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CURRENT AND PREDICTED ECOLOGICAL IMPACTS OF CLIMATE CHANGE TO ATLANTIC SALMON FRESHWATER PRODUCTIVITY IN THE NORTH ATLANTIC

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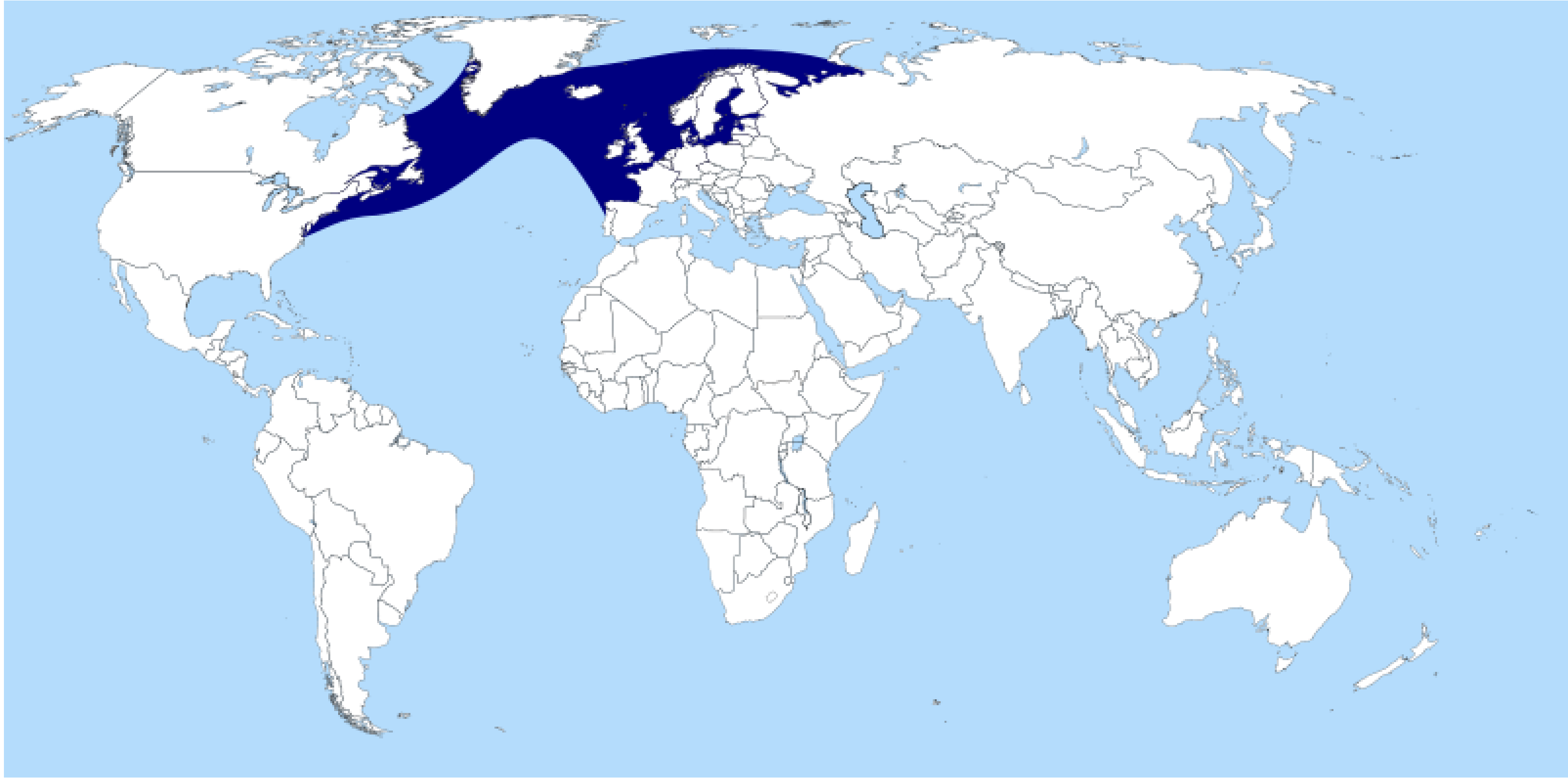
Atlantic Salmon Distribution



Two key variables for freshwater productivity that are impacted by climate change:

- Discharge
  - Habitat availability
  - Juvenile feeding rates
  - Migration (upstream by adults, downstream by smolts)
  - Spawning success
- River temperature
  - Metabolic rates
  - Physiological and behavioural changes (thermal tolerance varies with life stages).

Discharge trends in Northeastern U.S.A.

