Does genetic diversity of North American Atlantic salmon (*Salmo salar)* vary with temperature trend and conservation status?

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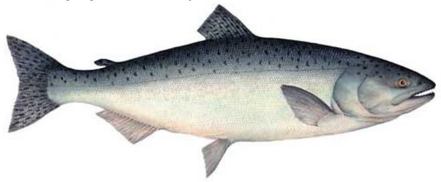
Introduction

Background

- Atlantic salmon (*Salmo salar*) are economically and socially important, and are useful indicators of healthy river systems (Wilson and Rannala 2003)
- Classified as Least Concern across their range, but considered endangered in southern Newfoundland rivers (Bailie & Groombridge 1996, COSEWIC 2010)
- Recent research found a cryptic genetic cline in Northwest Atlantic marine species with changing climate (Stanley et al. 2018)
- Assessing genetic differentiation between rivers in the context of a changing climate may aid in conservation



Questions

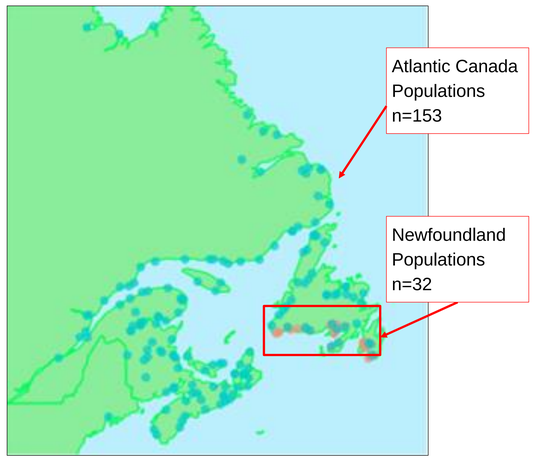
I. Are populations of **Atlantic** salmon genetically differentiated?
II. Are **threatened** populations of Atlantic Salmon less genetically diverse than populations throughout the range?
III. Are **decreases** in indices of **genetic diversity** (e.g. allelic richness and expected heterozygosity) correlated with **changing temperature** due to climate change?

Fun Facts

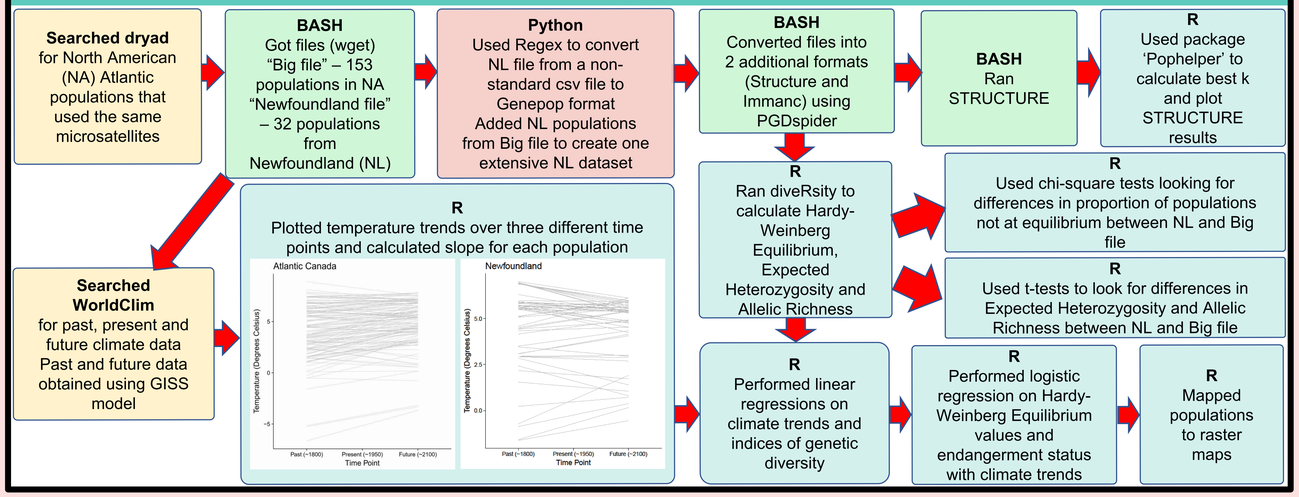
- Range from Lake Ontario southward to Connecticut in North America
- Atlantic salmon deposit pea-sized orange eggs in rivers during autumn
- Some populations become landlocked, where there never go to sea, and inhabit river and lakes that border the North Atlantic
- An Atlantic salmon's journey back to a riverbed can span up to 4,000 km, and can leap obstructions up to 3 m high (Atlantic Salmon Federation 2018)

