Northeast Fisheries Science Technical Memorandum 329

# Maine Atlantic Salmon Rivers Water Temperature Monitoring Protocol

May 2025

Northeast Fisheries Science Technical Memorandum 329

# Maine Atlantic Salmon Rivers Water Temperature Monitoring Protocol

by Valerie Ouellet[1], Graham Goulette[2]

[1]*Maine Atlantic Salmon Water Temperature Group, NOAA Northeast Fisheries Science Center affiliate*

[2]*NOAA Fisheries Service, Northeast Fisheries Science Center, 17 Godfrey Drive, Suite 1, Orono, ME 04473*

**US DEPARTMENT OF COMMERCE**
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

May 2025

# Editorial Notes

**Information Quality Act Compliance:** In accordance with section 515 of Public Law 106-554, the Northeast Fisheries Science Center (NEFSC) completed both technical and policy reviews for this report. These pre-dissemination reviews are on file at the NEFSC Editorial Office.

**Species Names:** The NEFSC Editorial Office's policy on the use of s pecies names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and c ommon names for fishes, mollusks, and decapod crustaceans and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals. Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

**Statistical Terms:** The NEFSC Editorial Office's policy on the use of statistical terms in all technical communications is generally to follow the International Standards Organization's handbook of statistical methods.

This document may be cited as:

Ouellet, Valerie; Graham Goulette. 2025. Maine Atlantic Salmon Rivers Water Temperature Monitoring Protocol. US Dept Commerce, Northeast Fish Sci Tech Memo 329; 16 p.

# CONTENTS

# 1. COORDINATING WATER TEMPERATURE MONITORING

Many State, Federal, Tribal, Academic, and NGO initiatives collect water temperature data in Maine Atlantic salmon rivers. As a group, we benefit from and reduce individual costs by coordinating efforts and data sharing that results in more comprehensive sampling spatially and temporally. We use a data collection plan that facilitates information dissemination among interested groups, including: 1) rationale for the proposed data collection, 2) data to be collected, 3) spatial and temporal information pertaining to the data collection, and 4) adherence to collection protocols and defined responsibilities.

In January 2023, the Maine Atlantic Salmon Water Temperature Group agreed to meet biannually, in January and June. The January meeting aims to review plans for the upcoming field season, and the July meeting reviews protocols, project ideas, explore funding sources, and plan for grant applications with fall deadlines. The goal of this group is to coordinate temperature monitoring for Atlantic salmon. In addition, we will coordinate these efforts with the Maine Water Temperature Working Group to see whether we can homogenize protocols.

Appendices A and D present information relative to Atlantic salmon thermal tolerances and a figure linking environmental variables and salmon life stages that can be used for background information as needed, as well as a list of references on Atlantic salmon (Appendix D).

# 2. PRE-DEPLOYMENT PROCEDURES

## 2.1 Loggers

A variety of loggers are currently available for temperature monitoring purposes. Table 1 presents the main characteristics of the Maine Atlantic Salmon Water Temperature Groups most commonly used loggers; the choice of the logger will depend on study needs and budget.

**Table 1:** Characteristics of the Maine Atlantic Salmon Water Temperature Groups most commonly used loggers to monitor water temperature.

| Model | Accuracy (°C) | Precision (°C) | Stability (drift, °C) | Battery life (years) |
|---|---|---|---|---|
| HOBO V2 pro ($159) | ±0.21 | 0.02 | 0.1/year | 6 |
| HOBO Tidbit v2 ($169) | ±0.21 | 0.02 | 0.1/year | 5 |
| HOBO Tidbit MX400 Bluetooth ($149) and HOBO Tidbit MX5000 Bluetooth ($159) | ±0.25 (-20 to 0)<br>±0.2 (0 to 70) | 0.01 | <0.1/year | 3 (Bluetooth enabled)<br>5 (Bluetooth disabled) |
| HOBO Pendant MX Bluetooth ($69) | ±0.5 | 0.04 | <0.1/year | 1 (Bluetooth enabled)<br>2 (Bluetooth disabled) |

## 2.2 Logger Accuracy Check

All new loggers should be checked for accuracy before field deployment to maintain data quality control. Older loggers may need to be decommissioned when annual calibrations find accuracy has diminished below the advertised product specifications or when the expected battery life for that product has been exceeded. Applying a correction coefficient for logger drift is possible, however, contact the manufacturer to obtain a replacement if you detect differences when the loggers are new or observe logger drift during the warranty period. In addition, a certified field thermometer should be calibrated at the same time loggers are checked using the ice bath method. Performing the calibrtion will ensure the thermometer is accurate for field use and checking temperature loggers (see 3.3).