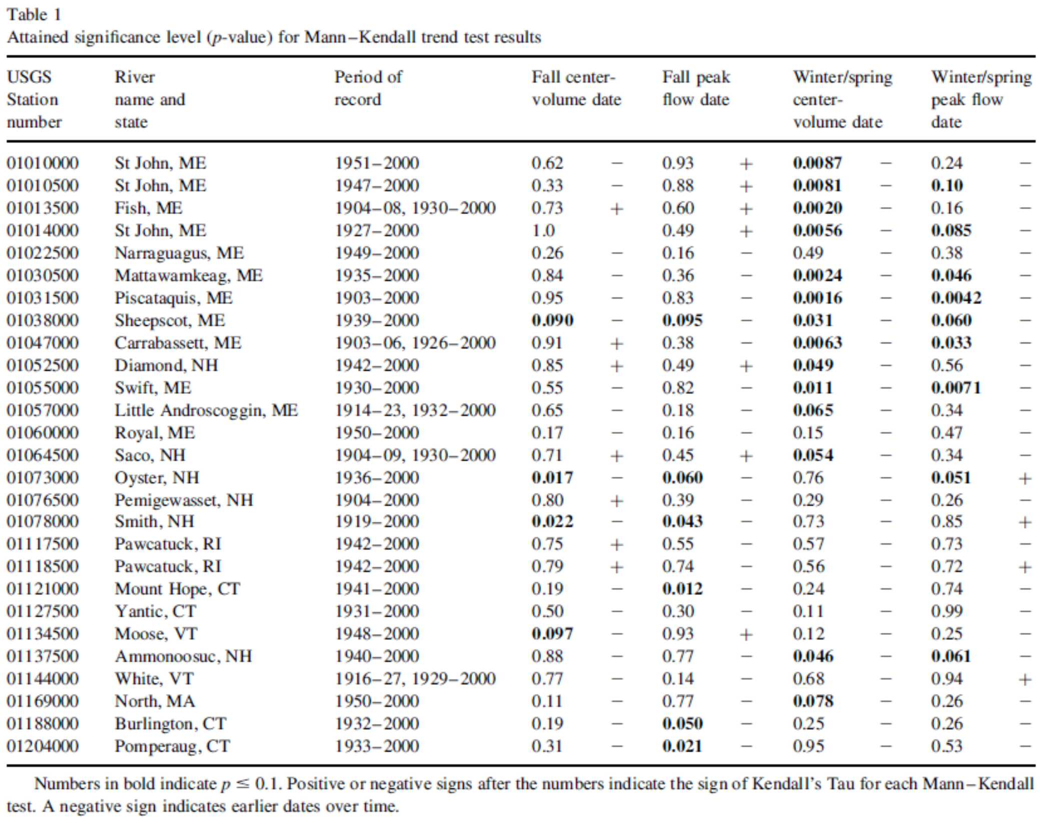


Table 1
Attained significance level (p-value) for Mann–Kendall trend test results

USGS Station number	River name and state	Period of record	Fall center-volume date		Fall peak flow date		Winter/spring center-volume date		Winter/spring peak flow date	
01010000	St John, ME	1951–2000	0.62	−	0.93	+	**0.0087**	−	0.24	−
01010500	St John, ME	1947–2000	0.33	−	0.88	+	**0.0081**	−	**0.10**	−
01013500	Fish, ME	1904–08, 1930–2000	0.73	+	0.60	+	**0.0020**	−	0.16	−
01014000	St John, ME	1927–2000	1.0		0.49	+	**0.0056**	−	**0.085**	−
01022500	Narraguagus, ME	1949–2000	0.26	−	0.16	−	0.49	−	0.38	−
01030500	Mattawamkeag, ME	1935–2000	0.84	−	0.36	−	**0.0024**	−	**0.046**	−
01031500	Piscataquis, ME	1903–2000	0.95	−	0.83	−	**0.0016**	−	**0.0042**	−
01038000	Sheepscot, ME	1939–2000	**0.090**	−	**0.095**	−	**0.031**	−	**0.060**	−
01047000	Carrabassett, ME	1903–06, 1926–2000	0.91	+	0.38	−	**0.0063**	−	**0.033**	−
01052500	Diamond, NH	1942–2000	0.85	+	0.49	+	**0.049**	−	0.56	−
01055000	Swift, ME	1930–2000	0.55	−	0.82	−	**0.011**	−	**0.0071**	−
01057000	Little Androscoggin, ME	1914–23, 1932–2000	0.65	−	0.18	−	**0.065**	−	0.34	−
01060000	Royal, ME	1950–2000	0.17	−	0.16	−	0.15	−	0.47	−
01064500	Saco, NH	1904–09, 1930–2000	0.71	+	0.45	+	**0.054**	−	0.34	−
01073000	Oyster, NH	1936–2000	**0.017**	−	**0.060**	−	0.76	−	**0.051**	+
01076500	Pemigewasset, NH	1904–2000	0.80	+	0.39	−	0.29	−	0.26	−
01078000	Smith, NH	1919–2000	**0.022**	−	**0.043**	−	0.73	−	0.85	+
01117500	Pawcatuck, RI	1942–2000	0.75	+	0.55	−	0.57	−	0.73	−
01118500	Pawcatuck, RI	1942–2000	0.79	+	0.74	−	0.56	−	0.72	+
01121000	Mount Hope, CT	1941–2000	0.19	−	**0.012**	−	0.24	−	0.74	−
01127500	Yantic, CT	1931–2000	0.50	−	0.30	−	0.11	−	0.99	−
01134500	Moose, VT	1948–2000	**0.097**	−	0.93	+	0.12	−	0.25	−
01137500	Ammonoosuc, NH	1940–2000	0.88	−	0.77	−	**0.046**	−	**0.061**	−
01144000	White, VT	1916–27, 1929–2000	0.77	−	0.14	−	0.68	−	0.94	+
01169000	North, MA	1950–2000	0.11	−	0.77	−	**0.078**	−	0.26	−
01188000	Burlington, CT	1932–2000	0.19	−	**0.050**	−	0.25	−	0.26	−
01204000	Pomperaug, CT	1933–2000	0.31	−	**0.021**	−	0.95	−	0.53	−

Numbers in bold indicate $p \leq 0.1$. Positive or negative signs after the numbers indicate the sign of Kendall's Tau for each Mann–Kendall test. A negative sign indicates earlier dates over time.

