Thermal profile of Margaree River in 2024-2025

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Rationale

The aim of this report is to provide a thermal variability profile of the Margaree River to identify potential warm, stressful areas as well as cold-water areas that could serve as candidates for cold-water refugia at the watershed level. This analysis builds on the NSSA's Watershed Stewardship Planning approach and was supported by projects funded through the Canada Nature Fund for Aquatic Species at Risk and the Aquatic Ecosystem Restoration Fund.

Methodology

Between June and September, the Margaree Salmon Association recorded water temperature at 27 sites in 2024 and 31 sites in 2025 across the watershed (Figure 1). At each site, the HOBO logger was deployed, and temperature was recorded every 15 minutes.

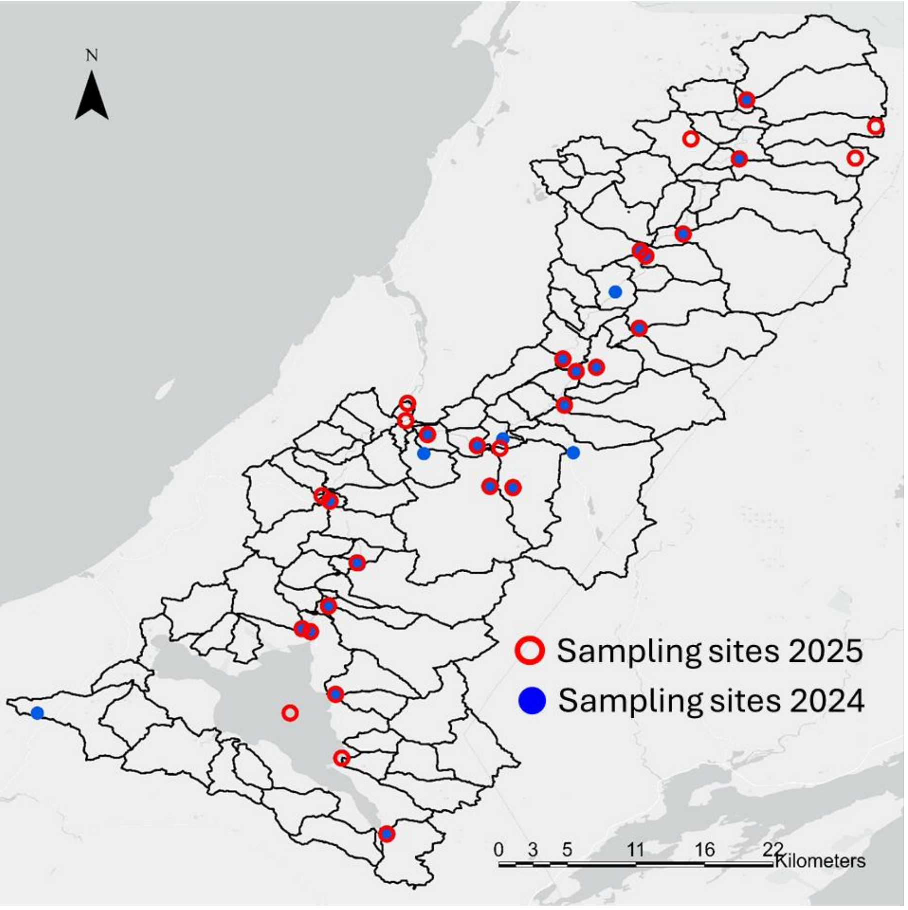

Figure 1. Location of sampling sites across the Margaree River watershed. Blue dots indicate datalogger deployments in 2024, and red dots indicate deployments in 2025.