### *Ice bath procedure (See Appendix B for the form)*

1. Place water and ice cubes in a cooler at approximately a 2:1 ratio to create an ice bath—see Figure 1. Use a sufficient amount of ice to ensure it distributes evenly throughout the ice bath. Loggers should be completely submerged during testing. Allow at least 30 minutes for the temperature in the ice bath to equilibrate.
2. Place the loggers in the ice bath at least 15 minutes before they begin recording temperatures to allow them to equilibrate. Ensure that the loggers are not touching each other.
3. Place the certified thermometer in the bath as well. The thermometer should be as close to the loggers as possible without touching them. Secure the thermometer so it does not touch the cooler's bottom or sides; a ring stand and clamp work well for this purpose.
4. Ideally, leave the loggers in the bath for 24 hours, allowing them to log temperature during the warming process. During a period of temperature change the differences are more noticeable. Periodically record the reading on the certified thermometer and note the time.
5. Take the data loggers out of the ice bath and download the temperature data. Create a spreadsheet for time versus temperatures recorded for the thermometer and each data logger.
6. Compare the temperatures recorded by each data logger to the temperature of the thermometer for each time interval.
7. Calculate and record any observed differences.
8. Differences between loggers should not be greater than the accuracy specified for each model in Table 1. Most certified thermometer accuracy is ±0.5 (some can also be more accurate, check your model specifications). The difference between the certified thermometer and the loggers should not be greater than the thermometer accuracy.
9. If differences greater than the thermometer's accuracy are found, a correction coefficient can be calculated, but ideally the logger should be exchanged and decommissioned, as the drift is most likely not going to be consistent.

**Figure 1:** Ice bath example. Note, a mix of water and ice is required—it's difficult to show because the ice floats. Loggers should be submerged, or at a minimum, their sensors should be submerged. *(Photo credit: Graham Goulette)*

## 2.3 Launching Logger

Loggers should be pre-set before field deployment with the following characteristics:

- Delayed start at midnight of the deployment day (this avoids having to manually cut off the first part of the time series).
- Logging intervals of 30 min or less (Maine Atlantic salmon water temperature group agreed upon this interval in January 2023).
- Use Eastern Standard Time (EST) only.
- Use $^{o}$C (Celsius) always.
- Select data averaged over the interval (rather than max value during the interval when the option is available).
- DO NOT choose "Wrap Around Data" in ADVANCED OPTIONS as this will result in overwriting existing data if a logger cannot be recovered before the memory is full.

When reading/swapping a logger in the field, if the logger can be redeployed with enough time to acclimate (varies between logger type—see manufacturer's details) before the next time interval, proceed without resetting the start time. Otherwise, set a delayed start time for midnight of that same day.

## 2.4 Logger Housing

The logger should be shaded from direct solar radiation by using a light-colored—i.e., will not absorb solar radiation and artificially warm—PVC pipe or other material for housing. The housing should have adequate holes (predrilled or precut) for securing points (either using zip ties or galvanized steel wire for a stronger hold) and to allow normal stream flow around the data logger. If possible, attach the logger so that the optic end of the logger is accessible for attaching the optic shuttle (not applicable for Bluetooth loggers) for an easy readout without having to dismantle the PVC housing every download—see Figure 2.

**Figure 2:** Example of one type of logger housing. *(Photo credit: Danielle Frechette)*

US Fish and Wildlife have also used steel housing units by welding 1⁄4” (0.64 cm)–thick steel rectangular tubing (1.5” inside length (3.8 cm)) and a 3” (7.6 cm)–wide steel plate together. The metal tube was cut to 2” (5.1 cm) length and the plate varies from 5” to 8.5” (12.7 to 20.3 cm). Four 1/8” (0.32 cm) holes were drilled into the tube for attaching a logger—see Figure 3. This type of housing can be warmed by solar radiation, thus the dimensions of the metal used should be considered.

**Figure 3:** Example of steel housing. **Note:** the metal chain is not currently attached to the housing units. A 3/8” shackle will attach a chain to the metal bar via the hole opposite the square tube end. *(Photo credit: Scott Craig)*

# 3. DEPLOYMENT PROCEDURES

## 3.1 Site Selection

Site selection for data loggers should be based on the objectives of the study at stream locations that can provide useful, representative data. Three basic levels of consideration apply; (1) The sample location is chosen to represent temperature at the *site level*. (2) Multiple sites provide information at the *reach level*. (3) Multiple reaches within a drainage provide information at the *watershed level*.