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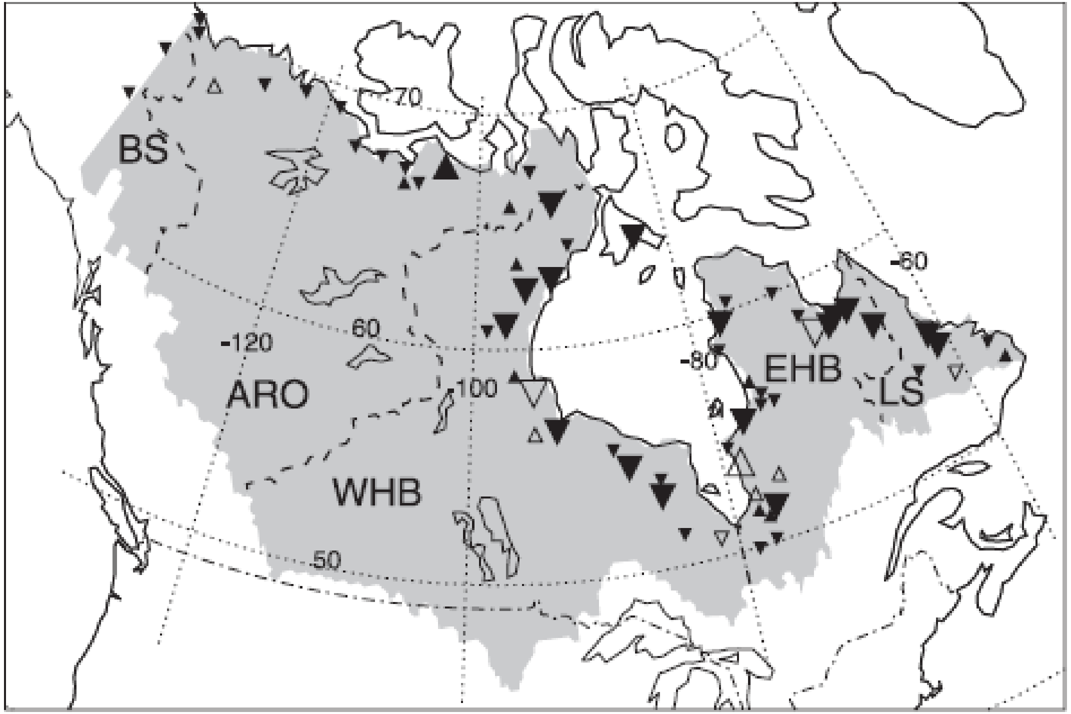
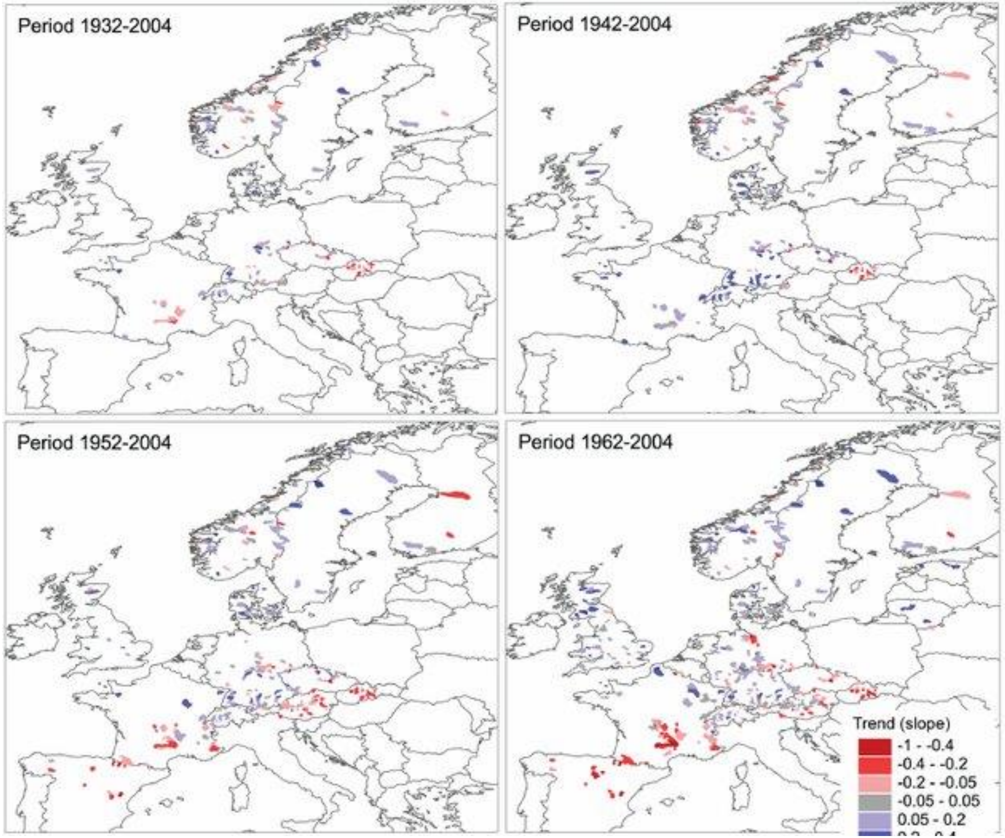
Discharge Trends in Northern Canada



Déry, S. J., Stadnyk, T. A., MacDonald, M. K., & Gauli-Sharma, B. (2016). Recent trends and variability in river discharge across northern Canada. *Hydrology and Earth System Sciences*, *20*(12), 4801-4818.

Discharge trends in European Rivers



[Streamflow trends in Europe: evidence from a dataset of near-natural catchments](https://doi.org/10.5194/hess-14-2367-2010)

K. Stahl, H. Hisdal, J. Hannaford, L. M. Tallaksen, H. A. J. van Lanen, E. Sauquet, S. Demuth, M. Fendekova, and J. Jódar
Hydrol. Earth Syst. Sci., 14, 2367–2382, https://doi.org/10.5194/hess-14-2367-2010, 2010

Trends in river temperature

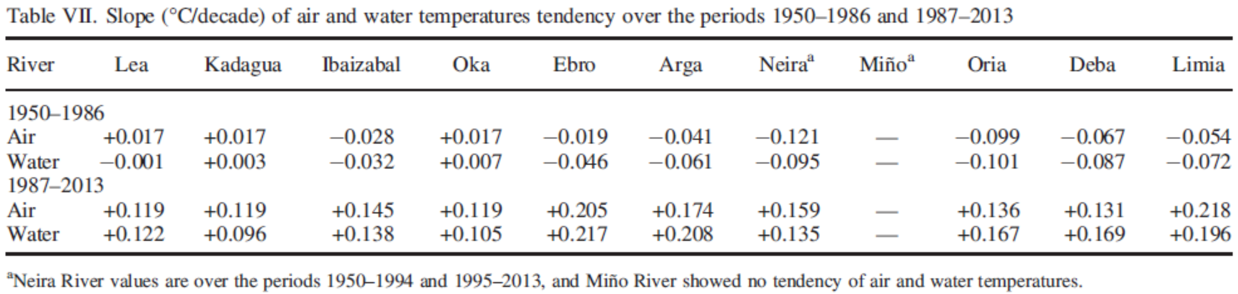
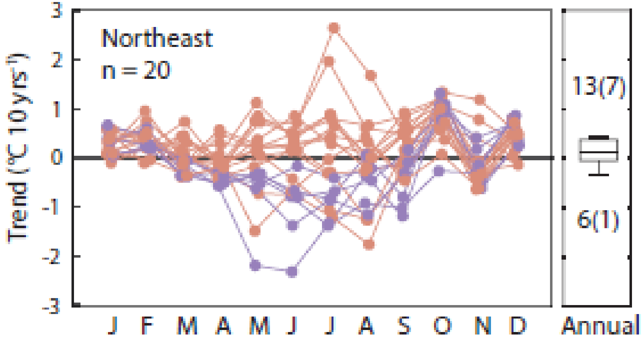