The temperature data were then used to predict thermal variability across the entire watershed using machine learning models. For this analysis, we calculated the average temperature between July 1 and August 31 to focus on the hottest period of the summer season. We also calculated the proportion of days when the maximum temperature exceeded 20°C, which is considered stressful for adult Atlantic salmon. These field-based temperature variables were used as response variables in the predictive models, while multiple environmental variables related to topography, land use, soil drainage and texture, and bedrock and surficial geology were used as predictors. These predictors were derived from the Interpreted Forest Inventory, Bedrock Geology, Surficial Geology, and Ecological Land Classification layers available from the Government of Nova Scotia's (GovNS) open data portal. We also used topographic LiDAR datasets downloaded as 1:10,000 products from the Nova Scotia Geomatics Centre's (NSGC) Elevation Explorer data portal to derive slope and riparian forest cover. Riparian forest cover was calculated within a 30 m buffer along streams, and both variables were used as predictors in the models.

Results and Discussion

The machine learning models produced robust predictions and final models with small errors. In 2024, the predictions had an error of 1.34°C for average temperature and 0.16 days for the proportion of days with maximum temperature above 20°C. In 2025, the error was 1.29°C for average temperature and 0.14 days for the proportion of days with maximum temperature above 20°C (Figure 2).

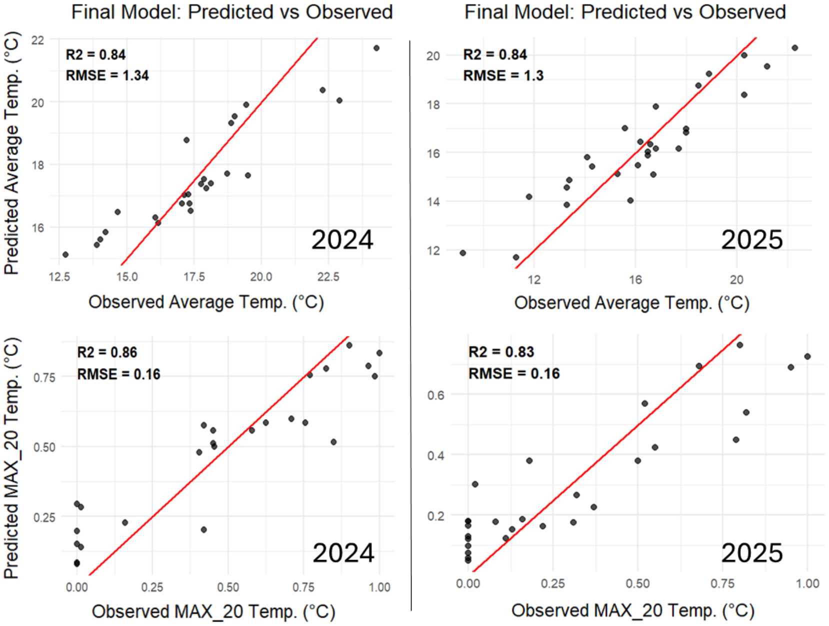

Figure 2: Observed versus predicted stream water temperature parameters from the final Random Forest model trained on all observed sites within Margaree River watershed. The red 1:1 line indicates perfect agreement, while the fitted points illustrate overall model accuracy.

Based on the water temperature data from Margaree River watershed 2024 was hotter than 2025. The average temperature and proportion of days with maximum temperature above 20 °C for 2024 were 17.8°C and 54% of the total sampling days, respectively. For 2025, average temperature and proportion of days with maximum temperature above 20°C was 16.2°C and 30% of the total sampling days, respectively (Figures 3 and 4). Areas with high riparian forest cover and steep slopes exhibited the coolest temperatures, whereas areas with extensive agricultural land and built-up areas showed a warmer effect. A higher proportion of imperfectly drained soils, to a lesser extent, also contributed to cooler water temperatures.

Riparian forest cover is a primary driver of cold-water conditions because canopy shade reduces direct solar radiation reaching the stream. Slope also influences thermal dynamics: steeper gradients tend to reduce water residence time, limiting prolonged exposure to sunlight and helping maintain cooler temperatures. In contrast to steep slopes, imperfectly drained soils increase water residence time, however extended residence time under dense riparian forest canopy offsets solar heating and can still promote cooling. Indeed, areas with imperfectly and poorly drained soils that lack canopy shading, such as lakes and open bogs, showed warmer temperatures. In the Margaree River watershed, Lake Ainslie provides a clear example, recording the highest observed water temperatures, with averages of 24.3 °C in 2024 and 23.0 °C in 2025, well above the 20 °C threshold considered stressful for adult Atlantic salmon.