Within each of these levels, we also need to consider the need to monitor the mainstem, tributaries, and coldwater patches, which can be used as coldwater refuges. Measuring both thermal refuge and mainstem temperature at the watershed scale can help understand a river’s thermal heterogeneity.

Optimization methods should be used to determine the best logger deployment locations for larger monitoring networks. Optimal deployments will allow for capturing changes in thermal patterns within a river system and help limit redundant information.

**(1) Site level.**

For mainstem:

1. Data loggers should be deployed at sites representative of the stream in a well-mixed area.
2. Somewhat turbulent and providing mixing such, as riffles, runs, or cascades.
3. Toward the deepest part of the channel (thalweg) and likely to provide flow throughout the summer and early fall months (periods of low flow).
4. Not directly affected by groundwater or tributary input.

For coldwater patches:

1. Consider the eight general riverine features that are now commonly accepted as areas where coldwater patches can form: tributary, confluence or plume, lateral seep, springbrook, side channel, alcove, hyporheic upwelling, and wall-based channel and pool.

### (2) Reach level.

A reach can be described as a section of a river or stream with relatively homogeneous characteristics, including gradient, valley form, discharge, vegetation, and substrate or soils. Some studies might concentrate on true distinct river reaches, while others might be targeting a subreach (a particular type of land use or discharge source). In either case, characterizing a reach requires that loggers are placed at upstream and downstream sites within the reach or directly adjacent to the reach.

### (3) Watershed level.

Data loggers placed along multiple reaches within a drainage can describe variations in stream temperature throughout the drainage. Sites monitored continuously over several years can help remove noise from data sets (e.g., high or low water years) and portray a more accurate picture regarding water temperature trends throughout the drainage.

For thermal heterogeneity and long-term monitoring:

1. At both reach and watershed levels, measuring thermal heterogeneity requires loggers placed in the mainstem (general thermal regime conditions), along with loggers strategically placed to capture important features, such as tributary influence or potential cold patches.
2. Long-term monitoring should develop a network at the watershed scale and inform on the river's general thermal regime and include indicators of thermal heterogeneity (e.g., the presence of coldwater and warmwater patches).

## 3.2 Anchoring Devices

Anchors can be site-dependent. At the coordination meetings, participants share their anchoring tips and methods that can be added to this document as needed.

Ideally, loggers and anchors would be difficult to see to prevent vandalism, but this is not always feasible. Small rocks (smaller than the size of a football) can be used to conceal loggers and to help hold them in place.

**Figure A**

**Figure B**

**Figure 4:** Example of anchoring methods; "**A**" on a piece of rebar and "**B**" on a chain with PVC housing (also see report's cover for a different idea). **Note:** anchoring methods depend on stream power, stream bed mobility and adjacent material, so always discuss with the group and share experiences to select the best method for a given context. *(Photo credit: Graham Goulette)*

## 3.3 Metadata

At each site, the following metadata should be collected (see field sheet in Appendix C):

- Record the logger serial number and site name. Site name should be consistent year to year (Use Maine Salmon Database as Name Repository) for proper data association.
- Record GPS coordinates (UTM in NAD 1983 Zone 19N or WGS 1984 same zone).
- Note any important landmark/information that can help with locating the loggers (e.g., mid-channel area by the boulder).
- Take a photo of the site or sketch the site on paper with logger location if there is no photo taken.
- When returning to read/swap the logger, note reading time, instantaneous temperature taken with the certified thermometer, and any other important information, such as delayed start of the logger or instant redeployment.
- Add any additional information that may be pertinent (e.g., logger exposed to air, low flow, etc.) for data interpretation.
- If the logger is to be taken back to the office and cannnot be stopped in the field, record the time that the logger was taken out of the water, so the additional data can be truncated when exporting the .csv file.

## 3.4 Back From the Field

1. Make sure to copy or scan the field sheets and apply the same site name to photos that is recorded on the field sheet, so all the information from a specific site can be easily cross-referenced.
2. Data files should follow the same naming convention, using both logger number and site name. Keep raw files in an archive. Plot your data in the hobo software for visual

validation. Export the .csv file for sharing and perform any additional validation steps as necessary (e.g., cut the end of the data series if the logger was out of the water before being stopped).

