and southwest Iceland. The Northeast Coast grilse and MSW salmon were, in contrast, feeding near the shelf breaks of the southern Norwegian Sea and the Bear Island Trench in the northern Norwegian Sea, respectively.

Marsh, J. E., Lauridsen, R. B., Gregory, S. D., Kratina, P., Scott, L. J., Cooling, D., & Jones, J. I. (2022). High summer macrophyte cover increases abundance, growth, and feeding of juvenile Atlantic salmon. *Ecological Applications,* 32(2). https://doi.org/10.1002/eap.2492

Aquatic habitats are severely threatened by human activities. For anadromous species, managing freshwater habitats to maximize production of more, larger juveniles could improve resilience to threats in marine habitats and enhance population viability. In some juvenile salmonid habitats, complexity created by large substrates provides resources and reduces competitive interactions, thereby promoting juvenile production. In lowland rivers, which lack large substrates, aquatic plants might provide similar complexity and enhance fish productivity. To test the influence of aquatic plants on juvenile Atlantic salmon and sympatric brown trout in a lowland river, we directly manipulated the cover of the dominant macrophyte, Ranunculus, in nine sites during summer and autumn for two years. We quantified the abundance, site retention and growth of salmon and trout under high, medium or low Ranunculus cover. To investigate the effects of Ranunculus cover on feeding opportunities and interspecific competition, we quantified available prey biomass and body size, fish diet composition and compared dietary niche overlap. Experimentally increased Ranunculus cover supported higher salmon abundance in summer and autumn, and higher site retention and growth of salmon in summer. Trout abundance and growth were not influenced by Ranunculus cover, but trout site retention doubled in high, relative to low, cover sites. Despite the weak effects of Ranunculus cover on prey availability, salmon and trout inhabiting high cover sites consumed larger prey and a higher biomass of prey. Furthermore, dietary

niche overlap was lower in high, relative to low, cover sites, suggesting that abundant Ranunculus reduced interspecific competition. This field experiment shows that high Ranunculus cover can support more and better growing juvenile salmon, and facilitate foraging and co-existence of sympatric salmonid species. Maintaining or enhancing natural macrophyte cover can be achieved through sympathetic in-river and riparian vegetation management and mitigating pressures on them, such as sediment inputs and low flows, or through planting. Further research should test whether macrophyte cover benefits propagate to subsequent life stages, particularly juvenile overwintering associated with high mortality. This knowledge, in combination with our findings, would further clarify whether beneficial juvenile habitat can improve the viability of at-risk salmonid populations. Overall, our findings suggest that the aims of river restoration might be achieved through promotion of in-stream aquatic vegetation.

Marttila, M., Louhi, P., Huusko, A., Vehanen, T., Maki-Petays, A., Erkinaro, J., . . . Muotka, T. (2019). Synthesis of habitat restoration impacts on young-of-the-year salmonids in boreal rivers. *Reviews in Fish Biology and Fisheries,* 29(3), 513-527. https://doi.org/10.1007/s11160-019-09557-z

River restoration offers the potential to enhance biological integrity, often measured as fish population changes. We used a meta-analytical approach to synthesize density responses to in-stream habitat restoration by young-of-the year (YOY) brown trout and Atlantic salmon in 28 rivers (overall 32 restoration projects) in Finland. We also examined which local and watershed-scale factors most influenced restoration success. Finally, we conducted an expert survey to obtain an independent estimate of a sufficient density enhancement for restoration to be considered successful. Despite strong context-dependency, habitat restoration had an overall positive effect on YOY salmonid density. When compared to target levels derived from the expert survey, density responses mainly reached the minimum expected success rate, but remained short of the level considered to reflect distinct success. Variability in restoration responses of trout was linked mainly to river size, predominant geology, water quality and potential interspecific competition (trout vs. European bullhead). Fishing mortality tended to obscure positive effects of restoration and stocking by YOY fish affected negatively trout's response to restoration, supporting a shift towards self-sustainable schemes in fisheries management. These results imply that habitat restoration is a useful approach for improving the ecological and conservational status of salmonid populations in boreal rivers. To further improve the success rate, and thereby public acceptance, of restorations they need to be complemented by other management measures that enhance the potential for the recovery of threatened salmonid populations.

Matsumoto, J., Hosmer, A. J., & Van Der Kraak, G. (2010). Survival and iono-regulatory performance in Atlantic salmon smolts is not affected by atrazine exposure. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology,* 152(3), 379-384. https://doi.org/10.1016/j.cbpc.2010.06.005

This study was conducted to determine the potential effects of atrazine exposure on survival and physiological performance in Atlantic salmon (Salmo salar) during the period of smoltification. This study involved two separate experiments in which juvenile Atlantic salmon were exposed to atrazine for a four day period in freshwater after which the fish were transferred to 50% seawater for two days and then to 100% seawater for five more days. The nominal concentrations of atrazine tested (1, 10 and 100

microg/L) were representative of and exceeded the levels measured in the North American freshwater environment. After seven days in seawater, fish were weighed, bled for the determination of plasma electrolyte levels, euthanized and samples collected for the determination of gonadosomatic index, muscle water content and gill Na+/K+-ATPase activity. Measured atrazine concentrations during the freshwater exposure period were 76-99% of nominal levels. There were no mortalities attributed to atrazine exposure. There were also no statistically significant differences in body weight, plasma sodium, potassium, magnesium and chloride levels, muscle water content or gill Na+/K+-ATPase activity between control and atrazine treated fish. Measurement of testis and ovary weights showed that there were no treatment effects on relative gonad size in male or female fish. These studies have shown that short term exposure to atrazine during the freshwater phase of their lifecycle had no effects on subsequent survival, body weight, relative gonad size or various measures of iono-regulatory performance in juvenile Atlantic salmon upon transfer to seawater. The concentrations of atrazine tested exceed those likely to be experienced in the natural aquatic environment suggesting that short term exposure to atrazine does not pose a risk to Atlantic salmon during the period of smoltification.

McCormick, S. D., Keyes, A., Nislow, K. H., & Monette, M. Y. (2009). Impacts of episodic acidification on in-stream survival and physiological impairment of Atlantic salmon (Salmo salar) smolts. *Canadian Journal of Fisheries and Aquatic Sciences,* 66(3), 394-403. https://doi.org/10.1139/f09-002

We conducted field Studies to determine the levels of acid and aluminum (Al) that affect survival, smolt development, ion homeostasis, and stress in Atlantic salmon (Salmo salar) smolts in restoration streams of the Connecticut River in southern Vermont. USA. Fish were held in cages in five streams encompassing a wide range of acid and At levels for two 6-day intervals during the peak of smolt development in late April and early May. Physiological parameters were unchanged from initial sampling at the hatchery and the high water quality reference site (pH > 7.0, inorganic At < 12 mu g.L-1). Mortality, substantial loss of plasma chloride, and gill Na+/K+-ATPase activity, and elevated gill At Occurred at sites with the lowest pH (5.4-5.6) and highest inorganic Al (50-80 mu g.L-1). Moderate loss of plasma chloride, increased plasma cortisol and glucose, and moderately elevated gill Al occurred at less severely impacted sites. Gill Al was a better predictor of integrated physiological impacts than water chemistry alone. The results indicate that At and low pH under field conditions in some New England streams can cause mortality and impair smolt development in juvenile Atlantic salmon and provide direct evidence that episodic acidification is impacting conservation and recovery of Atlantic salmon in the northeastern USA.

McCormick, S. D., & Regish, A. M. (2018). Effects of ocean acidification on salinity tolerance and seawater growth of Atlantic salmon *Salmo salar* smolts. *Journal of Fish Biology,* 93(3), 560-566. https://doi.org/10.1111/jfb.13656

Human activity has resulted in increasing atmospheric carbon dioxide (CO 2), which will result in reduced pH and higher levels of CO 2 in the ocean, a process known as ocean acidification. Understanding the effects of ocean acidification (OA) on fishes will be important to predicting and mitigating its consequences. Anadromous species such as salmonids may be especially at risk because of their rapid movements between fresh water and seawater, which could minimize their ability to

acclimate. In the present study, we examine the effect of future OA on the salinity tolerance and early seawater growth of Atlantic salmon Salmo salar smolts. Exposure to 610 and 1010 µatm CO 2 did not alter salinity tolerance but did result in slightly lower plasma chloride levels in smolts exposed to seawater compared with controls (390 µatm). Gill Na + -K + -ATPase activity, plasma cortisol, glucose and haematocrit after seawater exposure were not altered by elevated CO 2 . Growth rate in the first 2 weeks of seawater exposure was greater at 1010 µatm CO 2 than under control conditions. This study of the effects of OA on S. salar during the transition from fresh water to seawater indicates that elevated CO 2 is not likely to affect osmoregulation negatively and may improve early growth in seawater.

Melnyk, L. J., Lin, J., Kusnierz, D. H., Pugh, K., Durant, J. T., Suarez-Soto, R. J., . . . Stover, M. A. (2021). Risks from mercury in anadromous fish collected from Penobscot River, Maine. *Science of The Total Environment,* 781, 146691. https://doi.org/10.1016/j.scitotenv.2021.146691

Levels of total mercury were measured in tissue of six species of migratory fish (alewife, American shad, blueback herring, rainbow smelt, striped bass, and sea lamprey), and in roe of American shad for two consecutive years collected from the Penobscot River or its estuary. The resultant mercury levels were compared to reference doses as established in the U.S. Environmental Protection Agency (EPA) Integrated Risk Information System and wildlife values. Mercury concentrations ranged from 4 µg/kg ww in roe to 1040 µg/kg ww in sea lamprey. Sea lamprey contained the highest amounts of mercury for both seasons of sampling. Current health advisories are set at sufficient levels to protect fishers from harmful consumption of the fish for mercury alone, except for sea lamprey. Based upon published wildlife values for mink, otter, and eagle, consumption of rainbow smelt, striped bass, or sea lamprey poses a risk to mink; striped bass and sea lamprey to otter; and sea lamprey to eagle. For future consideration, the resultant data may serve as a reference point for both human health and wildlife risk assessments for the consumption of anadromous fish. U.S. EPA works with federally recognized Tribes across the nation greatly impacted by restrictions on sustenance fishing, to develop culturally sensitive risk assessments.

Mobley, K. B., Granroth-Wilding, H., Ellmen, M., Orell, P., Erkinaro, J., & Primmer, C. R. (2020). Time spent in distinct life history stages has sex-specific effects on reproductive fitness in wild Atlantic salmon. *Molecular Ecology,* 29(6), 1173-1184. https://doi.org/10.1111/mec.15390

In species with complex life cycles, life history theory predicts that fitness is affected by conditions encountered in previous life history stages. Here, we use a 4-year pedigree to investigate if time spent in two distinct life history stages has sex-specific reproductive fitness consequences in anadromous Atlantic salmon (Salmo salar). We determined the amount of years spent in fresh water as juveniles (freshwater age, FW, measured in years), and years spent in the marine environment as adults (sea age, SW, measured in sea winters) on 264 sexually mature adults collected on a river spawning ground. We then estimated reproductive fitness as the number of offspring (reproductive success) and the number of mates (mating success) using genetic parentage analysis (>5,000 offspring). Sea age is significantly and positively correlated with reproductive and mating success of both sexes whereby older and larger individuals gained the highest reproductive fitness benefits (females: 62.2% increase in offspring/SW and 34.8% increase in mate number/SW; males: 201.9% offspring/SW and 60.3% mates/SW). Younger freshwater age was significantly related to older sea age and thus increased reproductive fitness, but

only among females (females: -33.9% offspring/FW and -32.4% mates/FW). This result implies that females can obtain higher reproductive fitness by transitioning to the marine environment earlier. In contrast, male mating and reproductive success was unaffected by freshwater age and more males returned at a younger age than females despite the reproductive fitness advantage of later sea age maturation. Our results show that the timing of transitions between juvenile and adult phases has a sex-specific consequence on female reproductive fitness, demonstrating a life history trade-off between maturation and reproduction in wild Atlantic salmon.

Moore, A., Bendall, B., Barry, J., Waring, C., Crooks, N., & Crooks, L. (2012). River temperature and adult anadromous Atlantic salmon, *Salmo salar*, and brown trout, *Salmo trutta*. *Fisheries Management and Ecology,* 19(6), 518-526. https://doi.org/10.1111/j.1365-2400.2011.00833.x

In terms of the spawning migration of adult salmon, Salmo salar L., water flow is often considered the primary factor controlling river entry and fluctuations in flow controlling when the fish subsequently migrate upstream. However, water temperature has also been suggested to modify the spawning migration of salmon, particularly their movements within estuaries and the timing of freshwater entry. Freshwater temperature is more likely to impact salmonid biology than flow, particularly in relation to temperature dependant metabolic costs, time of spawning and fecundity. Therefore, temperature may be more of a factor regulating salmonid populations in fresh water than flow itself. This study focuses on two aspects of the impact of temperature on salmonids in fresh water: first, how salmon may modify their behaviour to adapt to changes in temperature and second the potential relationship between temperature, environmental conditions (e.g. water quality) and physiology (e.g. maturation and olfaction) in regulating adult migration.

Moore, A., Cotter, D., Quayle, V., Rogan, G., Poole, R., Lower, N., & Privitera, L. (2008). The impact of a pesticide on the physiology and behaviour of hatchery-reared Atlantic salmon, *Salmo salar*, smolts during the transition from fresh water to the marine environment. *Fisheries Management and Ecology,* 15(5-6), 385-392. https://doi.org/10.1111/j.1365-2400.2008.00622.x

Atlantic salmon, Salmo salar L., smolts were exposed to environmental levels of the pesticide atrazine in a hatchery, tagged with acoustic transmitters and released into fresh water at the peak of the smolt run. The subsequent movements of the smolts were monitored within the freshwater and immediate coastal zones using an array of acoustic receivers. In laboratory-based studies, exposure to a 0.1 mu g L-1 concentration of atrazine over a 72-h period significantly reduced gill Na+K+ ATPase activity but not plasma thyroxine (T-4) and triiodothyronine (T-3) levels compared with the control group, and on transfer to 33 parts per thousand saltwater resulted in 100% mortality. However, exposure to atrazine did not have a significant effect on the subsequent movements of the smolts in the freshwater, estuarine and marine environments. The results are discussed in relation to the impact of diffuse pollution on salmon populations.

Moran, P., Cal, L., Cobelo-Garcia, A., Almecija, C., Caballero, P., & de Leaniz, C. G. (2018). Historical legacies of river pollution reconstructed from fish scales. *Environmental Pollution,* 234, 253-259. https://doi.org/10.1016/j.envpol.2017.11.057

Many rivers have been impacted by heavy metal pollution in the past but the long-term legacies on biodiversity are difficult to estimate. The River Ulla (NW Spain) was impacted by tailings from a copper mine during the 1970-1980s but absence of baseline values and lack of subsequent monitoring have prevented a full impact assessment. We used archived fish scales of Atlantic salmon to reconstruct levels of historical copper pollution and its effects on salmon fitness. Copper bioaccumulation significantly increased over baseline values during the operation of the mine, reaching sublethal levels for salmon survival. Juvenile growth and relative population abundance decreased during mining, but no such effects were observed in a neighbouring river unaffected by mining. Our results indicate that historical copper exposure has probably compromised the fitness of this Atlantic salmon population to the present day, and that fish scales are suitable biomarkers of past river pollution.

Moriarty, P. E., Byron, C. J., Pershing, A. J., Stockwell, J. D., & Xue, H. (2016). Predicting migratory paths of post-smolt Atlantic salmon (Salmo salar). *Marine Biology,* 163(4). https://doi.org/10.1007/s00227-016-2847-5

Atlantic salmon is a highly migratory species that has experienced severe population declines. High mortality during the post-smolt period, when fish are migrating from rivers to their open-ocean wintering grounds, may be limiting population recovery, but little is known about this life stage. We used an individual-based model to evaluate the potential influences of ocean conditions (currents, temperature) on post-smolt salmon migration in the Gulf of Maine. A range of orientation behaviors were tested and results indicated that Atlantic salmon migration varied by year, natal river, and orientation behavior. The rate at which post-smolt salmon were able to make it across the Gulf of Maine was negatively correlated with coastal current strength. The response of migration rates to these factors varied among the potential orientation behaviors. For temperature-dependent orientation behaviors, migration was positively correlated with temperature. This modeling approach, based on field observations, is a useful technique for investigating variability in migration of endangered populations when in situ experiments are not possible.

Nieves-Puigdoller, K., Bjornsson, B. T., & McCormick, S. D. (2007). Effects of hexazinone and atrazine on the physiology and endocrinology of smolt development in Atlantic salmon. *Aquatic Toxicology,* 84(1), 27-37. https://doi.org/10.1016/j.aquatox.2007.05.011

Exposure to hexazinone (HEX) and atrazine (ATZ), highly mobile and widely used herbicides along rivers in the United States, is potentially harmful to Atlantic salmon, which have been listed as an endangered species. To determine the effects of these contaminants on smolt development, juvenile Atlantic salmon were exposed under flow-through conditions to 100 mu g l(-1) HEX, 10 and 100 mu g l(-1) ATZ in fresh water (FW) for 21 days at 10 degrees C beginning in mid-April. Twelve fish per treatment were sampled in FW, following a 24 h seawater (SW) challenge and after growth for 3 months in SW. Exposure to 100 mu g l(-1) HEX or 10 mu g l(-1) ATZ caused no mortalities of smolts in FW or after SW challenge, while 9% of the fish exposed to 100 mu g l(-1) ATZ died during exposure. Fish exposed to 100 mu g l(-1) ATZ reduced feeding after 10 days of exposure and had an impaired growth rate in FW and during the first

month in SW; compensatory growth occurred in the second and third month in SW. HEX and ATZ at 10 mu g l(-1) exposure had no effect on plasma levels of cortisol, growth hormone (GH), insulin growth factor I (IGF-I), thyroxine (T-4) and plasma 3,5,3'-triiodo-L-thyronine (T-3) Cl-, Mg2+, Na+, Ca2+ in FW or after SW challenge. FW smolts exposed to 100 mu g l(-1) ATZ had decreased plasma Cl-, Mg2+, Na+ and Ca2+ ions and increased cortisol. No effect on plasma levels of GH, IGF-I, T-4 or T-3 was found in FW smolts exposed to 100 mu g l(-1) ATZ. Following SW challenge, fish previously exposed to 100 mu g l(-1) ATZ had significant increases in hematocrit, plasma cortisol, Cl-, Mg2+, Na+, Ca2+ and a decrease in T-4 and T-3. It is concluded that under the conditions imposed in this study, HEX does not affect salinity tolerance of Atlantic salmon smolts, while ATZ causes ionoregulatory, growth and endocrine disturbance.

Nikoleris, L., & Hansson, M. C. (2015). Unraveling the estrogen receptor (er) genes in Atlantic salmon (Salmo salar) reveals expression differences between the two adult life stages but little impact from polychlorinated biphenyl (PCB) load. *Molecular and Cellular Endocrinology,* 400(C), 10-20. https://doi.org/10.1016/j.mce.2014.11.009

Estrogen receptors (ers) not only are activated by hormones but also interact with many humanderived environmental contaminants. Here, we present evidence for four expressed er genes in Atlantic salmon cDNA two more ers (er alpha 2 and er beta 2) than previously published. To determine if er gene expression differs between two adult life-stages we sampled 20 adult salmon from the feeding phase in the Baltic Sea and during migration in the River Morrum, Sweden. Results show that all four er genes are present in the investigated tissues, except for er alpha 2 not appearing in the spleen. Overall, a profile analysis reveals the er alpha 1 gene to be the most highly expressed er gene in both female and male Baltic Sea salmon tissues, and also in female River Morrum salmon. In contrast, this gene has the lowest gene expression level of the four er genes in male salmon from the River Morrum. The er alpha 2 gene is expressed at the lowest levels in both female/male Baltic Sea salmon and in female River Morrum salmon. Statistical analyses indicate a significant and complex interaction where both sex and adult life stage can impact er gene expression. Regression analyses did not demonstrate any significant relationship between polychlorinated biphenyl (PCB) body burden and er gene expression level, suggesting that accumulated pollutants from the Baltic Sea may be deactivated inside the salmon's lipid tissues and have limited impact on er activity. This study is the first comprehensive analysis of four er gene expression levels in two wild salmon populations from two different adult life stages where information about PCB load is also available.

Olsvik, P. A., Urke, H. A., Nilsen, T. O., Ulvund, J. B., & Kristensen, T. (2015). Effects of mining chemicals on fish: exposure to tailings containing Lilaflot D817M induces CYP1A transcription in Atlantic salmon smolt. *BMC research notes,* 8(1), 389-389. https://doi.org/10.1186/s13104-015-1342-2

Mine tailings, containing metals and production chemicals such as flotation chemicals and flocculants, may pose an environmental threat to aquatic organisms living in downstream ecosystems. The aim of this work was to study to which degree Lilaflot D817M, a flotation chemical extensively used by the mining industry, represents a hazard for migrating salmon in rivers affected by mining activity. Smoltifying Atlantic salmon were exposed to four concentrations of iron-ore mine tailings containing residual Lilaflot D817M [water versus tailing volumes of 0.002 (Low), 0.004 (Medium), 0.013 (High) and

0.04 (Max)]. After 96 h of exposure, gill and liver tissues were harvested for transcriptional responses. Target genes included markers for oxidative stress, detoxification, apoptosis and DNA repair, cell signaling and growth. Of the 16 evaluated markers, significant transcriptional responses of exposure to tailings enriched with Lilaflot D817M were observed for CYP1A, HSP70 and HMOX1 in liver tissue and CYP1A in gill tissue. The significant induction of CYP1A in both liver and gills suggest that the flotation chemical is taken up by the fish and activates cytochrome P450 detoxification via phase I biotransformation in the cells. The overall weak transcriptional responses to short-term exposure to Lilaflot D817M-containing iron-ore tailings suggest that the mining chemical has relatively low toxic effect on fish. The underlying mechanisms behind the observed CYP1A induction should be studied further.

Otero, J., L'Abee-Lund, J. H., Castro-Santos, T., Leonardsson, K., Storvik, G. O., Jonsson, B., . . . Vollestad, L. A. (2014). Basin-scale phenology and effects of climate variability on global timing of initial seaward migration of Atlantic salmon (Salmo salar). *Global Change Biology,* 20(1), 61-75. https://doi.org/10.1111/gcb.12363

Migrations between different habitats are key events in the lives of many organisms. Such movements involve annually recurring travel over long distances usually triggered by seasonal changes in the environment. Often, the migration is associated with travel to or from reproduction areas to regions of growth. Young anadromous Atlantic salmon (Salmo salar) emigrate from freshwater nursery areas during spring and early summer to feed and grow in the North Atlantic Ocean. The transition from the freshwater (parr') stage to the migratory stage where they descend streams and enter salt water (smolt') is characterized by morphological, physiological and behavioural changes where the timing of this parr-smolt transition is cued by photoperiod and water temperature. Environmental conditions in the freshwater habitat control the downstream migration and contribute to within- and among-river variation in migratory timing. Moreover, the timing of the freshwater emigration has likely evolved to meet environmental conditions in the ocean as these affect growth and survival of the post-smolts. Using generalized additive mixed-effects modelling, we analysed spatio-temporal variations in the dates of downstream smolt migration in 67 rivers throughout the North Atlantic during the last five decades and found that migrations were earlier in populations in the east than the west. After accounting for this spatial effect, the initiation of the downstream migration among rivers was positively associated with freshwater temperatures, up to about 10 degrees C and levelling off at higher values, and with sea-surface temperatures. Earlier migration occurred when river discharge levels were low but increasing. On average, the initiation of the smolt seaward migration has occurred 2.5days earlier per decade throughout the basin of the North Atlantic. This shift in phenology matches changes in air, river, and ocean temperatures, suggesting that Atlantic salmon emigration is responding to the current global climate changes.