Table VII. Slope (°C/decade) of air and water temperatures tendency over the periods 1950–1986 and 1987–2013

River	Lea	Kadagua	Ibaizabal	Oka	Ebro	Arga	Neira[a]	Miño[a]	Oria	Deba	Limia
1950–1986											
Air	+0.017	+0.017	−0.028	+0.017	−0.019	−0.041	−0.121	—	−0.099	−0.067	−0.054
Water	−0.001	+0.003	−0.032	+0.007	−0.046	−0.061	−0.095	—	−0.101	−0.087	−0.072
1987–2013											
Air	+0.119	+0.119	+0.145	+0.119	+0.205	+0.174	+0.159	—	+0.136	+0.131	+0.218
Water	+0.122	+0.096	+0.138	+0.105	+0.217	+0.208	+0.135	—	+0.167	+0.169	+0.196

[a] Neira River values are over the periods 1950–1994 and 1995–2013, and Miño River showed no tendency of air and water temperatures.

Soto, B. 2016. « Assessment of Trends in Stream Temperatures in the North of the Iberian Peninsula Using a Nonlinear Regression Model for the Period 1950-2013: Stream Temperatures in the Iberian Peninsula ». *River Research and Applications* 32 (6): 1355-64. https://doi.org/10.1002/rra.2971.



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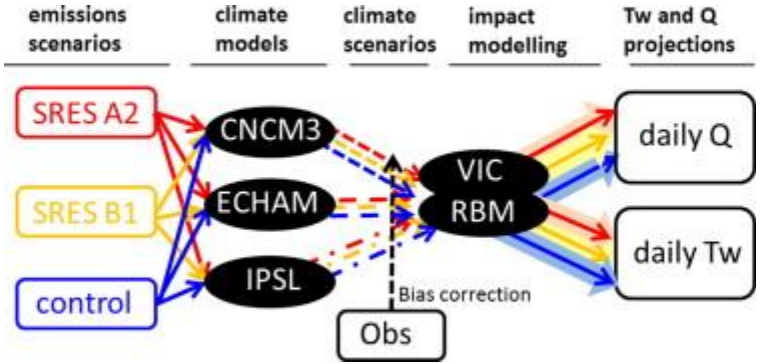
Future Scenarios



