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Conservation genomics of Atlantic salmon in North America: old questions, new answers

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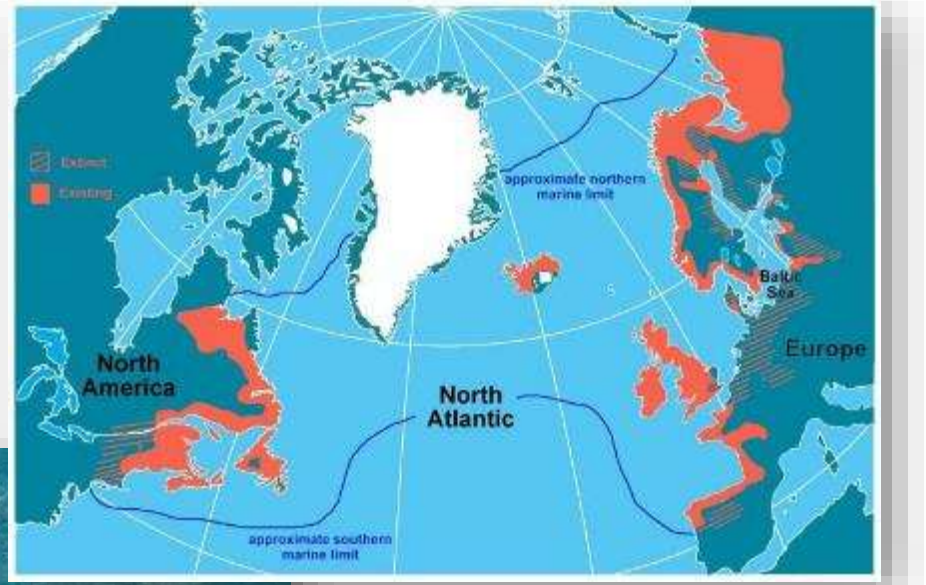
Canada

Atlantic salmon biology and range

Atlantic salmon widely found across North Atlantic

Long distance migrations, trans-Atlantic straying reported, high rates of natal homing

Southern populations at risk



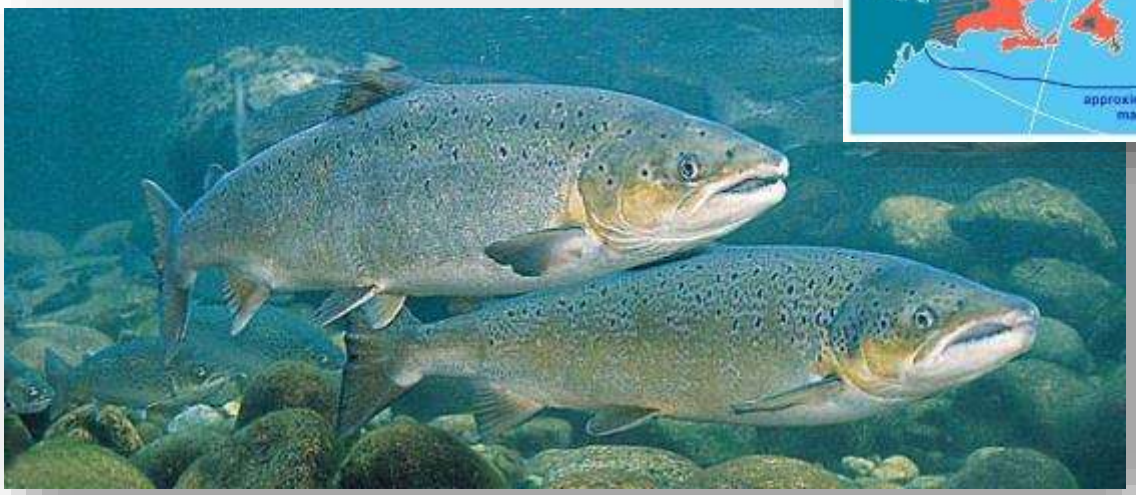
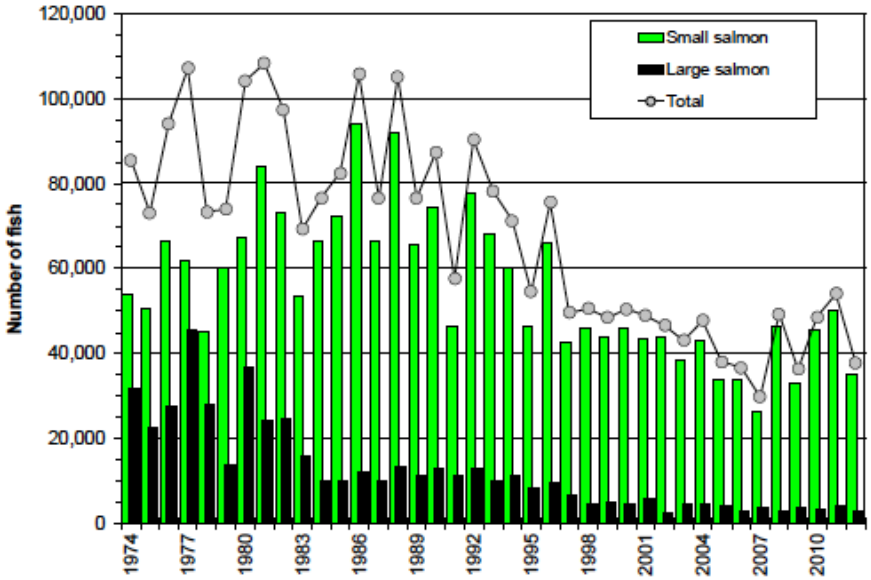


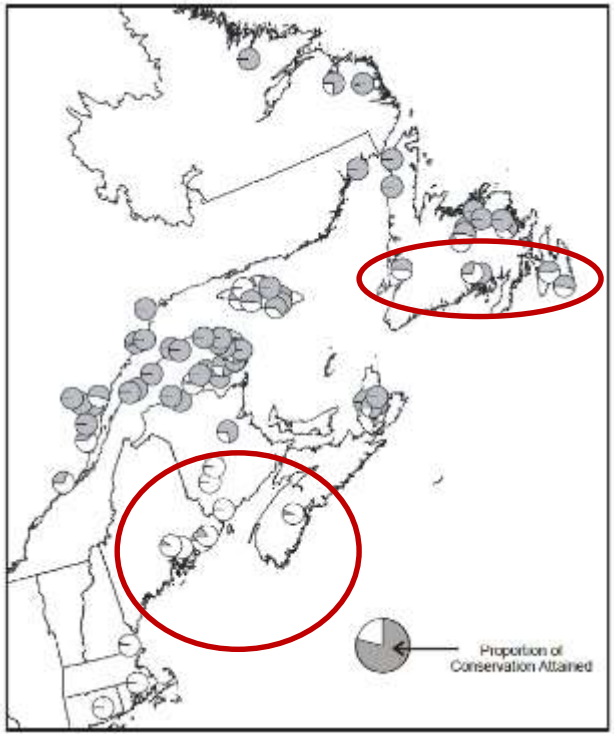
Photo: Maine Atlantic Salmon Commission

North American Atlantic Salmon Conservation



Declines in Northwest Atlantic

Southern Newfoundland and Maritimes / USA populations at risk



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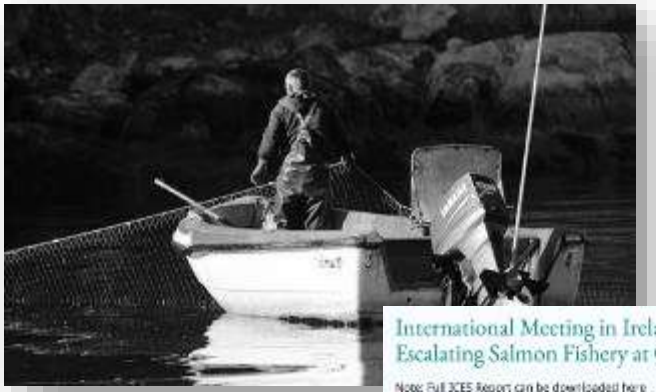
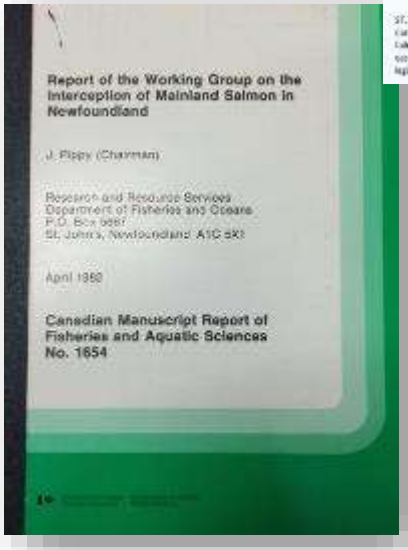
Threats known / difficult to quantify





Interceptory Fisheries

Interactions with aquaculture

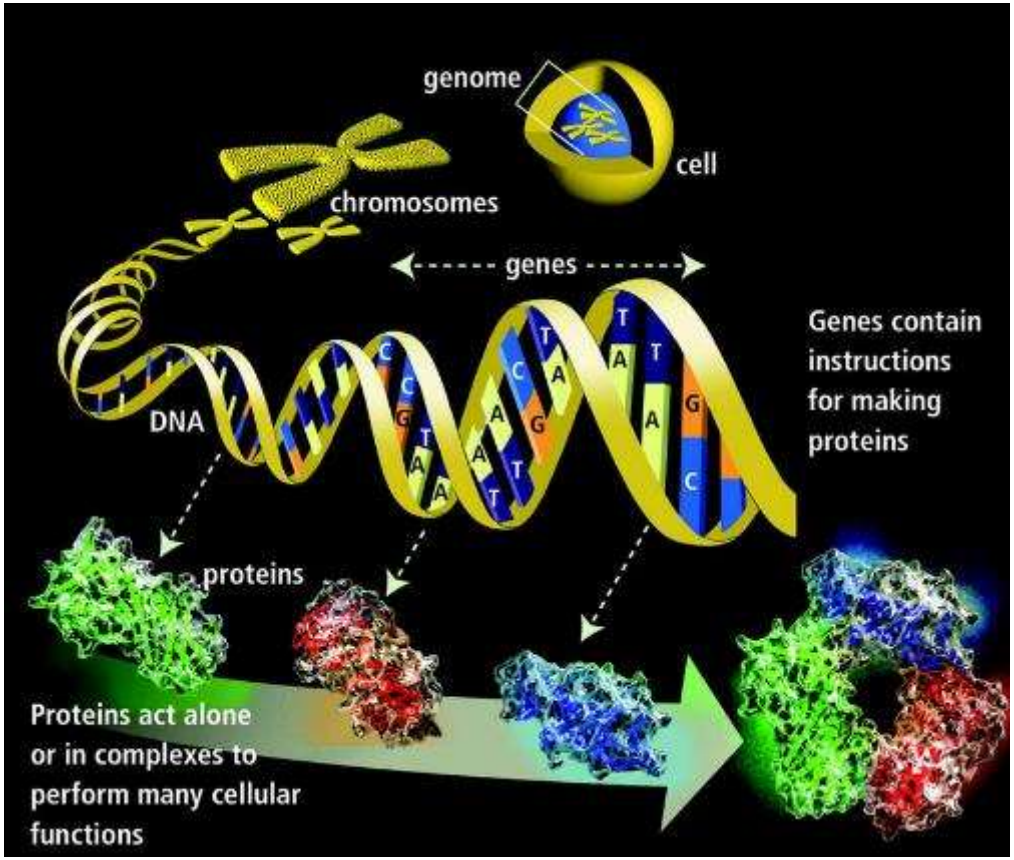
DNA, genes, and genomes

A full set of instructions, every cell contains a complete copy, written in the four-letter language of DNA (A, C, T, and G)

Salmon genome contains 3 billion of these "letters" or bases, divided into 27 volumes, called chromosomes

Each chromosome contains genes - "sentences" of genetic instructions of how to make proteins

About 20,000 genes

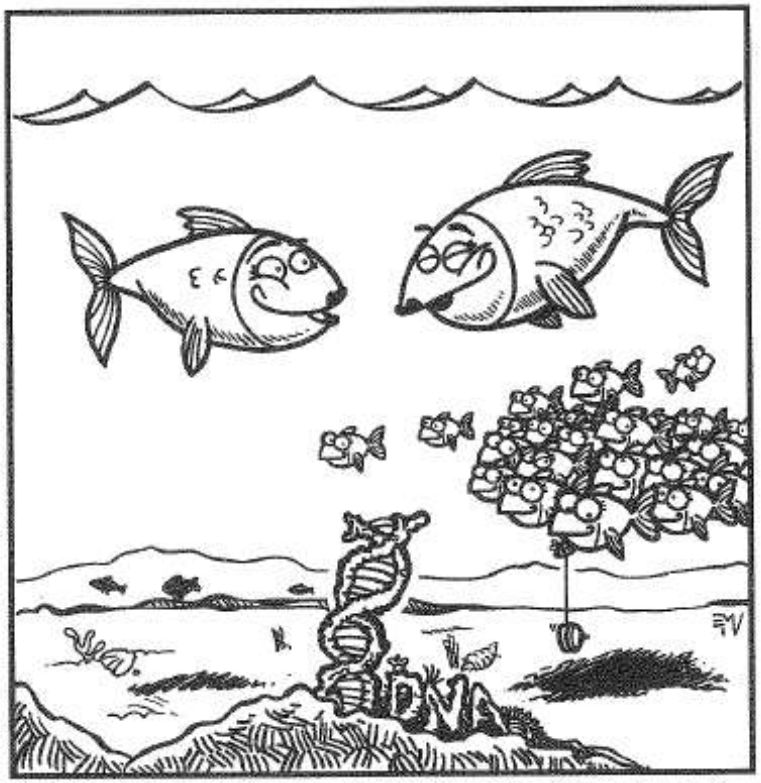


Genomics for conservation

An individual's genome is a record of its history and local adaptation

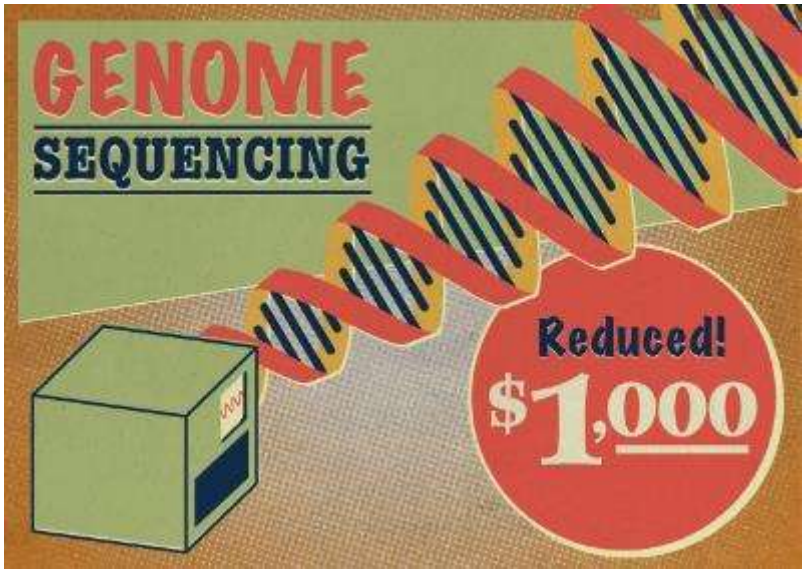
Allows unprecedented power to identify individuals, populations, and functional genetic variation – what makes then unique