Piou, C., & Prevost, E. (2013). Contrasting effects of climate change in continental vs. oceanic environments on population persistence and microevolution of Atlantic salmon. *Global Change Biology,* 19(3), 711-723. https://doi.org/10.1111/gcb.12085

Facing climate change (CC), species are prone to multiple modifications in their environment that can lead to extinction, migration or adaptation. Identifying the role and interplay of different potential

stressors becomes a key question. Anadromous fishes will be exposed to both river and oceanic habitat changes. For Atlantic salmon, the river water temperature, river flow and oceanic growth conditions appear as three main stressing factors. They could act on population dynamics or as selective forces on life-history pathways. Using an individual-based demo-genetic model, we assessed the effects of these factors (1) to compare risks of extinction resulting from CC in river and ocean, and (2) to assess CC effects on life-history pathways including the evolution of underlying genetic control of phenotypic plasticity. We focused on Atlantic salmon populations from Southern Europe for a time horizon of three decades. We showed that CC in river alone should not lead to extinction of Southern European salmon populations. In contrast, the reduced oceanic growth appeared as a significant threat for population persistence. An increase in river flow amplitude increased the risk of local extinction in synergy with the oceanic effects, but river temperature rise reduced this risk. In terms of life-history modifications, the reduced oceanic growth increased the age of return of individuals through plastic and genetic responses. The river temperature rise increased the proportion of sexually mature parr, but the genetic evolution of the maturation threshold lowered the maturation rate of male parr. This was identified as a case of environmentally driven plastic response that masked an underlying evolutionary response of plasticity going in the opposite direction. We concluded that to counteract oceanic effects, river flow management represented the sole potential force to reduce the extinction probability of Atlantic salmon populations in Southern Europe, although this might not impede changes in migration life history.

Robinson, C. D., Robinson, N., Redshaw, J., & Davies, I. M. (2008). Assessment of oestrogenic endocrine disruption in wild scottish salmon and trout. *FRS collaborative/contract reports*(01), 37. Retrieved from https://web.archive.org/web/20160616021049/http://www.gov.scot/Uploads/Documents/Coll0108.pdf

A previous scoping report highlighted the requirement to assess whether fish in Scottish rivers may be exposed to endocrine disrupting (oestrogenic) substances as has been found in English rivers. Various potential endocrine-disrupting pressures on Scottish rivers were identified and characterised through preliminary risk assessment (e.g. wastewater treatment works discharges). A number of sites suitable for fish sampling were identified in order to investigate the effects of such exposure on salmonid fish. It is known that laboratory exposure of anadromous fish to oestrogens can affect smoltification, migration, and salt-water survival. Wild brown trout (Salmo trutta) and Atlantic salmon parr (Salmo salar) were collected from five of the candidate sites in mid-September to mid-October 2006 and blood plasma concentrations of vitellogenin (Vtg) protein were assayed using a commercially available enzyme linked immuno-sorbent assay (ELISA). Vtg protein is naturally produced by maturing female fish and is produced by male fish exposed to oestrogenic contaminants. Significantly elevated Vtg concentrations were found in male Atlantic salmon collected from one site located downstream of a secondary (activated sludge) wastewater treatment works (WWTW) discharge. Although the sample size was small (n=7), this indicates that these fish were exposed to oestrogenic compounds. The scientific literature suggests that steroid hormones are likely to form the main oestrogenic component of the effluent discharge, although other weakly oestrogenic compounds may also be present. The blood plasma Vtg concentrations of the male Atlantic salmon sampled downstream of the discharge (925 plus or minus 1072 ng/ml) were approximately 30-times higher than those recorded in salmon sampled upstream of it. Similar levels of Vtg induction have been reported in rainbow trout caged within English rivers receiving WWTW effluent, although higher induction levels were found close to outfalls in those studies; levels of

induction in other wild fish studies are higher than those reported here. Brown trout collected from below a second WWTW (biological filtration) discharge and from an area of intensive dairy agriculture did not exhibit elevated plasma Vtg concentrations. Further work is recommended to assess the nature and extent of the oestrogenic contamination at the site where elevated Vtg was measured and to investigate whether oestrogenic substances are present at other sites highlighted in the risk assessment (but not included in this survey). There is also a need to investigate whether oestrogenic contamination is present in Scottish freshwater environments that do not support wild populations of salmonid fish. This study shows that some wild Scottish salmon exhibit symptoms typical of those induced by exposure to oestrogenic contaminants. The effect of such environmental exposure on smoltification and migration of wild fish populations is unclear and warrants investigation.

Russell, I. C., Aprahamian, M. W., Barry, J., Davidson, I. C., Fiske, P., Ibbotson, A. T., . . . Todd, C. D. (2012). The influence of the freshwater environment and the biological characteristics of Atlantic salmon smolts on their subsequent marine survival. *ICES Journal of Marine Science,* 69(9), 1563-1573. https://doi.org/10.1093/icesjms/fsr208

Atlantic salmon have declined markedly in the past 20-30 years throughout their range. Much of the focus for this decline has been on increased mortality during the marine phase of the life cycle. However, marine mortality does not operate independently of factors acting in freshwater and the biological characteristics of smolts migrating to sea. Over recent decades, juvenile salmon in many rivers have grown faster and migrated to sea at a younger age, so have been typically smaller than earlier. This has shortened the generation time for many individuals and may dampen the impact of increased marine mortality, assuming that expected higher in-river survival prior to smolting is not outweighed by increased mortality of smaller smolts at sea. Over the same period, smolt run-timing across the geographic range has been earlier, at an average rate of almost 3 d per decade. This has given rise to growing concerns about smolts potentially missing the optimum environmental migration "window", the timing of which may also be changing. Contaminants and other factors operating in freshwater also impact smolt quality with adverse consequences for their physiological readiness for life at sea. Given that managers have very limited ability to influence the broad scale factors limiting salmon survival at sea, it is vital that freshwater habitats are managed to both maximize the smolt output and to minimize the impact of factors acting in freshwater that may compromise salmon once they migrate to sea.

Saltveit, S. J., & Brabrand, A. (2013). Incubation, hatching and survival of eggs of Atlantic salmon (Salmo salar) in spawning redds influenced by groundwater. *Limnologica,* 43(5), 325-331. https://doi.org/10.1016/j.limno.2013.05.009

Many west coastal and northern Norwegian rivers run through deep, confined valleys with permeable layers of glacial and alluvial deposits. Groundwater flows through these permeable layers and enter lakes and rivers as underwater seepage and springs. Groundwater inflow to inland Norwegian rivers may constitute 40-100% of total water discharge during low flow periods in late summer and winter. Juvenile salmonids may take advantage of groundwater upwellings and actively seek out such patches. In regulated rivers groundwater influx may create refuges during low flow or hydropeaking episodes. The importance of groundwater for salmon redd site selection and egg survival is also clear, although less known and documented in regulated rivers. Eggs of Atlantic salmon (Salmo salar) are deposited in redds

in river bed gravels lacking fine sediments and with high oxygen levels. Egg development is therefore dependent on the interaction of a number of environmental factors such as groundwater influx, oxygen and temperature. Atlantic salmon in the regulated River Suldalslagen, Western Norway, spawn relatively late compared to other Norwegian rivers, with a peak in early January. Newly emerged fry are found from the end of May to the beginning of June, i.e. "swim up" one month earlier than expected using models for egg and alevin development and river water temperatures. The most plausible explanation is that groundwater has a higher and more stable temperature than surface river water. In field experiments, fertilized salmon eggs were placed in boxes close to natural spawning redds in the river bed at sites influenced and those not influenced by groundwater. A difference of up to 40 days in 50% hatching was found, and "swim up" occurred at the end of May in boxes influenced by groundwater. Preliminary studies have revealed that groundwater also plays an important role in survival of salmon eggs in the River Suldalslagen when dewatered in winter. Eggs placed in boxes in groundwater seepage areas during winter in the dewatered river bed survived even when covered by ice and snow. The survival from fertilization until 30 April, one month before hatching, was 91%, the same survival as found for eggs placed in boxes in the wetted river bed. However, mortality from fertilization to hatching was higher compared to the eggs placed in wetted river bed, 57 and 91% respectively. Groundwater creates a horizontal and vertical mosaic of temperatures in spawning redd areas leading to potentially greater variation in spawning sites, time of hatching and "swim up". This is likely to increase egg survival during low flow periods in regulated rivers. In conclusion, the interaction between groundwater and surface river water should therefore be considered when managing fish populations in regulated rivers.

Sauliute, G., & Svecevicius, G. (2017). Heavy Metals (Zn, Cu, Ni, Cr, Pb, Cd) In Water And Body Tissues Of Young Atlantic Salmon Salmo Salar In Two Rivers Of Different Pollution Level: A Comparison With Fish Condition Parameters. *Fresenius Environmental Bulletin,* 26(1A), 666-673. Retrieved from https://www.prt-parlar.de/download_feb_2017/

Relationship between priority heavy metal (Zn, Cu, Ni, Cr, Pb, Cd) concentration in water, their content in main body tissues (gills, liver, kidneys and muscle) and condition parameters [condition factor (CF), branchio-, hepato-, reno- and viscero-somatic indices (BSI, HSI, RSI and VSI), respectively] of Atlantic salmon smolts at the same age (1+ year) in two hydrologically similar but of different pollution level salmonid rivers of Lithuania (Vilnia and Siesartis) was investigated. Evident relation between heavy metal concentration in site water and fish tissue levels was determined. The well-being of fish from unpolluted site was significantly higher in comparison with those from polluted site: their CF and VSI were lower, while BSI was higher (had enlarged gills) indicating toxic effects of pollution. Condition factor was the most informative among parameters studied, followed by BSI and VSI, which could be successfully used in the monitoring of young Atlantic salmon river population state and environmental risk assessment.

Sauterleute, J. F., Hedger, R. D., Hauer, C., Pulg, U., Skoglund, H., Sundt-Hansen, L. E., . . . Ugedal, O. (2016). Modelling the effects of stranding on the Atlantic salmon population in the Dale River, Norway. *Science of The Total Environment,* 573, 574-584. https://doi.org/10.1016/j.scitotenv.2016.08.080

Rapid dewatering in rivers as a consequence of hydropower operations may cause stranding of juvenile fish and have a negative impact on fish populations. We implemented stranding into an Atlantic salmon population model in order to evaluate long-term effects on the population in the Dale River, Western Norway. Furthermore, we assessed the sensitivity of the stranding model to dewatered area in comparison-to biological parameters, and compared different methods for calculating wetted area, the main abiotic input parameter to the population model. Five scenarios were simulated dependent on fish life-stage, season and light level. Our simulation results showed largest negative effect on the population abundance for hydropeaking during winter daylight Salmon smolt production had highest sensitivity to the stranding mortality of older juvenile fish, Suggesting that stranding of fish at these life-stages is likely to have greater population impacts than that of earlier life-stages. Downstream retention effects on the ramping velocity were found to be negligible in the stranding model, but are suggested to be important in the context of mitigation measure design.

Sear, D. A., Jones, J. I., Collins, A. L., Hulin, A., Burke, N., Bateman, S., . . . Naden, P. S. (2016). Does fine sediment source as well as quantity affect salmonid embryo mortality and development? *Science of The Total Environment,* 541, 957-968. https://doi.org/10.1016/j.scitotenv.2015.09.155

Fine sediments are known to be an important cause of increased mortality in benthic spawning fish. To date, most of the research has focussed on the relationship between embryo mortality and the quantity of fine sediment accumulated in the egg pocket. However, recent evidence suggests a) that the source of fine sediment might also be important, and b) that fitness of surviving embryos post-hatch might also be impacted by the accumulation of fine sediments. In this paper, we report an experiment designed to simulate the incubation environment of brown trout (Salmo trutta) and Atlantic salmon (Salmo salar). During the experiment, the incubating embryos were exposed to different quantities of fine (<63 mu m) sediment derived from four different sources; agricultural topsoils, damaged road verges, eroding river channel banks and tertiary level treated sewage. Results showed that mass and source are independently important for determining the mortality and fitness of alevin. Differences between species were observed, such that brown trout are less sensitive to mass and source of accumulated sediment. We demonstrate for the first time that sediment source is an additional control on the impact of fine sediment, and that this is primarily controlled by the organic matter content and oxygen consumption of the catchment source material.

Sheehan, T. F., Reddin, D. G., Chaput, G., & Renkawitz, M. D. (2012). SALSEA North America: a pelagic ecosystem survey targeting Atlantic salmon in the Northwest Atlantic. *ICES Journal of Marine Science,* 69(9), 1580-1588. https://doi.org/10.1093/icesjms/fss052

Pelagic ecosystem surveys were conducted in the Labrador Sea during 2008 and 2009 as part of SALSEA North America. In total, 107 Atlantic salmon (Salmo salar) were captured using a pelagic surface trawl and multipanel surface gillnets. Surface trawling provided a broad spatial sampling of the fish and

macroinvertebrate communities in the upper 10 m of the water column, but caught few salmon (23). Gillnetting was more effective at capturing post-smolt (60) and adult (24) salmon. Multiple smolt cohorts were captured, indicating that post-smolts and returning adults from different rivers in North America have similar autumnal habitat requirements. Post-smolts were caught at night and in water temperatures exceeding 10 degrees C, both novel results. Post-smolts and adults consumed similar and diverse prey species, although Themisto compressa was the most important prey item. Intestinal macroparasite loads were substantial and could be a significant source of mortality. Concurrent planktonic assemblage and oceanographic conditions were also quantified. A full exploration of these data, historical datasets, and parallel data collected during SALSEA Greenland and SALSEA-Merge will further understanding of the ecology of marine-phase Atlantic salmon and inform investigations into stock-specific differences in marine productivity.

Simmons, O. M., Gregory, S. D., Gillingham, P. K., Riley, W. D., Scott, L. J., & Britton, J. R. (2021). Biological and environmental influences on the migration phenology of Atlantic salmon *Salmo salar* smolts in a chalk stream in southern England. *Freshwater Biology,* 66(8), 1581-1594. https://doi.org/10.1111/fwb.13776

Migration enables animals to access important resources throughout their lifetime but exists in a trade-off with elevated mortality risk. In spring, juvenile Atlantic salmon (smolts) migrate from their natal rivers for marine feeding grounds, with the timing of their marine entry a potentially important determinant of their long-term survival. However, there is relatively little known on how the interaction of biological and environmental factors affect smolt migration phenology at the individual level, and how these vary throughout the duration of the smolt seaward migration (run). Using 15-year tag, recapture, and detection datasets of individual smolts (marked with passive integrated transponder tags) from a chalk stream in southern England, the influences of a range of biological and environmental variables were tested on the run timing of individual smolts, measured as the timing of their arrival in a lower river reach. The probability of smolts arriving earlier in the lower river reach was elevated following winters that were relatively warm, and when there were larger positive daily changes in water temperature and discharge during the run. Early migrants tended to be larger individuals and from sites lower in the catchment, from where the smolts had to migrate relatively shorter distances. Later migrants were more likely to migrate in schools, but with schooling behaviour also more likely to occur during daylight than at night. The relative influence of some of these variables altered throughout the run. Relative changes in daily water temperature were not important during the middle period of the smolt run but were important at the start and end of the run. Relative changes in daily discharge were most influential towards the end of the run, when even relatively small changes in discharge had a strong influence on migration. These results reveal the importance of a wide range of biological and environmental variables on the phenology of smolt migrations, and how their influence can alter throughout the run. With predictions of annually increasing river temperatures, more frequent and intense discharge events, and associated shifts to earlier migration, these results emphasise that such changes in climate are likely to have substantial consequences on the future success of smolt migrations and thereby future numbers of returning adult spawners.

Soto, D. X., Trueman, C. N., Samways, K. M., Dadswell, M. J., & Cunjak, R. A. (2018). Ocean warming cannot explain synchronous declines in North American Atlantic salmon populations. *Marine Ecology Progress Series,* 601, 203-213. https://doi.org/10.3354/meps12674

Atlantic salmon Salmo salar populations have suffered global, synchronous declines over the past decades. These declines are coincident with improvements in river habitats and reductions in high seas fisheries, implying higher rates of natural marine mortality that have been widely linked to increasing ocean temperatures in the North Atlantic. The mechanisms linking temperature to marine mortality in Atlantic salmon, however, are unclear. During the period 1980-2010, populations of S. salar returning to the St. John River, New Brunswick, Canada, after spending either 1 or multiple winters at sea have shown similar patterns of decline, coincident with recent ocean warming in the North Atlantic Ocean. Here we used stable isotope data from historic scale collections to investigate the relationship between foraging location, experienced ocean temperature and population trends for S. salar returning to the St. John River. We show that salmon spending either 1 or multiple winters at sea before returning to the St. John River consistently fed in different regions of the North Atlantic and experienced different ocean warming trends. However, both cohorts show synchronous progressive population declines over the study period. We therefore suggest that ocean warming cannot be the principal cause of increased marine mortality for salmon returning to the St. John River. Both cohorts experience similar conditions during the initial post-smolt period, and increased post-smolt mortality could underpin population declines. Our results support concentrating management and conservation efforts to reduce mortality in the post-smolt phase of salmon lifecycles.

Stenberg, S. K., Velle, G., Pulg, U., & Skoglund, H. (2022). Acute effects of gas supersaturation on Atlantic salmon smolt in two Norwegian rivers. *Hydrobiologia,* 849(2), 527-538. https://doi.org/10.1007/s10750-020-04439-z

Total dissolved gas (TDG) supersaturation downstream of hydropower plants may cause gas bubble disease (GBD) and harmful effects in fish. Little is known about tolerance levels of TDG supersaturation on Atlantic salmon (Salmo salar Linnaeus, 1758) in natural rivers. The present study investigated the effects of TDG supersaturation on the survival of Atlantic salmon smolts at two field sites in Norway. Here, we kept smolts in cages at increasing distances from hydropower plants known to cause TDG supersaturation and at control sites. We recorded fish mortality and examined for GBD using a stereo microscope. Mortality and symptoms of GBD commenced in fish exposed to an average of 108.3% TDG (maximum 111.0%, water depth 0.55 m) for 2 days. Significant differences in time before mortality at the control sites and test sites commenced at 110.2% TDG (maximum 111.8%) for 3 days. The study indicates that Atlantic salmon may be more vulnerable to TDG supersaturation than Pacific salmonids, which are considered at risk when the TDG is above 110%. In addition, the study provides important data to link effects caused by TDG in the laboratory and in the field.

Stephansen, D. A., Svendsen, T. C., Vorkamp, K., & Frier, J.-O. (2011). Changes in patterns of persistent halogenated compounds through a pelagic food web in the Baltic Sea. *Marine Environmental Research,* 73, 17-24. https://doi.org/10.1016/j.marenvres.2011.10.006

The concentrations and patterns of persistent halogenated compounds (PHCs), including polychlorinated biphenyls (PCBs), DDT, hexachlorocyclohexanes (HCHs), hexachlorobenzene (HCB) and

polybrominated diphenyl ethers (PBDEs) were examined in a pelagic food web from the southern Baltic Sea consisting of sediment, zooplankton, sprat, Atlantic salmon and anadromous brown trout. Lipid-normalized concentrations generally increased from low trophic levels to high trophic levels, with the exception of HCHs. Due to high concentrations of PBDEs in some zooplankton samples, biomagnification of BDE-47 was only observed for salmon/sprat and trout/sprat. Sprat collected individually and from salmon stomach had significantly different lipid-normalized concentrations and varied in their PHC pattern as well, possibly indicating a large natural variation within the Baltic Sea. The highest lipid-normalized concentrations were found in brown trout. Salmon and brown trout were similar in their PHC pattern suggesting similar food sources. Variation in PHC patterns among trophic levels was not smaller than that among geographically distinct locations, confirming the importance of comparable trophic levels for the assessment of PHC patterns, e.g. for tracing migratory fish.

Sterud, E., Forseth, T., Ugedal, O., Poppe, T. T., Jorgensen, A., Bruheim, T., . . . Mo, T. A. (2007). Severe mortality in wild Atlantic salmon *Salmo salar* due to proliferative kidney disease (PKD) caused by *Tetracapsuloides bryosalmonae* (Myxozoa). *Diseases of Aquatic Organisms,* 77(3), 191-198. https://doi.org/10.3354/dao01846

Extensive mortality in Atlantic salmon fry was reported in the River Aelva from 2002 to 2004. Dead fish were collected in late summer 2006, and live fish were sampled by electrofishing in September the same year. At autopsy and in histological sections, the fish kidneys were found to be pale and considerably enlarged. Proliferative lesions with characteristic PKX cells were seen in a majority of the fish. DNA from kidney samples of diseased fish was subjected to PCR and sequencing, and the amplified sequences matched those of Tetracapsuloides bryosalmonae. We concluded that this myxozoan transmitted from bryozoans was the main cause of the observed mortality in salmon fry in 2006. Results from quantitative electrofishing in 2005 and 2006, combined with the observed fry mortality from 2002 to 2004, show that the smolt production in the river is severely reduced and that T bryosalmonae is the most likely explanation for this decline. The present study is the first to report a considerable negative population effect in wild Atlantic salmon due to proliferative kidney disease (PKD). It also represents the northernmost PKD outbreak in wild fish. The river is regulated for hydroelectric power purposes, causing reduced water flow and elevated summer temperatures, and the present PKD outbreak may serve as an example of increased disease vulnerability of northern fish populations in a warmer climate.

Strand, J. E. T., Davidsen, J. G., Jorgensen, E. H., & Rikardsen, A. H. (2011). Seaward migrating Atlantic salmon smolts with low levels of gill Na+, K+ -ATPase activity; is sea entry delayed? *Environmental Biology of Fishes,* 90(3), 317-321. https://doi.org/10.1007/s10641-010-9737-3

Two groups of migrating wild Atlantic salmon (Salmo salar) smolts caught within a 1 week interval in the River Alta, northern Norway, were tagged with acoustic transmitters and measured for gill Na+, K+ -ATPase activity in order to compare their smolt status with timing of sea entry. The first group of smolts had low levels of gill Na+, K+ -ATPase activity and resided in the lower part of the river twice as long as the second group that had high levels of gill Na+, K+ -ATPase activity. This indicates that early migrating smolts may not be completely physiologically adapted for salt water and delay their sea entry, thereby also synchronizing their seaward migration with the later migrating smolts.

Svendsen, T. C., Vorkamp, K., Ronsholdt, B., & Frier, J. O. (2008). Retrospective determination of primary feeding areas of Atlantic salmon (Salmo salar) using fingerprinting of chlorinated organic contaminants. *ICES Journal of Marine Science,* 65(6), 921-929. https://doi.org/10.1093/icesjms/fsn071

Atlantic salmon (Salmo salar) undertake extensive marine migrations. In the marine environment, the Atlantic salmon appears to suffer from heavy mortality, indicating the need for increased knowledge of its movements and habitat use at sea. Persistent organo-chlorine compounds (OCs) are found in measurable concentrations in all marine ecosystems. Geographically varying sources of OCs, transport, and transformation processes lead to different OC concentrations and compositions in the various ecosystems. As the principal source of organochlorine uptake in salmon is diet, populations utilizing different feeding areas may accumulate pollutant loads corresponding to their primary feeding areas. This hypothesis was tested by comparing the OC composition in Atlantic salmon from four locations: Lake Vattern (Sweden), Lake Vanern (Sweden), the Baltic Sea (off Denmark), and the River Imsa (Norway). Muscle and liver samples from each fish were analysed for 30 organochlorines (polychlorinated biphenyls, dichlorodiphenyltrichloroethanes, HCHs, hexachlorobenzene, and trans-nonachlor). Principal component analysis on normalized OC concentrations (OC pattern) showed separation of the salmon populations according to location; contaminant patterns were similar for liver and muscle tissue. It is therefore suggested that OC fingerprinting may be a valuable tool in identifying primary foraging areas of salmonids.