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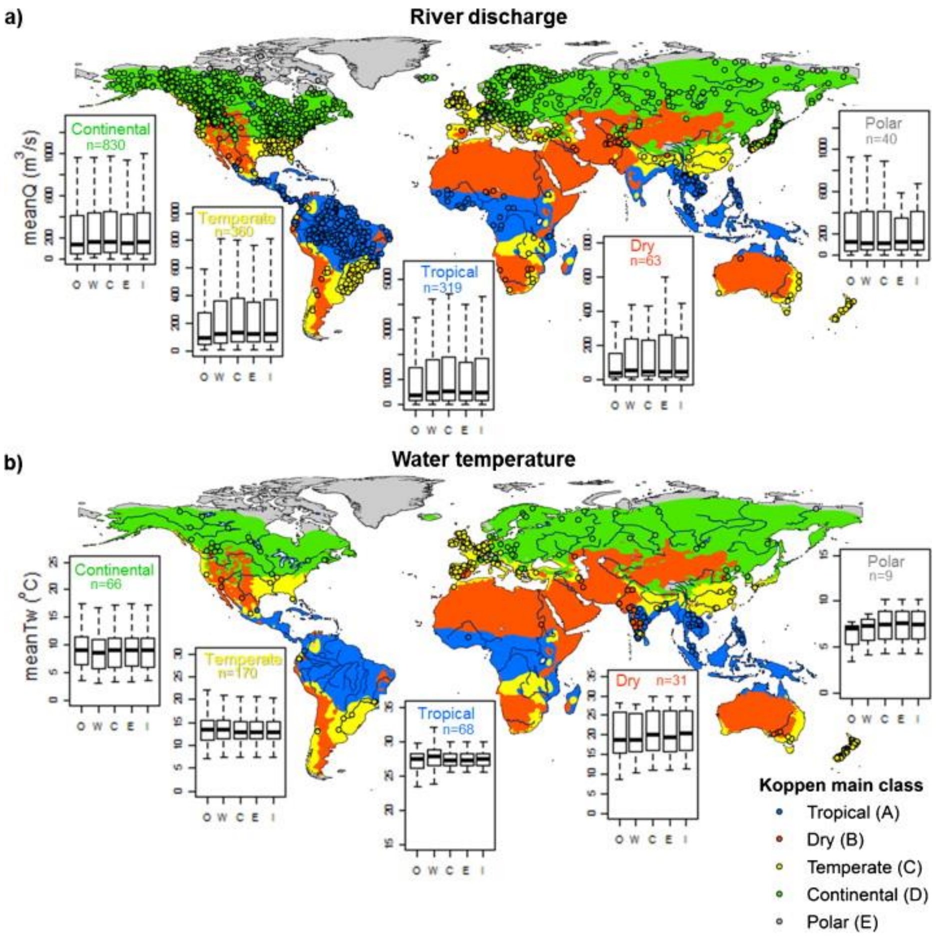
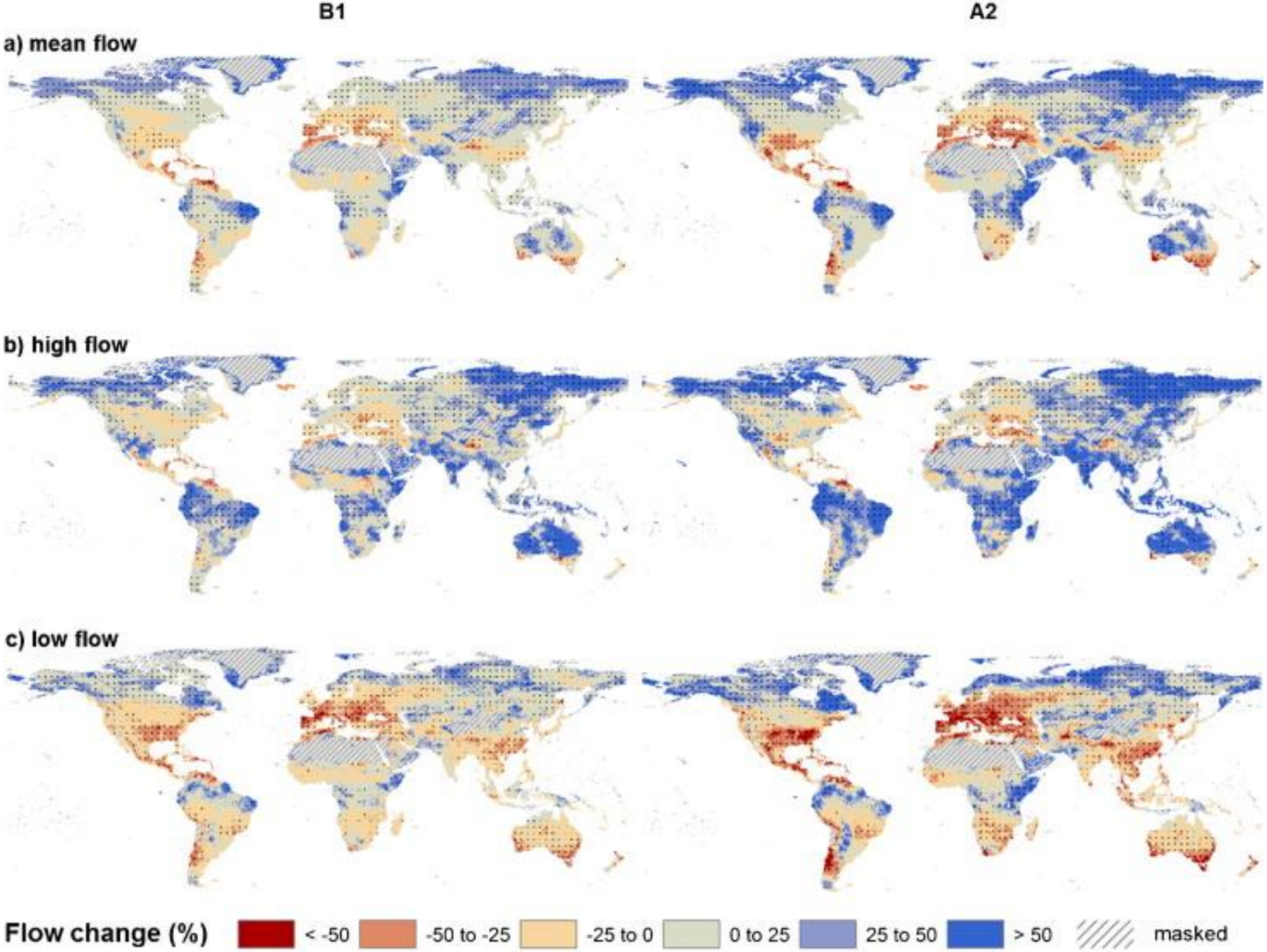