3. The group agreed that, presently, we do a visual validation of the data and cut the beginning of the series (if delayed start has not been employed) and the end of the series if the logger could not be stopped right away. By following this protocol, we collect quality data comparable among streams and rivers. Further data validation is the responsibility of the data user and tools, such as EcoSHEDs, may be useful for data validation purposes.

## REFERENCES CITED


Bal, G., Rivot, E., Baglinière, J., White, J., and Prévost, E., 2014. A Hierarchical Bayesian Model to Quantify Uncertainty of Stream Water Temperature Forecasts. *PLoS ONE* 9 (12): e115659. https://doi.org/10.1371/journal.pone.0115659.

Barrett, H.S. and Armstrong, J.B., 2022. Move, migrate, or tolerate: Quantifying three tactics for cold-water fish coping with warm summers in a large river. *Ecosphere*, *13*(6), p.e4095. https://doi.org/10.1002/ecs2.4095.

Bell, D.A., Kovach, R.P., Vulstek, S.C., Joyce, J.E. and Tallmon, D.A., 2017. Climate-induced trends in predator–prey synchrony differ across life-history stages of an anadromous salmonid. *Canadian Journal of Fisheries and Aquatic Sciences*, *74*(9), pp.1431-1438. http://dx.doi.org/10.1139/cjfas-2016-0309

Breau, C., 2013. Knowledge of fish physiology used to set water temperature thresholds for inseason closures of Atlantic salmon (*Salmo salar*) recreational fisheries. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/163. iii + 24 p.

Breau, C., Cunjak, R.A. and Peake, S.J., 2011. Behaviour during elevated water temperatures: can physiology explain movement of juvenile Atlantic salmon to cool water?. *Journal of Animal Ecology*, *80*(4), pp.844-853. https://doi.org/10.1111/j.1365-2656.2011.01828.x

Breau, C., Cunjak, R.A. and Bremset, G., 2007. Age-specific aggregation of wild juvenile Atlantic salmon Salmo salar at cool water sources during high temperature events. *Journal of Fish Biology*, *71*(4), pp.1179-1191. https://doi.org/10.1111/j.1095-8649.2007.01591.x

Breau, C., Weir, L.K. and Grant, J.W., 2007. Individual variability in activity patterns of juvenile Atlantic salmon (Salmo salar) in Catamaran Brook, New Brunswick. *Canadian Journal of Fisheries and Aquatic Sciences*, *64*(3), pp.486-494. https://doi.org/10.1139/f07-026

Corey, E., Linnansaari, T., Dugdale, S.J., Bergeron, N., Gendron, J.F., Lapointe, M. and 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), pp.50-62. https://doi.org/10.1111/eff.12487.

Daigle, A., Caudron, A., Vigier, L. and Pella, H., 2017. Optimization methodology for a river temperature monitoring network for the characterization of fish thermal habitat. *Hydrological Sciences Journal*, *62*(3), pp.483-497. https://doi.org/10.1080/02626667.2016.1242869.

Dugdale, S.J., Bergeron, N.E. and St-Hilaire, A., 2015. Spatial distribution of thermal refuges analysed in relation to riverscape hydromorphology using airborne thermal infrared imagery. *Remote Sensing of Environment*, *160*, pp.43-55. doi: 10.1016/j.rse.2014.12.021.

Ebersole, J.L., Liss, W.J. and Frissell, C.A., 2003. Thermal heterogeneity, stream channel morphology, and salmonid abundance in northeastern Oregon streams. *Canadian Journal of Fisheries and Aquatic Sciences*, *60*(10), pp.1266-1280. https://doi.org/10.1139/f03-107

Elliott, J.M. and Hurley, M.A., 1997. A functional model for maximum growth of Atlantic salmon parr, Salmo salar, from two populations in northwest England. *Functional Ecology*, *11*(5), pp.592-603. https://doi.org/10.1046/j.1365-2435.1997.00130.x

Fay, C., Barron, M., Craig, S.D., Hecht, A., Pruden, J., Saunders, R., Sheehan, T.F., Trial, J.G. and McCollough, M., 2006. Status review for anadromous Atlantic salmon (Salmo salar) in the United States.

Frechette, D.M., Dugdale, S.J., Dodson, J.J. and Bergeron, N.E., 2018. Understanding summertime thermal refuge use by adult Atlantic salmon using remote sensing, river temperature monitoring, and acoustic telemetry. *Canadian Journal of Fisheries and Aquatic Sciences*, *75*(11), pp.1999-2010. https://doi.org/10.1139/cjfas-2017-0422.