Todd, C. D., Hughes, S. L., Marshall, C. T., Maclean, J. C., Lonergan, M. E., & Biuw, E. M. (2008). Detrimental effects of recent ocean surface warming on growth condition of Atlantic salmon. *Global Change Biology,* 14(5), 958-970. https://doi.org/10.1111/j.1365-2486.2007.01522.x

Ocean climate impacts on survivorship and growth of Atlantic salmon are complex, but still poorly understood. Stock abundances have declined over the past three decades and 1992-2006 has seen widespread sea surface temperature (SST) warming of the NE Atlantic, including the foraging areas exploited by salmon of southern European origin. Salmon cease feeding on return migration, and here we express the final growth condition of year-classes of one-sea winter adults at, or just before, freshwater re-entry as the predicted weight at standard length. Two independent 14-year time series for a single river stock and for mixed, multiple stocks revealed almost identical temporal patterns in growth condition variation, and an overall trend decrease of 11-14% over the past decade. Growth condition has fallen as SST anomaly has risen, and for each year-class the midwinter (January) SST anomalies they experienced at sea correlated negatively with their final condition on migratory return during the subsequent summer months. Stored lipids are crucial for survival and for the prespawning provisioning of eggs in freshwater, and we show that under-weight individuals have disproportionately low reserves. The poorest condition fish (similar to 30% under-weight) returned with lipid stores reduced by similar to 80%. This study concurs with previous analyses of other North Atlantic top consumers (e.g. somatic condition of tuna, reproductive failure of seabirds) showing evidence of major, recent climate-driven changes in the eastern North Atlantic pelagic ecosystem, and the likely importance of bottom-up control processes. Because salmon abundances presently remain at historical lows, fecundity of recent year-classes will have been increasingly compromised. Measures of year-class growth condition should therefore be incorporated in the analysis and setting of numerical spawning escapements for threatened stocks, and conservation limits should be revised upwards conservatively during periods of excessive ocean climate warming.

Trueman, C. N., MacKenzie, K. M., & Palmer, M. R. (2012). Stable isotopes reveal linkages between ocean climate, plankton community dynamics, and survival of two populations of Atlantic salmon (Salmo salar). *ICES Journal of Marine Science,* 69(5), 784-794. https://doi.org/10.1093/icesjms/fss066

Trueman, C. N., MacKenzie, K. M., and Palmer, M. R. 2012. Stable isotopes reveal linkages between ocean climate, plankton community dynamics, and survival of two populations of Atlantic salmon (Salmo salar). – ICES Journal of Marine Science, 69: 784–794. An 18-year record of stable isotopes from Atlantic salmon (Salmo salar) migrating to two different regions of the North Atlantic reveals climate-driven subdecadal variations. Time-series of carbon isotopes in one salmon stock, thought to feed in the Faroes/Iceland Basin area, show Subpolar Gyre (SPG) modal variability, which is not seen in fish feeding in the Norwegian Sea. At times of weak SPG circulation, when waters in the Iceland Basin are relatively warm, carbon isotope values are somewhat negative, suggesting possible changes in phytoplankton community structure. The fluctuations in plankton community dynamics suggested by the stable isotope values are coincident with fluctuations in the estimates of marine mortality in one sea-winter fish feeding in the Norwegian Sea, but not in those feeding in the Iceland Basin. Marine mortality in salmon feeding in the Iceland Basin is therefore likely to be more strongly influenced by factors other than bottom–up control. Time-series analysis of stable isotopes in consumer tissues provides information on the interaction between climate and ecosystem dynamics on the scale of individual stocks and cohorts.

Urke, H. A., Koksvik, J., Arnekleiv, J. V., Hindar, K., Kroglund, F., & Kristensen, T. (2010). Seawater tolerance in Atlantic salmon, *Salmo salar L.*, brown trout, *Salmo trutta L.*, and *S. salar* x *S. trutta* hybrids smolt. *Fish Physiology and Biochemistry,* 36(4), 845-853. https://doi.org/10.1007/s10695-009-9359-x

High levels of hybridization between Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) have been reported in the Gyrodactylus salaris infected Rivers Vefsna and Driva in Norway The survival and behaviour during the sea phase of such hybrids is unknown The reported work documents ionoregulatory status after 24 h seawater challenge tests (24hSW) and gill Na+/K+-ATPase (NKA) activity of migrating wild smolts of Atlantic salmon, brown trout and hybrids at two sampling dates during the 2006 smolt run in River Driva Salmon, trout and hybrids contributed to 27, 52 and 21% of the catches, respectively The large contribution of hybrids suggests both a high hybridization rate and a high survival rate from fry to smolt Both salmon and hybrids had a well-developed seawater tolerance at the time of downstream migration, revealed by small ionoregulatory effects and no or low mortality rates during the 24hSW tests The trout were not fully adapted to seawater, and high mortality rates were observed (71 and 92%) during the 24hSW tests The NKA activity was not significantly different between salmon and hybrids Most of the hybrids were physiologically capable of direct entry to full strength seawater The incomplete seawater tolerance in trout compared to salmon corresponds well with differences in life-history patterns between these two species The life history strategy of the hybrids during the sea phase is not known, and further investigations on the marine behaviour and survival is needed to evaluate the role of hybrids in the risk of spreading G salaris to nearby river systems.

Van Leeuwen, T. E., Dempson, B., Cote, D., Kelly, N. I., & Bates, A. E. (2021). Catchability of Atlantic salmon at high water temperatures: Implications for river closure temperature thresholds to catch and release angling. *Fisheries Management and Ecology,* 28(2), 147-157. https://doi.org/10.1111/fme.12464

Warming water temperatures, combined with increased mortality following catch and release, could have synergistic consequences if rivers remain open to catch and release at high water temperatures, and catchability of fish remains similar across water temperatures. Here archived data for Atlantic salmon, Salmo salar L., were used to (a) quantify the influence of water temperature on catchability and (b) refine estimates of absolute catch and release mortality to incorporate the relationship between temperature and catchability. A significant decline in the number of Atlantic salmon caught at warmer water temperatures was found after accounting for the effects of river water height, fishing effort, run duration and year-to-year differences in fish abundance. Overall, absolute catch and release mortalities were predicted to be infrequent at cool river temperatures. At river temperatures sometimes associated with fishing closures, mortality due to the catch and release ranged from 6% to 14%. Although post-release mortality increases with water temperature, it is somewhat compensated by the reduced catchability of Atlantic salmon. Thus, the catchability component of catch and release is an integral consideration when evaluating the effectiveness of river closure temperature thresholds when managing catch and release angling.

Van Leeuwen, T. E., Dempson, J. B., Burke, C. M., Kelly, N. I., Robertson, M. J., Lennox, R. J., . . . Bates, A. E. (2020). *Influence of water temperature on mortality of Atlantic Salmon after catch and release angling.* Retrieved from https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40925900.pdf

Average global air temperature has increased in recent decades resulting in accompanying changes in river temperatures. Poikilotherms, like Atlantic Salmon (Salmo salar L.), are vulnerable to temperature fluctuations. At the same time, many Atlantic Salmon populations are subject to catch and release angling. Catch and release mortality is influenced by angler practices and water temperature. Because Atlantic Salmon are commonly caught by anglers during the warmest months, angled fish can be exposed to physiologically stressful and potentially lethal water temperatures. Here we test interactions between river warming and mortality in recreational Atlantic Salmon fisheries. We first quantify the range of mortality rates observed at a given water temperature for caught and released Atlantic Salmon by compiling and analyzing published and unpublished data on catch and release mortality. We then focus on the region of Newfoundland and Labrador, Canada, and provide mortality estimates for caught and released Atlantic Salmon on an individual river basis by combining estimates for number of caught and released salmon from angler survey data with river temperature data. Lastly we update and compare regional and temporal trends (~61978 to 2018) for river temperatures and river closures due to high water temperatures and/or low water levels.

Vollset, K. W., Skoglund, H., Wiers, T., & Barlaup, B. T. (2016). Effects of hydropeaking on the spawning behaviour of Atlantic salmon *Salmo salar* and brown trout *Salmo trutta*. *Journal of Fish Biology,* 88(6), 2236-2250. https://doi.org/10.1111/jfb.12985

An in situ camera set-up was used to study the spawning activity of Atlantic salmon Salmo salar and brown trout Salmo trutta throughout two consecutive seasons in a spawning area affected by hydropower-related pulse flows due to hydropeaking. The purpose was to test whether the flow variation discouraged spawning in shallow areas or motivated spawning into areas with elevated risk of incubation mortality. There were more S. salar observed on the spawning ground during days with high discharge. The presence of S. salar in the spawning grounds was not affected by the hydropeaking cycles of the preceding night. Female S. salar were observed preparing nests within the first hour after water discharge had increased to levels suitable for spawning. In contrast, the number of S. trutta was not correlated with flow and nest preparation was also observed at a discharge corresponding to the lowest discharge levels during a hydropeaking cycle. Survival was generally high in nests excavated the following winter, with only 5·4% suffering mortality due to dewatering. The results suggest that S. salar may respond rapidly to variable-flow conditions and utilize short windows with suitable flows for spawning. Smaller S. trutta may utilize low-flow conditions to spawn in areas that are not habitable by larger S. salar during low flow.

Vorobyov, V. (2022). Anthropogenic impact on populations of Atlantic salmon (Salmo salar L.) in the Arctic basin of the Russian Federation. *Fisheries,* 2022(5), 34-46. https://doi.org/10.37663/0131-6184-2022-5-34-46

The global problems of anthropogenic impact on the planet Earth and marine ecosystems, pollution in the 21st century of the World Ocean, including the Arctic seas, negatively affecting the reproduction of marine biological resources are considered. For more than half a century, the intensively developing exploitation of the bioresources of the World Ocean shelf has led to a de-crease in the number of mammals, fish, mollusks, crustaceans, algae and other valuable aquatic organisms. In many developed countries, due to economic activity and industrial pollution of coastal territories, there is a depression in the number and a de-crease in intraspecific diversity, due to the loss of populations of passing marine "wild" Atlantic salmon and other aquatic organ-isms. Since the late 1980s, natural Atlantic salmon stocks have declined significantly. In the main spawning rivers of the Murmansk region, the content of pollutants in the spring is marked on the scale as high and extremely high levels of pollution. The oxygen content and water quality in rivers decrease, the number of saprophytic bacteria increases, the species diversity of zoo-plankton and phytoplankton decreases. Diseases and death of populations of spawning Atlantic salmon occur. A program has been developed to comprehensively investigate the causes of mass disease and death of Atlantic salmon populations, and to de-velop measures to restore a genetically healthy salmon population in the Arctic region of Russia.

Vuorinen, P. J., Keinänen, M., Kiviranta, H., Koistinen, J., Kiljunen, M., Myllylä, T., . . . Karjalainen, J. (2012). Biomagnification of organohalogens in Atlantic salmon (Salmo salar) from its main prey species in three areas of the Baltic Sea. *Science of The Total Environment,* 421, 129-143. https://doi.org/10.1016/j.scitotenv.2012.02.002

Factors affecting the biomagnification of organohalogens in Baltic salmon from sprat, herring and three-spined stickleback were assessed in three feeding areas. Second sea-year salmon contained (in fresh weight of whole fish) 79-250ngg(-1) polychlorinated biphenyls (ΣPCB), 0.9-2.7pgg(-1) dibenzo-p-dioxins (ΣPCDD), 8-19pgg(-1) dibenzofurans (ΣPCDF), 96-246pgg(-1) coplanar PCBs, 2.4-3.6ngg(-1) polybrominated diphenylethers (ΣPBDE), and 39-136ngg(-1) Σ(indicator) PCB6. The EU limits for WHO toxic equivalent concentrations in fish feed were already exceeded in one-year-old sprat and herring and were exceeded many-fold in older age groups. The differences in the biomagnification rates of organohalogens in salmon appeared to be related to the feeding area, principal prey species, and the fat content and growth rate of the prey species.

Vuorinen, P. J., Kiviranta, H., Koistinen, J., Pöyhönen, O., Ikonen, E., & Keinänen, M. (2013). Organohalogen concentrations and feeding status in Atlantic salmon (Salmo salar L.) of the Baltic Sea during the spawning run. *Science of The Total Environment,* 468, 449-456. https://doi.org/10.1016/j.scitotenv.2013.08.075

Changes in the concentrations of polychlorinated dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs), and biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) in Baltic salmon muscle were studied during the spawning migration from the southern Baltic Sea to rivers flowing into the northern Gulf of Bothnia and during the spawning period. The aim was to obtain information to facilitate the arrangement of salmon fisheries such that the human dioxin intake is taken into account. The EC maximum allowable total toxic equivalent concentration (WHO-TEQPCDD/F+PCB) was exceeded in the muscle of the majority of the migrating salmon, except in the Baltic Proper. The fresh-weight-based concentrations of all toxicant groups in salmon tended to be the lowest in the Baltic Proper and the Northern Quark, and all toxicant concentrations, except PCDDs and PCDFs, were significantly higher in the spawning salmon than in the salmon caught during the spawning run. The fat content of the salmon muscle decreased by 60% during the spawning run, and the lipid-based total toxicant concentrations were consequently 4.2-6.2 times higher during the spawning period than during the spawning migration. However, the toxicants were concentrated just before spawning, and thus there is no essential difference related to whether the salmon are caught in the sea or the recreational river fishery.

Vuorinen, P. J., Rokka, M., Ritvanen, T., Käkelä, R., Nikonen, S., Pakarinen, T., & Keinänen, M. (2020). Changes in thiamine concentrations, fatty acid composition, and some other lipid-related biochemical indices in Baltic Sea Atlantic salmon (Salmo salar) during the spawning run and pre-spawning fasting. *Helgoland Marine Research,* 74(1), 10. https://doi.org/10.1186/s10152-020-00542-9

Salmonines in the Baltic Sea and North American lakes suffer from thiamine (vitamin B1) deficiency, which is connected to an abundant lipid-rich diet containing substantial amounts of polyunsaturated fatty acids (PUFAs). In the Baltic region, this is known as the M74 syndrome. It affects both adult salmon (Salmo salar) and especially their offspring, impairing recruitment. However, very little is known about

the thiamine and lipid metabolism of salmon during feeding and spawning migrations in the Baltic Sea. In this study, salmon females were sampled along the spawning run from the southern Baltic Proper in four locations at sea and finally at spawning in a river at the Bothnian Bay in a year with insignificant M74 mortality. Changes in concentrations of thiamine and its components in muscle, ovaries, and the liver and other biochemical indices potentially relating to lipid and fatty acid metabolism were investigated. The results provide further evidence of the role of peroxidation of PUFAs in eliciting thiamine deficiency in salmon: During the entire spawning run, the muscle total lipid content decreased by 50%, palmitic acid (16:0) by 62%, and docosahexaenoic acid (DHA, 22:6n-3) by 45%. The concentration of total thiamine decreased significantly until the spawning in the liver and ovaries, 66 and 70% respectively. In the muscle, the proportion of thiamine pyrophosphate of total thiamine increased with the use of muscular lipid stores. There was no trend in the concentration of total carotenoids during the spawning run. The doubling of the concentration of hepatic malondialdehyde indicated peroxidation of PUFAs, and the mobilisation of body lipids suppressed the activity of glucose-6-phosphate dehydrogenase, as consumed dietary lipids would also have done.

Yazdani, M., Andresen, A. M. S., & Gjoen, T. (2016). Short-term effect of bisphenol-a on oxidative stress responses in Atlantic salmon kidney cell line: a transcriptional study. *Toxicology Mechanisms and Methods,* 26(4), 295-300. https://doi.org/10.1080/15376516.2016.1177864

Bisphenol A (BPA) is regularly detected in aquatic ecosystems due to increased use of products based on polycarbonate plastics and epoxy resins. It migrates from these products directly into rivers and marine waters or indirectly through effluents from wastewater treatment plants and landfilled sites. BPA can affect aquatic organisms both chronically and acutely at sensitive live stages. Despite reports indicating harmful effects of BPA, little is known about its role in oxidative stress responses in fish. In this study, we investigated the transcriptional effect of BPA (0, 1, 10, 100 mu M) on an Atlantic salmon kidney (ASK) cell line for 6 h and 24 h by monitoring expression of 11 genes: elongation factor 1-alpha (ef1a), 18S ribosomal RNA (18s), gluthation (gsh), superoxide dismutase (sod), thioredoxin (txd), Salmo salar oxidative stress-responsive serine-rich 1 (oxr), glucose-regulated protein 78 (grp78), heat shock protein 70 (hsp70), sequestosome1 (p62), interleukin-1 beta (il-1beta) and toll-like receptor 8 (tlr8). In general, only the 100 mu M concentration treatment altered the mRNA expression. BPA down-regulated the expression of gsh and sod genes for both exposure-times while txd gene was the only down-regulated after 6-h exposure. The up-regulation of genes in the ASK cell line exposed for 6 h was only observed in il-1beta, while the 24-h exposure resulted in the up-regulation of oxr, tlr8, hsp70, p62 and il-1beta genes. The last three genes increased several fold compared to the others. The results showed that BPA exposure at 100 mu M imposed oxidative stress on the ASK cell line and longer exposure time involved transcriptional responses of immune-related genes. This may indicate the possible role of BPA-associated oxidative stress in induction of inflammatory response in this macrophage-like cell type.

Section 4: Blueback Herring (Alosa aestivalis)

Bowlby, H. D. (2016). *Quantitative recovery planning: understanding how human activities in watersheds can influence population dynamics and genetic structuring of diadromous fishes.* (Ph.D.), Memorial University, Retrieved from https://research.library.mun.ca/12529/

Developing quantitative relationships that link human-induced environmental change with changes in population dynamics for species of conservation concern is hindered by: (1) a limited understanding of the cumulative effect (and relative importance) of population regulation, spatial dynamics, and demographic processes, (2) issues with detectability for species-environment interactions owing to data characteristics and (3) the cumulative or confounding nature of multiple threats. Taking a single-species approach based on endangered Atlantic salmon, I have partially addressed these challenges in my four research chapters. In chapter two, I characterized the conditions under which metapopulation structure would be expected to benefit a population assemblage and found that straying can reduce abundance and heighten extinction risk when productivity is low. For species of conservation concern, I would expect that remediation actions designed to influence demographic rates (e.g. mortality rates) would be more beneficial than actions influencing spatial dynamics. In chapter three, I accounted for the effects of observation and measurement error when quantifying relationships between hydrological variation and survival. Beyond the potential to change our interpretation of ecological relationships, I was able to infer the types of threats affecting juveniles in specific watersheds. In chapter four, I used patterns of effective dispersal to surmise the behavioural mechanism leading to watershed choice among straying adult salmon as well as the relative importance of multiple concurrent threats. My conclusions contradict some current perceptions on threats and suggest new directions for future research. In chapter five, I was able to develop a spatial tool that could inform management decisions or identify priority areas for restoration efforts. However, I was unable to fully characterize how environmental variation influences habitat utilization, distribution patterns, or population-level responses to human activities at multiple spatial extents. The relationships I describe are among the first to be developed for endangered Atlantic salmon in Nova Scotia at a population level. Several of the analyses represent novel applications to conservation questions and have the potential to be extended or more widely applied. Because freshwater fishes, including diadromous fishes, are collectively one of the most imperiled species groups in the world, such research represents a timely contribution to conservation biology.

de Eyto, E., Kelly, S., Rogan, G., French, A., Cooney, J., Murphy, M., . . . Poole, R. (2022). Decadal Trends in the Migration Phenology of Diadromous Fishes Native to the Burrishoole Catchment, Ireland. *Frontiers in Ecology and Evolution,* 10. https://doi.org/10.3389/fevo.2022.915854

Migration is an important ecological trait that allows animals to exploit resources in different habitats, obtaining extra energy for growth and reproduction. The phenology (or timing) of migration is a highly heritable trait, but is also controlled by environmental factors. Numerous studies have reported the advancement of species life-events with climate change, but the rate and significance of such advancement is likely to be species specific, spatially variable and dependent on interactions with population and ecosystem changes. This is particularly true for diadromous fishes which are sentinels of change in both freshwater and marine domains, and are subject to considerable multiple stressors including overfishing and habitat degradation. Here, we describe trends in the migration phenology of three native Irish migratory fishes over half a century, Atlantic salmon (Salmo salar), brown trout (Salmo trutta) and European eel (Anguilla anguilla). The trends were derived from daily counts of 745,263 fish

moving upstream and downstream through the fish traps of the Burrishoole catchment, an internationally important monitoring infrastructure allowing a full census of migrating fish. We found that the start of the seaward migration of eel has advanced by one month since 1970. The commencement of the salmon smolt migration has advanced by one week, although the rest of the migration, and the entirety of the trout smolt run has remained stable. The beginning of the upstream migration of trout to freshwater has advanced by 20 days, while the end of the run is more than one month later than in the 1970's. The greatest phenological shift has been in the upstream migration of adult salmon, with at least half of migrating fish returning between one and two months earlier from the marine environment compared to the 1970's. The earlier return of these salmon is coincident with reduced marine survival and decreasing body size, indicating considerable oceanic challenges for this species. Our results demonstrate that the impacts of climate change on the phenology of diadromous fish are context-dependent and may interact with other factors. The mobilization of long-term datasets are crucial to parse the ecological impacts of climate change from other anthropogenic stresses.

Ezzard, A. D. (2017). *Early Life History Of Larval River Herring In A Coastal Watershed: Abundance, Growth, And Mortality.* (Master's), East Carolina University, Retrieved from https://thescholarship.ecu.edu/handle/10342/6540

River herring are two closely-related, anadromous fish species, Alewife (Alosa aestivalis) and Blueback Herring (A. pseudoharengus), which have been historically, commercially, and ecologically important along the North American Atlantic coast for hundreds of years. However, recent decades have been marked by their dramatic population declines and a collapse of the fishery. Historical records show that the coastal watershed of North Carolina's Chowan River was an epicenter for river herring harvest and spawning from pre-1700 through the late 1980s. I spatiotemporally characterized the early life history of river herring larvae in the Chowan River and its tributaries in the spring spawning season of 2011 by calculating larval abundance, growth, mortality, and diet relative to water quality and chemistry. Results show that the Chowan River and its tributaries supported relatively high numbers of river herring larvae in 2011 compared to an early 1980s study, with mean catches per unit effort (CPUEs) ranging from 52.87 + 71.68 larvae/100 m3 to 1583.53 + 2698.18 larvae/100 m3 compared to a similar and neighboring riverine system - the Roanoke River - with mean CPUEs ranging from 4.1 + 20.9 larvae/100 m3 in 2008 to 30.8 + 149.8 larvae/100 m3 from a study in 2009. A concurrent study to my research indicated that larval river herring diets are very similar between the adjacent systems, consisting primarily of copepods and rotifers in both the lower Chowan and the lower Roanoke River. Also, analyses of abundance, growth rates, and mortality rates suggest that density-dependent mechanisms likely control larval river herring trends throughout the Chowan system. Although all nursery habitats are worthy of research and conservation efforts, the Chowan River has continually proved to be a regional epicenter for successful reproduction and early life history of river herring and, therefore, merits special attention as a Strategic Habitat Area (SHA) by the State of North Carolina.