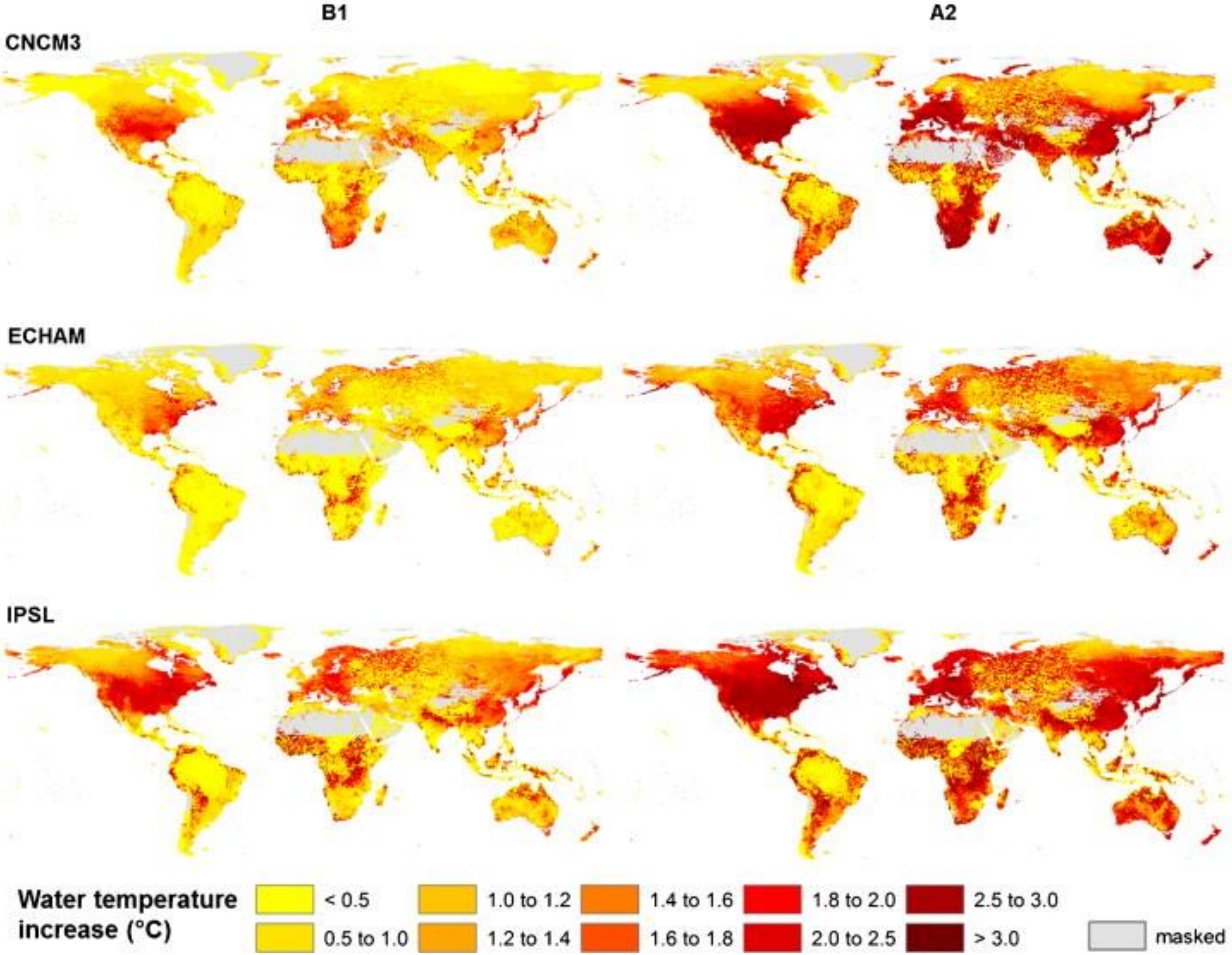
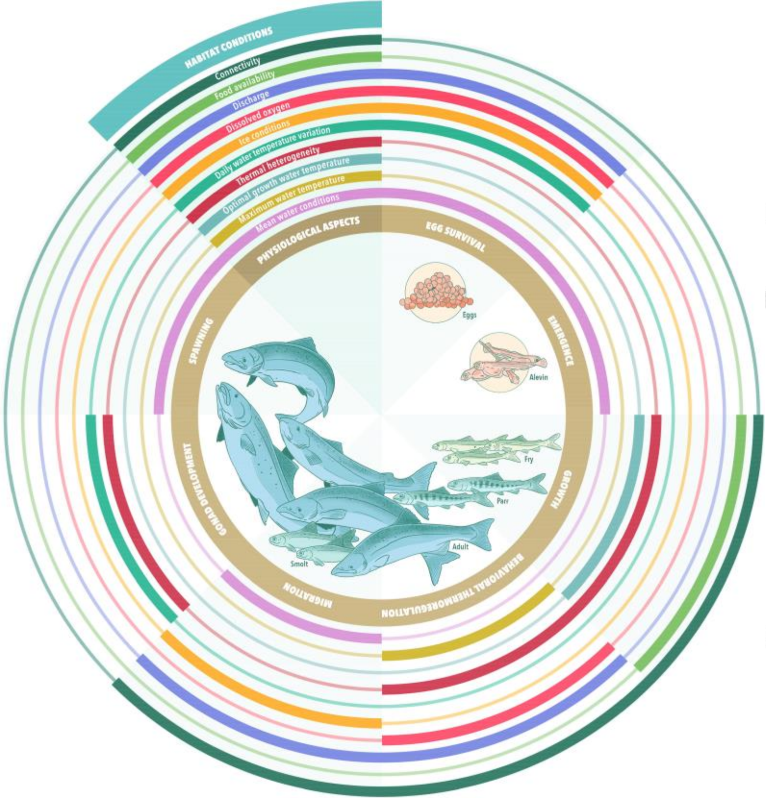
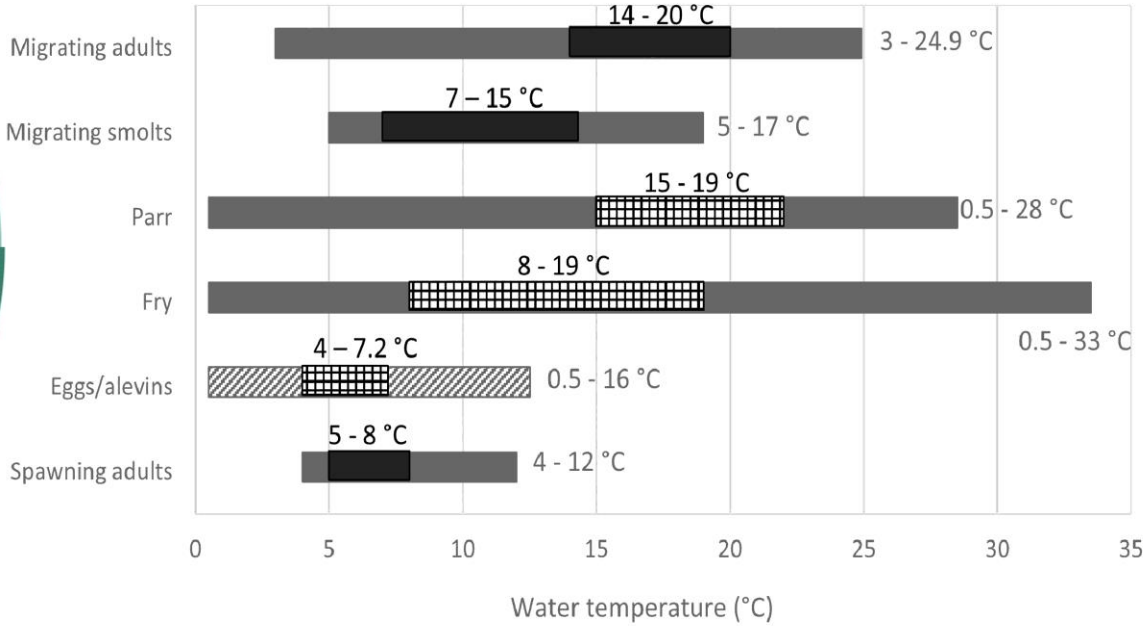
https://doi.org/10.1016/j.gloenvcha.2012.11.002.