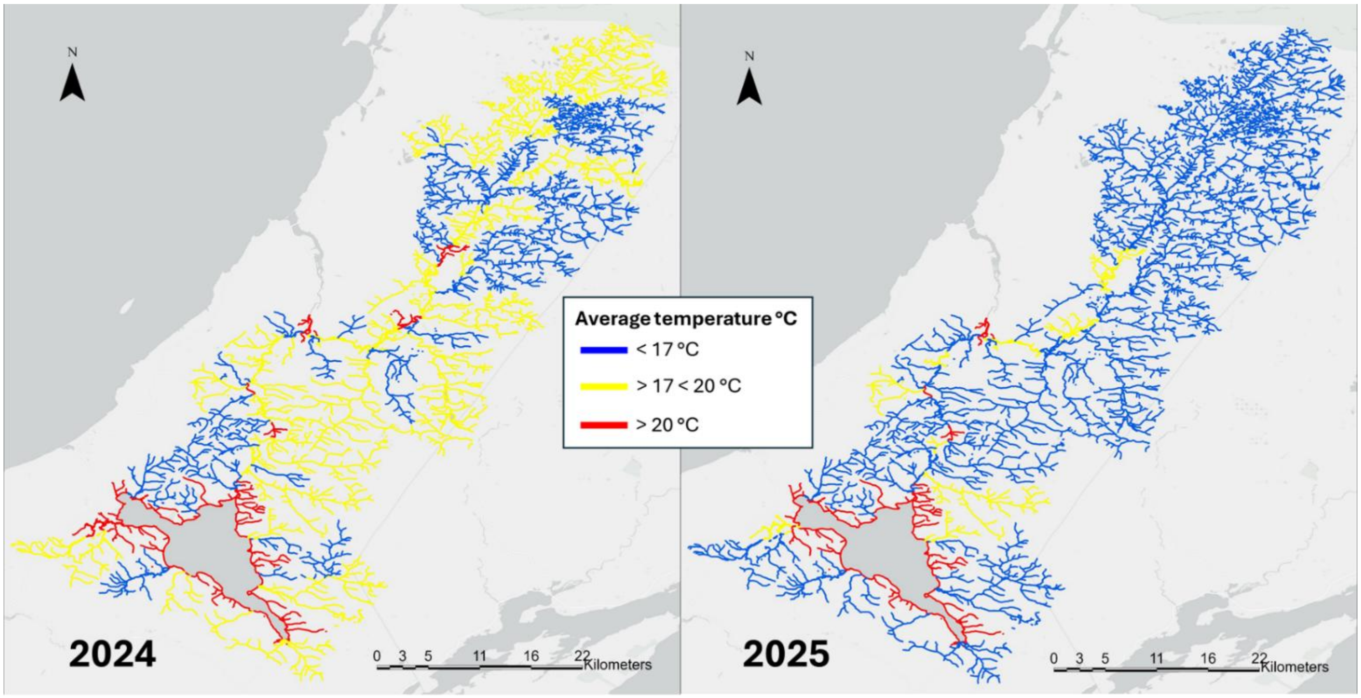

Figure 3. Thermal suitability map for adult Atlantic Salmon within Margaree River based on average temperature for 2024 and 2025. River channels in blue excellent thermal conditions with average temperature below 17°C, channels in yellow indicate suitable waters (Avg. temp. > 17 < 20°C) but not ideal, and channels in red indicate stressful thermal conditions with average temperature above 20°C.