Overton, A. S., Jones, N. A., & Rulifson, R. (2012). Spatial and Temporal Variability in Instantaneous Growth, Mortality, and Recruitment of Larval River Herring in Tar-Pamlico River, North Carolina. *Marine and Coastal Fisheries,* 4(1), 218-227. https://doi.org/10.1080/19425120.2012.675976

We estimated the variation in the instantaneous rates of growth and mortality between cohorts of larval alewife Alosa pseudoharengus and blueback herring A. aestivalis in the Tar-Pamlico River, Pamlico Sound, North Carolina. The age of larvae captured by push net was estimated by counting the daily rings on sagittal otoliths. Weight-at-age and abundance-at-age data were used to generate instantaneous daily growth (G) and mortality rates (M) for 7-d cohorts. The instantaneous daily growth rate was relatively constant between cohorts, ranging from 0.103 to 0.277 for alewives and from 0.105 to 0.200 for blueback herring. The instantaneous daily mortality rate was more variable between cohorts, ranging from 0.064 to 0.270 for alewives and from 0.100 to 0.251 for blueback herring. All but one blueback herring cohort had an M/G value exceeding 1.0, indicating that these cohorts were losing biomass during the early larval stage. For alewives, M/G values were more variable, with 50% of the cohorts having values less than 1.0. The effect of habitat was consistent between species, with M/G values being higher and closer to 1.0 at sites in tributary creeks and backwater areas of Tar River. The overall M/G values were 0.57 for alewives and 1.60 for blueback herring from both backwater and main-channel sites, indicating that the environmental conditions in the Tar-Pamlico River are more favorable for alewives.

Riley, K. L. P. (2012). *Recruitment of Estuarine-Dependent Alosines to Roanoke River and Albemarle Sound, North Carolina.* (Ph.D.), East Carolina University, Retrieved from https://thescholarship.ecu.edu/handle/10342/3867

The deleterious effects of dams on alosine populations are widely documented in many rivers along the Atlantic coast. Alterations to the natural hydrologic regime can disrupt spawning egg dispersal and recruitment of larvae to nursery habitats. The goal of this study was to investigate the ecological processes that influence recruitment of river herring (blueback herring Alosa aestivalis and alewife A. pseudoharengus) to nursery habitats within lower Roanoke River and Albemarle Sound North Carolina. It was hypothesized that variability in abiotic conditions and fluctuations in food abundance could structure nursery habitat and severely restrict recruitment. Ichthyoplankton and zooplankton samples were collected concurrently March through June 2008-09 at 19 stations within three areas: River Delta and Sound. Significant spatial and temporal differences were observed for river herring abundances. Abundances (number/100m^3 ± SD) were significantly higher in 2009 (30.8 ± 149.8) than in 2008 (4.1 ± 20.9). Across both years abundances within the River (21.0 ± 127.6) were significantly higher than those in Delta (7.4 ± 35.4) and Sound (4.6 ± 24.8). Yolk-sac larvae were prevalent throughout samples (32%); however larvae collected were predominantly preflexion stage (66%). Fish ages ranged from 4 to 19 days after hatch. Growth rates were similar for blueback herring (0.29 ± 0.16 mm/d) and alewife (0.30 ± 0.14 mm/d). Growth estimates were indicative of habitat quality and suggested riverine habitats supported the highest growth rates. Mortality estimates for blueback herring (0.76 ± 0.23 per day) were significantly higher than mortality estimates for alewife (0.64 ± 0.17 per day). High mortality for both years was probably related to larval dispersal and advective loss. Larvae do not appear to be food limited in this system as indicated by diet analyses and the spatiotemporal overlap between river herring and zooplankton. Decreasing zooplankton abundance was correlated with larval abundance and suggests foraging by larval alosines could negatively alter the structure of the zooplankton community. Diets varied little with early ontogeny and the smallest taxa (copepod nauplii and rotifers) accounted for

over 85% of the diet. Because of a high-level of dietary overlap intraspecific and interspecific competition is substantial for anadromous alosines. The result of long-term data analysis (1984 - 2009) for larval and juvenile river herring confirms Roanoke-Albemarle stocks are in decline. Larval fish abundance was negatively affected by spring river flow ($r^2 = 0.62$). High flows (> 300 m^3/s) resulted in larval advection from Roanoke River. Spring river flow was positively correlated with juvenile abundance ($r = 0.95$) and best recruitment of juveniles occurs in years with moderate spring river flow (141 - 311 m^3/s).

Waters, C. T., & Hightower, J. E. (2007). *Effect of Water Quality on Hatching Success of Blueback Herring Eggs in the Chowan River Basin, North Carolina.* Paper presented at the Annual Conference, Southeastern Association of Fish and Wildlife Agencies. Retrieved from http://www.lib.ncsu.edu/resolver/1840.2/2245

River herring (alewife (Alosa pseudoharengus) and blueback herring (A. aestivalis)) within the Albemarle Sound basin in North Carolina once supported large commercial fisheries that have declined dramatically since the 1970s. Overfishing, poor water quality, and habitat loss have been sug- gested as causes of this decline. The objective of this study was to examine the effect of water quality on the hatching success of blueback herring eggs in the Chowan River, a major tributary to Albemarle Sound. We combined eggs and milt obtained from running-ripe fish and placed incubators contain- ing fertilized eggs at 11 sites throughout the basin. Mean hatch rates at field sites ranged from 26% to 89%, compared to a mean of 92% for control trials carried out using distilled water. An analysis of covariance indicated that hatch rates were significantly related to the dissolved oxygen level and were lower at sites on smaller tributaries when compared to sites on the mainstem of the Chowan River. Of the water quality parameters for which published standards exist, dissolved oxygen was the only one not within documented levels for normal development of blueback herring eggs. Given the relatively high hatch rates at most sites, we conclude that mortality of blueback herring eggs due to poor water quality is unlikely to account for the declines in abundance that have been observed.

Section 5: Shortnose Sturgeon (Acipenser brevirostrum)

Cope, W. G., Holliman, F. M., Kwak, T. J., Oakley, N. C., Lazaro, P. R., Shea, D., . . . Ware, K. M. (2011). Assessing water quality suitability for shortnose sturgeon in the Roanoke River, North Carolina, USA with an in situ bioassay approach. *Journal of Applied Ichthyology,* 27(1), 1-12. https://doi.org/10.1111/j.1439-0426.2010.01570.x

P>The aim of this study was to determine the suitability of water quality in the Roanoke River of North Carolina for supporting shortnose sturgeon Acipenser brevirostrum, an endangered species in the United States. Fathead minnows Pimephales promelas were also evaluated alongside the sturgeon as a comparative species to measure potential differences in fish survival, growth, contaminant accumulation, and histopathology in a 28-day in situ toxicity test. Captively propagated juvenile shortnose sturgeon (total length 49 +/- 8 mm, mean +/- SD) and fathead minnows (total length 39 +/- 3 mm, mean +/- SD) were used in the test and their outcomes were compared to simultaneous measurements of water quality (temperature, dissolved oxygen, pH, conductivity, total ammonia nitrogen, hardness, alkalinity, turbidity) and contaminant chemistry (metals, polycyclic aromatic hydrocarbons, organochlorine pesticides, current use pesticides, polychlorinated biphenyls) in river water and sediment. In the in situ test, there were three non-riverine control sites and eight riverine test sites with three replicate cages (25 x 15-cm (OD) clear plexiglass with 200-mu m tear-resistant Nitex (R) screen over each end) of 20 shortnose sturgeon per cage at each site. There was a single cage of fathead minnows also deployed at each site alongside the sturgeon cages. Survival of caged shortnose sturgeon among the riverine sites averaged 9% (range 1.7-25%) on day 22 of the 28-day study, whereas sturgeon survival at the non-riverine control sites averaged 64% (range 33-98%). In contrast to sturgeon, only one riverine deployed fathead minnow died (average 99.4% survival) over the 28-day test period and none of the control fathead minnows died. Although chemical analyses revealed the presence of retene (7-isopropyl-1-methylphenanthrene), a pulp and paper mill derived compound with known dioxin-like toxicity to early life stages of fish, in significant quantities in the water (251-603 ng L-1) and sediment (up to 5000 ng g-1 dry weight) at several river sites, no correlation was detected of adverse water quality conditions or measured contaminant concentrations to the poor survival of sturgeon among riverine test sites. Histopathology analysis determined that the mortality of the river deployed shortnose sturgeon was likely due to liver and kidney lesions from an unknown agent(s). Given the poor survival of shortnose sturgeon (9%) and high survival of fathead minnows (99.4%) at the riverine test sites, our study indicates that conditions in the Roanoke River are incongruous with the needs of juvenile shortnose sturgeon and that fathead minnows, commonly used standard toxicity test organisms, do not adequately predict the sensitivity of shortnose sturgeon. Therefore, additional research is needed to help identify specific limiting factors and management actions for the enhancement and recovery of this imperiled fish species.

Farrae, D. J., Albeke, S. E., Pacifici, K., Nibbelink, N. P., & Peterson, D. L. (2014). Assessing the influence of habitat quality on movements of the endangered shortnose sturgeon. *Environmental Biology of Fishes,* 97(6), 691-699. https://doi.org/10.1007/s10641-013-0170-2

Movements of the endangered shortnose sturgeon Acipenser brevirostrum in the Ogeechee River (Georgia, USA) may be limited by unsuitable habitat conditions during June-September. The research objective was to determine if habitat quality is likely to impede movements and spawning of shortnose sturgeon in this system. We inserted ultrasonic transmitters in 18 adult shortnose sturgeon to monitor

their monthly in-stream movements. Water quality data were collected at discrete locations along the Ogeechee River. We used geostatistical models based on Weighted Asymmetric Hydrologic Distance, in place of Euclidean distance, to predict water quality variables along the Ogeechee River, avoiding problems associated with linear distance metrics in a river network. Using ArcGIS, we constructed habitat quality models based on physiological tolerance to water temperature, dissolved oxygen, and salinity. During the summer months, tagged fish remained congregated above the fresh-saltwater interface. However, individuals appeared to move in response to changing water quality conditions. Seasonal habitat availability in other southern rivers should be similarly analyzed to assess potential relationships between the habitat and sturgeon movements. Although further laboratory and field studies are needed to better understand latitudinal variation in life history and environmental tolerances of shortnose sturgeon, the results of our study suggest that temporal and spatial variability in water quality affect habitat availability of southern populations of shortnose sturgeon.

Fire, S. E., Pruden, J., Couture, D., Wang, Z. H., Bottein, M. Y. D., Haynes, B. L., . . . Wippelhauser, G. (2012). Saxitoxin exposure in an endangered fish: association of a shortnose sturgeon mortality event with a harmful algal bloom. *Marine Ecology Progress Series,* 460, 145-153. https://doi.org/10.3354/meps09768

Saxitoxin (STX)-producing blooms of the toxic dinoflagellate genus Alexandrium have been responsible for devastating ecosystem-wide impacts in coastal waters of the northeastern USA. In the summer of 2009, a severe Alexandrium bloom in New England coastal waters co-occurred with a shortnose sturgeon Acipenser brevirostrum mortality event in Sagadahoc Bay, Maine, USA. Thirteen individuals of this endangered fish species were found dead on 10 July 2009, and this die-off was associated with extremely high Alexandrium cell densities, record-breaking toxin burdens (>80 000 ng g(-1)) in shellfish, and closures of shellfish beds affecting nearly the entire Maine coastline. STX-like activity was detected in sturgeon (n = 3) stomach contents and liver and gill tissues via neuroblastoma assay and receptor-binding assay at concentrations ranging between 37 and 2300 ng STX-eq. g(-1) (STX equivalents per gram sample). Stomach content analyses of the 3 necropsied sturgeon carcasses showed a large number of amethyst gem clams Gemma gemma. Liquid chromatography-mass spectrometry confirmed the presence of STX and related congeners in sturgeon stomach contents, at concentrations between 311 and 743 ng g(-1). The present study marks the first reported detection of STXs in shortnose sturgeon, and provides evidence of trophic transfer of Alexandrium toxins as a potential cause of mortality in this event, as well as a threat to the health of this endangered population of fish.

Matsche, M. A., & Gibbons, J. (2012). Annual variation of hematology and plasma chemistry in shortnose sturgeon, *Acipenser brevirostrum*, during a dam-impeded spawning run. *Fish Physiology and Biochemistry,* 38(6), 1679-1696. https://doi.org/10.1007/s10695-012-9664-7

Shortnose sturgeon (Acipenser brevirostrum) spawning migrations on the Cooper River are impeded by Pinopolis Dam, Lake Moultrie, South Carolina. Sturgeon and other species aggregate below the dam in late winter/early spring and are subjected to a variety of stressors stemming from crowding, poor habitat quality, and injuries that appear to be caused by boat propeller or turbine strikes. Spawning has been documented in the tailrace, but reproductive success has not been verified as no juveniles have been captured. Fish within the dam tailrace were captured by gill net during winter, 2005 and 2007–

2011, and physiological condition was assessed using a panel of hematologic and biochemical indices. Plasma phosphorus and calcium were significantly higher in females, while PCV and aspartate aminotransferase were significantly higher in males, indicating sex-specific physiological changes triggered during maturity. A marked leucopenia, accompanied by lymphopenia and neutrophilia, was evident in both sexes and was consistent across years, indicating that these fish were under chronic stress. Testosterone and estradiol levels and hematologic and biochemical reference intervals are provided for comparative purposes.

Roy, N. K., Candelmo, A., DellaTorre, M., Chambers, R. C., Nádas, A., & Wirgin, I. (2018). Characterization of AHR2 and CYP1A expression in Atlantic sturgeon and shortnose sturgeon treated with coplanar PCBs and TCDD. *Aquatic Toxicology,* 197, 19-31. https://doi.org/10.1016/j.aquatox.2018.01.017

Atlantic sturgeon and shortnose sturgeon co-occur in many estuaries along the Atlantic Coast of North America. Both species are protected under the U.S. Endangered Species Act and internationally on the IUCN Red list and by CITES. Early life-stages of both sturgeons may be exposed to persistent aromatic hydrocarbon contaminants such as PCBs and PCDD/Fs which are at high levels in the sediments of impacted spawning rivers. Our objective was to compare the PCBs and TCDD sensitivities of both species with those of other fishes and to determine if environmental concentrations of these contaminants approach those that induce toxicity to their young life-stages under controlled laboratory conditions. Because our previous studies suggested that young life-stages of North American sturgeons are among the more sensitive of fishes to coplanar PCB and TCDD-induced toxicities, we were interested in identifying the molecular bases of this vulnerability. It is known that activation of the aryl hydrocarbon receptor 2 (AHR2) in fishes mediates most toxicities to these contaminants and transcriptional activation of xenobiotic metabolizing enzymes such as cytochrome P4501A (CYP1A). Previous studies demonstrated that structural and functional variations in AHRs are the bases for differing sensitivities of several vertebrate taxa to aromatic hydrocarbons. Therefore, in this study we characterized AHR2 and its expression in both sturgeons as an initial step in understanding the mechanistic bases of their sensitivities to these contaminants. We also used CYP1A expression as an endpoint to develop Toxicity Equivalency Factors (TEFs) for these sturgeons. We found that critical amino acid residues in the ligand binding domain of AHR2 in both sturgeons were identical to those of the aromatic hydrocarbon-sensitive white sturgeon, and differed from the less sensitive lake sturgeon. AHR2 expression was induced by TCDD (up to 6-fold) and by three of four tested coplanar PCB congeners (3–5-fold) in Atlantic sturgeon, but less so in shortnose sturgeon. We found that expression of AHR2 and CYP1A mRNA significantly covaried after exposure to TCDD and PCB77, PCB81, PCB126, but not PCB169 in both sturgeons. We also determined TEFs for the four coplanar PCBs in shortnose sturgeon based on comparison of CYP1A mRNA expression across all doses. Surprisingly, the TEFs for all four coplanar PCBs in shortnose sturgeon were much higher (6.4–162 times) than previously adopted for fishes by the WHO.

Roy, N. K., Walker, N., Chambers, R. C., & Wirgin, I. (2011). Characterization and expression of cytochrome P4501A in Atlantic sturgeon and shortnose sturgeon experimentally exposed to coplanar PCB 126 and TCDD. *Aquatic Toxicology,* 104(1-2), 23-31. https://doi.org/10.1016/j.aquatox.2011.03.009

The AHR pathway activates transcription of CYP1A and mediates most toxic responses from exposure to halogenated aromatic hydrocarbon contaminants such as PCBs and PCDD/Fs. Therefore, expression of CYP1A is predictive of most higher level toxic responses from these chemicals. To date, no study had developed an assay to quantify CYP1A expression in any sturgeon species. We addressed this deficiency by partially characterizing CYP1A in Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus) and shortnose sturgeon (Acipenser brevirostrum) and then used derived sturgeon sequences to develop reverse transcriptase (RT)-PCR assays to quantify CYP1A mRNA expression in TCDD and PCB126 treated early life-stages of both species. Phylogenetic analysis of CYP1A, CYP1B, CYP1C and CYP3A deduced amino acid sequences from other fishes and sturgeons revealed that our putative Atlantic sturgeon and shortnose sturgeon CYP1A sequences most closely clustered with previously derived CYP1A sequences. We then used semi-quantitative and real-time RT-PCR to measure CYP1A mRNA levels in newly hatched Atlantic sturgeon and shortnose sturgeon larvae that were exposed to graded doses of waterborne PCB126 (0.01-1000 parts per billion (ppb)) and TCDD (0.001-10 ppb). We initially observed significant induction of CYP1A mRNA compared to vehicle control at the lowest doses of PCB126 and TCDD used, 0.01 ppb and 0.001 ppb, respectively. Significant induction was observed at all doses of both chemicals although lower expression was seen at the highest doses. We also compared CYP1A expression among tissues of i.p. injected shortnose sturgeon and found significant inducibility in heart, intestine, and liver, but not in blood, gill, or pectoral fin clips. For the first time, our results indicate that young life-stages of sturgeons are sensitive to AHR ligands at environmentally relevant concentrations, however, it is yet to be determined if induction of CYP1A can be used as a biomarker in environmental biomonitoring.

Section 6: Winter Flounder (Pseudopleuronectes americanus)

Cernadas-Martin, S., Rountos, K. J., Nye, J. A., Frisk, M. G., & Pikitch, E. K. (2021). Composition and Intraspecific Variability in Summer Flounder (Paralichthys dentatus) Diets in a Eutrophic Estuary. *Frontiers in Marine Science,* 8. https://doi.org/10.3389/fmars.2021.632751

This study assessed the diet of Summer flounder (SF, Paralichthys dentatus) in Shinnecock Bay, NY. Summer flounder are a recreationally and commercially important marine flatfish species found along the Eastern United States coastline. Despite their importance, few studies have examined the trophodynamics of a broad size spectrum of this species. Diet composition of summer flounder (n = 88) was assessed from 2014 to 2016 throughout Shinnecock Bay, a eutrophic bar-built estuary in New York. Species consumed and diet species richness differed significantly amongst SF size classes, with large [>= 375 mm total length (TL)] and medium (225: <375 mm) summer flounder showing higher levels of piscivory and more diverse diets than small-sized (<= 225 mm) conspecifics. As voracious plastic predators, trends in annual and monthly diet variation generally followed prey availability in Shinnecock Bay. One exception to this general pattern occurred for winter flounder (Pseudopleuronectes americanus). Despite their low relative abundance in the bay, winter flounder was highly preferred as prey by summer flounder (Chesson index, alpha = 0.35) and was their predominant prey item accounting for 12.3% (SD +/- 3.9%) of the diet by weight. Other factors that explained the variability of the diet of summer flounder were year, month, dissolved oxygen concentration, bay region and habitat, with a cumulative variance of 10.3%. Interestingly, clear differences in the diet (i.e., species richness and abundance) of summer flounder were found within regions of Shinnecock Bay, with a decrease in teleost biomass and species richness observed in the western region where water quality is more degraded and less seagrass is available compared to the more pristine eastern region. Distinct trophic dynamics in degraded habitats suggests fundamentally different food webs that could have important consequences to ecosystem stability and resilience. As coastal areas continue to experience degradation, diet studies of economically and ecologically important species can aid in the development of effective ecosystem-based management plans.

Dolan, T. E., McElroy, A. E., Cerrato, R., Hice-Dunton, L. A., Fede, C., & Frisk, M. G. (2021). Winter Flounder Navigate the Postsettlement Gauntlet with a Bet-Hedging Strategy. *Marine and Coastal Fisheries,* 13(5), 435-449. https://doi.org/10.1002/mcf2.10168

Winter Flounder Pseudopleuronectes americanus, a coastal flatfish species of historically economic and cultural importance, have declined throughout the past few decades within the southern New England and mid-Atlantic region of the United States, reaching a low point of less than 9% of their historic biomass in 2009. Unusually high postsettlement mortality is thought to impose a critical recruitment bottleneck on the population, potentially stalling recovery of Winter Flounder populations despite management measures. Survival and growth during early life history play a key role in the recruitment dynamics of marine fishes. Spatiotemporal differences in these vital rates from young-of-the-year (i.e., age-0) Winter Flounder have been variously linked to environmental gradients, anthropogenic stressors, differences in the timing of settlement, and location. To better understand local declines in recruitment productivity, we assessed vital rates of age-0 Winter Flounder in five different bays in Long Island, New York. A weekly or biweekly beam-trawl survey targeting age-0 Winter Flounder was implemented over five summers. We compared survey-based estimates of age-0 mortality and growth, finding significant differences between locations in growth but not mortality. A consistently high abundance of age-0

Winter Flounder in Shinnecock Bay and Mattituck Creek was prolonged by a secondary settlement pulse later in the season. Hypothesizing that multiple settlement pulses are a bet-hedging strategy against temporally varying environmental conditions, we compared mortality, growth, and occupied habitat conditions between settlement pulses (cohorts), finding differences in growth and habitat occupancy that varied across years.

Klein, E. S., Smith, S. L., & Kritzer, J. P. (2017). Effects of climate change on four New England groundfish species. *Reviews in Fish Biology and Fisheries,* 27(2), 317-338. https://doi.org/10.1007/s11160-016-9444-z

Multiple groundfish stocks in New England remain depleted despite management measures that have been effective elsewhere. A growing body of research suggests that environmental change driven by increasing concentrations of carbon dioxide in the atmosphere and ocean is unfolding more rapidly in New England than elsewhere, and is an important factor in the failure of these stocks to respond to management. We reviewed research on effects of changes in temperature, salinity, dissolved oxygen, pH, and ocean currents on pelagic life stages, post-settlement life stages, and reproduction of four species in the New England groundfish fishery: Atlantic cod (Gadus morhua), haddock (Melanogrammus aeglefinus), winter flounder (Pseudopleuronectes americanus), and yellowtail flounder (Limanda ferruginea). The volume of research on cod was nearly equal to that on the other three species combined. Similarly, many more studies examined effects of temperature than other factors. The majority of studies suggest adverse outcomes, with less evidence for mixed or positive effects. However, for all of the factors other than temperature, there are more knowledge gaps than known effects. Importantly, most work to date examines impacts in isolation, but effects might combine in nonlinear ways and cause stronger reductions in stock productivity than expected. Management strategies will need to account for known effects, nonlinear interactions, and uncertainties if fisheries in New England are to adapt to environmental change.