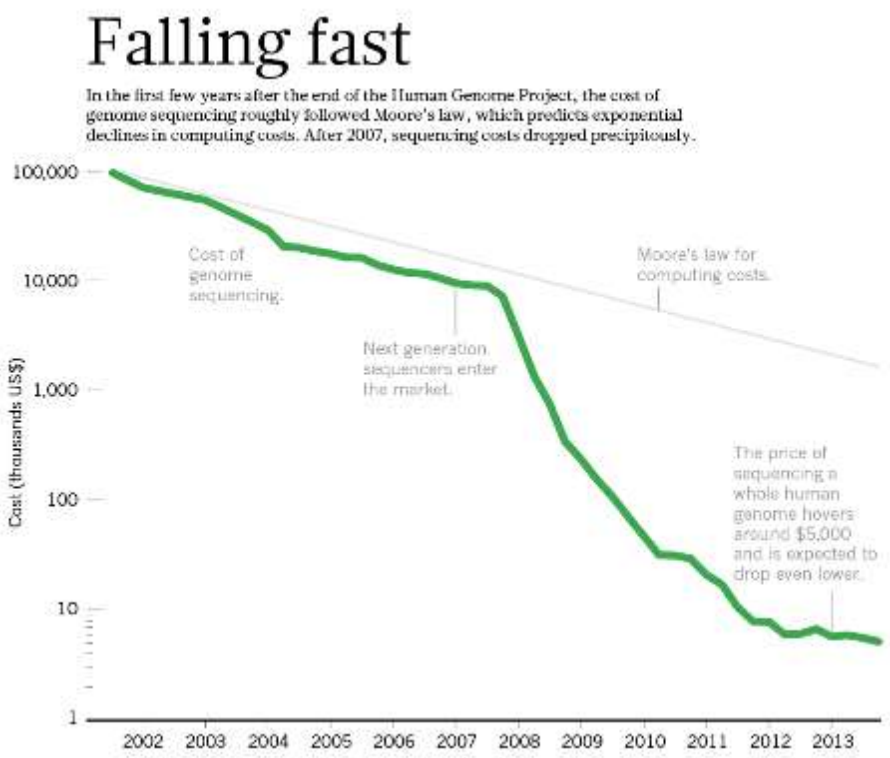
New sequencing technologies allow 1000's of genes to be identified and examined in 100's of individuals at low cost



Oh Gladys! Just how do you do it?
You ve got so many healthy little ones!

DNA Sequencing Revolution





Nature ***507, 294–295 (20 March 2014)***

Genomics and salmon conservation

Effective conservation of wild Atlantic salmon requires:

1) Accurate understanding of conservation units
2) Ability to assess salmon mortality due to exploitation
3) Understanding the impacts of salmon aquaculture

Goal:
Use genomic tools to address these needs and to inform conservation and management of Atlantic salmon

Question 1: Taking stock, what do we have?

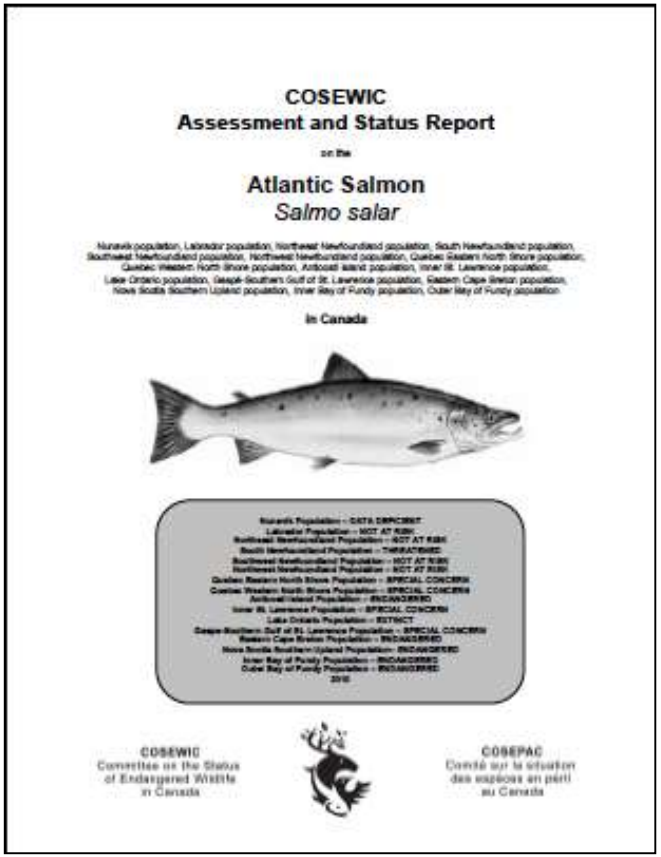
Portfolio effects promote stability and persistence in the face of disturbance

Stock = population of interbreeding individuals defined by thresholds for exchange (genetic, tagging, etc)

Diversity = Stability

Portfolio Effects – systems with greater diversity have a buffer for change

Management units (DU) in Canada



COSEWIC
Assessment and Status Report
on the
Atlantic Salmon
Salmo salar

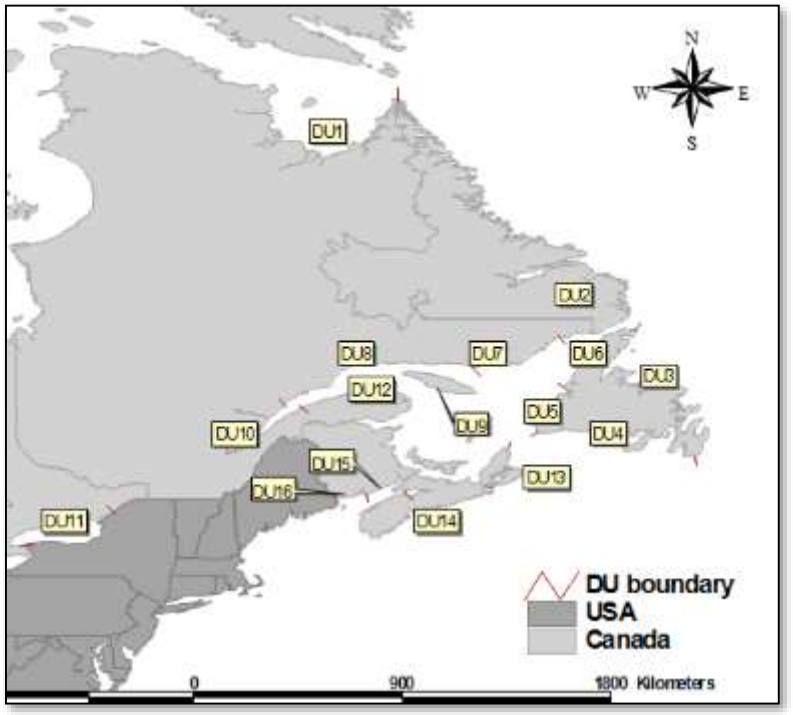
Nunavik population, Labrador population, Northeast Newfoundland population, South Newfoundland population, Southeast Newfoundland population, Northwest Newfoundland population, Quebec Eastern North Shore population, Quebec Western North Shore population, Anticosti Island population, Inner St. Lawrence population, Lake Ontario population, Gaspé-Southern Gulf of St. Lawrence population, Eastern Cape Breton population, Nova Scotia Southern Upland population, Inner Bay of Fundy population, Outer Bay of Fundy population

in Canada

2010

COSEWIC
Committee on the Status of Endangered Wildlife in Canada

COSEPAC
Comité sur la situation des espèces en péril au Canada



Management units (i.e. DUs) too large?

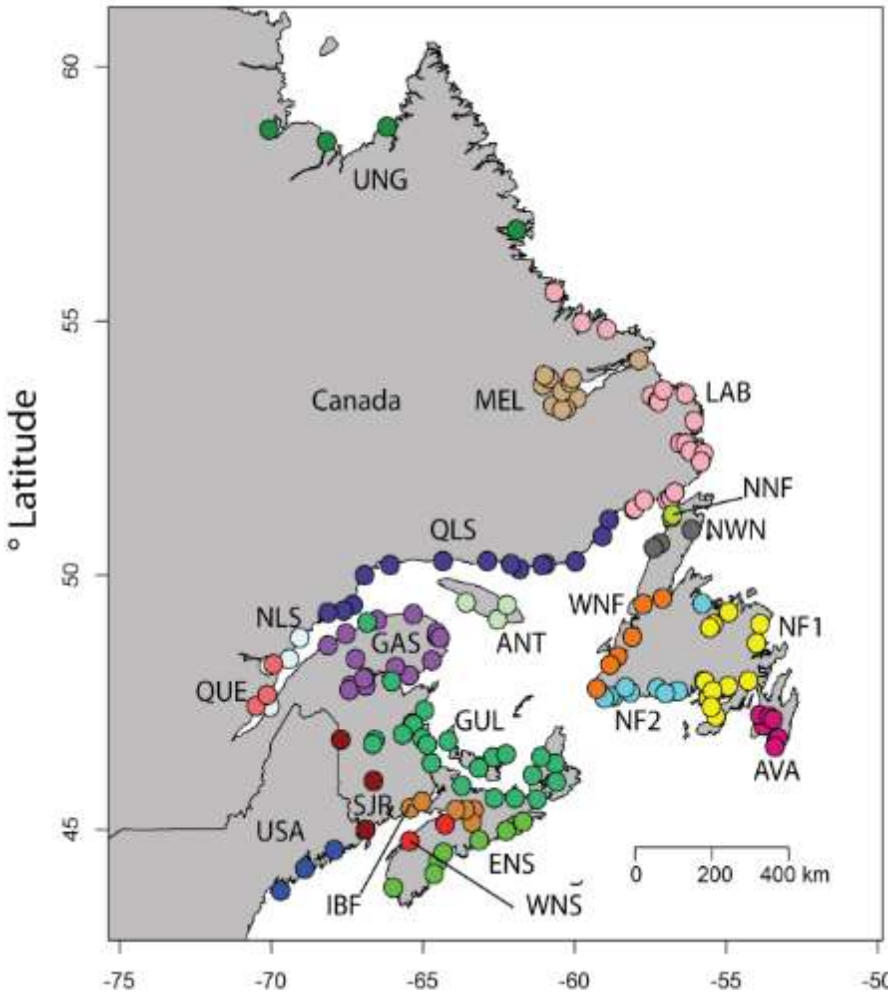
Canada

Eradion

Salmon SNP Baseline

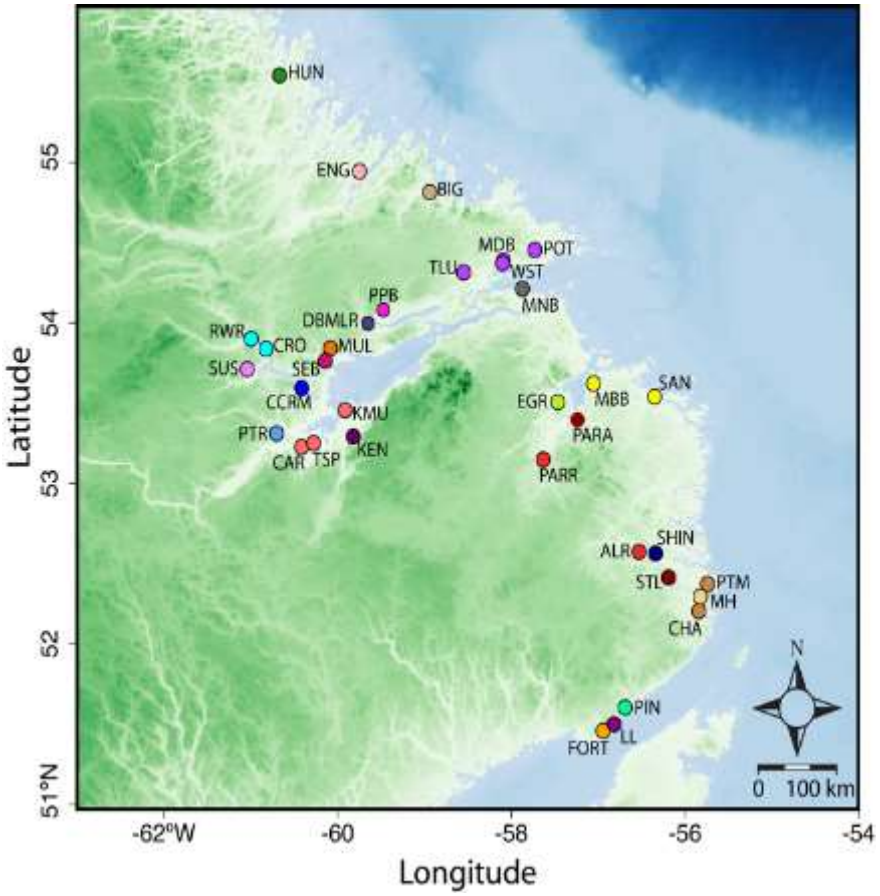
Range wide SNP baseline, ~300 populations and 7239 individuals for 96 SNPs

