Biogeography of Atlantic Salmon (*Salmo salar*) in the Cape Breton Highlands, Nova Scotia, Canada

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Key words: salmonid, distribution, fisheries management, conservation

Abstract
Atlantic salmon (*Salmo salar*) populations have experienced significant declines in recent decades. In Canada, conservation efforts are divided into 16 designatable units (DUs) to address unique regional challenges among genetically distinct populations. The Cape Breton Highlands are a particularly understudied region in Atlantic Canada, characterized by limited assessments and outdated distribution data. The Cape Breton Highlands are divided into two DUs; the Eastern Cape Breton (ECB) and Gulf of St. Lawrence, in which salmon are listed as "endangered" and "special concern," respectively. This study aimed to update the distribution and abundance of Atlantic salmon in the Cape Breton Highlands describing the community composition of lesser known systems and identifying environmental variables that influence salmon presence. Electrofishing surveys conducted across 24 rivers in the ECB and Gulf DUs targeted lesser-known systems with potential to support small salmon populations. Species assemblages were analyzed using non-metric multidimensional scaling (NMDS) to compare community composition between DUs which revealed no significant difference between management units. A generalized additive model (GAM) assessed salmon abundance between the two DUs, indicating that salmon populations are similar between DUs, underscoring the importance for new conservation designations. Ongoing monitoring and reassessment of salmon is critical for an up-to-date perspective on the status of the species. These data will provide usable insights for environmental managers by offering accurate data on the present status of salmon populations in the Cape Breton Highlands.

Introduction

Atlantic salmon (*Salmo salar*) populations have declined precipitously in recent decades, intensifying their risk of extirpation in much of their native range (Parrish et al, 1998., Long et al, 2023). Atlantic salmon exhibit a high degree of homing to their natal rivers, and regional adaptations have produced geographically distinct subpopulations of fish (King et al, 2010., Verspoor et al, 2005., DFO, 2024). In 2010, COSEWIC divided Atlantic salmon populations into 16 independently managed designatable units, in an effort to recognize and preserve the diversity within wild subpopulations. By dividing salmon into designatable units (DUs), agencies can implement actions that target the unique needs and threats facing each unit, rather than treating Atlantic salmon as a homogenous group (COSEWIC. 2010). This approach is unique to Canada and differs from conservation frameworks in other Atlantic salmon jurisdictions. In contrast, Ireland's conservation limits are imposed based on an annual stock assessment, which is compared to a biological reference point for healthy salmon returns (NASCO. 2004). In Atlantic Canada there are 16 DUs, including two in the Cape Breton Highlands, which are an understudied region for salmon in the country. The Cape Breton Highlands are divided into distinct salmon DUs based on watershed boundaries; the Eastern Cape Breton and the Gulf of St. Lawrence, among which Atlantic salmon are listed by COSEWIC as “Endangered” and “Special Concern” respectively (COSEWIC. 2010).

The Eastern Cape Breton (ECB) DU is characterized by steeper stream gradients, higher water quality and lower anthropogenic impact compared to other rivers along Nova Scotia’s Atlantic coast (Amiro et al. 2006). Eastern Cape Breton is thought to have 45 watersheds supporting Atlantic salmon between the northern tip of the Cape Breton Highlands, along the Atlantic coast to the Canso Causeway (NASCO Rivers Database). However, a large number of smaller, unassessed watersheds are thought to likely support Atlantic salmon as well, which would include additional distinct populations of fish (Gibson et al. 2014). While freshwater habitat availability is not considered a limiting factor for salmon abundance in the ECB DU (Gibson & Bowlby, 2009), data from recreational catches, adult counts, and juvenile electrofishing surveys indicate that current salmon abundance is well below the capacity supported by available habitat (Levy & Gibson, 2014; Gibson & Bowlby, 2009). Although habitat quantity and quality are sufficient, threats such as habitat alteration, barriers to migration, invasive species, and genetic introgression from farmed fish pose challenges. These threats can be disproportionately impactful to small systems, where minor disturbances may significantly affect salmon populations (Gibson et al. 2014). On the opposite coast of Cape Breton, The Gulf of St. Lawrence DU incorporates all Nova Scotian rivers draining into the Gulf, 55 of which are known to host populations of Atlantic Salmon (Breau et al, 2009., Daigle, 2023). Given the size of the Gulf unit, most assessments for salmon are limited to index rivers; large systems with high rates of returning salmon. The index river in the Cape Breton Highlands is the Margaree River, which is characterized by a high proportion of large (> 63cm), predominantly male salmon (Chaput et al, 2006). In 2023, estimates indicated that large and small salmon returns had declined over the previous 16 years by 25% and 46% respectively (Daigle, 2023). The decline in returns over the recent years can likely be attributed to the same existential threats facing Atlantic salmon in the rest of their range; natural system modifications, invasive species and climate change (Daigle, 2023).