Kopec, A. D., Kidd, K. A., Fisher, N. S., Bowen, M., Francis, C., Payne, K., & Bodaly, R. A. (2019). Spatial and temporal trends of mercury in the aquatic food web of the lower Penobscot River, Maine, USA, affected by a chlor-alkali plant. *Science of The Total Environment,* 649, 770-791. https://doi.org/10.1016/j.scitotenv.2018.08.203

Mercury (Hg) concentrations in aquatic biota, including fish and shellfish, were measured over the period 2006-2012 in the lower Penobscot River and upper estuary (Maine, USA). The Penobscot is a system contaminated with Hg by a chlor-alkali plant that operated from 1967 to 2000, discharging 6-12 tons of mercury into the river. Mercury levels in aquatic biota were highest at sites downstream of the chlor-alkali plant and spatial trends were similar to those of sediments. Mean total Hg concentrations in fish muscle (adjusted for size or age) in the most affected areas were 521 (480, 566; 95% CI) ng/g ww in American eels, 321 (261,395) in mummichog, 121 (104, 140) in rainbow smelt, 155 (142,169) in tomcod, 55.2 (42.7,71.4) in winter flounder, and 328 (259,413) in American lobster tail and 522 (488,557) ng/g dw in blue mussel. Levels exceeded the 50 ng/g ww considered protective for piscivorous predators and were of concern for human health, with American eels and American lobster exceeding Maine's mercury action level of 200 ng/g ww. Calculations of trophic position (using nitrogen isotopes) suggested that the spatial patterns observed in total Hg concentrations were not due to changes in feeding habits of the

species. Fish feeding in benthic food webs, as defined by stomach content and stable carbon isotope analyses, showed no change in Hg concentrations over time. In contrast, declining trends in Hg were found in two species dependent on pelagic food webs. The absence of declines in Hg concentrations in the benthically-based food webs, despite the fact that most Hg was discharged into the system >40 years ago, is consistent with the long recovery predicted from dated sediment cores and from similar studies elsewhere.

Langan, J. A., Bell, R. J., & Collie, J. S. (2023). Taking stock: Is recovery of a depleted population possible in a changing climate? *Fisheries Oceanography,* 32(1), 15-27. https://doi.org/10.1111/fog.12599

As the impacts of climate change become more severe throughout the global oceans, fisheries managers will be increasingly challenged to rebuild stocks exhibiting declining productivity. In such cases, detailed knowledge of species life history will be necessary to both restrict harvest and manage other environmental conditions, where possible, that impact survivorship. A current example of these challenges, the Southern New England/Mid-Atlantic Bight winter flounder stock remains in a persistently depleted state due to a combination of past harvest and the effects of climate change mediated through increased predation. To explore the recovery capacity of a subpopulation of this stock, a life-cycle model was fit to 29 year classes of stage-specific winter flounder data from surveys conducted in Narragansett Bay, Rhode Island and used to project future subpopulation abundance. Supporting a prevailing hypothesis, the results indicated that environmental factors influencing juvenile mortality were largely responsible for inhibiting recovery. Furthermore, recovery of the subpopulation to past levels of abundance was determined to be unlikely even under optimistic future conditions resulting from aggressive management interventions. Taken together, the findings of this work pose important questions regarding the realism of assessing climate-challenged populations against biological reference points set under past environmental regimes and the degree to which harvest restrictions to promote recovery of such stocks should be allowed to limit warm-water fisheries thriving in a warming ocean.

Manderson, J., Pessutti, J., Shaheen, P., & Juanes, F. (2007). Dynamics of early juvenile winter flounder predation risk on a North West Atlantic estuarine nursery ground. *Marine Ecology Progress Series,* 328, 249-265. https://doi.org/10.3354/meps14178

In an effort to determine the characteristics of estuarine habitats suitable for early juvenile winter flounder Pseudopleuronectes americanus survivorship, we examined piscivorous fish distributions and diets, and flounder predation risk along estuarine gradients in the Navesink River/Sandy Hook Bay estuarine system, New Jersey, USA. Demersal fish, striped searobin Prionotus evolans and summer flounder Paralichthys dentatus, were more important predators of winter flounder than pelagic fish (Pomatomus saltatrix, Cynoscion regalis, Morone saxatilis) based on diet analysis of 4 yr of gill (1998 and 1999) and trammel net (2001 and 2002) fish collections. From April through June newly settled winter flounder 20ppt. Fish >20 mm standard length (SL) were consumed by summer flounder in shallow habitats in June and July. In May and June tethering experiments, Age-0 winter flounder predation risk was high in habitats with salinities >19ppt and temperatures >20 degree C. In 3 yr, salinities were 20ppt in upstream habitats where searobins ate large numbers of settling winter flounder and predation risk was high. These results suggest that the volume of estuarine habitat suitable for early juvenile flounder survivorship is determined, in part, by predator and prey responses to spatially dynamic physico-

chemical gradients. Because gradient dynamics are controlled by climate forcing, climate variation may cause nursery habitat volumes to contract or expand resulting in variation in the local production of Age-0 recruits.

Montie, E. W., Letcher, R. J., Reddy, C. M., Moore, M. J., Rubinstein, B., & Hahn, M. E. (2010). Brominated flame retardants and organochlorine contaminants in winter flounder, harp and hooded seals, and North Atlantic right whales from the Northwest Atlantic Ocean. *Marine Pollution Bulletin,* 60(8), 1160-1169. https://doi.org/10.1016/j.marpolbul.2010.04.002

Various brominated flame retardants (BFRs), including polybrominated diphenyl ethers (PBDEs) and current-use, non-PBDE BFRs, as well as organochlorine (OC) pesticides and polychlorinated biphenyls (PCBs), were measured in winter flounder, harp and hooded seals, and North Atlantic right whales from the Eastern United States and Canada. The concentrations of PBDEs in winter flounder and right whales were similar in magnitude to the levels of PCBs, which was unlike the pattern observed in seals. In these marine mammals, the levels of PBDEs were orders of magnitude lower than the levels of OCs and PCBs detected. Evidence existed for the accumulation of methoxylated (MeO)-PBDEs of natural origin in seals and right whales. Current-use, non-PBDE BFRs (including hexabromocyclododecane, pentabromoethylbenzene, hexabromobenzene, and pentabromotoluene) were detected in winter flounder and marine mammals. Future research should focus on monitoring PBDEs, current-use, non-PBDE BFRs, and MeO-BDEs of natural origin in marine organisms from Massachusetts and Cape Cod Bays.

Payne, E. J., & Taylor, D. L. (2010). Effects of Diet Composition and Trophic Structure on Mercury Bioaccumulation in Temperate Flatfishes. *Archives of Environmental Contamination and Toxicology,* 58(2), 431-443. https://doi.org/10.1007/s00244-009-9423-7

The summer flounder Paralichthys dentatus and winter flounder Pseudopleuronectes americanus support valuable fisheries along the northeastern United States. The importance of these flatfish as a human dietary resource indicates they are potential sources of mercury (Hg) to fish-consuming citizens. In this study, summer flounder (SF) and winter flounder (WF) were collected from the Narragansett Bay (Rhode Island, USA) and were measured for total Hg burden in whole-body or dorsal muscle tissue. Interspecies differences in Hg contamination were analyzed relative to flounder body size, age, and Hg content of preferred prey. Stable isotope signatures were also used to elucidate the effect of trophic processes on Hg accumulation in the estuarine food web. The mean Hg content of SF exceeded concentrations measured in WF across multiple life-history stages (0.039-0.100 and 0.016-0.029 mg Hg/kg wet weight for SF and WF, respectively), and observed values for both species were lower than the US Environmental Protection Agency regulatory threshold of 0.3 mg Hg/kg wet weight. Total Hg concentrations were also positively correlated with flounder age and length, verifying that both flatfish bioaccumulate Hg. SF accumulate Hg at an accelerated rate, however, owing to this species consuming Hg-enriched prey (teleosts, squid, and macrocrustaceans; mean Hg content = 0.023 mg Hg/kg wet weight), whereas WF feed on prey with low Hg levels (amphipods and polychaetes; mean Hg content = 0.013 mg Hg/kg wet weight). The positive correlation observed between mean biota Hg content and stable nitrogen (delta N-15) isotope signatures further indicates that Hg is trophically transferred through the food web, and higher trophic level organisms (i.e., enriched delta N-15) have increased Hg

concentrations. Therefore, results from this study suggest that dietary preference and trophic structure are the main factors affecting Hg bioaccumulation in the estuary. Total Hg concentrations of flatfish from the Narragansett Bay, however, do not necessarily reflect coastwide contamination patterns. This reinforces the importance of having research conducted at sufficiently small spatial scales, including the local assessment of Hg contamination for the purpose of issuing state consumption advisories.

Taylor, D. L., Cribari, K. J., & Scro, A. (2019). Piscivory in age-0 summer flounder Paralichthys dentatus with a focus on predator-induced mortality of post-settlement winter flounder Pseudopleuronectes americanus. *Marine Ecology Progress Series,* 612, 7-28. https://doi.org/10.3354/meps12885

We examined the piscivorous diet of age-0 summer flounder Paralichthys dentatus in southern New England tidal rivers, with a focus on their predatory impact on post-settlement winter flounder Pseudopleuronectes americanus. The population density, size-structure, and growth of age-0 summer flounder and winter flounder were evaluated in the Seekonk and Taunton Rivers (Rhode Island and Massachusetts, USA, respectively) between May and August/September 2009 through 2015. For a subsample of summer flounder collected during this time (20-181 mm total length, TL; n = 743), diet was assessed using direct visual analysis and PCR-based assays that detect winter flounder mitochondrial DNA within predator stomach contents. Summer flounder were generalist piscivores consuming 8 distinct fish prey taxa from both epibenthic and pelagic guilds. The most frequently observed fishes in the diet of summer flounder were age-0 winter flounder and herring (Clupeidae) with frequencies of occurrence, %F, of 2.6 and 2.0%, respectively, and overall %F of fish equal to 13.6%. Fish were absent in the stomachs of summer flounder <44 mm TL, beyond which piscivory increased significantly with increasing predator size. Summer flounder 50-153 mm TL preyed on winter flounder ranging from 19-54 mm TL, resulting in predator-to-prey size ratios of 2.2-3.6 (mean +/- SD = 2.8 +/- 0.3). Incidences of summer flounder predation on winter flounder were positively related to body size ratios, and this relationship was attributed to the enlarged mouth gape and improved prey capture abilities of larger predators. Summer flounder predation on fishes, including winter flounder, also demonstrated significant spatiotemporal variability, reflecting riverine and seasonal differences in flounder population size structure and dynamics in prey composition and availability. Deterministic model simulations estimated that age-0 summer flounder account for 0.7 % of the daily mortality of post-settlement winter flounder (range = 0.0-2.9%), and consumed 3.0% of the total winter flounder year-class annually (range = 0.0-12.8 %). Therefore, relative to other predatory fishes and decapod crustaceans, age-0 summer flounder likely have a nominal effect on winter flounder populations in tidal river nurseries. Summer flounder predation may be substantial, however, when multiple age-classes are considered and elevated age-0 summer flounder densities elicit a strong effect on winter flounder survival, albeit at local scales.

Taylor, D. L., Fehon, M. M., Cribari, K. J., & Scro, A. K. (2022). Blue crab *Callinectes sapidus* dietary habits and predation on juvenile winter flounder *Pseudopleuronectes americanus* in southern New England tidal rivers. *Marine Ecology Progress Series,* 681, 145-167. https://doi.org/10.3354/meps13909

Blue crabs Callinectes sapidus have expanded their geographic range northward in the NW Atlantic with possible trophodynamic effects on benthic communities. In this study, we examined the blue crab's diet

in 2 southern New England tidal rivers (USA) and expounded on their predator-prey interaction with juvenile winter flounder Pseudopleuronectes americanus. Blue crabs (8-185 mm carapace width [CW]; n = 1835) were collected from the Seekonk River, Rhode Island, and Taunton River, Massachusetts, between May and August 2012 to 2016, and their feeding habits were assessed via stomach content, stable isotope, and molecular genetic analyses. Blue crabs were found to be generalist carnivores-omnivores with diets varying throughout ontogeny, yet shifts in prey composition had no effect on size-based nitrogen isotope signatures and trophic position (3.50 +/- 0.35, mean +/- SD). Carbon isotope values indicated that detritus-macroalgae were the dominant carbon source to the food web, with additional contributions from terrestrially derived organic matter and phytoplankton in oligohaline and polyhaline waters, respectively. The main prey of blue crabs 549 mm CW were amphipods, shrimp, and unidentified crustaceans, and larger conspecifics fed on bivalves, crabs, and fish. Winter flounder remains, e.g. sagittal otoliths, were identified in the diet of 2.5% of field-collected blue crabs, whereas PCR-based assays detected winter flounder DNA in 17.7% of crab stomachs. Blue crabs 23 to 160 mm CW preyed on winter flounder ranging from 26 to 66 mm total length, with occurrences of predation most closely associated with increases in crab size. Blue crab predation on winter flounder also varied spatially in the rivers, reflecting site-specific differences in flounder densities, abundances of other preferred prey, and dissolved oxygen concentrations that altered predator-prey dynamics. Lastly, the current predatory impact of blue crabs on juvenile winter flounder is nearly equivalent to other portunid crab species. Anticipated temperature-mediated increases in blue crab densities at northern latitudes, however, will intensify the predator-induced mortality of winter flounder and likely hinder their recovery in southern New England.

Wilber, D. H., Clarke, D. G., Gallo, J., Alcoba, C. J., Dilorenzo, A. M., & Zappala, S. E. (2013). Identification of Winter Flounder (Pseudopleuronectes americanus) Estuarine Spawning Habitat and Factors Influencing Egg and Larval Distributions. *Estuaries and Coasts,* 36(6), 1304-1318. https://doi.org/10.1007/s12237-013-9642-z

A long-term (2002-2011), spatially robust, ichthyoplankton sampling program conducted in the New York/New Jersey Harbor produced 3,033 epibenthic samples from which the relationships between winter flounder egg and larval distributions and environmental parameters were examined. Variations in water temperature, sediment characteristics, and tidal phase were all significantly associated with egg distributions. Inferences about spawning habitats were based on the presence of early-stage eggs (ES1 and ES2). In the Lower Bay (LB), these habitats were primarily non-channel and characterized by more sandy substrates, averaging 96.5 % sand, 2.3 % silt/clay, 0.2 % total organic carbon (TOC), and shallower water (average depths of 5.3 m) compared to LB non-channel stations without ES1 and ES2 eggs (50.2 % sand, 42.0 % silt/clay, 2.1 % TOC, and 7.9 m depths). Occurrences of all stages of eggs in channels were associated with strong tides and severe cold winter water temperatures. These conditions increase the probability of egg transport from shallow spawning sites through increased vertical mixing (strong tides) and delayed development that prolongs the risk of displacement (cold temperatures). Yolk-sac (YS) and Stage-2 larvae were smaller in 2010 when spring water temperatures were highest. Overall, YS larval size decreased with warmer winters (cumulative degree-days for the month preceding peak YS larval collections, $r(2) = 0.82$, $p < 0.05$). In all years, YS larvae collected in LB were smaller and Stage-3 larvae collected in channels were larger and possibly older than those from non-channel habitat. Because estuarine winter flounder populations are highly localized, adverse effects experienced during egg and larval stages are likely to propagate resulting in detrimental consequences for the year class in the natal estuary.

Yencho, M. A., Jordaan, A., Cerrato, R. M., Baumann, H., & Frisk, M. G. (2015). Growth and Mortality in Coastal Populations of Winter Flounder: Implications for Recovery of a Depleted Population. *Marine and Coastal Fisheries,* 7(1), 246-259. https://doi.org/10.1080/19425120.2015.1045960

We studied growth, mortality, and settlement distributions of juvenile Winter Flounder Pseudopleuronectes americanus in two bays of Long Island, New York, to better understand localized population dynamics of a species experiencing a protracted population decline. Juvenile mortality in Long Island bays ranged between 0.02 and 0.04 per day and was as high as or higher than values reported for other systems. Settlement distributions had multiple peaks (cohorts) occurring between March and late July in 2007 and between February and May in 2008. The presence of multiple cohorts limited the usefulness of field-derived, length-based estimates of growth, resulting in unrealistic values compared with otolith-based measures (field based: −0.05 to 0.25 cm/d; otolith based: 0.05–0.06 cm/d). Thus, we recommend the use of otolith methods or the repeated measurement of individuals to estimate growth of juvenile Winter Flounder. Otolith-based growth rate was significantly higher for Port Jefferson Harbor during 2007 than for all other year × location combinations. Together with previous research showing genetic differentiation and migratory diversity, our finding of multiple spawning cohorts in Long Island Winter Flounder suggests a degree of isolation, and local management will be needed to support healthy populations. Future research to determine adult spawning, migratory behavior, stock structure, duration of the larval period, and settlement timing is required to unravel the complex behavior of Winter Flounder.

Section 7: Multiple Species

Able, K. W., Grothues, T. M., Shaw, M. J., VanMorter, S. M., Sullivan, M. C., & Ambrose, D. D. (2020). Alewife (Alosa pseudoharengus) spawning and nursery areas in a sentinel estuary: spatial and temporal patterns. *Environmental Biology of Fishes,* 103(11), 1419-1436. https://doi.org/10.1007/s10641-020-01032-0

Spatial and temporal distribution of anadromous alewife (Alosa pseudoharengusWilson) spawning and nursery habitats were determined by sampling in the Mullica River - Great Bay watershed (New Jersey, USA) in a combination of long- and short-term observational and quantitative studies. Reproduction was confirmed by examination of developing gonads, visual observations of spawning, and egg collections. Spawning typically lasted 2-4 days in discrete waves in freshwater tributaries from late March to late April. Nursery habitats for larvae and young-of-the-year alewife included low-salinity tributaries near the freshwater-saltwater interface and high salinity waters through early fall before departure to the ocean in late fall. Predation on eggs by fish predators, especially American eel (Anguilla rostrataLesueur), occurred below a dam. This predation was also observed in the laboratory on eggs and larvae. These findings point out that this dam provided for enhanced predation on alewife early life history stages, and may cause an ecological hotspot for predation-prey interactions for this anadromous species and its catadromous predator.

Bowlby, H. D. (2016). *Quantitative recovery planning: understanding how human activities in watersheds can influence population dynamics and genetic structuring of diadromous fishes.* (Ph.D.), Memorial University, Retrieved from https://research.library.mun.ca/12529/

Developing quantitative relationships that link human-induced environmental change with changes in population dynamics for species of conservation concern is hindered by: (1) a limited understanding of the cumulative effect (and relative importance) of population regulation, spatial dynamics, and demographic processes, (2) issues with detectability for species-environment interactions owing to data characteristics and (3) the cumulative or confounding nature of multiple threats. Taking a single-species approach based on endangered Atlantic salmon, I have partially addressed these challenges in my four research chapters. In chapter two, I characterized the conditions under which metapopulation structure would be expected to benefit a population assemblage and found that straying can reduce abundance and heighten extinction risk when productivity is low. For species of conservation concern, I would expect that remediation actions designed to influence demographic rates (e.g. mortality rates) would be more beneficial than actions influencing spatial dynamics. In chapter three, I accounted for the effects of observation and measurement error when quantifying relationships between hydrological variation and survival. Beyond the potential to change our interpretation of ecological relationships, I was able to infer the types of threats affecting juveniles in specific watersheds. In chapter four, I used patterns of effective dispersal to surmise the behavioural mechanism leading to watershed choice among straying adult salmon as well as the relative importance of multiple concurrent threats. My conclusions contradict some current perceptions on threats and suggest new directions for future research. In chapter five, I was able to develop a spatial tool that could inform management decisions or identify priority areas for restoration efforts. However, I was unable to fully characterize how environmental variation influences habitat utilization, distribution patterns, or population-level responses to human activities at multiple spatial extents. The relationships I describe are among the first to be developed for endangered Atlantic salmon in Nova Scotia at a population level. Several of the analyses represent novel

applications to conservation questions and have the potential to be extended or more widely applied. Because freshwater fishes, including diadromous fishes, are collectively one of the most imperiled species groups in the world, such research represents a timely contribution to conservation biology.

Cernadas-Martin, S., Rountos, K. J., Nye, J. A., Frisk, M. G., & Pikitch, E. K. (2021). Composition and Intraspecific Variability in Summer Flounder (Paralichthys dentatus) Diets in a Eutrophic Estuary. *Frontiers in Marine Science,* 8. https://doi.org/10.3389/fmars.2021.632751

This study assessed the diet of Summer flounder (SF, Paralichthys dentatus) in Shinnecock Bay, NY. Summer flounder are a recreationally and commercially important marine flatfish species found along the Eastern United States coastline. Despite their importance, few studies have examined the trophodynamics of a broad size spectrum of this species. Diet composition of summer flounder (n = 88) was assessed from 2014 to 2016 throughout Shinnecock Bay, a eutrophic bar-built estuary in New York. Species consumed and diet species richness differed significantly amongst SF size classes, with large [>= 375 mm total length (TL)] and medium (225: <375 mm) summer flounder showing higher levels of piscivory and more diverse diets than small-sized (<= 225 mm) conspecifics. As voracious plastic predators, trends in annual and monthly diet variation generally followed prey availability in Shinnecock Bay. One exception to this general pattern occurred for winter flounder (Pseudopleuronectes americanus). Despite their low relative abundance in the bay, winter flounder was highly preferred as prey by summer flounder (Chesson index, alpha = 0.35) and was their predominant prey item accounting for 12.3% (SD +/- 3.9%) of the diet by weight. Other factors that explained the variability of the diet of summer flounder were year, month, dissolved oxygen concentration, bay region and habitat, with a cumulative variance of 10.3%. Interestingly, clear differences in the diet (i.e., species richness and abundance) of summer flounder were found within regions of Shinnecock Bay, with a decrease in teleost biomass and species richness observed in the western region where water quality is more degraded and less seagrass is available compared to the more pristine eastern region. Distinct trophic dynamics in degraded habitats suggests fundamentally different food webs that could have important consequences to ecosystem stability and resilience. As coastal areas continue to experience degradation, diet studies of economically and ecologically important species can aid in the development of effective ecosystem-based management plans.

Crooks, L. E. (2011). *Organic contaminants in salmonid spawning grounds: occurrences and effects on the early life stages of salmonids.* (Ph.D.), University of Portsmouth, Retrieved from https://researchportal.port.ac.uk/en/studentTheses/organic-contaminants-in-salmonid-spawning-grounds

The factors regulating salmonid populations remain poorly understood, although contamination of the freshwater environment has been implicated as a causative factor. Depletion of stocks has become an increasing concern and it is believed that the early life stages are potentially the most vulnerable. Reduction in salmonid stocks has been reportedly linked to water quality and this current study has shown that freshwater pollution can affect the survival and development of salmonids. Environmental concentrations measured in this study varied greatly and high levels of sediment-bound contaminants were found, especially polycyclic aromatic hydrocarbons. Concentrations of waterborne contaminants were similar to levels previously measured, with some high level peaks in triazine metabolites. Field

studies, as previous literature has suggested, found a higher mortality in river sites of greater sediment and nutrient loading and in sites with a greater proportion of fine sediment (<63µm). The River Avon was found to have a higher concentration of fine sediment and mortality of implanted eggs in this site was significantly higher than in the Rivers Wylye and Nadder. Although mortality of eggs implanted in river field sites was generally high, few morphometrics and biochemical effects were observed. Laboratory studies examined the toxicity of environmentally relevant levels of water-borne and sediment-bound contaminants on the brown trout (Salmo trutta) but found few acute effects and no specific trends were observed. The results did reveal a higher frequency of yolk sac oedemas for contaminant-exposed alevins in the laboratory trials compared to the control groups. In general survival was high for both the eyed egg and alevin stages when exposed to the water-borne contaminants. However, survival was greatly reduced when the water-borne contaminant exposures were carried out from the fertilisation stage compared to the eyed stage. Generally, sedimentbound contaminants had a greater effect on survival at the egg stage and mortalities were found to be reduced at the fry stage. Additionally, the results from the comet assays revealed that exposure to sediment-bound organochlorine pesticides and polycyclic aromatic hydrocarbons did induce significant acute effects in the form of DNA damage when compared to the control. Such results could indicate that certain pollutants may be problematic for the species at later stages of their development and on into adulthood. In general the findings of this research proved largely inconclusive in terms of specific impacts of contaminants on the early developmental stages of Atlantic salmon and brown trout. The results of these studies did show that the presence of common pollutants within the freshwater environment can have impacts on the survival and development of salmonids. These impacts may have serious implications throughout the lifecycle and could impact heavily on recruitment and survival at both the juvenile and adult life stages, potentially leading to a reduction of wild populations.