Data

- 15 microsatellites
- 2439 individuals from **32 Atlantic salmon populations** in **Newfoundland** (Bradbury et al. 2015)
- 9142 individuals from **153 populations** across the **North Atlantic** range, including Newfoundland (Moore et al. 2014)
- Past (~1800), current (~1950), and future (~2100) mean annual temperature for each river site from both datasets (WorldClim database; Hijmans et al. 2015)



Methods



Genetic Data Results

Indices of Genetic Diversity

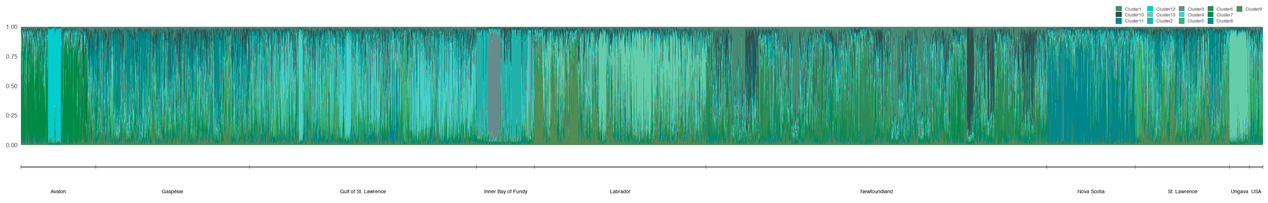
- **Allelic Richness:** significantly higher in Newfoundland populations than in all Atlantic Canada populations (*t = -26.27, d.f. = 87, p = 2.2^{-16}).*
- **Expected Heterozygosity:** no significant difference between H_e in Newfoundland and H_e in all Atlantic Canada populations *(t = -1.19, d.f. = 142, p = 0.2325).*
- **Hardy-Weinberg Equilibrium:** no significant difference between the proportion of populations at Hardy-Weinberg Equilibrium in Newfoundland and Atlantic Canada *(X^2 = 0.81, d.f. = 1, p = 0.3675).*

Pairwise G_{ST}

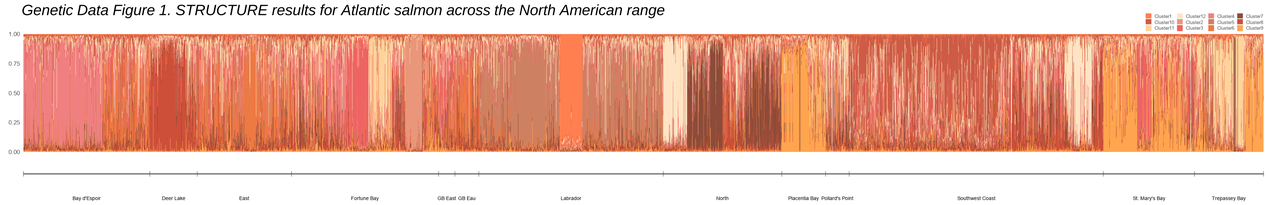
- **North Atlantic:** Range = 0.027-0.29, Mean = 0.13
- **Newfoundland:** Range = 0.049-0.317, Mean = 0.26

STRUCTURE results

- **North Atlantic**: 13 genetic clusters (see Genetic Data Fig. 1)
- **Newfoundland**: 12 genetic clusters (see Genetic Data Fig. 2)
- Neither analysis demonstrated clear genetic sub-populations within the data



Genetic Data Figure 1. STRUCTURE results for Atlantic salmon across the North American range



Genetic Data Figure 2. STRUCTURE results for Atlantic salmon within Newfoundland

Conclusions

I. Some populations of salmon had very high or very low differentiation (G_{ST} > 0.25 and G_{ST} < 0.1), however, the average G_{ST} was mid-range.
II. Threatened populations of Atlantic Salmon in Newfoundland were **not** less genetically diverse than non-threatened populations in Newfoundland. However, Newfoundland populations had significantly higher allelic richness than populations throughout their range.
III. Atlantic Salmon are **not** displaying decreased genetic diversity with changing mean annual temperature or with conservation status. In fact, Atlantic salmon populations may be displaying increased genetic diversity with increasing mean annual temperature.