Fullerton, A.H., Torgersen, C.E., Lawler, J.J., Steel, E.A., Ebersole, J.L. and Lee, S.Y., 2018. Longitudinal thermal heterogeneity in rivers and refugia for coldwater species: effects of scale and climate change. *Aquatic Sciences*, *80*, pp.1-15. https://doi.org/10.1007/s00027-017-0557-9.

Isaak, D.J., Wollrab, S., Horan, D. and Chandler, G., 2012. Climate change effects on stream and river temperatures across the northwest US from 1980–2009 and implications for salmonid fishes. *Climatic change*, *113*, pp.499-524. https://doi.org/10.1007/s10584-011-0326-z

Jones, L.A., Muhlfeld, C.C., Marshall, L.A., McGlynn, B.L. and Kershner, J.L., 2014. Estimating thermal regimes of bull trout and assessing the potential effects of climate warming on critical habitats. *River Research and Applications*, *30*(2), pp.204-216. https://doi.org/10.1002/rra.2638

Jonsson, B. and 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), pp.2381-2447. https://doi.org/10.1111/j.1095-8649.2009.02380.x

Jørgensen, K.T., Sørensen, J.G. and Bundgaard, J., 2006. Heat tolerance and the effect of mild heat stress on reproductive characters in Drosophila buzzatii males. *Journal of Thermal Biology*, *31*(3), pp.280-286. https://doi.org/10.1016/j.jtherbio.2005.11.026.

Kaushal, S.S., Likens, G.E., Jaworski, N.A., Pace, M.L., Sides, A.M., Seekell, D., Belt, K.T., Secor, D.H. and Wingate, R.L., 2010. Rising stream and river temperatures in the United States. *Frontiers in Ecology and the Environment*, *8*(9), pp.461-466. https://doi.org/10.1890/090037

Lobón-Cerviá, J., 2014. Recruitment and survival rate variability in fish populations: density-dependent regulation or further evidence of environmental determinants?. *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(2), pp.290-300. https://doi.org/dx.doi.org/10.1139/cjfas-2013-0320

Moore, R.D., Nelitz, M. and Parkinson, E., 2013. Empirical modelling of maximum weekly average stream temperature in British Columbia, Canada, to support assessment of fish habitat suitability. *Canadian Water Resources Journal*, *38*(2), pp.135-147. https://doi.org/10.1080/07011784.2013.794992.

Montgomery, D.R., Buffington, J.M., Peterson, N.P., Schuett-Hames, D. and Quinn, T.P., 1996. Stream-bed scour, egg burial depths, and the influence of salmonid spawning on bed surface mobility and embryo survival. *Canadian Journal of Fisheries and Aquatic Sciences*, *53*(5), pp.1061-1070. https://doi.org/10.1139/f96-028.

O'Sullivan, A.M., Wegscheider, B., Helminen, J., Cormier, J.G., Linnansaari, T., Wilson, D.A. and Curry, R.A., 2020. Catchment-scale, high-resolution, hydraulic models and habitat maps–a salmonid's perspective. *Journal of Ecohydraulics*, *6*(1), pp.53-68. https://doi.org/10.1080/24705357.2020.1768600

Porcelli, D., Gaston, K.J., Butlin, R.K. and Snook, R.R., 2017. Local adaptation of reproductive performance during thermal stress. *Journal of Evolutionary Biology*, *30*(2), pp.422-429. https://doi.org/10.1111/jeb.13018.

Robinson, J.M., Josephson, D.C., Weidel, B.C. and Kraft, C.E., 2010. Influence of variable interannual summer water temperatures on brook trout growth, consumption, reproduction, and mortality in an unstratified Adirondack lake. *Transactions of the American Fisheries Society*, *139*(3), pp.685-699. https://doi.org/10.1577/T08-185.1.

Rossi, G.J., Power, M.E., Carlson, S.M. and Grantham, T.E., 2022. Seasonal growth potential of Oncorhynchus mykiss in streams with contrasting prey phenology and streamflow. *Ecosphere*, *13*(9), p.e4211. https://doi.org/10.1002/ecs2.4211

Shepard, S.L., 1995. Atlantic salmon spawning migrations in the Penobscot River, Maine: fishways, flows and high temperatures. M.Sc. thesis, University of Maine, Orono, Maine.

St-Hilaire, A., Caissie, D., Bergeron, N.E., Ouarda, T.B. and Boyer, C., 2021. Climate change and extreme river temperature. In *Climate change and extreme events* (pp. 25-37). Elsevier. https://doi.org/10.1016/B978-0-12-822700-8.00011-1.