Crosby, S. C., Cantatore, N. L., Smith, L. M., Cooper, J. R., Fraboni, P. J., & Harris, R. B. (2018). Three Decades of Change in Demersal Fish and Water Quality in a Long Island Sound Embayment. *Estuaries and Coasts,* 41(7), 2135-2145. https://doi.org/10.1007/s12237-018-0414-7

Estuaries are impacted by multiple anthropogenic stressors from eutrophication to climate change. Long-term observational datasets allow the determination of trends in estuarine indicators and the prediction of future conditions. Here, a dataset of water quality and demersal fish community composition in a Long Island Sound embayment (Norwalk Harbor, Connecticut) from 1987 to 2016 was examined. Mean water column water temperature increased, dissolved oxygen decreased, and salinity increased over the study period, with simultaneous changes in the demersal fish community. Fish abundance declined overall, with declines in CPUE observed across multiple species including the commercially important winter flounder (Pseudopleuronectes americanus). As fish can serve as effective indicators of estuarine health, these changes suggest a negative shift in the health of this Long Island Sound embayment. Climate change presents an increasing threat to estuaries and the ecosystem services they provide, especially when coupled with other anthropogenic stressors. Management actions are needed at multiple spatial scales, from local to global, to combat these threats to estuarine health.

Ezzard, A. D. (2017). *Early Life History Of Larval River Herring In A Coastal Watershed: Abundance, Growth, And Mortality.* (Master's), East Carolina University, Retrieved from https://thescholarship.ecu.edu/handle/10342/6540

River herring are two closely-related, anadromous fish species, Alewife (Alosa aestivalis) and Blueback Herring (A. pseudoharengus), which have been historically, commercially, and ecologically important along the North American Atlantic coast for hundreds of years. However, recent decades have been marked by their dramatic population declines and a collapse of the fishery. Historical records show that the coastal watershed of North Carolina's Chowan River was an epicenter for river herring harvest and spawning from pre-1700 through the late 1980s. I spatiotemporally characterized the early life history of river herring larvae in the Chowan River and its tributaries in the spring spawning season of 2011 by calculating larval abundance, growth, mortality, and diet relative to water quality and chemistry. Results show that the Chowan River and its tributaries supported relatively high numbers of river herring larvae in 2011 compared to an early 1980s study, with mean catches per unit effort (CPUEs) ranging from 52.87 + 71.68 larvae/100 m3 to 1583.53 + 2698.18 larvae/100 m3 compared to a similar and neighboring riverine system - the Roanoke River - with mean CPUEs ranging from 4.1 + 20.9 larvae/100 m3 in 2008 to 30.8 + 149.8 larvae/100 m3 from a study in 2009. A concurrent study to my research indicated that larval river herring diets are very similar between the adjacent systems, consisting primarily of copepods and rotifers in both the lower Chowan and the lower Roanoke River. Also, analyses of abundance, growth rates, and mortality rates suggest that density-dependent mechanisms likely control larval river herring trends throughout the Chowan system. Although all nursery habitats are worthy of research and conservation efforts, the Chowan River has continually proved to be a regional epicenter for successful reproduction and early life history of river herring and, therefore, merits special attention as a Strategic Habitat Area (SHA) by the State of North Carolina.

Foley, M., Askin, N., Belanger, M. P., & Wittnich, C. (2022). Anadromous fish as biomarkers for the combined impact of marine and freshwater heavy metal pollution. *Ecotoxicology and Environmental Safety,* 230. https://doi.org/10.1016/j.ecoenv.2021.113153

Rivers along the eastern seaboard of the United States and Canada are becoming increasingly contaminated with heavy metals. This includes the Tusket River (Nova Scotia, Canada) which empties into the Gulf of Maine, near the Bay of Fundy. Whether anadromous fish such as alewife (Alosa pseudoharengus), exposed both to marine and freshwater contaminants, are accumulating these heavy metals and experiencing any changes in their morphology was explored in this study. Adult (4-6 years of age) Tusket River alewife (n = 38) were harvested and had external examinations including morphometrics (fork length, weight). Biopsies were taken and structural abnormalities noted. Morphometric data was compared to historical alewife reference data from 1985. Biopsies of muscle, liver and kidney had heavy metal profiles assessed. Major findings of this study include detectable levels (mu g/g wet weight) of a number of heavy metals and concerning maximum concentrations achieved of arsenic (liver: 14 mu g/g), cadmium (kidney: 2.6 mu g/g), mercury (liver: 0.26 mu g/g), magnesium (muscle: 460 mu g/g), selenium (kidney: 4.0 mu g/g) and zinc (liver: 38.0 mu g/g). As well, reduced body weight for length and in 87% of fish, presence of spine curvatures (3-24 degrees) not visible externally were noted. This study is the first detailed report in alewife of key tissue heavy metals, some at levels of concern, reductions in weight for length and spine abnormalities. These findings validate concerns regarding potential impacts of deteriorating conditions of rivers and their surrounding waters such as the Gulf of Maine on anadromous fish species.

Jahnke, A., Mayer, P., Adolfsson-Erici, M., & McLachlan, M. S. (2011). Equilibrium sampling of environmental pollutants in fish: Comparison with lipid-normalized concentrations and homogenization effects on chemical activity. *Environmental Toxicology and Chemistry,* 30(7), 1515-1521. https://doi.org/10.1002/etc.534

Equilibrium sampling of organic pollutants into the silicone polydimethylsiloxane (PDMS) has recently been applied in biological tissues including fish. Pollutant concentrations in PDMS can then be multiplied with lipid/PDMS distribution coefficients (D(Lipid,PDMS)) to obtain concentrations in fish lipids. In the present study, PDMS thin films were used for equilibrium sampling of polychlorinated biphenyls (PCBs) in intact tissue of two eels and one salmon. A classical exhaustive extraction technique to determine lipid-normalized PCB concentrations, which assigns the body burden of the chemical to the lipid fraction of the fish, was additionally applied. Lipid-based PCB concentrations obtained by equilibrium sampling were 85 to 106% (Norwegian Atlantic salmon), 108 to 128% (Baltic Sea eel), and 51 to 83% (Finnish lake eel) of those determined using total extraction. This supports the validity of the equilibrium sampling technique, while at the same time confirming that the fugacity capacity of these lipid-rich tissues for PCBs was dominated by the lipid fraction. Equilibrium sampling was also applied to homogenates of the same fish tissues. The PCB concentrations in the PDMS were 1.2 to 2.0 times higher in the homogenates (statistically significant in 18 of 21 cases, $p < 0.05$), indicating that homogenization increased the chemical activity of the PCBs and decreased the fugacity capacity of the tissue. This observation has implications for equilibrium sampling and partition coefficients determined using tissue homogenates.

Jonsson, B., & Jonsson, N. (2009). A review of the likely effects of climate change on anadromous Atlantic salmon *Salmo salar* and brown trout *Salmo trutta*, with particular reference to water temperature and flow. *Journal of Fish Biology,* 75(10), 2381-2447. https://doi.org/10.1111/j.1095-8649.2009.02380.x

The present paper reviews the effects of water temperature and flow on migrations, embryonic development, hatching, emergence, growth and life-history traits in light of the ongoing climate change with emphasis on anadromous Atlantic salmon Salmo salar and brown trout Salmo trutta. The expected climate change in the Atlantic is for milder and wetter winters, with more precipitation falling as rain and less as snow, decrease in ice-covered periods and frequent periods with extreme weather. Overall, thermal limits for salmonids are species specific. Scope for activity and growth and optimal temperature for growth increase with temperature to an optimal point before constrain by the oxygen content of the water. The optimal temperature for growth decreases with increasing fish size and varies little among populations within species, whereas the growth efficiency may be locally adapted to the temperature conditions of the home stream during the growth season. Indirectly, temperature influences age and size at smolting through its effect on growth. Time of spawning, egg hatching and emergence of the larvae vary with temperature and selective effects on time of first feeding. Traits such as age at first maturity, longevity and fecundity decrease with increasing temperature whilst egg size increases with temperature. Water flow influences the accessibility of rivers for returning adults and speed of both upstream and downstream migration. Extremes in water flow and temperature can decrease recruitment and survival. There is reason to expect a northward movement of the thermal niche of anadromous salmonids with decreased production and population extinction in the southern part of the distribution areas, migrations earlier in the season, later spawning, younger age at smolting and sexual maturity and increased disease susceptibility and mortality. Future research challenges are summarized at the end of the paper.

Jonsson, B., & Jonsson, N. (2019). Phenotypic plasticity and epigenetics of fish: embryo temperature affects later-developing life-history traits. *Aquatic Biology,* 28, 21-32. https://doi.org/10.3354/ab00707

Temperature during embryonic development affects ecological traits and influences the ability to rapidly adapt to the prevailing conditions in changing environments. Here, we review examples of how these developmental effects are manifested in life-history traits from studies of various fish species, with examples of impacts on somatic growth, age at migration and maturation, allocation of resources to gonads and egg size. Temperature during embryogenesis appears important for some behavioural decisions, such as when maturing Atlantic salmon Salmo salar return home from the ocean for spawning in distant rivers during summer. In some species, early temperature influences sex determination. The temperature level during embryogenesis may preadapt the fish to maximize offspring production under the thermal conditions encountered at the embryo stage. This thermal influence is a phenotypically plastic response that triggers polyphenism in salmonids and may be a first step in speciation of North American darters (Percidae). The responses to early temperature appear to be regulated by epigenetic mechanisms, such as DNA methylation, histone modification and micro RNAs.

Kesler, M., Kangur, M., & Vetemaa, M. (2011). Natural re-establishment of Atlantic salmon reproduction and the fish community in the previously heavily polluted River Purtse, Baltic Sea. *Ecology of Freshwater Fish,* 20(3), 472-477. https://doi.org/10.1111/j.1600-0633.2010.00483.x

The River Purtse was historically a significant Atlantic salmon spawning river in the Gulf of Finland (Baltic Sea). After the establishment of oil shale mining and processing in the catchment area in the late 1920s, the salmon population went extinct. By the 1970s, the river was heavily polluted and the lower reaches lacked any fish fauna. However, since the 1990s, pollution from oil shale mines was greatly reduced and water quality started to improve. The first fish species to repopulate the polluted area were gudgeon and nine-spined stickleback. The first salmon parr from wild spawning were recorded in 2006. Up to 2009, a total of fifteen fish species have been recorded including trout and the sensitive bullhead. This study illustrates the natural recovery of the fish fauna following water quality improvement.

King, J. J. (2015). Ecology And Economics Of Fish Kills: Mortality And Recovery Of Brown Trout (Salmo Trutta L.) And Atlantic Salmon (Salmo Salar L.) In An Irish River. *Biology and Environment-Proceedings of the Royal Irish Academy*(3), 157-170. https://doi.org/10.3318/bioe.2015.16

There is a small international scientific literature, principally from North America, on recovery of fish communities following substantial fish kill events and a smaller literature on monetary assessment of losses in such events. A chemical discharge led to over 90% loss of brown trout (Salmo trutta L.) and Atlantic salmon (Salmo salar L.) age classes in 31km of the River Boyne catchment, a major Irish salmon-producing and angling fishery in July 1997. Subsequent investigations permitted a novel study that examined both the changes in the fish community composition over time and also a monetary assessment of losses. The population structure and density of 1 and older brown trout took four to five years to recover. The population of 1+ salmon increased substantially during the recovery period, to levels threefold higher than those recorded prior to the pollution event. Financial loss assessment was examined through 'replacement cost' and through consequential loss models. An examination of the monetary modelling, in the light of the fish community recovery, showed there was an ecological

justification for the potential loss model used. This approach to appraisal of loss is considered to have an international relevance, in the context of ecosystem processes and the 'polluter pays' principle.

Klein, E. S., Smith, S. L., & Kritzer, J. P. (2017). Effects of climate change on four New England groundfish species. *Reviews in Fish Biology and Fisheries,* 27(2), 317-338. https://doi.org/10.1007/s11160-016-9444-z

Multiple groundfish stocks in New England remain depleted despite management measures that have been effective elsewhere. A growing body of research suggests that environmental change driven by increasing concentrations of carbon dioxide in the atmosphere and ocean is unfolding more rapidly in New England than elsewhere, and is an important factor in the failure of these stocks to respond to management. We reviewed research on effects of changes in temperature, salinity, dissolved oxygen, pH, and ocean currents on pelagic life stages, post-settlement life stages, and reproduction of four species in the New England groundfish fishery: Atlantic cod (Gadus morhua), haddock (Melanogrammus aeglefinus), winter flounder (Pseudopleuronectes americanus), and yellowtail flounder (Limanda ferruginea). The volume of research on cod was nearly equal to that on the other three species combined. Similarly, many more studies examined effects of temperature than other factors. The majority of studies suggest adverse outcomes, with less evidence for mixed or positive effects. However, for all of the factors other than temperature, there are more knowledge gaps than known effects. Importantly, most work to date examines impacts in isolation, but effects might combine in nonlinear ways and cause stronger reductions in stock productivity than expected. Management strategies will need to account for known effects, nonlinear interactions, and uncertainties if fisheries in New England are to adapt to environmental change.

Kopec, A. D., Kidd, K. A., Fisher, N. S., Bowen, M., Francis, C., Payne, K., & Bodaly, R. A. (2019). Spatial and temporal trends of mercury in the aquatic food web of the lower Penobscot River, Maine, USA, affected by a chlor-alkali plant. *Science of The Total Environment,* 649, 770-791. https://doi.org/10.1016/j.scitotenv.2018.08.203

Mercury (Hg) concentrations in aquatic biota, including fish and shellfish, were measured over the period 2006-2012 in the lower Penobscot River and upper estuary (Maine, USA). The Penobscot is a system contaminated with Hg by a chlor-alkali plant that operated from 1967 to 2000, discharging 6-12 tons of mercury into the river. Mercury levels in aquatic biota were highest at sites downstream of the chlor-alkali plant and spatial trends were similar to those of sediments. Mean total Hg concentrations in fish muscle (adjusted for size or age) in the most affected areas were 521 (480, 566; 95% CI) ng/g ww in American eels, 321 (261,395) in mummichog, 121 (104, 140) in rainbow smelt, 155 (142,169) in tomcod, 55.2 (42.7,71.4) in winter flounder, and 328 (259,413) in American lobster tail and 522 (488,557) ng/g dw in blue mussel. Levels exceeded the 50 ng/g ww considered protective for piscivorous predators and were of concern for human health, with American eels and American lobster exceeding Maine's mercury action level of 200 ng/g ww. Calculations of trophic position (using nitrogen isotopes) suggested that the spatial patterns observed in total Hg concentrations were not due to changes in feeding habits of the species. Fish feeding in benthic food webs, as defined by stomach content and stable carbon isotope analyses, showed no change in Hg concentrations over time. In contrast, declining trends in Hg were found in two species dependent on pelagic food webs. The absence of declines in Hg concentrations in

the benthically-based food webs, despite the fact that most Hg was discharged into the system >40 years ago, is consistent with the long recovery predicted from dated sediment cores and from similar studies elsewhere.

Melnyk, L. J., Lin, J., Kusnierz, D. H., Pugh, K., Durant, J. T., Suarez-Soto, R. J., . . . Stover, M. A. (2021). Risks from mercury in anadromous fish collected from Penobscot River, Maine. *Science of The Total Environment,* 781, 146691. https://doi.org/10.1016/j.scitotenv.2021.146691

Levels of total mercury were measured in tissue of six species of migratory fish (alewife, American shad, blueback herring, rainbow smelt, striped bass, and sea lamprey), and in roe of American shad for two consecutive years collected from the Penobscot River or its estuary. The resultant mercury levels were compared to reference doses as established in the U.S. Environmental Protection Agency (EPA) Integrated Risk Information System and wildlife values. Mercury concentrations ranged from 4 µg/kg ww in roe to 1040 µg/kg ww in sea lamprey. Sea lamprey contained the highest amounts of mercury for both seasons of sampling. Current health advisories are set at sufficient levels to protect fishers from harmful consumption of the fish for mercury alone, except for sea lamprey. Based upon published wildlife values for mink, otter, and eagle, consumption of rainbow smelt, striped bass, or sea lamprey poses a risk to mink; striped bass and sea lamprey to otter; and sea lamprey to eagle. For future consideration, the resultant data may serve as a reference point for both human health and wildlife risk assessments for the consumption of anadromous fish. U.S. EPA works with federally recognized Tribes across the nation greatly impacted by restrictions on sustenance fishing, to develop culturally sensitive risk assessments.

Montie, E. W., Letcher, R. J., Reddy, C. M., Moore, M. J., Rubinstein, B., & Hahn, M. E. (2010). Brominated flame retardants and organochlorine contaminants in winter flounder, harp and hooded seals, and North Atlantic right whales from the Northwest Atlantic Ocean. *Marine Pollution Bulletin,* 60(8), 1160-1169. https://doi.org/10.1016/j.marpolbul.2010.04.002

Various brominated flame retardants (BFRs), including polybrominated diphenyl ethers (PBDEs) and current-use, non-PBDE BFRs, as well as organochlorine (OC) pesticides and polychlorinated biphenyls (PCBs), were measured in winter flounder, harp and hooded seals, and North Atlantic right whales from the Eastern United States and Canada. The concentrations of PBDEs in winter flounder and right whales were similar in magnitude to the levels of PCBs, which was unlike the pattern observed in seals. In these marine mammals, the levels of PBDEs were orders of magnitude lower than the levels of OCs and PCBs detected. Evidence existed for the accumulation of methoxylated (MeO)-PBDEs of natural origin in seals and right whales. Current-use, non-PBDE BFRs (including hexabromocyclododecane, pentabromoethylbenzene, hexabromobenzene, and pentabromotoluene) were detected in winter flounder and marine mammals. Future research should focus on monitoring PBDEs, current-use, non-PBDE BFRs, and MeO-BDEs of natural origin in marine organisms from Massachusetts and Cape Cod Bays.

Outfall. (2022). *Recommendations of the Outfall Monitoring Science Advisory Panel to the U. S. Environmental Protection Agency (Region 1) and Massachusetts Department of Environmental Protection.* Retrieved from https://seagrant.mit.edu/wp-content/uploads/2022/09/Framework_Understanding_Contaminants_Concern_7_2022.pdf

The attached documents are a set of reviews or white papers about three general types of contaminants of emerging concern (CECs) in domestic wastewater effluent, specifically as it applies to the Massachusetts Water Resources Authority's (MWRA) outfall discharge into Massachusetts Bay. These reviews evolved from the discussions during a November 13, 2018 public workshop, 2300 Days at Sea: Monitoring the Impacts of the Outfall on Massachusetts Bay, hosted by MIT Sea Grant, Save the Harbor/Save the Bay, and the Outfall Monitoring Science Advisory Panel (OMSAP). As part of its National Pollutant Discharge Elimination System (NPDES) permit, MWRA has developed and implemented a monitoring plan to evaluate whether its discharge adversely impacts Massachusetts Bay. At the November 2018 workshop, participants were asked to review the 25 plus years of MWRA monitoring results, to evaluate whether the current monitoring questions are still relevant, and to determine whether other emerging questions or threats related to the outfall discharge should be addressed by the monitoring program. Attendees concluded that three categories of CECs—persistent or long-lived chemicals, pseudopersistent (short-lived but released frequently) compounds, and microplastics were potential risks for Massachusetts Bay. To better understand the issues associated with the three categories of CECs, OMSAP, a scientific panel that reports to Massachusetts Department of Environmental Protection (MADEP) and the U.S. Environmental Protection Agency (EPA), focused on developing white papers that included per- and polyfluoroalkyl substances (PFAS), a persistent organic chemical group of thousands of compounds; pharmaceuticals and personal care products (PPCPs), a diverse group of relatively short-lived, but consistently released chemicals; and microplastics (MPs), small plastic particles that persist for a few to 100s of years that were either manufactured or broken down from larger pieces and contain over 4,000 additives. These reviews focus on the potential discharge of CECs from the MWRA outfall; their chemistry, sources, transport, fate and effect in the ecosystem; and their impacts to marine life and human health. EPA and MADEP have recently started adding monitoring requirements for six PFAS compounds to NPDES permits for wastewater treatment plant (WWTP) discharges with new recommendations that 40 PFAS parameters are to be monitored in drinking water and receiving waters, however, currently there are no monitoring requirements for PPCPs, or MPs.

Payne, E. J., & Taylor, D. L. (2010). Effects of Diet Composition and Trophic Structure on Mercury Bioaccumulation in Temperate Flatfishes. *Archives of Environmental Contamination and Toxicology,* 58(2), 431-443. https://doi.org/10.1007/s00244-009-9423-7

The summer flounder Paralichthys dentatus and winter flounder Pseudopleuronectes americanus support valuable fisheries along the northeastern United States. The importance of these flatfish as a human dietary resource indicates they are potential sources of mercury (Hg) to fish-consuming citizens. In this study, summer flounder (SF) and winter flounder (WF) were collected from the Narragansett Bay (Rhode Island, USA) and were measured for total Hg burden in whole-body or dorsal muscle tissue. Interspecies differences in Hg contamination were analyzed relative to flounder body size, age, and Hg content of preferred prey. Stable isotope signatures were also used to elucidate the effect of trophic processes on Hg accumulation in the estuarine food web. The mean Hg content of SF exceeded concentrations measured in WF across multiple life-history stages (0.039-0.100 and 0.016-0.029 mg

Hg/kg wet weight for SF and WF, respectively), and observed values for both species were lower than the US Environmental Protection Agency regulatory threshold of 0.3 mg Hg/kg wet weight. Total Hg concentrations were also positively correlated with flounder age and length, verifying that both flatfish bioaccumulate Hg. SF accumulate Hg at an accelerated rate, however, owing to this species consuming Hg-enriched prey (teleosts, squid, and macrocrustaceans; mean Hg content = 0.023 mg Hg/kg wet weight), whereas WF feed on prey with low Hg levels (amphipods and polychaetes; mean Hg content = 0.013 mg Hg/kg wet weight). The positive correlation observed between mean biota Hg content and stable nitrogen (delta N-15) isotope signatures further indicates that Hg is trophically transferred through the food web, and higher trophic level organisms (i.e., enriched delta N-15) have increased Hg concentrations. Therefore, results from this study suggest that dietary preference and trophic structure are the main factors affecting Hg bioaccumulation in the estuary. Total Hg concentrations of flatfish from the Narragansett Bay, however, do not necessarily reflect coastwide contamination patterns. This reinforces the importance of having research conducted at sufficiently small spatial scales, including the local assessment of Hg contamination for the purpose of issuing state consumption advisories.