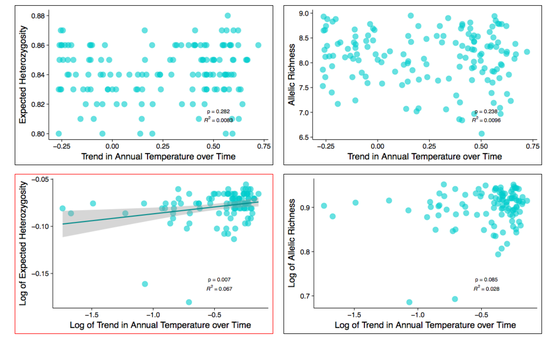
References

1. Atlantic Salmon Federation. 2018. http://www.asf.ca/atlantic-salmon-overview.html. 2. Baillie, J. and B. Groombridge. 1996. IUCN Red List of Threatened Species. IUCN. 3. Bradbury, I.R., Hamilton, L.C., Dempson, B., Robertson, M.J., Bourret, V., Bernatchez, L., et al. 2015. Molecular Ecology 24: 5130–5144. 4. Do, C., Waples, R.S., Peel, D., Macbeth, G.M., Tillett, B.J. & Ovenden, J.R. 2013. Molecular Ecology Resources 14: 209–214. 5. Falush, D., Stephens, M. & Pritchard, J.K. 2007. Molecular Ecology Notes 7: 574–578. 6. Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. & Jarvis, A. 2005. International Journal of Climatology 25: 1965–1978. 7. Keenan, K., McGinnity, P., Cross, T.F., Crozier, W.W. & Prodöhl, P.A. 2013. Methods in Ecology and Evolution 4: 782–788. 8. Lischer, H.E.L. & Excoffier, L. 2011. Bioinformatics 28: 298–299. 9. Moore, J.-S., Bourret, V., Dionne, M., Bradbury, I., O'Reilly, P., Kent, M., et al. 2014. Molecular Ecology 23: 5680–5697. 10. Stanley, R.R.E., DiBacco, C., Lowen, B., Beiko, R.G., Jeffery, N.W., Van Wyngaarden, M., et al. 2018. Science Advances 4: eaaq0929. 11. Wilson, G.A. and Rannala, B. 2003. Genetics 163(3): 1177-1191.

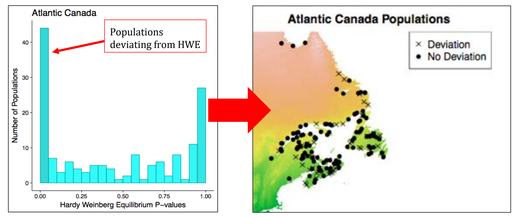
Climate Data Results

Atlantic Canada Populations

- No significant correlation between indices of genetic diversity and trends in annual temperature over time, except for the log-transformed linear regression for H_e, indicating a possible positive correlation between increasing temperature and genetic diversity



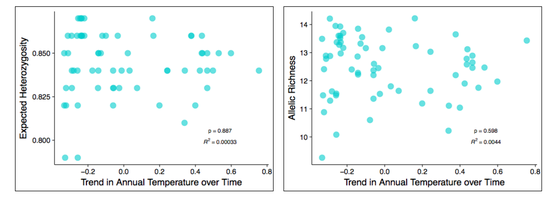
Climate Data Figure 1. Linear regressions and log-transformed linear regressions of indices of genetic diversity with trends in annual temperature for the Atlantic Canada dataset.



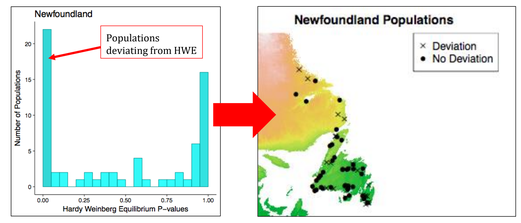
Climate Data Figure 2. Histogram displaying Hardy-Weinberg Equilibrium (HWE) p-values for the Atlantic Canada dataset. Populations with HWE p-values < 0.05 are deviating from HWE, meaning that one or more assumptions of Hardy-Weinberg have been violated. These assumptions include: no gene flow, no mutation, no selection, and infinite population size. Locations of deviating populations are plotted on a temperature heat map.

Newfoundland Populations

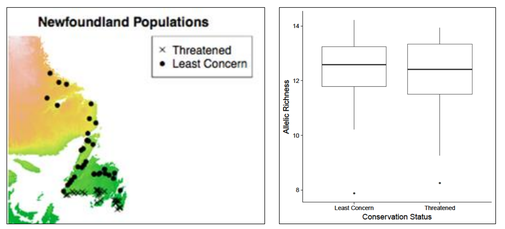
- No significant correlation between indices of genetic diversity and trends in annual temperature over time, or between indices of genetic diversity with conservation status



Climate Data Figure 3. Linear regressions of indices of genetic diversity with trends in annual temperature over time in the Newfoundland dataset.



Climate Data Figure 4. Histogram displaying Hardy-Weinberg Equilibrium (HWE) p-values for the Newfoundland dataset. Populations with HWE p-values < 0.05 are deviating from HWE. Locations of deviating populations are plotted on a temperature heat map.



Climate Data Figure 5. Locations of Threatened and Least Concern Atlantic Salmon populations on a map. We found no significant associations between conservation status and indices of genetic diversity.