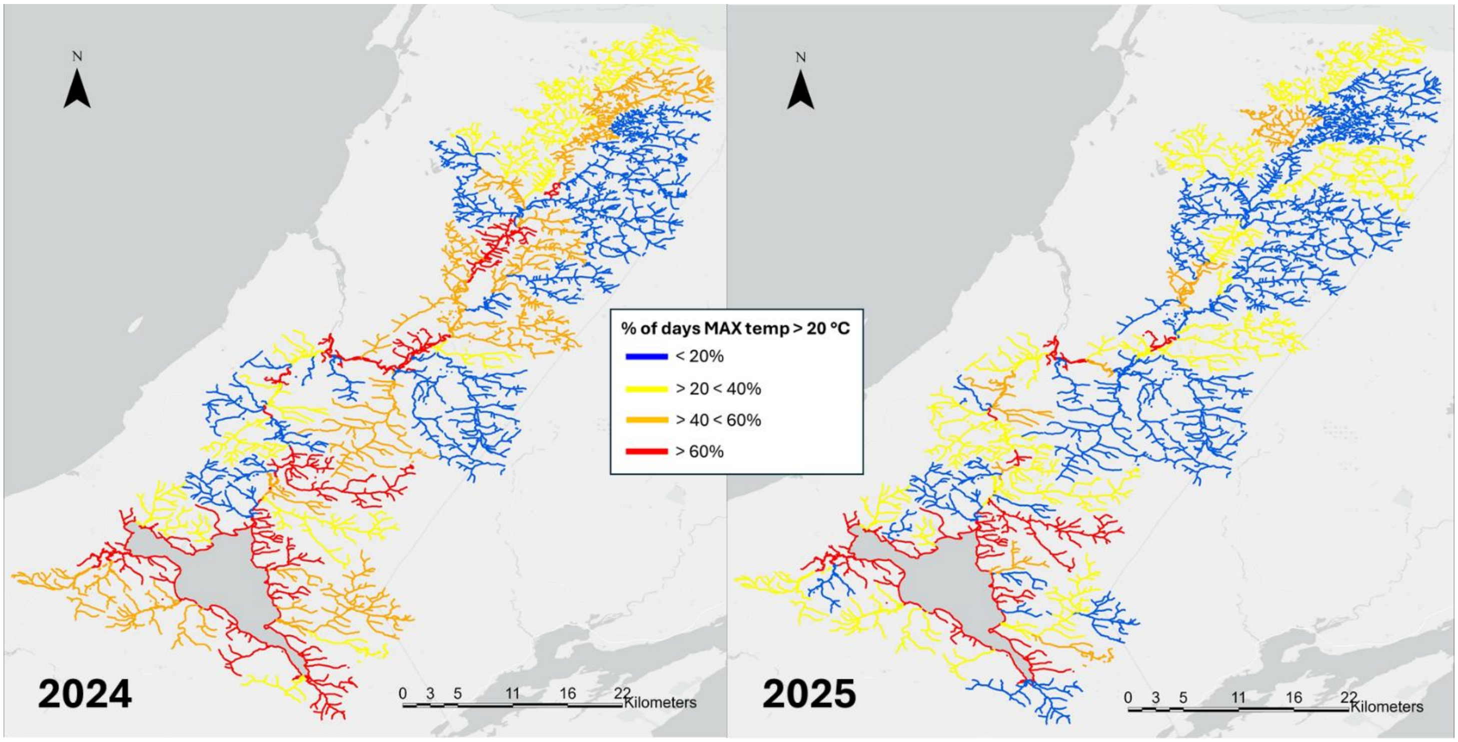

Figure 4. Thermal suitability map for adult Atlantic Salmon within the Margaree River based on the proportion of days when the maximum temperature exceeded 20 °C for 2024 and 2025. River channels in dark blue represent excellent thermal conditions, with maximum temperatures exceeding 20 °C (MAX20) on less than 20% of the sampling period. Channels in yellow indicate okay conditions with MAX20 > 20 < 40%, orange represents marginal suboptimal conditions MAX > 40 < 60%, and red denotes unsuitable conditions MAX > 60% of the sampling period.