Piou, C., Taylor, M. H., Papaix, J., & Prevost, E. (2015). Modelling the interactive effects of selective fishing and environmental change on Atlantic salmon demogenetics. *Journal of Applied Ecology,* 52(6), 1629-1637. https://doi.org/10.1111/1365-2664.12512

Changes in life-history traits have been observed in many fish species over past decades. This led to the fisheries-induced evolution' hypothesis proposing that fisheries may be causing genetic changes to populations through selective harvesting. Another hypothesis, which is not mutually exclusive, is that observed changes are due to phenotypic plasticity in response to environmental changes. Using an individual-based demogenetic model, we investigate the relative importance of selective fishing and environmental change scenarios on the Atlantic salmon Salmo salar. In simulation experiments, results show that poor oceanic growth conditions resulting from environmental change drove mainly phenotypic responses, such as a shift towards a multiple-sea-winter life history accompanied by a decline in population size. These changes were attributable to the longer time needed to reach maturation and the resulting increase in cumulative mortality during the oceanic phase. Increased selective fishing against multiple-sea-winter fish mainly induced an evolutionary effect in the form of a lower maturation threshold in females, increasing the proportion of one sea-winter fish. The maturation threshold of males was not modified by selective fishing due to their earlier reproduction and return after a single winter at sea, thereby avoiding most of the selective effects of fishing.Policy implications. The results suggest that given the present configuration of traditional fisheries, fishing is likely to worsen the effects of oceanic environmental change. Management strategies avoiding targeting multiple-sea-winter fish may need to be considered in order to ensure the populations' resilience to poor oceanic conditions for growth.

Roy, N. K., Candelmo, A., DellaTorre, M., Chambers, R. C., Nádas, A., & Wirgin, I. (2018). Characterization of AHR2 and CYP1A expression in Atlantic sturgeon and shortnose sturgeon treated with coplanar PCBs and TCDD. *Aquatic Toxicology,* 197, 19-31. https://doi.org/10.1016/j.aquatox.2018.01.017

Atlantic sturgeon and shortnose sturgeon co-occur in many estuaries along the Atlantic Coast of North America. Both species are protected under the U.S. Endangered Species Act and internationally on the IUCN Red list and by CITES. Early life-stages of both sturgeons may be exposed to persistent aromatic hydrocarbon contaminants such as PCBs and PCDD/Fs which are at high levels in the sediments of impacted spawning rivers. Our objective was to compare the PCBs and TCDD sensitivities of both species with those of other fishes and to determine if environmental concentrations of these contaminants approach those that induce toxicity to their young life-stages under controlled laboratory conditions. Because our previous studies suggested that young life-stages of North American sturgeons are among the more sensitive of fishes to coplanar PCB and TCDD-induced toxicities, we were interested in identifying the molecular bases of this vulnerability. It is known that activation of the aryl hydrocarbon receptor 2 (AHR2) in fishes mediates most toxicities to these contaminants and transcriptional activation of xenobiotic metabolizing enzymes such as cytochrome P4501A (CYP1A). Previous studies demonstrated that structural and functional variations in AHRs are the bases for differing sensitivities of several vertebrate taxa to aromatic hydrocarbons. Therefore, in this study we characterized AHR2 and its expression in both sturgeons as an initial step in understanding the mechanistic bases of their sensitivities to these contaminants. We also used CYP1A expression as an endpoint to develop Toxicity Equivalency Factors (TEFs) for these sturgeons. We found that critical amino acid residues in the ligand binding domain of AHR2 in both sturgeons were identical to those of the aromatic hydrocarbon-sensitive white sturgeon, and differed from the less sensitive lake sturgeon. AHR2 expression was induced by TCDD (up to 6-fold) and by three of four tested coplanar PCB congeners (3–5-fold) in Atlantic sturgeon, but less so in shortnose sturgeon. We found that expression of AHR2 and CYP1A mRNA significantly covaried after exposure to TCDD and PCB77, PCB81, PCB126, but not PCB169 in both sturgeons. We also determined TEFs for the four coplanar PCBs in shortnose sturgeon based on comparison of CYP1A mRNA expression across all doses. Surprisingly, the TEFs for all four coplanar PCBs in shortnose sturgeon were much higher (6.4–162 times) than previously adopted for fishes by the WHO.

Roy, N. K., Walker, N., Chambers, R. C., & Wirgin, I. (2011). Characterization and expression of cytochrome P4501A in Atlantic sturgeon and shortnose sturgeon experimentally exposed to coplanar PCB 126 and TCDD. *Aquatic Toxicology,* 104(1-2), 23-31. https://doi.org/10.1016/j.aquatox.2011.03.009

The AHR pathway activates transcription of CYP1A and mediates most toxic responses from exposure to halogenated aromatic hydrocarbon contaminants such as PCBs and PCDD/Fs. Therefore, expression of CYP1A is predictive of most higher level toxic responses from these chemicals. To date, no study had developed an assay to quantify CYP1A expression in any sturgeon species. We addressed this deficiency by partially characterizing CYP1A in Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus) and shortnose sturgeon (Acipenser brevirostrum) and then used derived sturgeon sequences to develop reverse transcriptase (RT)-PCR assays to quantify CYP1A mRNA expression in TCDD and PCB126 treated early life-stages of both species. Phylogenetic analysis of CYP1A, CYP1B, CYP1C and CYP3A deduced amino acid sequences from other fishes and sturgeons revealed that our putative Atlantic sturgeon and

shortnose sturgeon CYP1A sequences most closely clustered with previously derived CYP1A sequences. We then used semi-quantitative and real-time RT-PCR to measure CYP1A mRNA levels in newly hatched Atlantic sturgeon and shortnose sturgeon larvae that were exposed to graded doses of waterborne PCB126 (0.01-1000 parts per billion (ppb)) and TCDD (0.001-10 ppb). We initially observed significant induction of CYP1A mRNA compared to vehicle control at the lowest doses of PCB126 and TCDD used, 0.01 ppb and 0.001 ppb, respectively. Significant induction was observed at all doses of both chemicals although lower expression was seen at the highest doses. We also compared CYP1A expression among tissues of i.p. injected shortnose sturgeon and found significant inducibility in heart, intestine, and liver, but not in blood, gill, or pectoral fin clips. For the first time, our results indicate that young life-stages of sturgeons are sensitive to AHR ligands at environmentally relevant concentrations, however, it is yet to be determined if induction of CYP1A can be used as a biomarker in environmental biomonitoring.

Sear, D. A., Jones, J. I., Collins, A. L., Hulin, A., Burke, N., Bateman, S., . . . Naden, P. S. (2016). Does fine sediment source as well as quantity affect salmonid embryo mortality and development? *Science of The Total Environment,* 541, 957-968. https://doi.org/10.1016/j.scitotenv.2015.09.155

Fine sediments are known to be an important cause of increased mortality in benthic spawning fish. To date, most of the research has focussed on the relationship between embryo mortality and the quantity of fine sediment accumulated in the egg pocket. However, recent evidence suggests a) that the source of fine sediment might also be important, and b) that fitness of surviving embryos post-hatch might also be impacted by the accumulation of fine sediments. In this paper, we report an experiment designed to simulate the incubation environment of brown trout (Salmo trutta) and Atlantic salmon (Salmo salar). During the experiment, the incubating embryos were exposed to different quantities of fine (<63 mu m) sediment derived from four different sources; agricultural topsoils, damaged road verges, eroding river channel banks and tertiary level treated sewage. Results showed that mass and source are independently important for determining the mortality and fitness of alevin. Differences between species were observed, such that brown trout are less sensitive to mass and source of accumulated sediment. We demonstrate for the first time that sediment source is an additional control on the impact of fine sediment, and that this is primarily controlled by the organic matter content and oxygen consumption of the catchment source material.

Stephansen, D. A., Svendsen, T. C., Vorkamp, K., & Frier, J.-O. (2011). Changes in patterns of persistent halogenated compounds through a pelagic food web in the Baltic Sea. *Marine Environmental Research,* 73, 17-24. https://doi.org/10.1016/j.marenvres.2011.10.006

The concentrations and patterns of persistent halogenated compounds (PHCs), including polychlorinated biphenyls (PCBs), DDT, hexachlorocyclohexanes (HCHs), hexachlorobenzene (HCB) and polybrominated diphenyl ethers (PBDEs) were examined in a pelagic food web from the southern Baltic Sea consisting of sediment, zooplankton, sprat, Atlantic salmon and anadromous brown trout. Lipid-normalized concentrations generally increased from low trophic levels to high trophic levels, with the exception of HCHs. Due to high concentrations of PBDEs in some zooplankton samples, biomagnification of BDE-47 was only observed for salmon/sprat and trout/sprat. Sprat collected individually and from salmon stomach had significantly different lipid-normalized concentrations and varied in their PHC

pattern as well, possibly indicating a large natural variation within the Baltic Sea. The highest lipid-normalized concentrations were found in brown trout. Salmon and brown trout were similar in their PHC pattern suggesting similar food sources. Variation in PHC patterns among trophic levels was not smaller than that among geographically distinct locations, confirming the importance of comparable trophic levels for the assessment of PHC patterns, e.g. for tracing migratory fish.

Stevenson, D. K., Johnson, M. R., Tuxbury, S., & Boelke, C. (2017). Shallow water benthic habitats in the Gulf of Maine: A summary of habitat use by life stages of common marine and estuarine species. *Greater Atlantic Region Policy Series,* 14(1). Retrieved from https://www.greateratlantic.fisheries.noaa.gov/policyseries/index.php/GARPS/article/view/4

Shallow-water estuarine and coastal marine habitats in the Gulf of Maine comprise some of the most productive habitats in the northeastern United States and have been identified as Essential Fish Habitat (EFH) [1] for many species of importance to commercial and recreational fisheries. However, these near-shore habitats are also the most vulnerable to human disturbances due to their proximity to coastal population centers. The purpose of this report is to describe the importance of shallow-water habitats (0-10 meters) for spawning, feeding, and growth to maturity for 16 fish and invertebrate species in the Gulf of Maine based on a literature review. The species include a mix of federally managed fishery species, state-managed fishery species and other species that are important members of the shallow-water marine ecosystem. Habitat use was assessed for individual life history stages of each species in eight shallow-water benthic habitats: mud, sand, gravel/cobble, boulder, eelgrass, macroalgae, salt marsh channels, and shellfish beds. Habitat use scores (0 = absent, 1 = present, and 2 = common or abundant) were assigned to each benthic life stage of each species known to occur in depths less than 10 meters. Scores were then summarized for all species in each habitat type. According to this evaluation, shallow-water habitats in the Gulf of Maine are used by young-of-the-year juveniles of all 16 species. Additionally, older juveniles of 12 species and adults of 11 species also rely on these habitats. Nine of the sixteen species spawn in one or more of these habitats. Further analysis shows that sand and gravel/cobble habitats are used by the most species and life stages, followed by mud, eelgrass, macroalgae, boulder, salt marsh channels, and shell (mussel) beds. Shallow-water habitats in the Gulf of Maine provide valuable ecological services for a variety of species. Mud, sand, gravel/cobble, and vegetated habitats are particularly important as juvenile nursery grounds for species such as Atlantic cod, Atlantic tomcod, American lobsters, winter flounder, soft-shell clams, and blue mussels. [1] As defined under the Magnuson-Stevens Act §3(10)

Sydney, T. B. (2023). Implications of Declining Ground Water and Water Quality in the Greater Okefenokee Swamp Basin for Survival and Recovery of Federally Endangered and Threatened Marine and Aquatic Species and Critical Habitat in the US Southeastern Coastal Plain Ecoregion—Part 2. *Journal of Geoscience and Environment Protection,* 11(04), 86-156. https://doi.org/10.4236/gep.2023.114008

The Floridan aquifer system underlies the United States (US) Southeastern Coastal Plain Physiographic Region. Anthropogenic groundwater declines in that regional karst aquifer system, via semi-confining zones, have been documented in published literature for decades. These anthropogenic groundwater declines reduce surfacewater levels and flows, which increases saltwater intrusion and alters the

physical, chemical, and biological integrity of the nation's waters, in violation of the US Clean Water Act (CWA) of 1972. Historic groundwater declines from mining and other anthropogenic groundwater withdrawals from this regional karst aquifer system already threaten the survival and recovery of marine and aquatic federally endangered and threatened species, as well as existing and proposed critical habitat for those species within the Southeastern Coastal Plain Ecoregion. Examples of marine and aquatic species and their designated critical habitat adversely affected by groundwater declines in the Greater Okefenokee Swamp Basin of this ecoregion include the federally endangered south Atlantic Distinct Population Segments (DPS) of the Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus), shortnose sturgeon (Acipenser brevirostrum), and oval pigtoe mussel (Pleurobema pyriforme), as well as the federally threatened Gulf subspecies of the Atlantic sturgeon (Acipenser oxyrinchus desotoi) and Suwannee moccasinshell (Medionidus walkeri). In 2020, rules were adopted by two federal agencies allowing significant further degradation of the physical, chemical, and biological integrity of the nation's waters that are essential for maintaining federally listed species and their habitat in this Ecoregion. The US Fish and Wildlife Service (USFWS) has acknowledged the harm to these species and critical habitat from mining and additional groundwater alterations, but no comprehensive Areawide Environmental Impact Statement (AEIS), similar to the AEIS required for mining within the Peace River Basin, has been conducted for any of the numerous mining projects that are expanding and proposed within the Greater Okefenokee Swamp Basin to evaluate all indirect and cumulative adverse impacts to all federally listed species.

van Treeck, R., Van Wichelen, J., & Wolter, C. (2020). Fish species sensitivity classification for environmental impact assessment, conservation and restoration planning. *Science of The Total Environment,* 708. https://doi.org/10.1016/j.scitotenv.2019.135173

Species conservation, river rehabilitation, stock enhancement, environmental impact assessment and related planning tools require indicators to identify significant impacts but also mitigation success. Since river systems are shaped by disturbances from floods and droughts, typical riverine fish species should have evolved life history traits providing resilience against such disturbances. This study compiled and analyzed resilience traits of European lampreys and fish species to derive a novel sensitivity classification of species to mortality. We assembled life history traits like maximum length, migration type, mortality, fecundity, age at maturity, and generation time of 168 species and created a novel method to weigh and integrate all traits to generate a final sensitivity score from one (low sensitivity) to three (high sensitivity) for each species. Large-bodied, diadromous, rheophilic and lithophilic species such as sturgeons, sea trout, and Atlantic salmon usually appeared to have high sensitivity to additional adult fish mortality, whereas small-bodied, limnophilic and phytophilic species with fast generation cycles were of low sensitivity. The final scoring and classification of 168 European lampreys and fish species according to their sensitivity can be easily regionalized by selecting the most sensitive candidates according to the local species pool. This sensitivity classification has major implications for advancing impact assessment, allowing better targeting of species for conservation measures, benchmarking progress during rehabilitation and enhancing the objective evaluation of the success of restoration projects.

Section 8: Other

Bayse, S. M., Regish, A. M., & McCormick, S. D. (2021). Survival and spawning success of American shad (Alosa sapidissima) in varying temperatures and levels of glochidia infection. *Fish Physiology and Biochemistry,* 47(6), 1821-1836. https://doi.org/10.1007/s10695-021-01018-4

Temperature fluctuations and climate change impacts may substantially affect spawning success of fish, especially migratory species with a limited spawning window. Factors affecting American shad (Alosa sapidissima) spawning success and survival were investigated at different temperatures and periods (peak- and late-spawning periods) during the Connecticut River, USA, spawning migration in 2017. Wild caught American shad were exposed to constant temperatures regimes of 15, 18, 21, 24 and 27 °C for 2 weeks. During the peak-spawning period, an increase in temperature (15–24 °C) was shown to increase spawning success factors, including spawning probability, number of eggs, and fertilization success, but decreased egg size. Temperatures between 18 and 27 °C did not affect these factors during the late-spawning period. Glochidia infection by the alewife floater (Anodonta implicata) was much higher in the late-spawning period and significantly decreased the survival of American shad. Further research should investigate the parasite-host relationship between the alewife floater and American shad to determine annual variability of glochidia infections and how they affect American shad from physiological and passage perspectives. Higher temperatures were shown to increase spawning success of American shad during the peak-spawning period, but temperature had no effect during the late-spawning period. However, any effect during the late-spawning period may have been masked by a high level of glochidia infection.

Cernadas-Martin, S., Rountos, K. J., Nye, J. A., Frisk, M. G., & Pikitch, E. K. (2021). Composition and Intraspecific Variability in Summer Flounder (Paralichthys dentatus) Diets in a Eutrophic Estuary. *Frontiers in Marine Science,* 8. https://doi.org/10.3389/fmars.2021.632751

This study assessed the diet of Summer flounder (SF, Paralichthys dentatus) in Shinnecock Bay, NY. Summer flounder are a recreationally and commercially important marine flatfish species found along the Eastern United States coastline. Despite their importance, few studies have examined the trophodynamics of a broad size spectrum of this species. Diet composition of summer flounder (n = 88) was assessed from 2014 to 2016 throughout Shinnecock Bay, a eutrophic bar-built estuary in New York. Species consumed and diet species richness differed significantly amongst SF size classes, with large [>= 375 mm total length (TL)] and medium (225: <375 mm) summer flounder showing higher levels of piscivory and more diverse diets than small-sized (<= 225 mm) conspecifics. As voracious plastic predators, trends in annual and monthly diet variation generally followed prey availability in Shinnecock Bay. One exception to this general pattern occurred for winter flounder (Pseudopleuronectes americanus). Despite their low relative abundance in the bay, winter flounder was highly preferred as prey by summer flounder (Chesson index, alpha = 0.35) and was their predominant prey item accounting for 12.3% (SD +/- 3.9%) of the diet by weight. Other factors that explained the variability of the diet of summer flounder were year, month, dissolved oxygen concentration, bay region and habitat, with a cumulative variance of 10.3%. Interestingly, clear differences in the diet (i.e., species richness and abundance) of summer flounder were found within regions of Shinnecock Bay, with a decrease in teleost biomass and species richness observed in the western region where water quality is more degraded and less seagrass is available compared to the more pristine eastern region. Distinct trophic dynamics in degraded habitats suggests fundamentally different food webs that could have important

consequences to ecosystem stability and resilience. As coastal areas continue to experience degradation, diet studies of economically and ecologically important species can aid in the development of effective ecosystem-based management plans.

Couillard, C. M., Courtenay, S. C., & Macdonald, R. W. (2008). Chemical-environment interactions affecting the risk of impacts on aquatic organisms: A review with a Canadian perspective - interactions affecting vulnerability. *Environmental Reviews,* 16, 19-44. https://doi.org/10.1139/a07-008

Environmental change can increase the vulnerability of aquatic species to toxic chemicals by challenging an organism's aptitude to respond to chemicals or to repair toxic injury or by modifying animal behaviours like migration or predation. On the other hand, xenobiotics may affect the capacity of aquatic species to adapt to environmental challenges that come with change (e.g., pathogens, temperature). Across Canada we have identified a number of circumstances where chemicals and environmental variability have likely worked together to affect vulnerability of aquatic organisms. For example in the Maritimes, exposure to municipal wastewater or bleached kraft pulp mill effluent altered immune function in bivalves and increased their risk of developing haemocytic neoplasia, a disease known to cause high mortality. Northwest Atlantic cod stocks have experienced large-scale changes in environment and exhibit marked seasonal cycles in energy reserves. The risk associated with subsequent redistribution of persistent chemicals in the body together with nutritional deficiency is presently under evaluation since it could affect the recovery of these endangered stocks. In the Great Lakes, the introduction of an invasive fish species, the alewife, modified the diet of salmonids, which led to a deficiency of the vitamin thiamine in eggs causing early mortality. Contaminants may interact with thiamine deficiency and thus critically impair recruitment of salmonids. Viewing the risks presented by toxic chemicals from the point of view of species vulnerability, offers managers opportunities to mitigate such risks, for example, through habitat, ocean and fisheries management. Further research is needed to develop biomarkers of vulnerability, identify most vulnerable life stages and populations, to understand the interactions between global environmental changes, nutritional status, pathogens and toxic chemicals, and to develop integrated approaches to manage vulnerability of aquatic ecosystems to toxic chemicals.

Dellinger, L. (2012). A Fisherman's Perspective. *Journal of Shellfish Research,* 31(2), 581-582. https://doi.org/10.2983/035.031.0218

Late spring 1996 was the first incidence of shell disease observed by Rhode Island lobster fishermen. Shell-diseased lobsters had never been observed in Rhode Island waters before this time. I say this after speaking with lobstermen whose parents and grandparents were lifelong lobstermen here in Rhode Island. Coincidently, on January 19 of that same year, the worst oil spill in Rhode Island s history occurred, with nearly 1 million gal home heating oil inundating the state s south shore. The fishing grounds were closed while the cleanup efforts were underway, and after some time, the fishing grounds were reopened. Shortly thereafter, the first lobsters infected with shell disease appeared in the catch. Some people would have you believe increased water temperature and climate change are the culprits of shell disease. These factors very well may have contributed to the spread and severity of the disease by further stressing the animals in later years as temperatures began to rise. One only needs to look to

the Atlantic States Marine Fisheries Commission (ASMFC) Technical Committee document Recruitment Failure in the Southern New England Lobster Stock to debunk this theory. As noted on page 3, temperatures started to increase in 1999, 3 y after shell disease was first observed in Rhode Island waters. Found on page 17 of this same document are tables of water temperatures from the region and the years they were recorded. The first shell-diseased lobster that I caught was in late spring 1996 in the mouth of the West Passage of Narragansett Bay. By 1999, shell disease was a very common occurrence in some locations of Narragansett Bay and Rhode Island Sound. Fast-forward to early fall 1999, and the massive lobster dieoff in Long Island Sound occurred. Incidentally, during late summer 1999, the first cases of West Nile Virus were diagnosed inNewYork City. Tragically, 7 elderly patients lost the battle to the virus. At this point it was deemed necessary to reduce mosquito populations in the region to protect human health. The southern New England states began aggressive mosquito abatement programs, and these programs are still in effect today. That fall, the remnants of Hurricane Floyd moved over Long Island Sound, bringing heavy rains and washing many of these pesticides into the Sound. Within days of the event, thousands of lobsters started coming up dead and dying in the traps of the fishermen who fished there. Here in Rhode Island, it was decided to treat most of the state s storm drain basins with a larvicide known as Altosid, although this practice was probably not put into place until spring 2000. The active ingredient in this pesticide is methoprene. The thousands of storm drains around Rhode Island all eventually drain into Narragansett Bay and other tributaries that lead to Rhode Island Sound. Methoprene is a known endocrine disruptor and is lethal to stage 1 lobster larvae at 1 part per billion. Methoprene is also lighter than water and therefore stratifies the surface of the water to which it is applied. Lobsters begin their lives on and near the surface of the waters where they are hatched. There is evidence of other endocrine-disrupting chemicals impacting the lobster resource, such as alkylphenols, used in the production of plastic bottles and such. Simple things that seem harmless, like antibacterial soaps, contain endocrinedisrupting chemicals. Our society has deemed it appropriate to treat wastewaters at sewer treatment plants with chlorine and the like to kill the bacteria it contains. These waters are then discharged into one tributary or another, and they ultimately end up in the ocean. This process does nothing to remove pharmaceutical drugs or harmful endocrine-disrupting chemicals that are also contained in these wastewaters. Lobster fishermen are convinced that lobsters are the canary in the coal mine. I have been a long-time observer of Narragansett Bay, first playing in and around it as a child, and later pursuing a career as a commercial fisherman. In the 30+ y of observations, the bay and the w terfront have changed dramatically. The island of Jamestown was once dotted with small summer cottages, as were most of the waterfront properties surrounding the bay. Today, nearly all these cottages have been torn down and replaced with mega homes. Many have landscaping suitable for the cover of Better Homes and Gardens. I wonder what chemicals are used to maintain these beautiful landscapes. The bay s waters have also changed dramatically in appearance and content. In my early years on the bay, the waters were frequently the color of tea or coffee. Today, the bay looks more like a swimming pool than an estuary. The bay s resident species are also very different. Winter flounder were once very abundant; today, they are almost nonexistent, even after many years of a total harvest moratorium. We currently have a single-species management strategy in place that manages all species to some high level of abundance, without consideration for the fact that big fish eat little fish. All species cannot coexist at these high levels without one species or another paying the price. At the time of this writing, our oceans are grossly out of balance. Dogfish are so abundant it has made it almost impossible for fishermen to work on some of their traditional grounds. These reports come from all sectors of the fishing community—both nearshore and off, commercial and recreational. I, personally, have had to give up fishing in some areas that were once some of my best lobster-producing grounds. At other times, it was black sea bass that caused me to give up fishing in an area. In some places in late summer and early fall, all I can catch is a trap full of sea bass that are closed to harvest at this time, or have a very small possession limit. These fish routinely regurgitate their

stomach contents on the ride up. To no surprise, they more often than not expel lobsters and crabs. Many of the managed species of finfish are at or above their targeted thresholds, as science has deemed it necessary to be considered a rebuilt stock.