B1
A2
a) mean flow
b) high flow
c) low flow
Flow change (%)
< -50
-50 to -25
-25 to 0
0 to 25
25 to 50
> 50
masked


B1
A2
CNCM3
ECHAM
IPSL
Water temperature increase (°C)
< 0.5
0.5 to 1.0
1.0 to 1.2
1.2 to 1.4
1.4 to 1.6
1.6 to 1.8
1.8 to 2.0
2.0 to 2.5
2.5 to 3.0
> 3.0
masked





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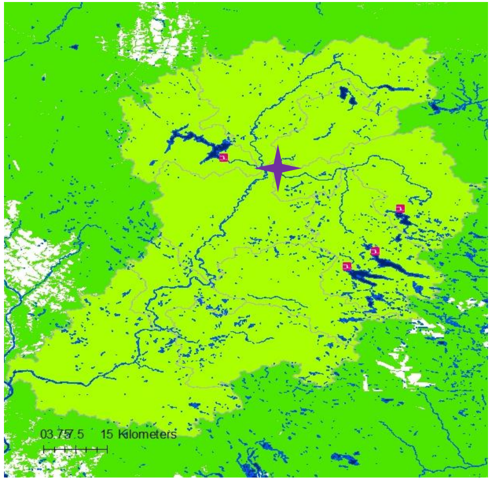
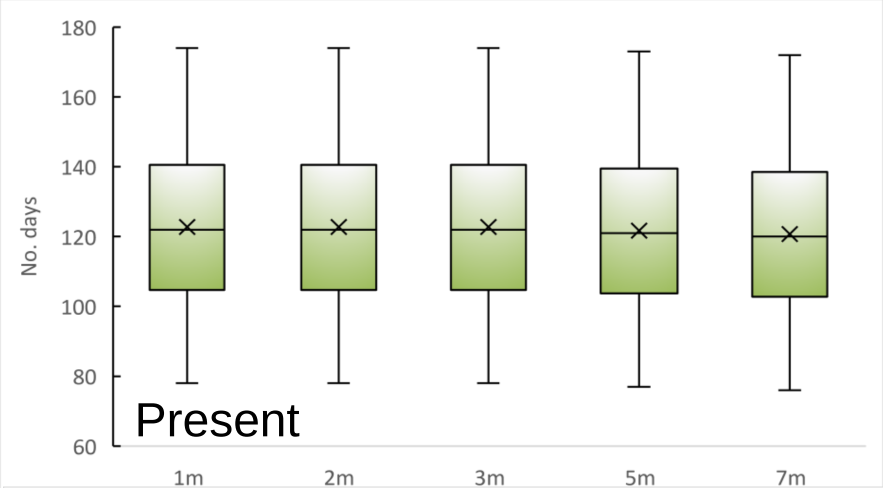
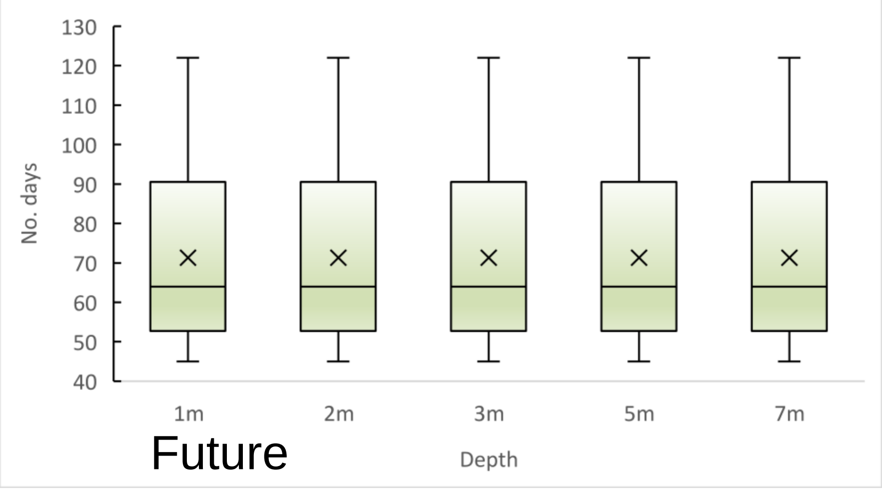
Spawning : Number of days to hatching







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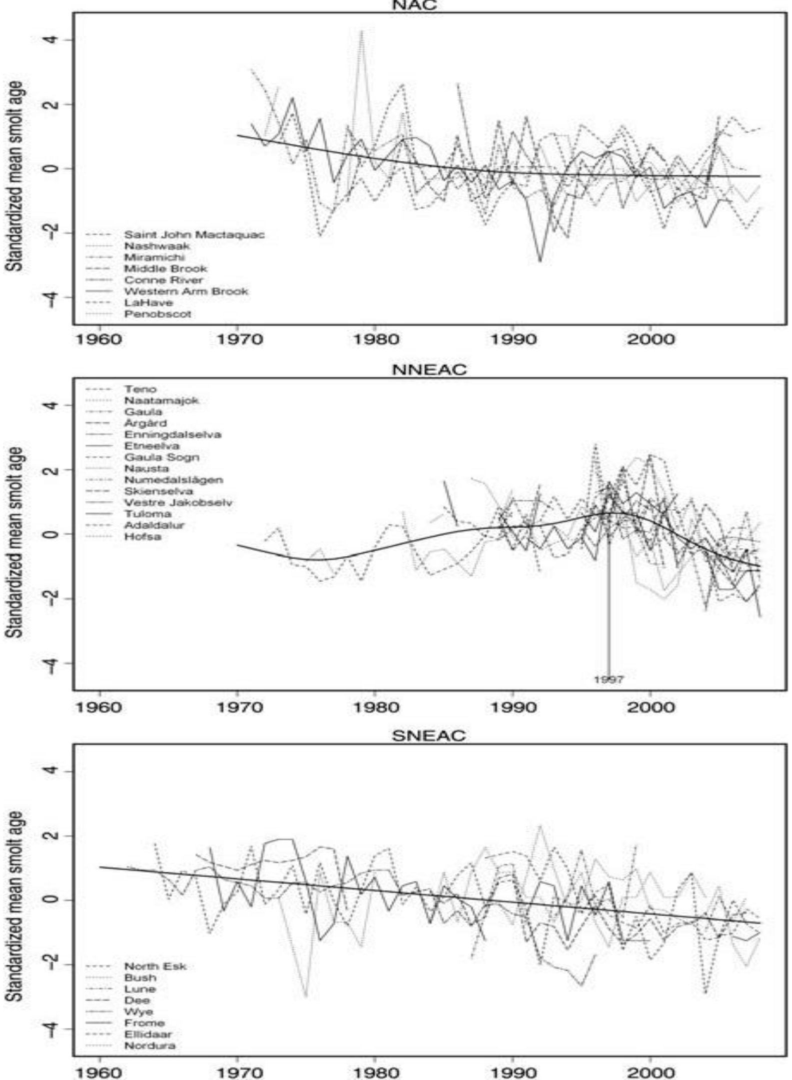
Fry and Parr

Component	Process	Variance explained
Fry		
PC1	Discharge between spawning and emergence	0.19
PC2	Discharge during growing period	0.15
PC3	Water temperature during growing period	0.14
PC4	Discharge at adult spawning time	0.13
PC5	Discharge during emergence	0.10
Parr		
PC1	Water temperature during spring growing period	0.19
PC2	Water temperature during summer growing period	0.18
PC3	Discharge during winter	0.13
PC4	Discharge during summer growing period	0.12
PC5	Discharge during spring growing period	0.11

Glover, Ross S., Chris Soulsby, Robert J. Fryer, Christian Birkel, et Iain A. Malcolm. 2020. « Quantifying the Relative Importance of Stock Level, River Temperature and Discharge on the Abundance of Juvenile Atlantic Salmon (*SALMO SALAR*) ». *Ecohydrology* 13 (6). https://doi.org/10.1002/eco.2231.