Differences in extreme temperatures (i.e., the proportion of days when maximum temperature exceeded 20 °C) between 2024 (hotter) and 2025 (drier) may partly reflect prediction error, but they may also highlight areas that are particularly sensitive to heat and groundwater dynamics. Notably, some areas exhibited a lower proportion of extreme temperature days in 2024 compared to 2025 (Figure 5), despite 2024 being the warmer year overall.

These results suggest that certain tributaries may be more resilient to heat waves due to groundwater inputs, allowing them to remain relatively cool during hot years such as 2024. However, this buffering capacity appears to diminish during drought conditions, as observed in 2025, when reduced groundwater discharge may increase thermal vulnerability. Under drought conditions, these systems may become more susceptible to elevated temperatures than non–groundwater-fed tributaries with high riparian forest cover. Given that heat waves and droughts are projected to increase in frequency and intensity under climate change, riparian reforestation should be considered a priority strategy for enhancing watershed climate resilience.

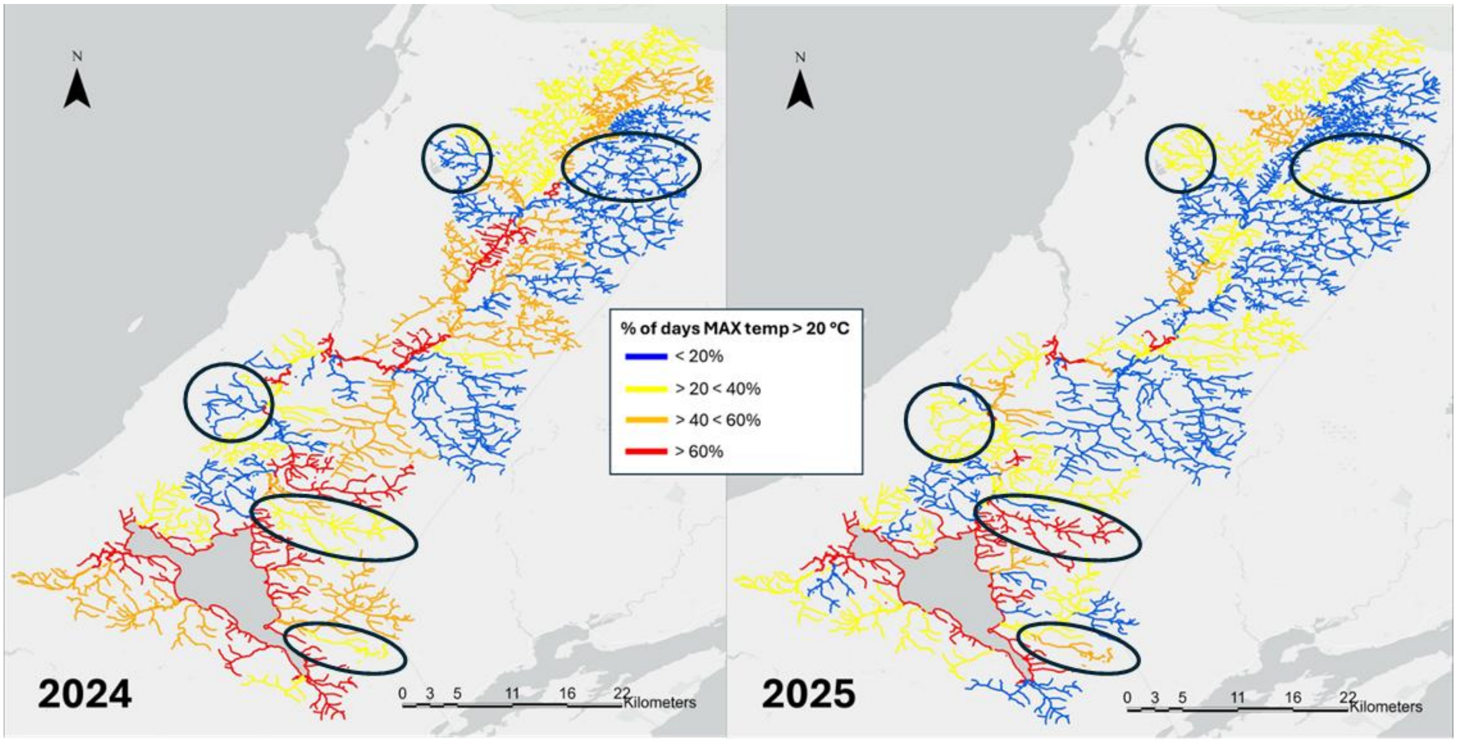

Figure 5. Thermal suitability map for adult Atlantic Salmon within the Margaree River based on the proportion of days when the maximum temperature exceeded 20 °C for 2024 and 2025. Black circles highlight sections of the watershed that showed lower proportion of extreme temperature days in 2024 compared to 2025, despite 2024 being the warmer year overall

Next steps

The next step is to improve the sampling effort to reduce prediction error and increase model accuracy. The machine learning model used to generate the predictions requires a substantial number of observations to effectively learn the environmental - temperature relationships and produce more reliable predictions. In this study, we used 27 observations in 2024 and 31 observations in 2025. Although the final models showed relatively small errors, the mean five-fold cross-validation results indicated higher prediction errors, with a RMSE = 2.4 °C for average temperature in 2024 and RMSE = 2.6 °C in 2025. Increasing the number of observations to approximately 40 - 50 would likely lead to lower errors and a substantial improvement in prediction accuracy.

Another important factor is the spatial distribution of observations. Ideally, sampling locations should be evenly distributed across the lower, middle, and upper sections of the watershed to better capture the environmental heterogeneity that characterizes the system. Increasing the number of observations and distributing them evenly across the watershed will likely enhance the predictive power of the models in identifying cold-water refugia at the watershed level.