Torgersen, C.E., Ebersole, J.L. and Keenan, D.M., 2012. Primer for identifying cold-water refuges to protect and restore thermal diversity in riverine landscapes. *USGS Report*, p.39.

van Vliet, M.T., Yearsley, J.R., Franssen, W.H.P., Ludwig, F., Haddeland, I., Lettenmaier, D.P. and Kabat, P., 2012. Coupled daily streamflow and water temperature modelling in large river basins. *Hydrology and Earth System Sciences*, *16*(11), pp.4303-4321. https://doi.org/10.5194/hess-16-4303-2012.

Wilkie, M.P., Brobbel, M.A., Davidson, K.G., Forsyth, L. and Tufts, B.L., 1997. Influences of temperature upon the postexercise physiology of Atlantic salmon (Salmo salar). *Canadian Journal of Fisheries and Aquatic Sciences*, *54*(3), pp.503-511. https://doi.org/10.1139/f96-305

# APPENDICES

## **Appendix A:** Background Information on Atlantic Salmon Thermal Preferences, Impact of Changing Thermal Regime and Important Environmental Variables To Consider

**From Gillis et al. 2023[1]**

River thermal regime is a key environmental factor controlling Atlantic salmon (*Salmo salar*) survival-based responses, such as activity patterns and growth (Jonsson and Jonsson 2009; Breau, Weir, and Grant 2007; Elliott and Hurley 1997), reproductive success (Jørgensen, Sørensen, and Bundgaard 2006; Robinson et al. 2010; Porcelli et al. 2017), prey abundance (Bal et al. 2014) and phenology (Bell et al. 2017; Rossi et al. 2022), and survival (Montgomery et al. 1996; Lobón-Cerviá 2014). Changing thermal regimes can impact the overall river ecology (e.g., food webs, predator-prey dynamics), which can indirectly affect salmonids like Atlantic salmon (Bell et al. 2017; Rossi et al. 2022). Atlantic salmon have a narrow thermal tolerance, and water temperature variations outside this tolerance range can induce a substantial amount of physiological stress (Breau, Cunjak, and Peake 2011). Changes in river temperature dynamics (e.g., daily variability, frequency, and duration of summer maximum, warmer thermal regimes) pose a distinct threat to Atlantic salmon populations throughout their range (Fay et al. 2006).

An increase in both mean river water temperatures and summer thermal maximums has already been observed in several rivers throughout North America (Kaushal et al. 2010; Isaak et al. 2012) and more locally across the range of Atlantic salmon rivers in eastern Canada (Daigle, Boyer, and St-Hilaire 2019; O'Sullivan et al. 2021; St-Hilaire et al. 2021). With continued projected warming, the duration and severity of warmer temperatures are expected to increase, which could impact thermal heterogeneity and within river temperature patterns (van Vliet et al. 2012; Moore, Nelitz, and Parkinson 2013; Jones et al. 2014; Fullerton et al. 2018). Thermal heterogeneity is defined as a mosaic of warm and cool water habitats that allow fish to complete their life cycle (Ebersole et al. 2003). Although thermal heterogeneity is relevant throughout the year, it is particularly critical during summer because it allows fish to survive warm water temperature events (Dugdale, Bergeron, and St-Hilaire 2015). During low flows and warmer conditions, thermal heterogeneity becomes essential to the resilience and survival of Atlantic salmon. Decreased thermal heterogeneity can have dramatic consequences for Atlantic salmon. For example, when temperatures reach 20-23 $^{o}$C, thermal stress occurs (Shepard 1995; Wilkie et al. 1997; Breau 2013), and salmons exhibit behavioral thermoregulation to avoid warmer areas by accessing cold water habitat patches called cold-water refuges (e.g., upstream shaded areas, tributaries, groundwater upwelling zones; Breau, Cunjak and Bremset 2007; Torgersen, Ebersole, and Keenan 2012; Barrett, Armstrong, and Barrett 2022). This ability to thermoregulate behaviorally becomes limited as thermal heterogeneity decreases and cold-water patches become less available (Frechette et al. 2018; Corey et al. 2020; O'Sullivan et al. 2021). The distribution, abundance, and persistence of these cool water patches are critical to the resilience of catchments to sustain wild Atlantic salmon populations.