Smolts

Trends in standardized mean smolt ages for various rivers in NASCO's NAC, SNEAC, and NNEAC areas



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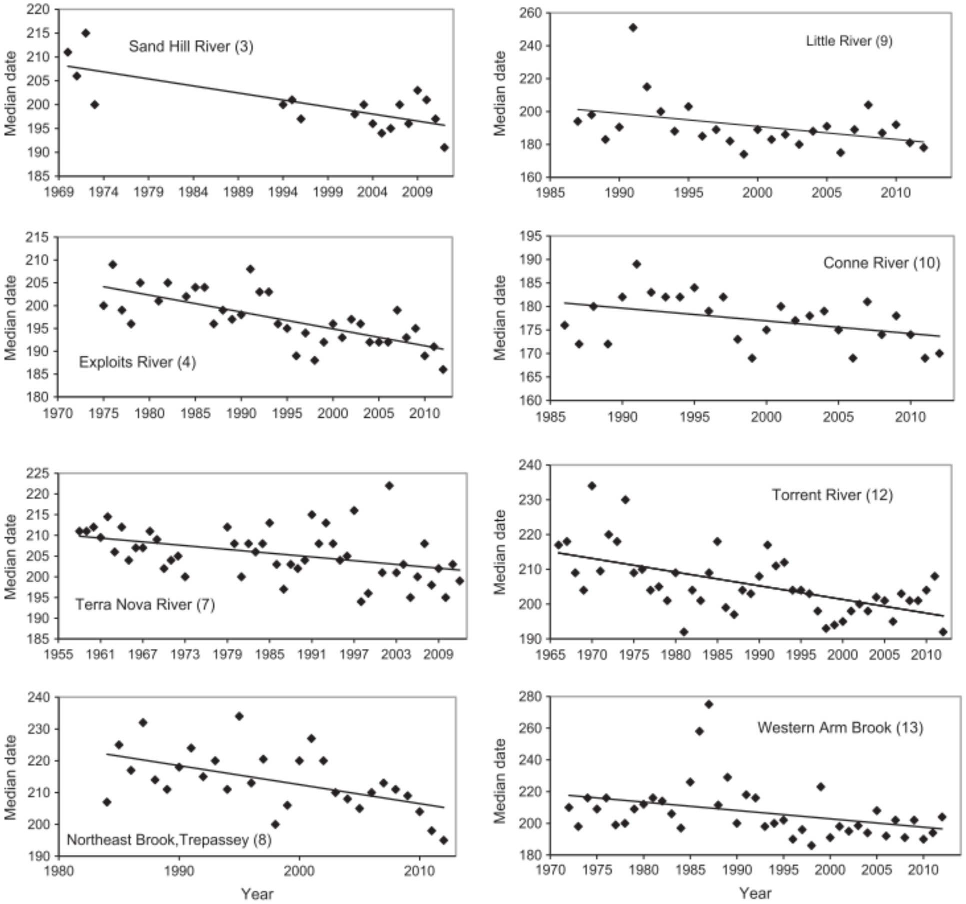
Adults

Earlier run timings for Newfoundland and Labrador rivers with warming water temperature



Dempson, B., C.J. Schwarz, I.R. Bradbury, M.J. Robertson, G. Veinott, R. Poole, E. Colbourne (2017). Influence of climate and abundance on migration timing of adult Atlantic salmon (*Salmo salar*) among rivers in Newfoundland and Labrador. *Ecology of Freshwater Fishes* 26: 245-259.

Life stage	Life function	Key period	Present	Predicted
Egg	Incubation	Winter	Negatively correlated with precipitation (proxy for discharge)	Increasing number of freeze and thaw events leading to reduced egg survival
			Reduced incubation time with higher temperature	Reduced incubation time with higher temperature
Fry, Parr	Rearing	Summer	Discharge correlates with invertebrate drift concentration, feeding behaviour, foraging efficiency	Possible decreased growth rate if temperature exceeds optimal thermal range for growth
			Increased development rate with temperature	Possible increased development rate with temperature
			Increased importance of thermal refuge	Increased importance of thermal refuge

Life stage	Life function	Key period	Present	Predicted
Smolt	Smoltification	Spring	Earlier smolt transition with earlier/higher spring temperatures	Earlier smolt transition with earlier/higher spring temperatures
	Movement	Spring	Higher spring discharges are correlated to successful downstream migration	Variability in spring freshets and mismatch with optimal ocean survival conditions
Adult	Upstream migration	Summer/fall	Earlier run timing	Increased flow variability and misleading spawning cues
	Reproduction	Fall	Decrease in spawning success with increasing temperatures	Increased risk of unsuccessful spawning due to prevalence of parasites, pathogens, and pollution

Recommendations

- Relative paucity of data and available forecasts have been identified as bottlenecks for future Atlantic salmon management efforts : expand monitoring. Starting with the low hanging fruits: temperatures and flows.
- Local trend analyses and local (downscaled) scenarios of discharge and temperature show variability: Homogenize methods, temporal and spatial scales.
- Short-term operational flow/temperature forecasting should be implemented
- Identify, protect, and if necessary, restore important thermal refuges in warming salmon rivers
- Investigate the bioenergetic benefits of thermal refuge used by Atlantic salmon of all life stages and the variability of thermal onset of movement to thermal refuges