Highly accurate regional assignment (91.3%) to 27 regional groups (20 North American, 7 European)



High Resolution Baselines

- Two to three groups identifiable in Labrador using large-scale baselines
- For 36 rivers in Labrador, 26 groups resolved, to river for most
- Expanding to other areas, Placentia Bay Newfoundland, Southern Gulf of St. Lawrence, Miramichi River



Bradbury et al. 2018
Evolutionary Applications

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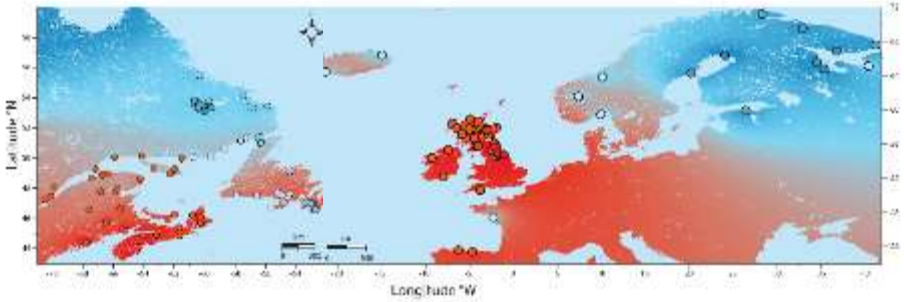
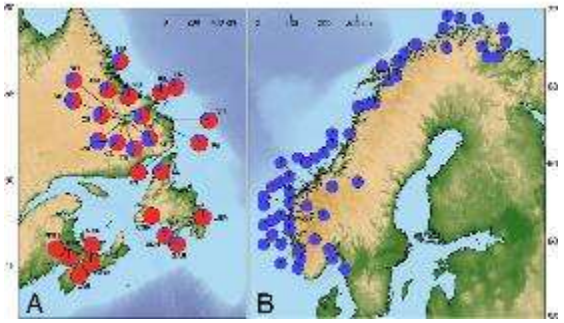
Structuring Forces

Adaptation



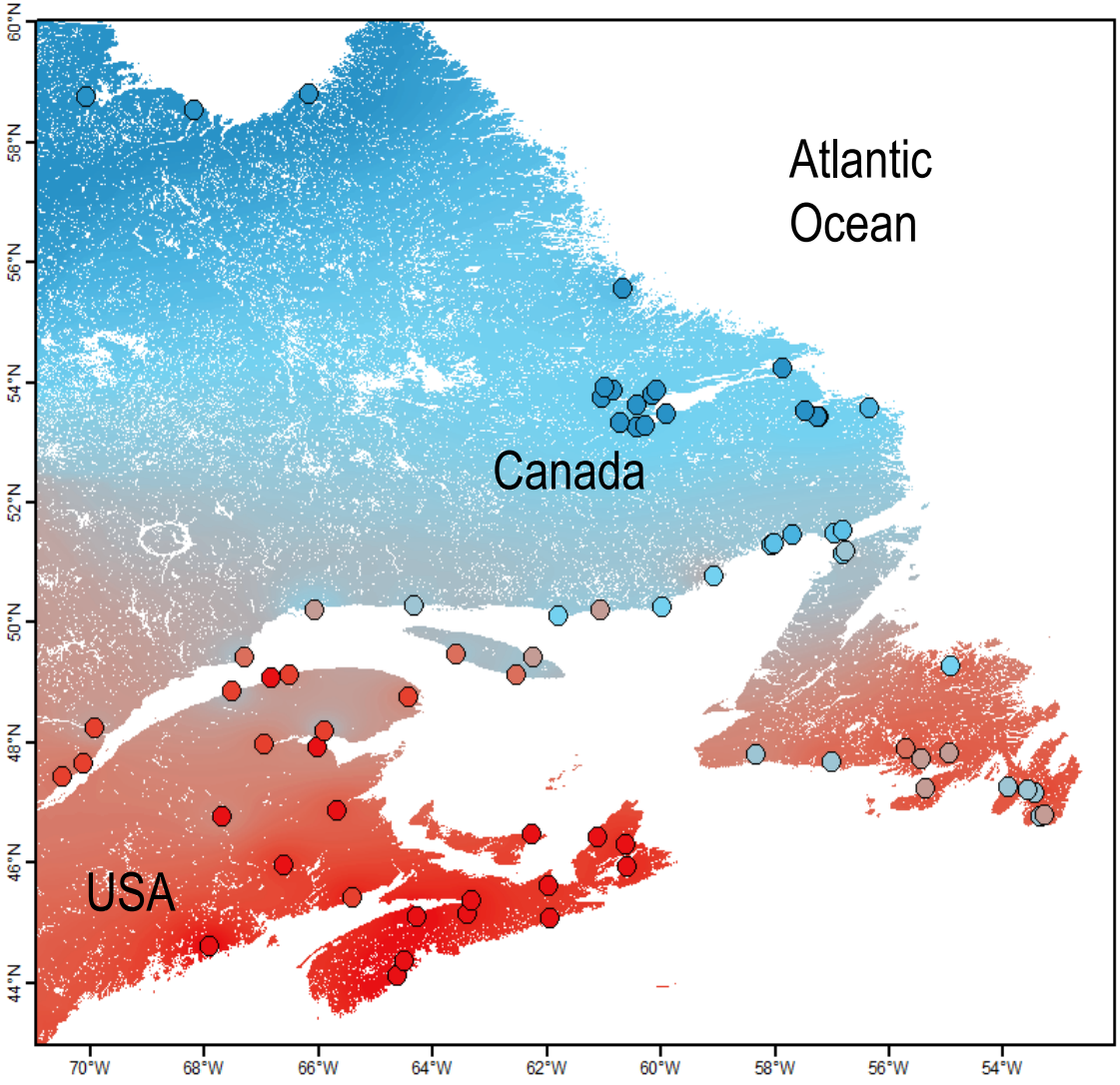
- Adaptation to local climate drives population structure in many regions
- Environmental extremes (e.g., periods hot or cold temperature) may be most critical
- Relationships critical to predicting population responses to climate change

Colonization history



- Population structure influenced by colonization history particularly follow periods of glaciation
- Previous of evidence of European colonization of North America, particularly southeastern Newfoundland

Temperature Adaptation – North America



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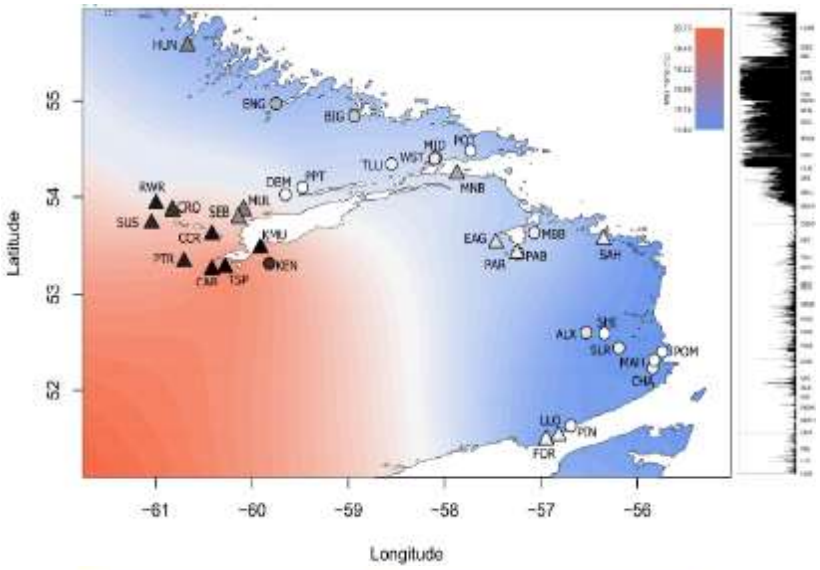
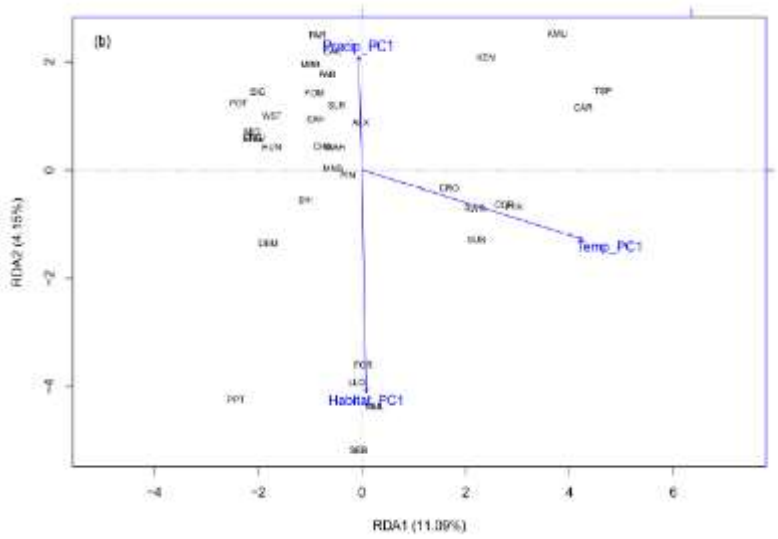
Regional analysis

Fine scale study within Labrador, clearly resolves Lake Melville as distinct

Temperature identified as significant driver of spatial structure, particularly extreme high temperatures

Regional structure consistent with temperature associated adaptive divergence





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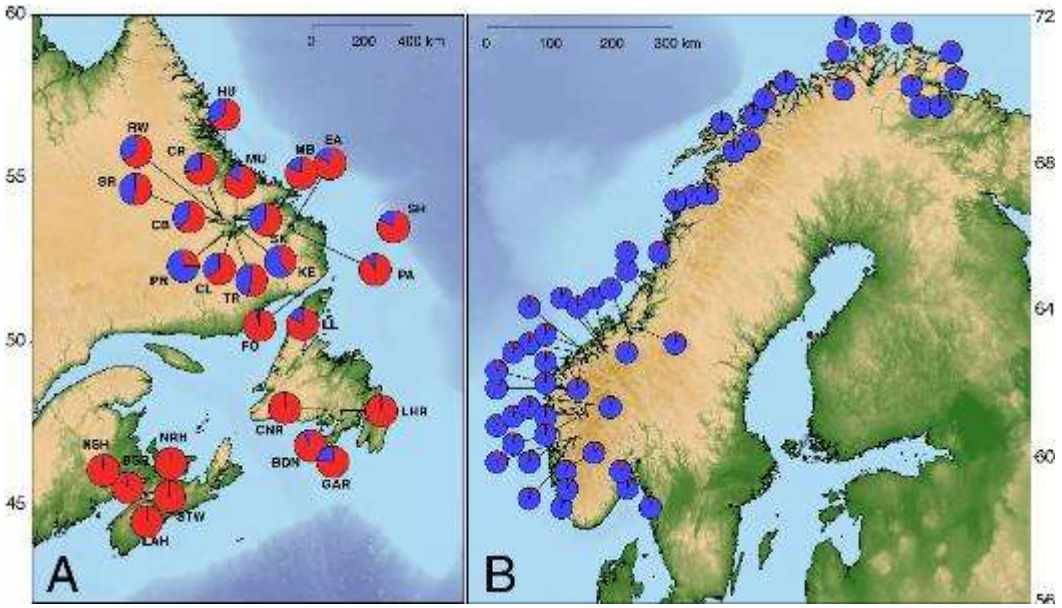
Structuring forces – Colonization history

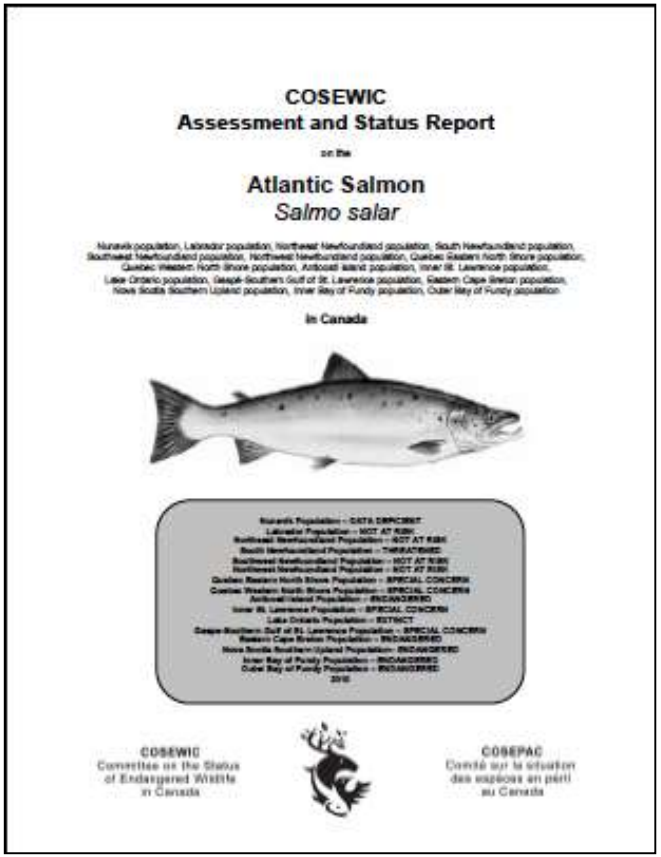
Salmon in Europe and North America highly divergent ~ 500 000 years