Recommendations

These results indicate that tributaries with high riparian forest cover highlighted in blue are priority areas for protection, as they contribute significantly to maintaining cold-water inputs within the system. Tributaries highlighted in yellow should be prioritise for restoration actions. Among restoration actions we highlight the importance of tree planting in riparian zones, as this is the most effective strategy to build resilience against climate change and rising water temperatures. Tree planting in heavily agricultural areas is particularly beneficial—not only for shading the water, but also for reducing the runoff of agrochemicals, especially pesticides known for their toxicity to aquatic wildlife and their negative effects on water quality (Willis & McDowell, 1982; Brausch & Smith, 2015; Ahmed et al., 2022; Chen et al., 2023; Zhao et al., 2024). Riparian tree planting also stabilizes riverbanks and reduces erosion (Abernethy & Rutherfurd, 2000; Simon & Collison, 2002). Additional benefits include improved sediment filtration by root systems (Lowrance et al., 1984; Polyakov et al., 2005), enhanced habitat complexity through the input of large woody debris and organic matter (Gregory et al., 1991; Wohl et al., 2019), increased nutrient uptake that helps mitigate eutrophication (Mayer et al., 2007; Vidon et al., 2010), greater flood attenuation through slowed runoff and increased infiltration (Tabacchi et al., 2000; Dixon et al., 2016), and the creation of biodiverse habitat corridors that support both aquatic and terrestrial species (Naiman et al., 2005; Sweeney et al., 2004).

We recommend planting larger native trees, between 2–4 meters in height, combining fast-growing pioneers (e.g., Alder, Balsam Poplar, Red Maple, Trembling Aspen) with slow-growing, long-lived species (e.g., Eastern Hemlock, Yellow Birch, Sugar Maple). The fast-growing pioneers provide immediate shade and stabilize soils, while the long-lived species ensure long-term resilience and thermal regulation. Planting larger trees accelerates the regeneration process and increases survival rates in restoration projects. Considering the more frequent droughts associated with climate change, attention to site preparation will improve success rates. For example, some jurisdictions utilize superabsorbent hydrogel (SAH) to the soil that can substantially reduce tree mortality without the need for constant watering.

Protection and restoration of habitat conditions in cool water tributaries remains a priority to optimize ecosystem resilience, and salmon and trout rearing habitats.

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