Ebel, J. D. (2017). *Nutrient cycling by large consumers at individual, population, and ecosystem levels.* (Ph.D.), Memorial University, Retrieved from https://research.library.mun.ca/12567/

Organisms modulate nutrient cycles by transforming, storing, and transporting nutrients. While the impact of microorganisms and autotrophs on local and global biogeochemical cycles is well studied, our understanding of the nutrient cycling role of macro-consumers is in its infancy. In the following thesis, I explore aspects of the role of aquatic vertebrates in ecosystem nutrient cycling. Recent studies demonstrate substantial intraspecific variability in body element composition arising from environmental conditions and ontogeny. First, I test whether body element concentration varies among life stages and populations of Atlantic salmon (Salmo salar) from three Newfoundland rivers. I demonstrate that most intraspecific variability is explained by life stage and inter-stage variability in element concentrations can be attributed to the energy and nutrient requirements of reproduction and migration. Second, using long-term population monitoring data, I test whether ontogenetic differences in body phosphorus (P) concentration influence the role of Atlantic salmon as net sources or sinks of freshwater P. I find that incorporating inter-stage variability in body composition into nutrient flux models qualitatively changes our assessment of these populations as P sources or sinks relative to assuming ontogenetic homogeneity of body P concentration. Third, I develop a framework to describe the stoichiometric traits of vertebrate populations and use the framework to evaluate ontogenetic variability in body stoichiometry and total nutrient storage in brook trout (Salvelinus fontinalis) populations and partition nutrients released by migrating Atlantic salmon between eggs and excretion. Finally, life history strategy may influence interspecific variation in the ecosystem effects of migratory animals. I derive a two ecosystem model to investigate the ecosystem effects of migratory top consumers as subsidies. I formalized the hypothesis that iteroparous migratory animals should have stronger top-down effects on their biotic resource stocks than semelparous migratory animals, and that the response of ecosystem fluxes depends on the efficiency of consumer-mediated nutrient recycling. Overall, my findings suggest that interactions between ontogenetic development and life history strategy shape the nutrient cycling role of vertebrates. Connecting population structure and dynamics to nutrient cycles in this way may be a new path for 21st century ecological research and wildlife management.

Gabrielsen, S. E., Lennox, R. J., Wiers, T., & Barlaup, B. T. (2021). Saltwater spawning grounds of sea-run brown trout (Salmo trutta) in tidal waters of a major Norwegian river. *Environmental Biology of Fishes,* 104(10), 1207-1213. https://doi.org/10.1007/s10641-021-01147-y

Sea-run brown trout (Salmo trutta) have a highly phenotypically plastic life history that allows them to be effective colonizers and competitors in freshwater. This paper documents a previously unknown spawning behaviour in a brackish, tidally influenced estuary 14 km from the mouth of the Vosso River, a major Atlantic salmon- and sea-run brown trout-producing river in western Norway. Putative spawning gravel was observed, and sea-run brown trout deposited eggs that hatched in April. Survival of recruits was high (> 95%) in the tidal spawning gravel. These areas are strongly tidally influenced with a peak of

23.17 psu recorded at the lowest spawning ground. The observation of spawning so far from the river mouth may be unique in such a system with a long estuary but provides important insight into the biology of sea trout. Invasion of pink salmon, also known to spawn in estuaries, may negatively affect the competitive balance of sea trout with other salmonids in rivers where sea trout populations rely on recruitment from these relatively extreme spawning areas. Restoration of estuaries that have been modified by dredging or channelization may be important to ensure quality and heterogenous habitat for sea trout spawning given that haline spawning grounds could contribute to population resilience.

Gregory, S. D., Bewes, V. E., Davey, A. J. H., Roberts, D. E., Gough, P., & Davidson, I. C. (2020). Environmental conditions modify density-dependent salmonid recruitment: Insights into the 2016 recruitment crash in Wales. *Freshwater Biology,* 65(12), 2135-2153. https://doi.org/10.1111/fwb.13609

Understanding the effects of density-dependent and density-independent factors on recruitment is often inhibited by difficulties quantifying their relative contributions in highly variable recruitment data. Use of data-driven statistical methods with data that include one or more extreme recruitment events could help overcome these difficulties. Juvenile Atlantic salmon and trout abundances in Wales have declined over the last 2 decades, and 2016 was a notably poor recruitment year in rivers around southern Europe, including England and Wales. The 2016 recruitment crash coincided with extreme winter weather conditions, leading to speculation that unusually warm temperatures and high flows adversely affect salmonid recruitment and caused the 2016 crash, although this remains untested. We developed data-driven statistical models to: (1) describe juvenile salmonid recruitment from density-dependent and density-independent factors; and (2) assess whether the density-independent factors probably contributed to the 2016 salmon recruitment crash. We compiled salmon and trout young-of-year juvenile abundances from electrofishing surveys, egg deposition estimates and river flow and air temperature data from 2001-2017 for seven Welsh rivers, broadly representative of rivers around Wales. We used river flow and air temperature data to derive ecologically and behaviourally meaningful density-independent explanatory variables. Salmonid recruitment in Wales was best described using density-dependent and density-independent factors, especially for salmon: after accounting for a concave relationship with egg deposition, salmon juvenile abundance was reduced under (1) warmer spawning temperatures that might inhibit spawning, and (2) higher flood frequencies during pre-emergence and emergence that might washout eggs or alevins. Results were less clear for trout, perhaps because they are behaviourally more plastic. Our findings provide empirical support for general and predictable effects of temperature and flow during spawning and emergence on salmonid-especially salmon-recruitment in Wales. Furthermore, we suggest that the 2016 salmon recruitment crash was caused-in part-by particularly inclement spawning and emergence conditions, which could be more common under future climate change. Our findings suggest that future salmonid stock assessment models could include the effects of density-independent variables on recruitment to improve their predictive power.

Heggenes, J., Alfredsen, K., Bustos, A. A., Huusko, A., & Stickler, M. (2018). Be cool: A review of hydro-physical changes and fish responses in winter in hydropower-regulated northern streams. *Environmental Biology of Fishes,* 101(1), 1-21. https://doi.org/10.1007/s10641-017-0677-z

Winter is an ecologically challenging season for ectothermic cold-water fish in natural streams because of reduced flow and freezing. Hydropower regulation in many northern rivers increase winter stream flow and temperatures, and reduce ice formation and surface ice cover. From a background review of knowledge about e.g. Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) winter survival strategies, we explore responses to hydropower impacts as a basis for adaptive management, mitigating strategies, and future research. Winter intensity and duration, hydrologic conditions and channel characteristics drive complex ice processes which become more complex and pervasive in smaller, high-gradient streams. Stream ice formation may be divided into the dynamic period 'freeze-up' in early winter with sub-surface ice, more stable 'mid-winter' with surface ice, and the ecologically challenging 'ice break-up' in winter-spring with potential mechanical ice runs and scouring. The characteristics of periods vary depending on climate and hydropower regulation. In reaches downstream of power-plant outlets water temperature may increase and reduce surface ice formation. The mid-winter period destabilize or become absent. In bypass reaches flows decrease and facilitate freezing and ice production. Knowledge about longitudinal water temperature changes is limited. Hydro-peaked systems may aggravate high-low flow effects. A basic winter survival strategy in salmon and trout is energy storage, but also reduced metabolism, tolerance and starvation effected by quiescence. Energy storage may depend on local conditions, but there is little indication of adaptation to local thermal climates. Intraspecific phenotypic plasticity is important. The main behavioural strategy is risk-reducing sheltering in the substratum or deep areas, and nocturnal activity. Local movements between daytime refuges and nighttime slow-current activity areas are usually limited to meters. Larger fish may move more and aggregate in restricted suitable deep-slow refuge habitats such as pools and deep glides. Fish cope with ordinary thermal ice phenomena, and do not appear to become trapped in ice. Surface ice may reduce fish metabolism, but other factors, e.g. availability of substrate shelter, may override this effect. Mechanical ice break-ups and less surface ice may reduce survival. An adaptive mitigating strategy may be higher regulated flows in winter which increase rearing and/or resting habitat and survival, but studies are few and knowledge is limited. However, higher regulated flows also affect temperature regime. Low flows increase ice formation, reduce and fragment available habitat, and may reduce egg and fish survival. Influx of ground water may mitigate these impacts, as will stabilize minimum flows. Sudden drops in regulated water discharge should be avoided. Fish may strand, in particular at low temperatures in the daytime when fish are less mobile and seek shelter. The challenging winter season is understudied, and important management considerations and future research areas for better adaptive management are suggested.

Jonsson, B., & Jonsson, N. (2009). Migratory timing, marine survival and growth of anadromous brown trout *Salmo trutta* in the River Imsa, Norway. *Journal of Fish Biology,* 74(3), 621-638. https://doi.org/10.1111/j.1095-8649.2008.02152.x

The aim of the paper was to study sea migration, growth and survival of brown trout Salmo trutta of the River Imsa, 1976-2005. The migratory S. trutta were individually tagged and fish leaving or entering the river were monitored daily in traps located near the river mouth. The mean annual duration of the sea sojourn was 6-9 months for first-time migrants moving to sea between January and June. It was 8-18 months for those migrating to sea between July and December. Veteran migrants stayed 12 months or

less at sea and most returned to the river in August. Early ascending fish stayed the longest in fresh water because most returned to sea in April to May. The day number of 50% cumulative smolt descent correlated negatively with mean water temperature in February to March and the February North Atlantic Oscillation index (NAOI). Mean annual sea growth during the first 2 years after smolting was higher for S. trutta spending the winter at sea than those wintering in the River Imsa. First year's sea growth was lower for S. trutta descending in spring than autumn. For first-time migrants, it correlated negatively with the February NAOI of the smolt year. Sea survival was higher for spring than autumn descending first-time migratory S. trutta with a maximum in May (14.9%). Number of anadromous S. trutta returning to the river increased linearly with the size of the cohort moving to sea, with no evidence of density-dependent sea mortality. Sea survival of S. trutta smolts moving to sea between January and June correlated positively both with the annual number of Atlantic Salmo salar smolts, the specific growth rate at sea, and time of seaward migration in spring. This is the first study indicating how environmental factors at the time of seaward migration influence the sea survival of S. trutta.

Jonsson, B., & Jonsson, N. (2009). A review of the likely effects of climate change on anadromous Atlantic salmon *Salmo salar* and brown trout *Salmo trutta*, with particular reference to water temperature and flow. *Journal of Fish Biology,* 75(10), 2381-2447. https://doi.org/10.1111/j.1095-8649.2009.02380.x

The present paper reviews the effects of water temperature and flow on migrations, embryonic development, hatching, emergence, growth and life-history traits in light of the ongoing climate change with emphasis on anadromous Atlantic salmon Salmo salar and brown trout Salmo trutta. The expected climate change in the Atlantic is for milder and wetter winters, with more precipitation falling as rain and less as snow, decrease in ice-covered periods and frequent periods with extreme weather. Overall, thermal limits for salmonids are species specific. Scope for activity and growth and optimal temperature for growth increase with temperature to an optimal point before constrain by the oxygen content of the water. The optimal temperature for growth decreases with increasing fish size and varies little among populations within species, whereas the growth efficiency may be locally adapted to the temperature conditions of the home stream during the growth season. Indirectly, temperature influences age and size at smolting through its effect on growth. Time of spawning, egg hatching and emergence of the larvae vary with temperature and selective effects on time of first feeding. Traits such as age at first maturity, longevity and fecundity decrease with increasing temperature whilst egg size increases with temperature. Water flow influences the accessibility of rivers for returning adults and speed of both upstream and downstream migration. Extremes in water flow and temperature can decrease recruitment and survival. There is reason to expect a northward movement of the thermal niche of anadromous salmonids with decreased production and population extinction in the southern part of the distribution areas, migrations earlier in the season, later spawning, younger age at smolting and sexual maturity and increased disease susceptibility and mortality. Future research challenges are summarized at the end of the paper.

King, J. J. (2015). Ecology And Economics Of Fish Kills: Mortality And Recovery Of Brown Trout (Salmo Trutta L.) And Atlantic Salmon (Salmo Salar L.) In An Irish River. *Biology and Environment-Proceedings of the Royal Irish Academy*(3), 157-170. https://doi.org/10.3318/bioe.2015.16

There is a small international scientific literature, principally from North America, on recovery of fish communities following substantial fish kill events and a smaller literature on monetary assessment of losses in such events. A chemical discharge led to over 90% loss of brown trout (Salmo trutta L.) and Atlantic salmon (Salmo salar L.) age classes in 31km of the River Boyne catchment, a major Irish salmon-producing and angling fishery in July 1997. Subsequent investigations permitted a novel study that examined both the changes in the fish community composition over time and also a monetary assessment of losses. The population structure and density of 1 and older brown trout took four to five years to recover. The population of 1+ salmon increased substantially during the recovery period, to levels threefold higher than those recorded prior to the pollution event. Financial loss assessment was examined through 'replacement cost' and through consequential loss models. An examination of the monetary modelling, in the light of the fish community recovery, showed there was an ecological justification for the potential loss model used. This approach to appraisal of loss is considered to have an international relevance, in the context of ecosystem processes and the 'polluter pays' principle.

Manderson, J., Pessutti, J., Shaheen, P., & Juanes, F. (2007). Dynamics of early juvenile winter flounder predation risk on a North West Atlantic estuarine nursery ground. *Marine Ecology Progress Series,* 328, 249-265. https://doi.org/10.3354/meps14178

In an effort to determine the characteristics of estuarine habitats suitable for early juvenile winter flounder Pseudopleuronectes americanus survivorship, we examined piscivorous fish distributions and diets, and flounder predation risk along estuarine gradients in the Navesink River/Sandy Hook Bay estuarine system, New Jersey, USA. Demersal fish, striped searobin Prionotus evolans and summer flounder Paralichthys dentatus, were more important predators of winter flounder than pelagic fish (Pomatomus saltatrix, Cynoscion regalis, Morone saxatilis) based on diet analysis of 4 yr of gill (1998 and 1999) and trammel net (2001 and 2002) fish collections. From April through June newly settled winter flounder 20ppt. Fish >20 mm standard length (SL) were consumed by summer flounder in shallow habitats in June and July. In May and June tethering experiments, Age-0 winter flounder predation risk was high in habitats with salinities >19ppt and temperatures >20 degree C. In 3 yr, salinities were 20ppt in upstream habitats where searobins ate large numbers of settling winter flounder and predation risk was high. These results suggest that the volume of estuarine habitat suitable for early juvenile flounder survivorship is determined, in part, by predator and prey responses to spatially dynamic physico-chemical gradients. Because gradient dynamics are controlled by climate forcing, climate variation may cause nursery habitat volumes to contract or expand resulting in variation in the local production of Age-0 recruits.

Moore, A., Bendall, B., Barry, J., Waring, C., Crooks, N., & Crooks, L. (2012). River temperature and adult anadromous Atlantic salmon, *Salmo salar*, and brown trout, *Salmo trutta*. *Fisheries Management and Ecology,* 19(6), 518-526. https://doi.org/10.1111/j.1365-2400.2011.00833.x

In terms of the spawning migration of adult salmon, Salmo salar L., water flow is often considered the primary factor controlling river entry and fluctuations in flow controlling when the fish subsequently

migrate upstream. However, water temperature has also been suggested to modify the spawning migration of salmon, particularly their movements within estuaries and the timing of freshwater entry. Freshwater temperature is more likely to impact salmonid biology than flow, particularly in relation to temperature dependant metabolic costs, time of spawning and fecundity. Therefore, temperature may be more of a factor regulating salmonid populations in fresh water than flow itself. This study focuses on two aspects of the impact of temperature on salmonids in fresh water: first, how salmon may modify their behaviour to adapt to changes in temperature and second the potential relationship between temperature, environmental conditions (e.g. water quality) and physiology (e.g. maturation and olfaction) in regulating adult migration.

Roussel, J. M., Perrier, C., Erkinaro, J., Niemelä, E., Cunjak, R. A., Huteau, D., & Riera, P. (2013). Stable isotope analyses on archived fish scales reveal the long-term effect of nitrogen loads on carbon cycling in rivers. *Global Change Biology,* 20(2), 523-530. https://doi.org/10.1111/gcb.12293

Stable isotope analysis of organic matter in sediment records has long been used to track historical changes in productivity and carbon cycling in marine and lacustrine ecosystems. While flow dynamics preclude stratigraphic measurements of riverine sediments, such retrospective analysis is important for understanding biogeochemical cycling in running waters. Unique collections of riverine fish scales were used to analyse δ(15) N and δ(13) C variations in the food web of two European rivers that experience different degrees of anthropogenic pressure. Over the past four decades, dissolved inorganic N loading remained low and constant in the Teno River (70°N, Finland); in contrast, N loading increased fourfold in the Scorff River (47°N, France) over the same period. Archived scales of Atlantic salmon parr, a riverine life-stage that feeds on aquatic invertebrates, revealed high δ(15) N values in the Scorff River reflecting anthropogenic N inputs to that riverine environment. A strong correlation between dissolved inorganic N loads and δ(13) C values in fish scales was observed in the Scorff River, whereas no trend was found in the Teno River. This result suggests that anthropogenic N-nutrients enhanced atmospheric C uptake by primary producers and its transfer to fish. Our results illustrate for the first time that, as for lakes and marine ecosystems, historical changes in anthropogenic N loading can affect C cycling in riverine food webs, and confirm the long-term interactions between N and C biogeochemical cycles in running waters.

Saaristo, M., Brodin, T., Balshine, S., Bertram, M. G., Brooks, B. W., Ehlman, S. M., . . . Arnold, K. E. (2018). Direct and indirect effects of chemical contaminants on the behaviour, ecology and evolution of wildlife. *Proceedings of the Royal Society B: Biological Sciences,* 285(1885), 20181297. https://doi.org/10.1098/rspb.2018.1297

Chemical contaminants (e.g. metals, pesticides, pharmaceuticals) are changing ecosystems via effects on wildlife. Indeed, recent work explicitly performed under environmentally realistic conditions reveals that chemical contaminants can have both direct and indirect effects at multiple levels of organization by influencing animal behaviour. Altered behaviour reflects multiple physiological changes and links individual- to population-level processes, thereby representing a sensitive tool for holistically assessing impacts of environmentally relevant contaminant concentrations. Here, we show that even if direct effects of contaminants on behavioural responses are reasonably well documented, there are significant knowledge gaps in understanding both the plasticity (i.e. individual variation) and evolution of contaminant-induced behavioural changes. We explore implications of multi-level processes by

developing a conceptual framework that integrates direct and indirect effects on behaviour under environmentally realistic contexts. Our framework illustrates how sublethal behavioural effects of contaminants can be both negative and positive, varying dynamically within the same individuals and populations. This is because linkages within communities will act indirectly to alter and even magnify contaminant-induced effects. Given the increasing pressure on wildlife and ecosystems from chemical pollution, we argue there is a need to incorporate existing knowledge in ecology and evolution to improve ecological hazard and risk assessments.

Taylor, D. L., Cribari, K. J., & Scro, A. (2019). Piscivory in age-0 summer flounder *Paralichthys dentatus* with a focus on predator-induced mortality of post-settlement winter flounder *Pseudopleuronectes americanus*. *Marine Ecology Progress Series,* 612, 7-28. https://doi.org/10.3354/meps12885

We examined the piscivorous diet of age-0 summer flounder Paralichthys dentatus in southern New England tidal rivers, with a focus on their predatory impact on post-settlement winter flounder Pseudopleuronectes americanus. The population density, size-structure, and growth of age-0 summer flounder and winter flounder were evaluated in the Seekonk and Taunton Rivers (Rhode Island and Massachusetts, USA, respectively) between May and August/September 2009 through 2015. For a subsample of summer flounder collected during this time (20-181 mm total length, TL; n = 743), diet was assessed using direct visual analysis and PCR-based assays that detect winter flounder mitochondrial DNA within predator stomach contents. Summer flounder were generalist piscivores consuming 8 distinct fish prey taxa from both epibenthic and pelagic guilds. The most frequently observed fishes in the diet of summer flounder were age-0 winter flounder and herring (Clupeidae) with frequencies of occurrence, %F, of 2.6 and 2.0%, respectively, and overall %F of fish equal to 13.6%. Fish were absent in the stomachs of summer flounder <44 mm TL, beyond which piscivory increased significantly with increasing predator size. Summer flounder 50-153 mm TL preyed on winter flounder ranging from 19-54 mm TL, resulting in predator-to-prey size ratios of 2.2-3.6 (mean +/- SD = 2.8 +/- 0.3). Incidences of summer flounder predation on winter flounder were positively related to body size ratios, and this relationship was attributed to the enlarged mouth gape and improved prey capture abilities of larger predators. Summer flounder predation on fishes, including winter flounder, also demonstrated significant spatiotemporal variability, reflecting riverine and seasonal differences in flounder population size structure and dynamics in prey composition and availability. Deterministic model simulations estimated that age-0 summer flounder account for 0.7 % of the daily mortality of post-settlement winter flounder (range = 0.0-2.9%), and consumed 3.0% of the total winter flounder year-class annually (range = 0.0-12.8 %). Therefore, relative to other predatory fishes and decapod crustaceans, age-0 summer flounder likely have a nominal effect on winter flounder populations in tidal river nurseries. Summer flounder predation may be substantial, however, when multiple age-classes are considered and elevated age-0 summer flounder densities elicit a strong effect on winter flounder survival, albeit at local scales.

Thorstad, E. B., Todd, C. D., Uglem, I., Bjørn, P. A., Gargan, P. G., Vollset, K. W., . . . Finstad, B. (2016). Marine life of the sea trout. *Marine Biology,* 163(3), 47. https://doi.org/10.1007/s00227-016-2820-3

An understanding of when and where sea trout Salmo trutta L. are located at sea is essential to the effective management of local populations and in evaluating their vulnerability to salmon lice and other anthropogenic threats. Here we review the available literature on sea trout life-history strategies, behaviour and habitat use in the marine environment, including feeding, growth, survival and homing. There is considerable variation in life-history strategies among individuals and populations and in the timing and duration of marine migration(s). Females tend to adopt the anadromous strategy more than do males. Smolts typically leave rivers in spring (March–June in European rivers), but also at other times of the year. Post-smolts may remain at sea during the summer and return to freshwater to over-winter; adults thereafter spend summers at sea and winters in freshwater, or they can remain at sea until they later return to freshwater for spawning. Sea trout frequently are recorded at sea during winter and can tolerate full-salinity sea water at water temperatures as low as 1–2 °C. Sea trout often remain within 80 km of their river of origin, but also may undertake longer-distance marine migrations (>500 km). The duration and timing of marine migration both are likely governed by trade-offs between mortality risk and growth potential in different habitats, and the most beneficial strategy may vary among individuals and populations. Reduced marine growth and increased marine mortality will reduce the benefit of marine migrations and may result in selection against anadromy.