Genetic analysis reveals high frequency of European form in Labrador with decreases to the south

Consistent with post-glacial colonization of Labrador by both North American and European salmon ~20,000 years ago



Management units (DU) in Canada



COSEWIC
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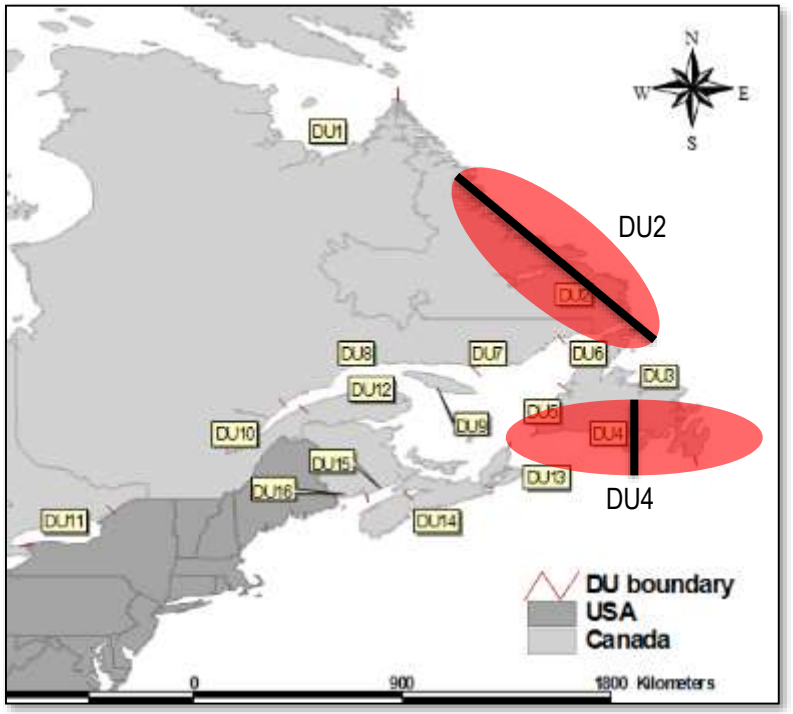

Management units (i.e. DUs) too large?

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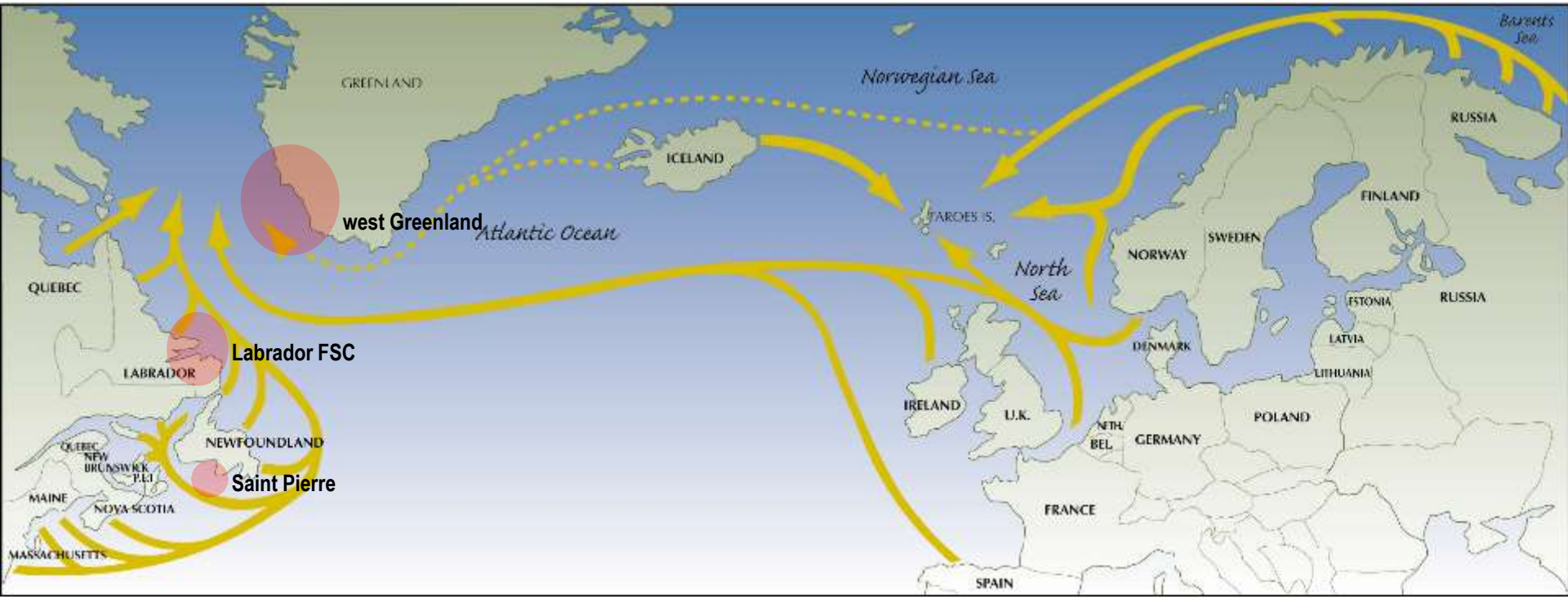
Question 2, who's catching our fish and how many?

Mixed stock fisheries



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Labrador FSC Fishery Analysis

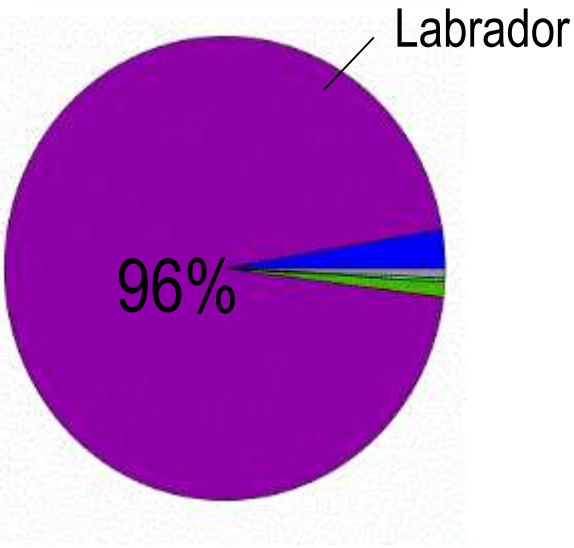
Four subsistence fisheries harvest salmon in Labrador ~10k to 15k individuals

Currently 93% of harvest occurs in rivers or estuaries (ICES, 2014)

Local fishery

Central Labrador represented the majority of the mixture estimated at 96.0% ± 0.7%

Contribution of all possible non-Labrador sources to the fishery is estimated as <3%



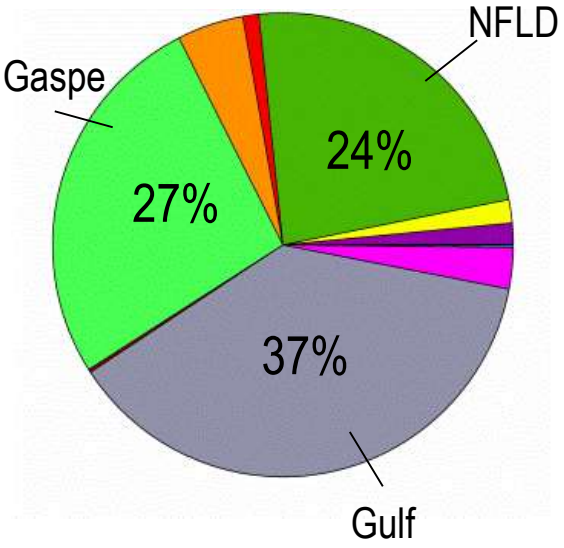
Saint Pierre and Miquelon Fishery

Interceptory harvest in the French territory of St. Pierre and Miquelon, professional and recreational gill net fishery

~5 tonnes in recent years, 98% of this catch originates from Canadian stocks, the identity of which remains unknown

Adjacent Southern Newfoundland DU considered threatened by COSEWIC

Genetic analyses suggest a mix of Newfoundland, Gulf, and Gaspe salmon, so southern or adjacent groups with migratory routes that pass



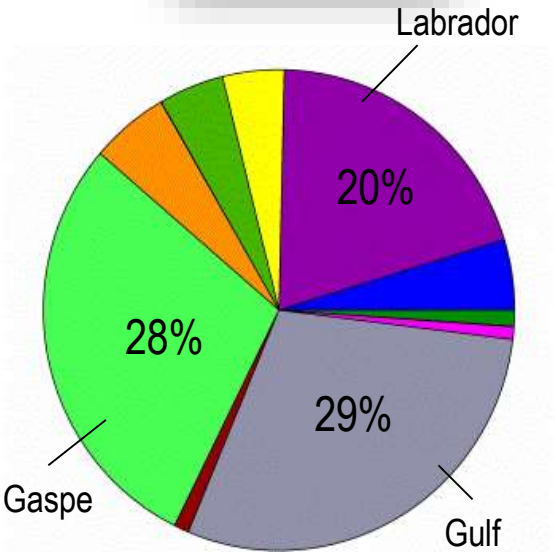
West Greenland Fishery

Interceptory fishery, targeting 2SW NA and EU salmon

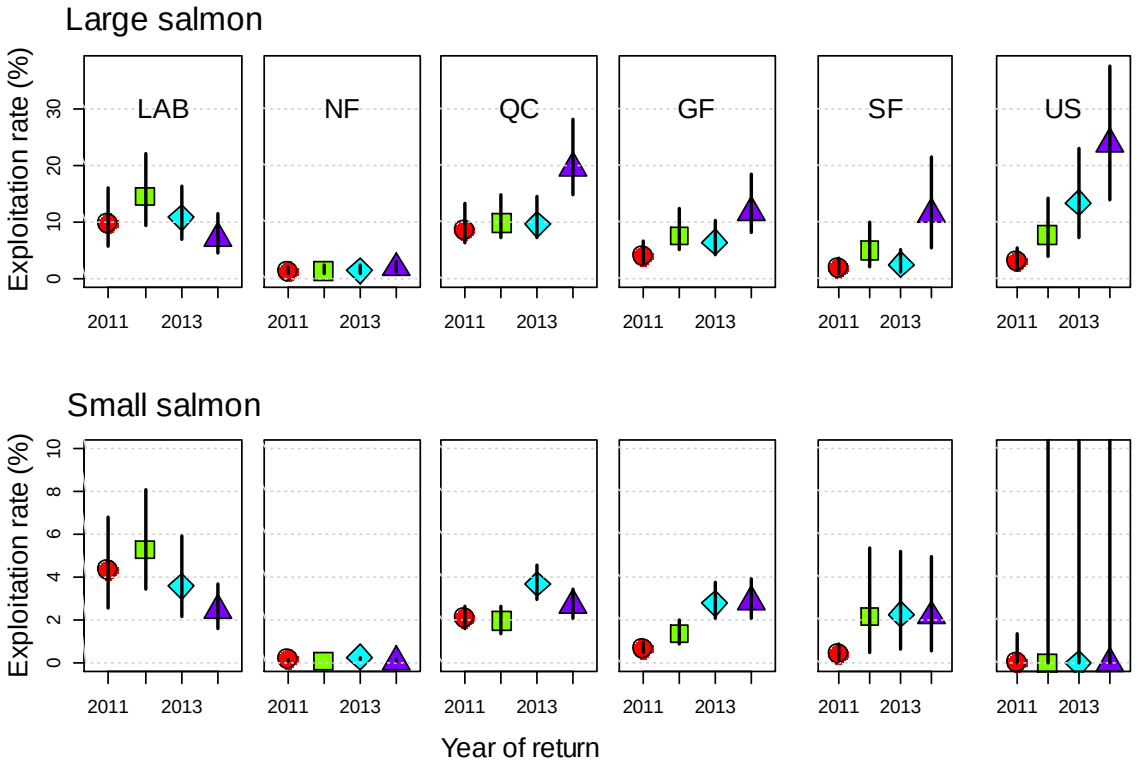
10-15K North American origin fish (80%) and approximately 2-3K European (20%)

Potential for exploitation of threatened Canadian and US stocks

Genetic analyses suggest a mix of Labrador, Gulf, and Gaspe salmon, so the largest MSW producing stocks



Overall exploitation rates (median, 95% percentile range) by regional group in the three marine mixed stock fisheries for year of return 2011 to 2014