---

[1]Gillis, C., Ouellet, V., Breau, C., Frechette, D. & N. Bergeron (2023) Assessing climate change impacts on North American freshwater habitat of wild Atlantic salmon - urgent needs for collaborative research, Canadian Water Resources Journal / Revue canadienne des ressources hydriques, DOI: 10.1080/07011784.2022.2163190

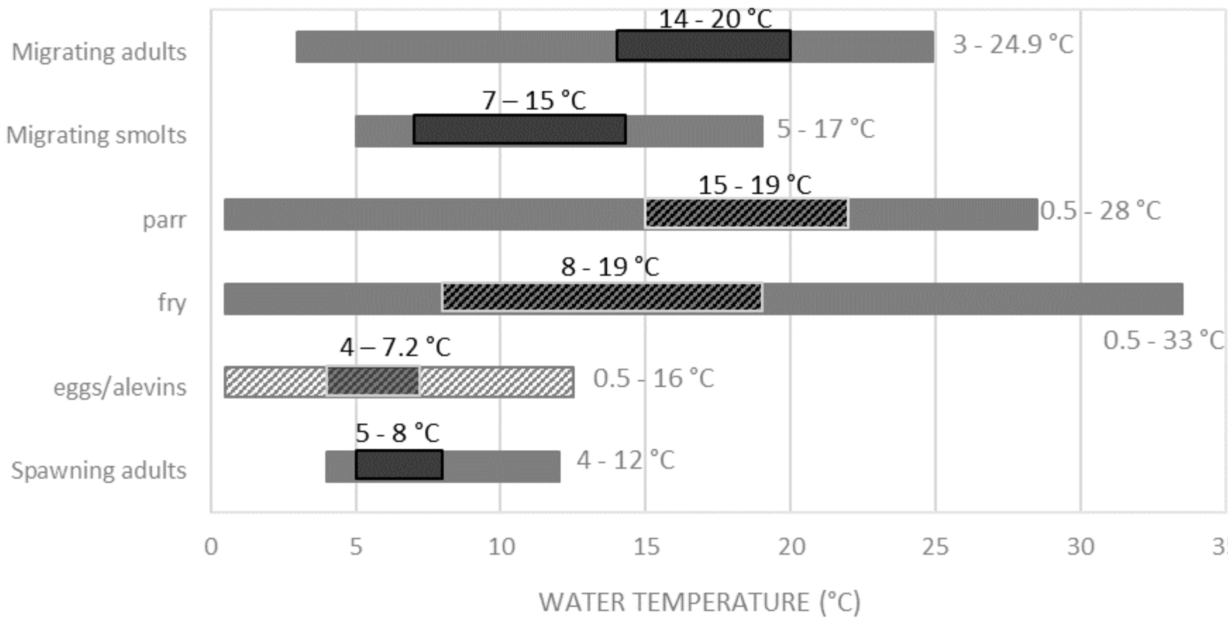


**Figure 3:** Relative thermal tolerance of Atlantic salmon by life stage. Data were predominantly from field studies (solid bars); findings from controlled experiments are denoted by dashed bars. Black bars (solid and dashed) represent the optimal water temperature range for activity; grey bars (solid and dashed) represent the lower and upper water temperature boundaries. Values collated from: Elson (1969); Danie, Trail, and Stanley (1984); Alabaster (1991); Grande and Andersen (1991); Jensen, Johnsen, and Heggberget (1991); Elliott (1991); Shepard (1995), Elliott and Elliott (1995); Elliott et al. (1998); Elliott and Elliott (2010).


**Figure 5:** Synthesis of the importance of temperature on physiological aspects and habitat conditions for each Atlantic salmon life stage. When the line is wider, it associates the specific life stage and physiological aspect primarily influenced by habitat conditions. This figure emphasizes the importance of incorporating temperature in study designs, as it drives key processes at each life stage and can have confounding effects in both individual and population-level responses.

**Appendix B:** Temperature Logger Accuracy Check Form

Reported by:_____________________________ Organization:______________________

Date:____________ Drainage to be used in:__________________________________

Model:_____________________________ Serial #:_________________________

Drainage Logger ID #:__________________________________

| **Time** | **Bath temperature (ºc)** | **Logger temperature (ºC)** | **Discrepancy (ºC)** |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Appendix C:** Field Deployment Form for Metadata

## TEMPERATURE LOGGER FIELD FORM

Reported by:______________ Organization:______________ Site name:______________________

Date:______________ Time:_____________ Drainage:_______________________

Branch:_____________ Subreach:___________________ Logger type:______________________

Logger #:____________ Delayed start at:______________

GPS coordinate:

**Sites Characteristics:**

| *Adjacent land* | *Primary stream substrate* | *Secondary stream substrate* |
|---|---|---|
| ☐ Wetland<br>☐ Forested- closed canopy<br>☐ Forested-open canopy<br>☐ Developed/urbanized<br>☐ Agriculture | ☐ Boulder (> than a basketball 10.1in)<br>☐ Cobble (tennis ball to basketball 2.5 - 10in)<br>☐ Gravel (peppercorn to tennis ball .08-2.4in)<br>☐ Sand (salt to peppercorn .002-.08in)<br>☐ Silt & Clay (finer than salt <.002in)<br>☐ Aquatic Vegetation | ☐ Boulder (> than a basketball 10.1in)<br>☐ Cobble (tennis ball to basketball 2.5 -10in)<br>☐ Gravel (peppercorn to tennis ball .08-2.4in)<br>☐ Sand (salt to peppercorn .002-.08in)<br>☐ Silt & Clay (finer than salt <.002in)<br>☐ Aquatic Vegetation |
| *Overhead canopy cover*<br>☐ 0-25%<br>☐ 26-50%<br>☐ 51-75%<br>☐ 76-100% | *Obstruction to fish passage*<br>☐ Culvert<br>☐ Low dam<br>☐ Roadbed<br>☐ Beaver dam<br>☐ Natural falls<br>☐ None observed | *Photos*<br>☐ General site (broad view)<br>☐ Logger location |

**General Comments/Notes:**

**Midseason Check:**

Reported by & organization:_____________________ Date & Time:__________ Water temperature:_______

Logger conditions/comments:

**Retrieval:**

Reported by & organization:_____________________ Date & Time:__________ Water temperature:_______

Logger conditions/comments:

**Procedures for Issuing Manuscripts**
**in the Northeast Fisheries Science Center Reference Document (CRD)**
**and the Technical Memorandum (TM) Series**

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of the nation's ocean resources and their habitat." As the research arm of the NMFS's Greater Atlantic Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS's mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (e.g., anonymously peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own series.

*NOAA Technical Memorandum NMFS-NE* – This series is issued irregularly. The series typically includes: data reports of long-term field or lab studies of important species or habitats; synthesis reports for important species or habitats; annual reports of overall assessment or monitoring programs; manuals describing program-wide surveying or experimental techniques; literature surveys of important species or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review, and most issues receive technical and copy editing.

*Northeast Fisheries Science Center Reference Document* – This series is issued irregularly. The series typically includes: data reports on field and lab studies; progress reports on experiments, monitoring, and assessments; background papers for, collected abstracts of, and/or summary reports of scientific meetings; and simple bibliographies. Issues receive internal scientific review, and most issues receive copy editing.

## CLEARANCE

All manuscripts submitted for issuance as CRDs must have cleared the NEFSC's manuscript/abstract/webpage review process. If your manuscript includes material from another work which has been copyrighted, you will need to work with the NEFSC's Editorial Office to arrange for permission to use that material by securing release signatures on the "NEFSC Use-of-Copyrighted-Work Permission Form."

## STYLE

The CRD series is obligated to conform to the style contained in the current edition of the United States Government Printing Office Style Manual; however, that style manual is silent on many aspects of scientific manuscripts. The CRD series relies more on the CSE Style Manual. Manuscripts should be prepared to conform to both style manuals.

The CRD series uses the Integrated Taxonomic Information System, the American Fisheries Society's guides, and the Society for Marine Mammalogy's guide for verifying scientific species names.

For in-text citations, use the name-date system. A special effort should be made to ensure all necessary bibliographic information is included in the list of references cited. Personal communications must include the date, full name, and full mailing address of the contact.

## PREPARATION

Once your document has cleared the review process, the Editorial Office will contact you with publication needs—for example, revised text (if necessary) and separate digital figures and tables if they are embedded in the document. Materials may be submitted to the Editorial Office as email attachments or intranet downloads. Text files should be in Microsoft Word, tables may be in Word or Excel, and graphics files may be in a variety of formats (JPG, GIF, Excel, PowerPoint, etc.).

## PRODUCTION AND DISTRIBUTION

The Editorial Office will perform a copy edit of the document and may request further revisions. The Editorial Office will develop the inside and outside front covers, the inside and outside back covers, and the title and bibliographic control pages of the document.

Once the CRD is ready, the Editorial Office will contact you to review it and submit corrections or changes before the document is posted online. Several organizations and individuals in the Northeast Region will be notified by e-mail of the availability of the document online.