<10% for large salmon

<5% for small salmon

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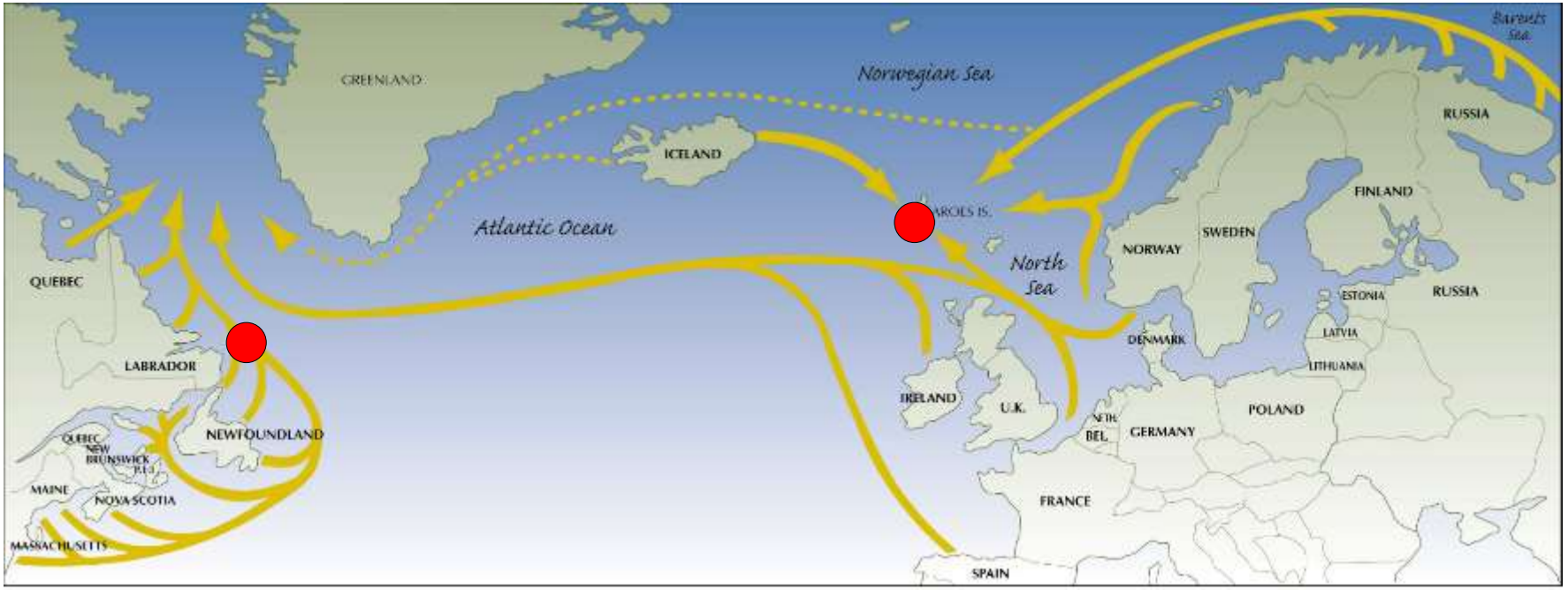
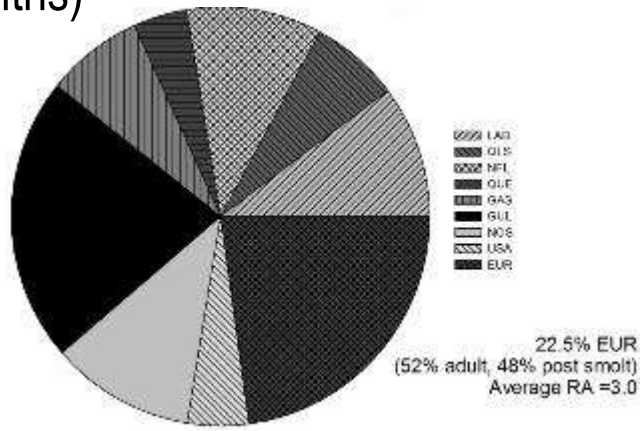
What can we learn about migration routes?



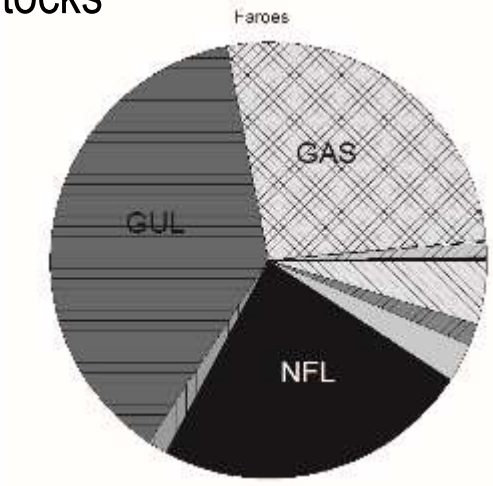
● Two samples of mixtures taken at sea (1980s-1990s)

Trans-Atlantic Migration?

Labrador sea- Samples of smolts and adults from 1987 and 1988 - 22% are European mostly Scottish (approx. 4000 km in ~3 months)



Faroes - Samples of large salmon (1990's) reveal 22% are NA in origin, mostly Maritime stocks



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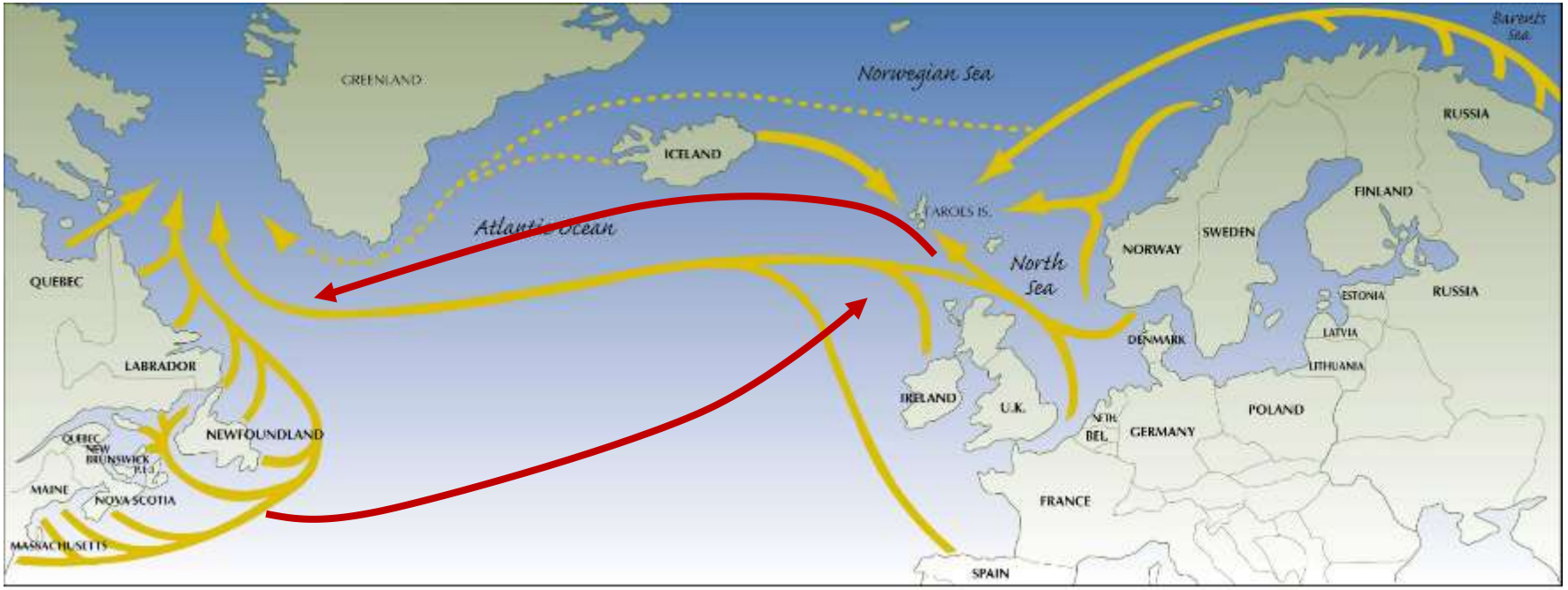
New trans-Atlantic connections??



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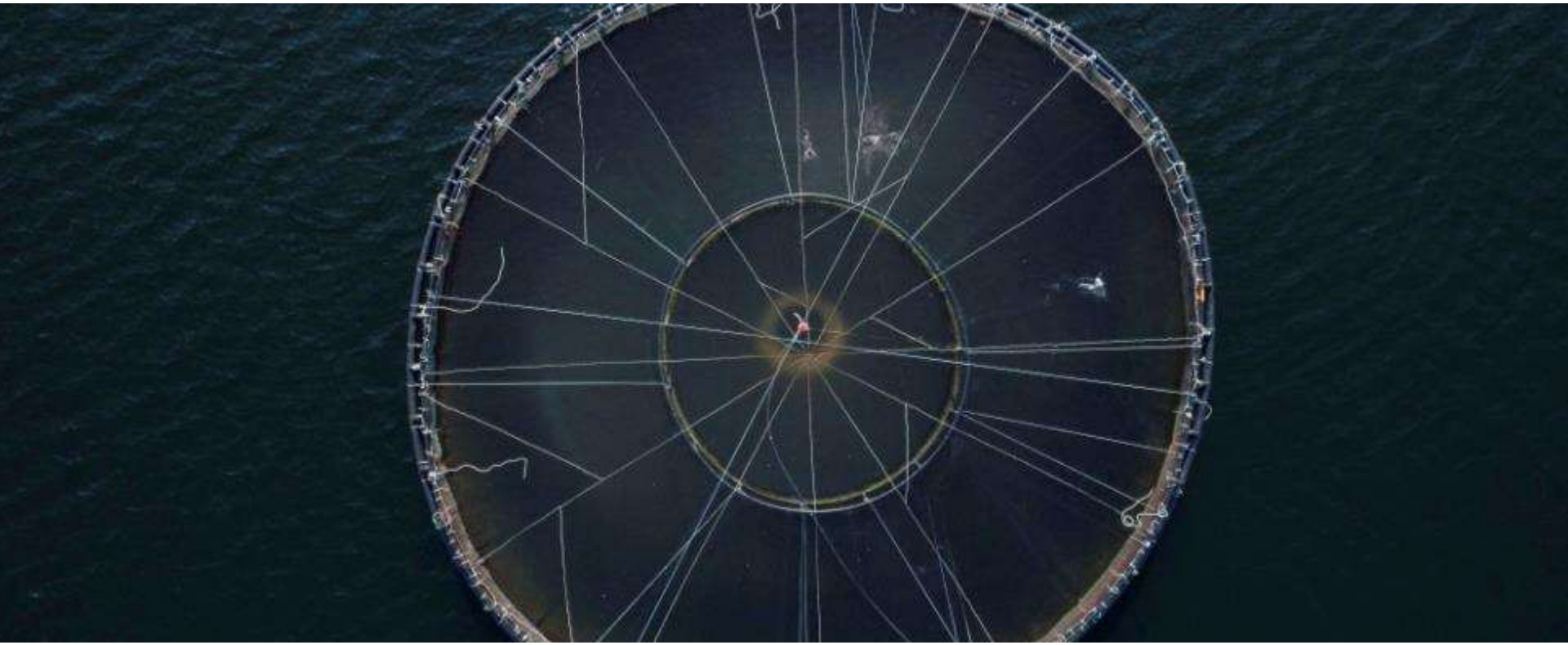

Question Three – what impact is salmon aquaculture having on wild populations?

Genetic impacts

Hybridization can make wild populations less productive and less resilient to change

How common are escapees?

Are escapees interbreeding with wild populations?

Garnish River, Oct 2013, mat F, 76.0 cm

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Counting fences – monitoring for escapees

Garnish River Escapees

2015 - 4
2016 - 5
2017 – 6
2018 -

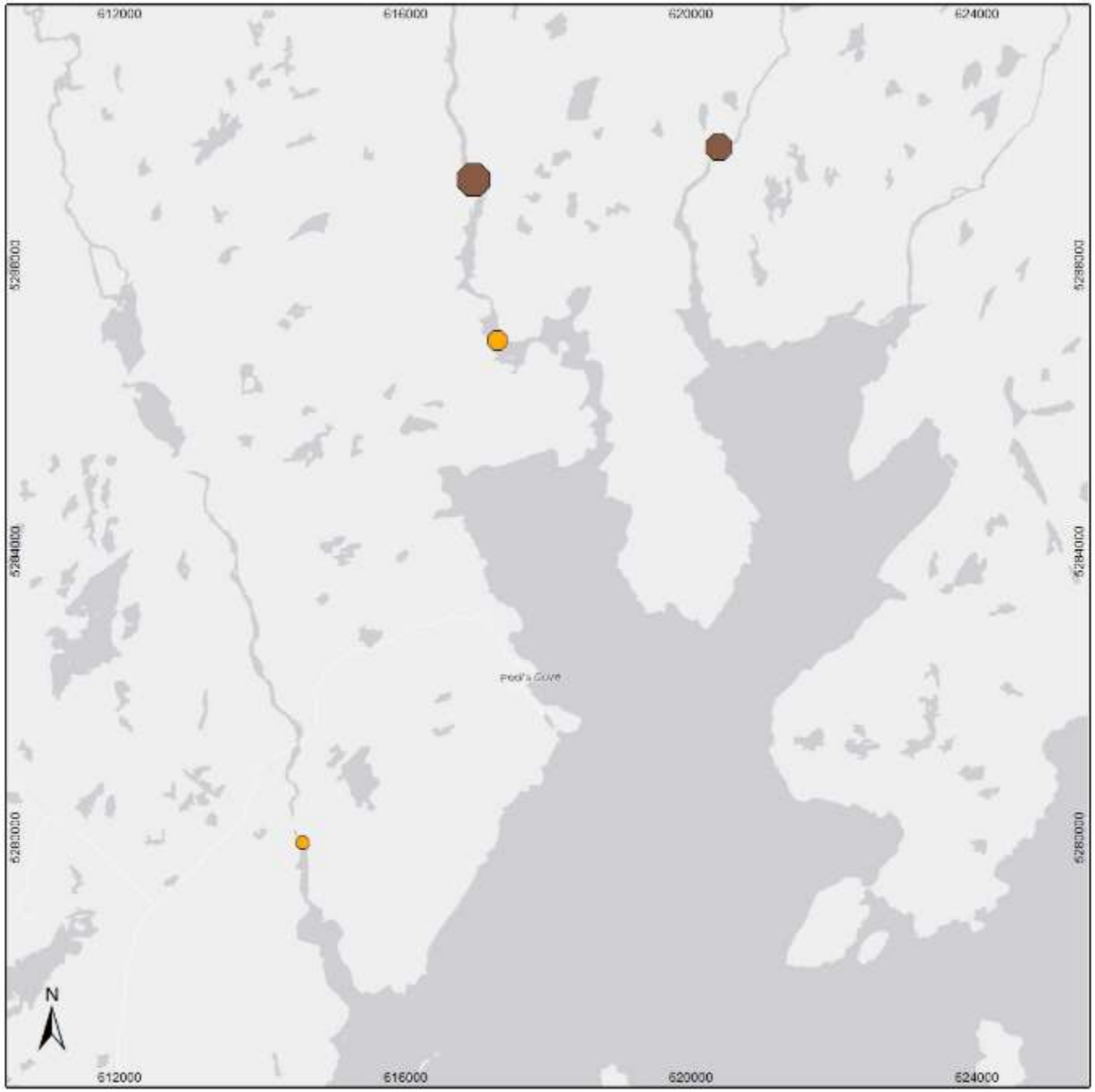
Canada

Escapee Fall Survey

Combined gillnet and angling survey throughout Fortune Bay and Bay d'Espoir

Survey Catches

2015 - 158
2016 - 0
2017 – 0
2018 - ?



Fisheries and Oceans Canada

Angling and Gillnetting Fall 2015

Fortune Bay and Bay d'Espoir, NL

Legend

Catch Totals

- 1
- 7
- 22
- 128

UTM Zone 21N
North American Datum 1983

1:75,889

0 0.5 1 2 km

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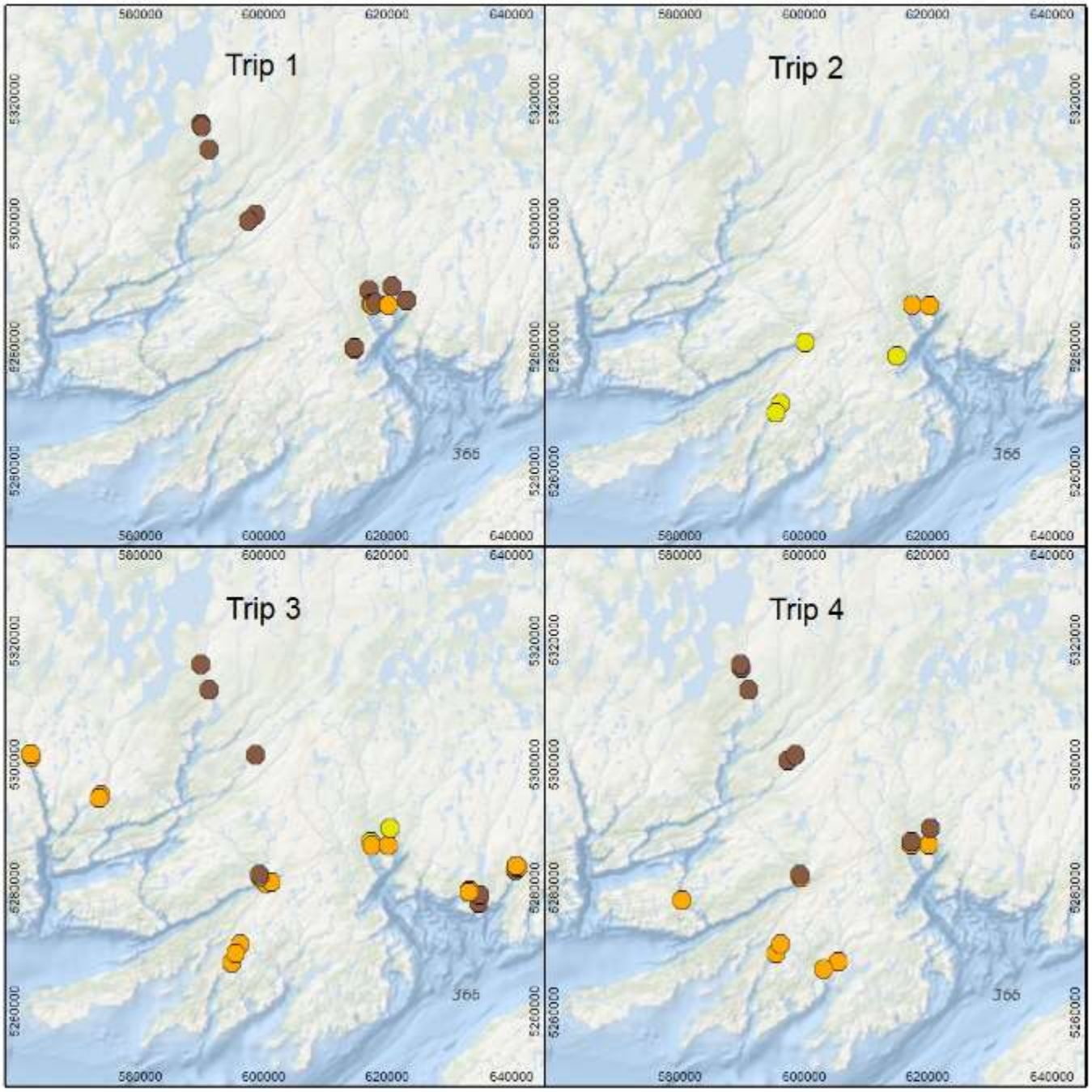

Fisheries and Oceans Canada

Angling and Gillnetting Fall 2016

Fortune Bay and Bay d'Espoir, NL

Legend

Gear Type

- Angling
- Gillnet
- Gillnet & Angling

UTM Zone 21N
North American Datum 1983

1:871,968

0 5 10 20 km

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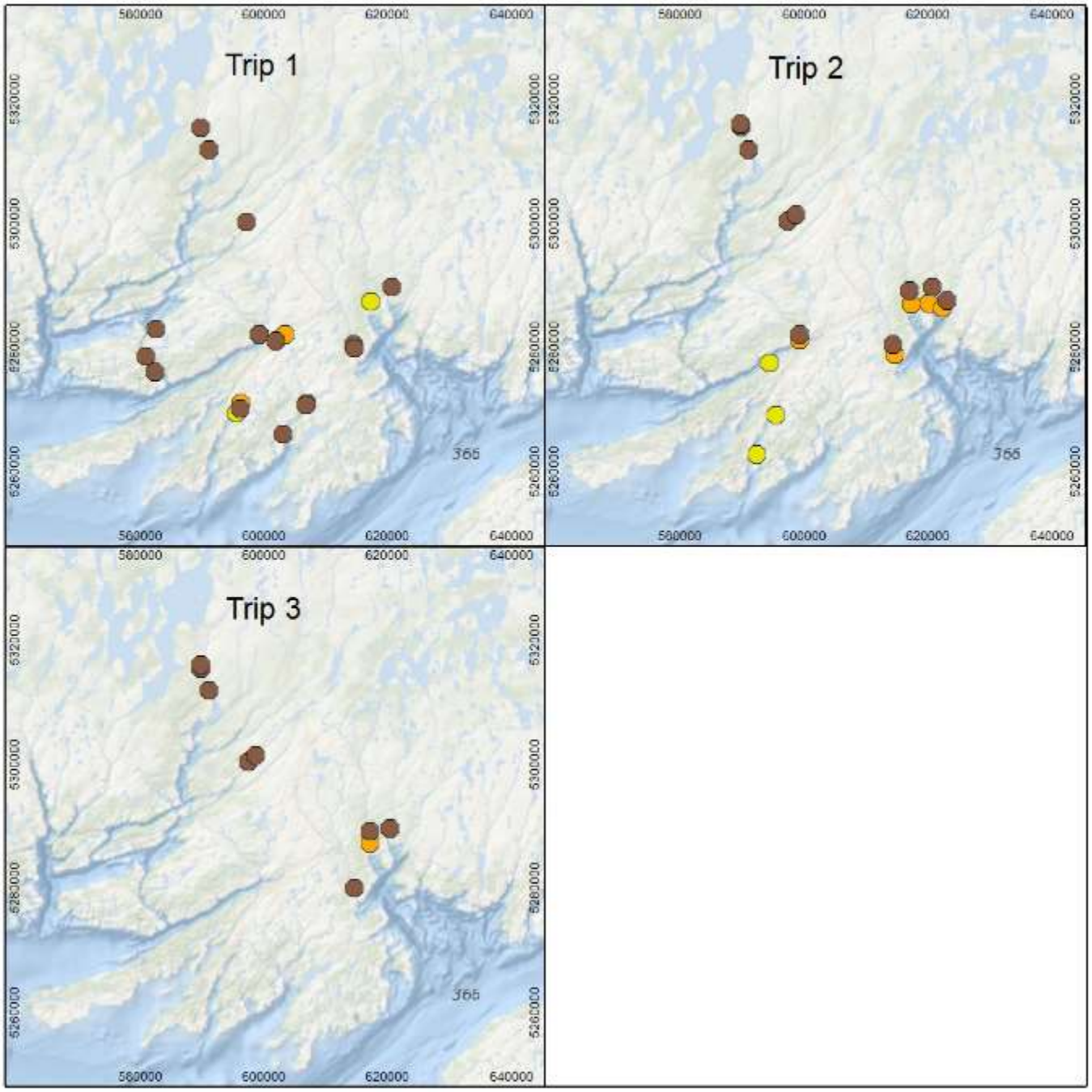

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Angling and Gillnetting
Fall 2017
Fortune Bay and
Bay d'Espoir, NL

Legend

Gear Type

- Angling
- Gillnet
- Gillnet & Angling

UTM Zone 21N
North American Datum 1983
1:871,968

0 5 10 20 km

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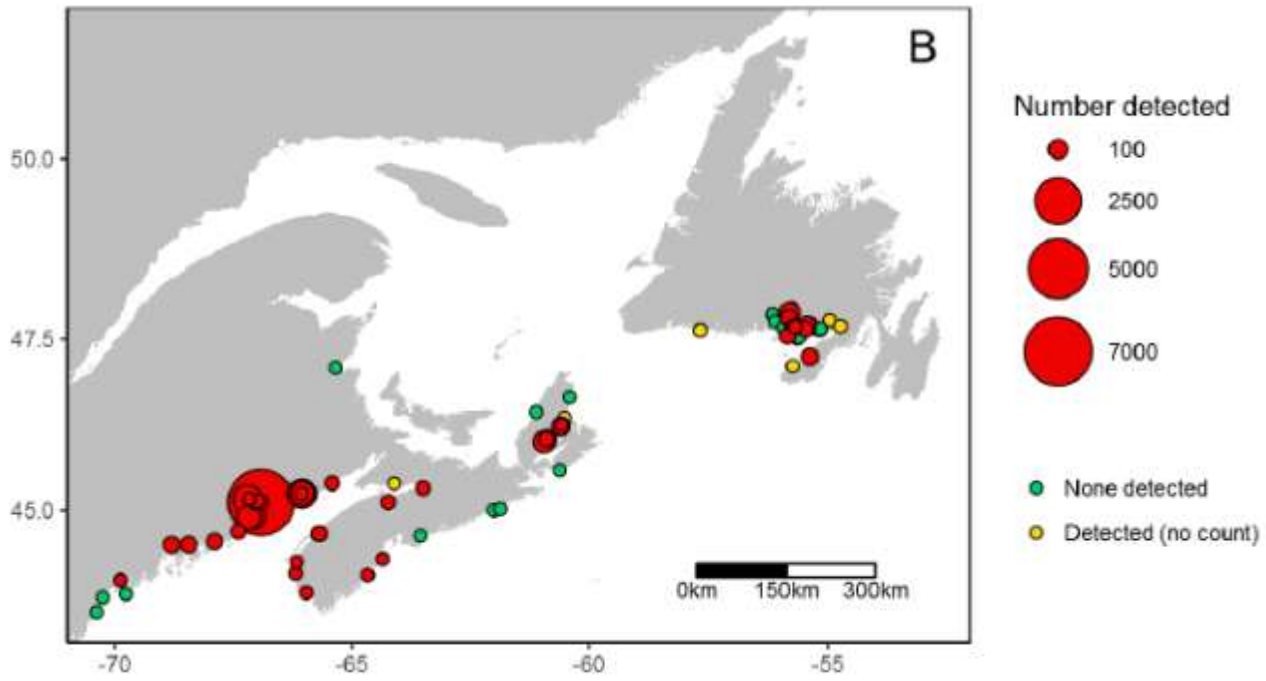
Distribution of escapees



Total of 467 records from the 1980s to 2016 from 112 rivers

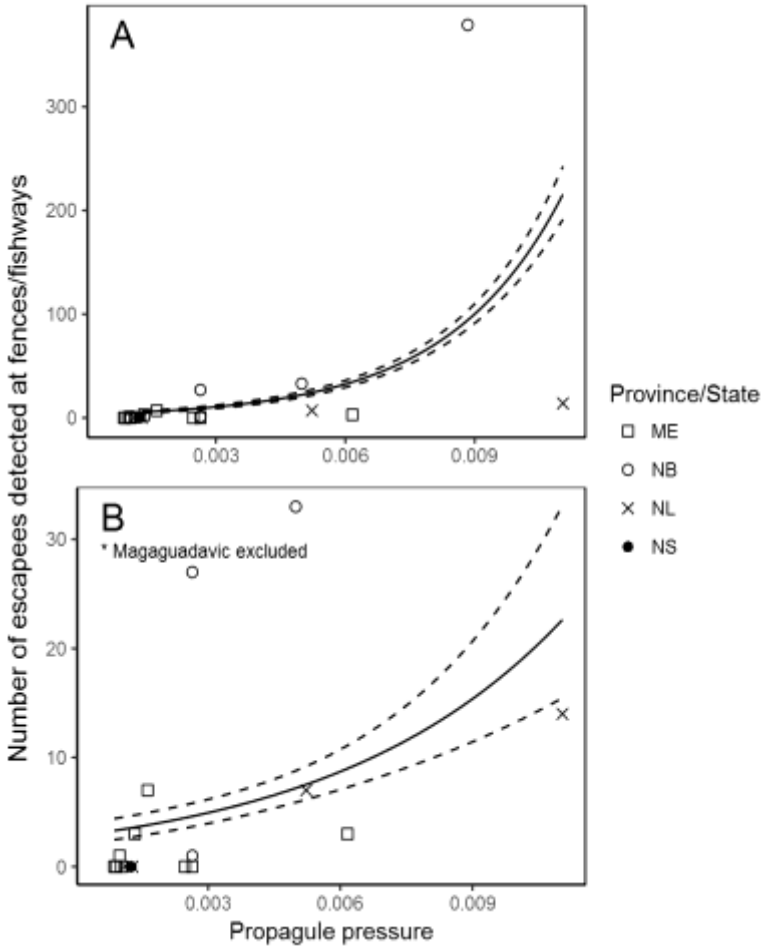
Updated database contains detections of 9236 escaped farmed salmon in Northwest Atlantic rivers.

Predicting the occurrence and impact of escapees

Review of the occurrence of escapees in Atlantic Canada

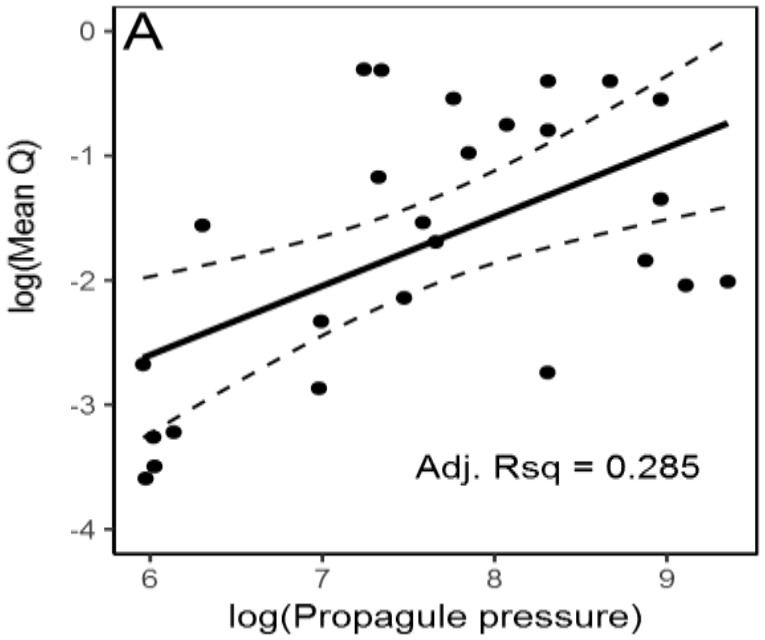
Reports of escaped farmed salmon from standardized facilities were significantly associated with production and geographic distance

Propagule pressure is defined as the sum of the number of fish in each cage / distance from each cage to a given river



Predicting the occurrence and impact of escapees

Positive relationship (p-value < 0.01) between genetic impacts and industry propagule pressures in Newfoundland



Keyser et al. In press. Canadian Journal of Fisheries and Aquatic Sciences

Annual Variation in Hybridization

2013 Escape event ~20K farmed salmon into south coast population ~20K wild salmon

Genetic screening of juvenile salmon started in 2014

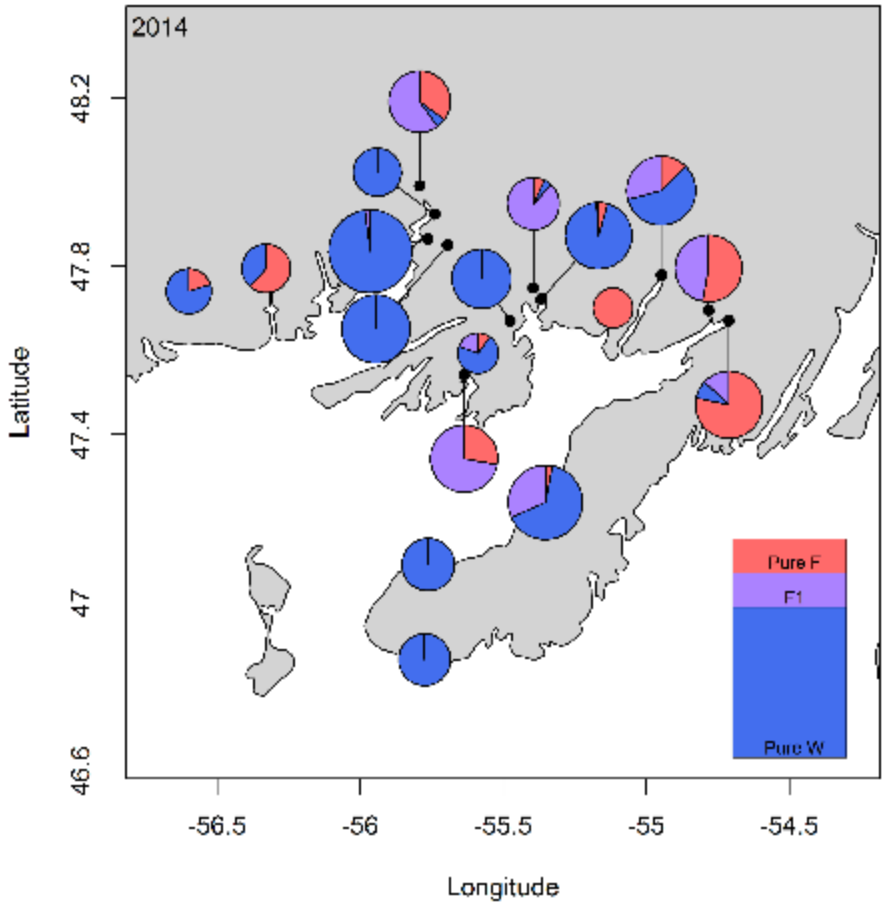
Each year between 1500-2000 young of year Atlantic salmon collected at ~18 locations

Hybridization

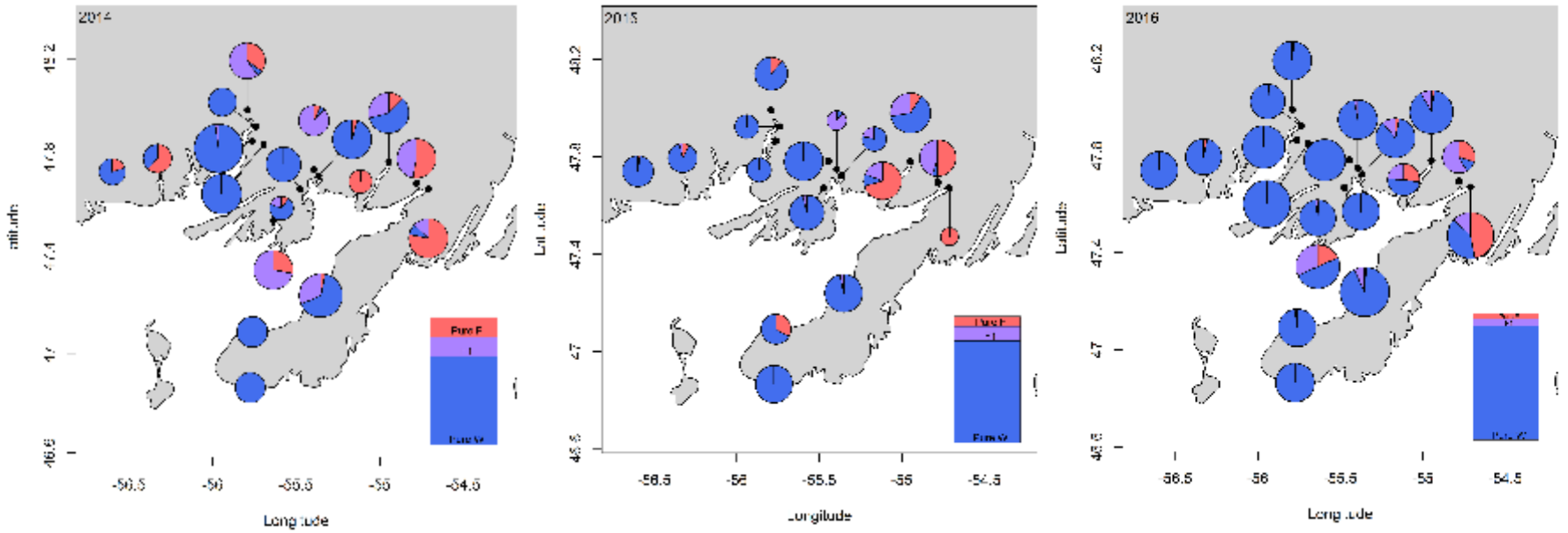
Screening identified 27.1% of the sampled YoY in 2014 as being wholly or partly of aquaculture ancestry

Hybrids were detected in 17 of the 18 rivers sampled, and feral offspring were detected in 13 rivers

F_1 hybrids were the most common hybrid class detected in 2014



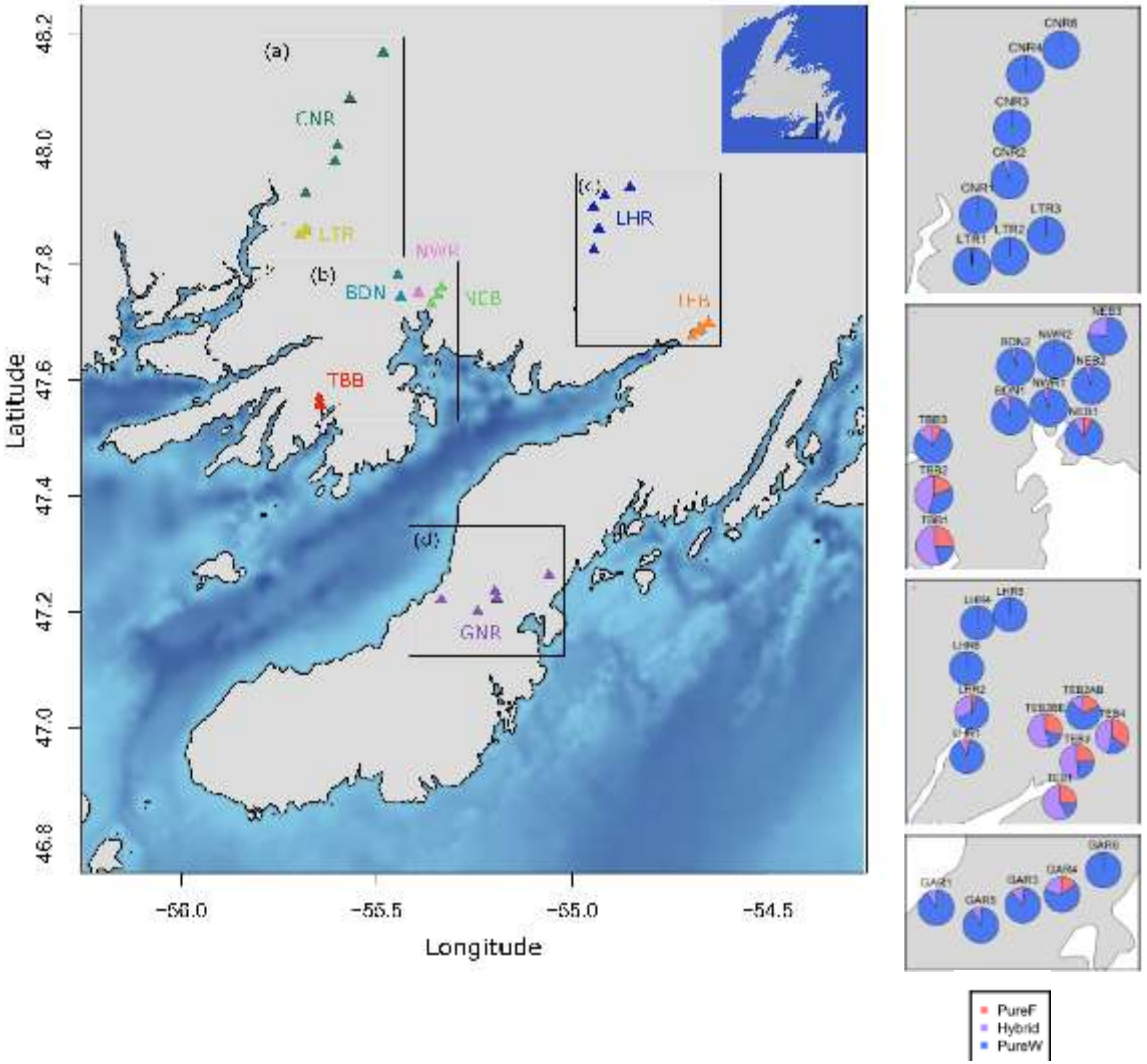
Hybridization since 2014



Repeated sampling shows that the number of F1 hybrids and feral salmon peaked in 2014 and has declined consistently (~10% per year, 91% wild 2016)

Data for 2017 and 2018 to be added

Hybrid distributions within watersheds



Nine watersheds sampled throughout the region in 2016

Rivers sampled vary in size and the migratory effort required to enter such as the elevation or the presence of partial obstructions

All samples classified as wild, farmed, or hybrid

Large variation in presence of hybrid individuals among and within river systems

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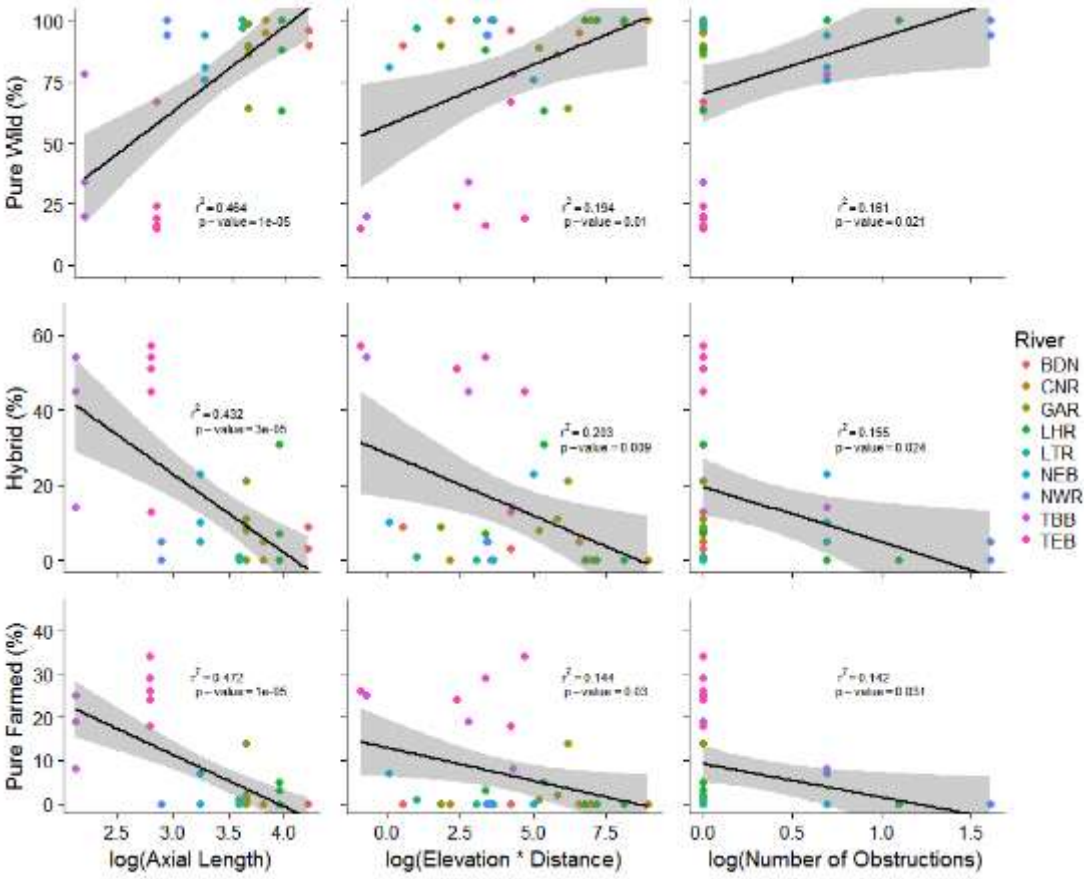
Increased prevalence of fish of hybrid or farmed origin associated with smaller rivers, and therefore smaller populations, while within-river distribution was strongly associated with migration effort.

Suggests escaped farmed salmon are less capable when challenged by migratory obstacles



Biological effects

Explore phenotypic differences among wild and hybrid juvenile salmon (NA aqua and Euro Aqua)

(1) **Survival:** Evaluate the proportion hybrids across freshwater and marine stages in several systems, involves sampling fry, parr, smolts and adults and genetic screening

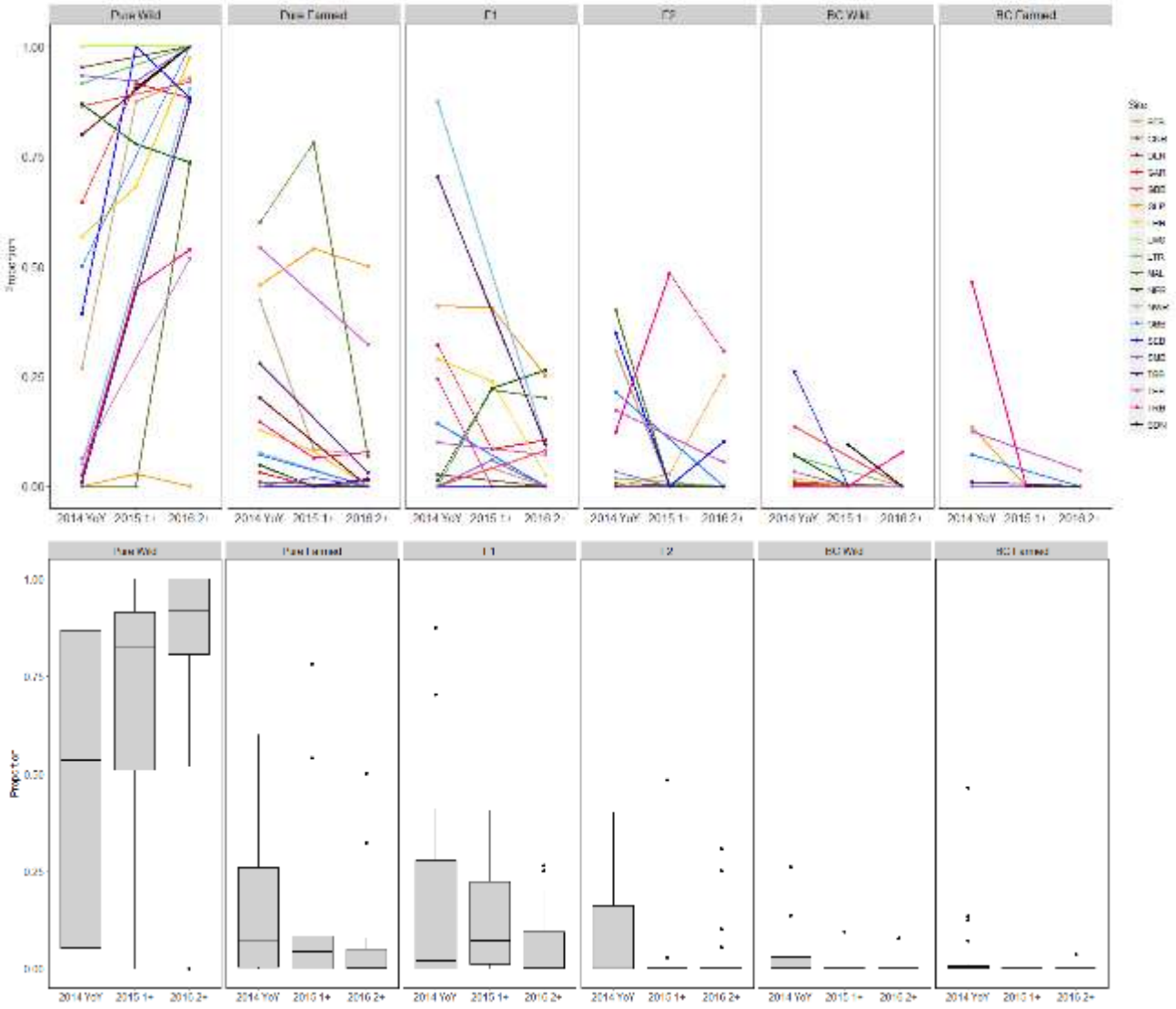
(2) **Morphology:** Geometric morphometric analysis comparing genetically identified wild and hybrid individuals. Images taken of all fish sampled in 2015 and 2016

3) **growth:** scale based age and growth estimates comparing genetically identified wild and hybrid individuals

Hybrids don't survive as well

Work in progress

Analysis of smolts from 2016 (Conne and Garnish) suggests very few hybrids present



Proportion of hybrids decreases

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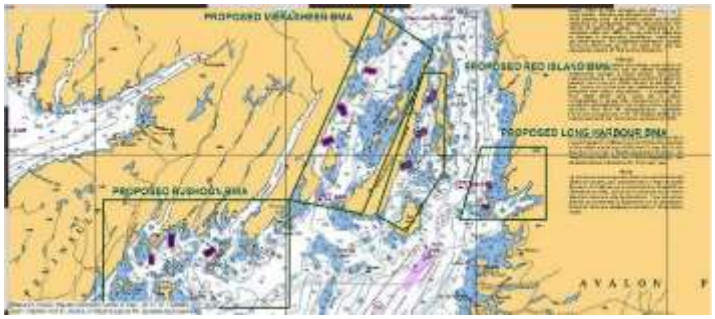
Baseline Genomic Data for Placentia Bay Newfoundland (2017- 2019)

Aquaculture expansion in Placentia Bay will produce ~7 million triploid Norwegian salmon annually



Goal - develop a genomic baseline data to allow future resolution any genetic (direct and indirect) impacts

Beth Watson MSc Student Dal

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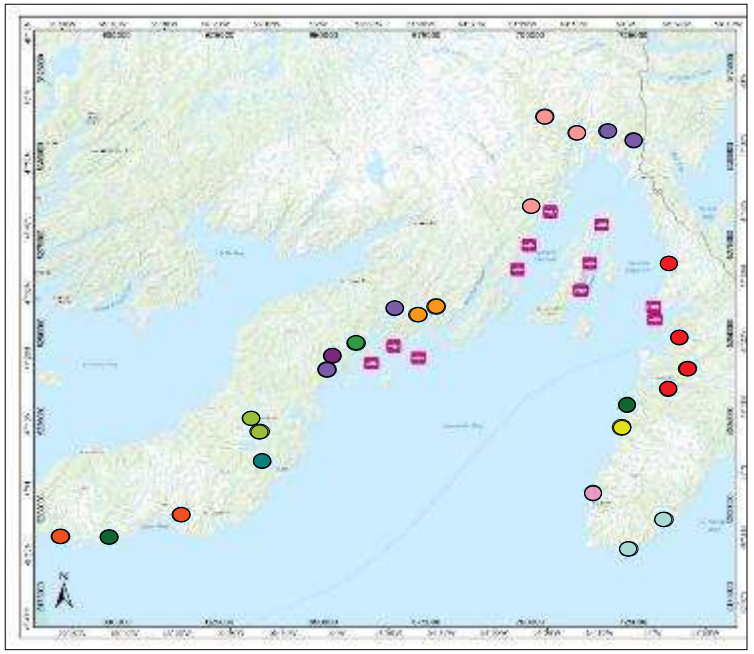
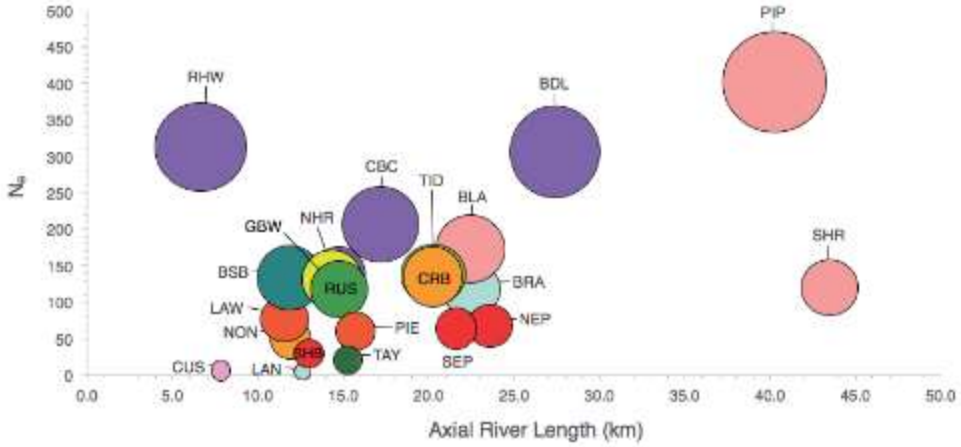
Placentia Bay Salmon Genetic Baseline

Indirect genetic effects difficult to quantify, large SNP arrays present new opportunities for genome-wide characterization adaptation and estimation of effective population size

Individual-based clustering analysis suggests 13 distinct genetic clusters within 26 populations

Preliminary estimates using sequenced microsatellite loci suggest generally small effective populations, < 500 individuals





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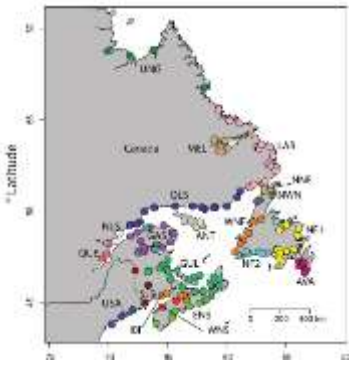
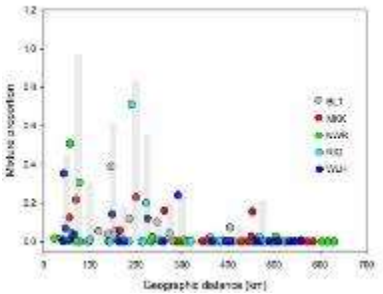
Atlantic Salmon Conservation Questions

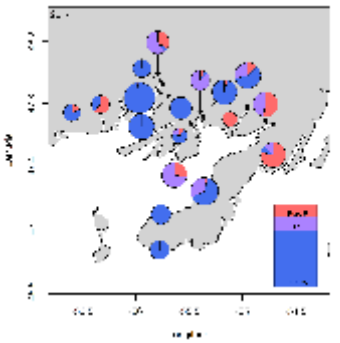
What do we have – regionals groups well resolved, ongoing work focusing on better understanding of fine scale differences and structuring forces

Who's catching it and in what proportions? - regional based exploitation well defined, ongoing work focusing on quantifying river specific exploitation and on what historic fishery samples can tell us about migration routes and timing

Aquaculture interactions? interbreeding between escapees and wild salmon quantified, ongoing work evaluating the biological consequences for individuals and populations, developing baseline data for indirect impacts, and developing monitoring tools (i.e. eDNA) to evaluate presence of escapees in natural environments







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Conclusions

Atlantic salmon (*Salmo salar*) is a species of conservation and management concern with declines in abundance over recent decades

Genomic and genetic tools have made significant contributions to salmon conservation and management in eastern North America

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