The exact number of rivers inhabited by Cape Breton Atlantic salmon is uncertain, but spawning adults and juvenile salmon likely once accessed all of the freshwater habitat available to them (Gibson et al. 2014). The most well-studied metapopulations of the Gulf of St. Lawrence and eastern Cape Breton DUs are described by catch estimates from recreational fisheries, limited electrofishing surveys and adult counts, and partial fish counts in the main systems known to host salmon (Gibson et al. 2014, 2015). Between 1996-2007 DFO conducted electrofishing surveys for juvenile salmon in the ECB DU, but had limited spatial coverage (Gibson et al. 2014). Notwithstanding any recent concerted effort to survey these systems, lower-order streams have been suggested as favorable habitat to larger rivers because despite being less stable to hydrological events, they support better spawning substrate and water quality (Gibson. 1993). Although these systems would likely not support robust populations of returning salmon, there may be ample spawning habitat for a handful of annual spawners and enough resources for many of their offspring to thrive. To modernize the management of Cape Breton's salmon populations, more complete data on the biogeography and critical habitat of Atlantic Salmon in Cape Breton is needed (Levy & Gibson. 2014). Effective conservation requires accurate, up-to-date data on the distribution and abundance of wild salmon populations. Knowledge gaps and outdated information risk the misallocation of critical resources (e.g., habitat restoration funding) and may hinder effective conservation strategies. The primary objective of this study is to update and enhance the current understanding of Atlantic salmon distribution in the Cape Breton Highlands. These data will allow us to compare between the ECB and Gulf of St. Lawrence DUs to verify the COSEWIC status listing of these two metapopulations. Using environmental data and landscape metrics of the Highlands, we also aim to identify habitat predictors for Atlantic salmon, which will inform future research focused on the distribution of Nova Scotia salmon, which is ever changing, and often ill-understood. Electrofishing surveys are a tractable survey option for collecting data on the population of juvenile fish compared to angling, visual surveys or traps, because they have the highest capture efficiency for small streams and rivers (Foley et al. 2015). These data will provide new insight into where salmon populations are located on the Cape Breton peninsula, and how the quality and composition of the habitat influences the abundance of salmon between DUs.

Methods

Study site

Cape Breton was once an island in northern Nova Scotia, situated between the Gulf of St. Lawrence and the Atlantic Ocean, encompassing an area of 11,700km^2. The former island receives a 30-year average annual precipitation of 1517mm and has an average temperature of 5.9°C (Bachler et al. 2015). The region is characterized by ancient mountains that precipitate into the ocean, atop which live a unique composition of flora and fauna, left pristine by their inaccessibility to humans. The ancient exhumed remnants of the Appalachian mountain belt have facilitated a variety of microbiomes within the region including Acadian, Boreal, and Taiga forest types, which host distinct and oftentimes non-overlapping faunal types (Baechler. 2015). With a unique geography dissimilar to anywhere on the mainland of Nova Scotia, Cape Breton hosts biomes whose species tolerate a much wider range of temperatures and conditions, like the ancient alpine-arctic plant species that reside within its cliffs (Belland & Schofield. 1993).
The Cape Breton Highlands have scores of rivers delineating the faults created by the formation of the Appelatian mountains during the Paleozoic, draining into the Maritimes Basin and the Atlantic Ocean. The drainages have been separated into the ECB and Gulf of St. Lawrence DUs,

respectively hosting populations of Atlantic salmon (COSEWIC, 2010). Each of these two DUs in Cape Breton are characterized by different habitat types and environmental conditions associated with the geography of the region.

Site selection

Twenty-four rivers were selected across the Northern Cape Breton Highlands peninsula (Figure 1). Each system was selected considering the following criteria: river size (width and depth), gradient, accessibility to surveyors and distribution across the area of interest. Ideal survey site candidates were shallow and narrow enough for optimal backpack electrofishing with two people, low enough gradient that salmonids could access them, and spaced evenly around the Cape Breton Highlands peninsula for an optimal estimate of the species composition of the entire region. Rivers with limited data from the DFO, Parks Canada, or other published reports were prioritized to fill knowledge gaps about biodiversity in the Highlands. The sites that were selected encompassed a range of habitat types, with substantial variation in water depth, flow, temperature, clarity, and substrate type in each system.

Field methods

For each site, three transects of ~300 meters were surveyed by a crew of 2 people or more, with one electrofisher operator and one dip-netter per crew. A Smith-Root LR24 electrofisher was used, with the capture parameters (duty cycle, frequency and voltage) adjusted based on the responses of the fish at each site. Surveyors would use the quick setup function on the electrofisher to establish baseline settings based on the conductivity of the water, and then adjust accordingly thereafter. Temperature and pH were recorded at each site prior to the beginning of surveying. If a system was warmer than 20°C, it was discarded to ensure the safety of the fish. Generally, transects were selected based on areas where the habitat for salmon was deemed optimal and where the river was shallow enough for the crew to fish. The distance between transects varied but never exceeded 1km. The crew would travel upstream from the access point, which was often the closest point to the Cabot Trail highway, which transected most of the study sites. Surveyors would fish a variety of habitat types (pools, riffles, runs, undercut banks etc) to avoid sampling bias and to obtain an accurate estimate of the community assemblages in each transect. Captured specimens were held in a 20L bucket with frequent water changes until the end of the transect, where they were identified by species and measured at fork length. Measurements were taken while the fish was partially submerged underwater, to minimize exposure to air. A genetic sample from the upper caudal fin of Atlantic salmon was collected and stored in ethanol, which was kept frozen for future gene banking analysis. American eel were noted when observed but not measured. Field equipment was decontaminated according to accepted aquatic invasive species prevention protocols using a diluted Virkon solution between sites (Stockton-Fiti & Moffitt. 2017).

Statistical analysis

To compare species assemblages between DUs, a non-metric multidimensional scaling analysis (NMDS) was used. NMDS enables the visualization of patterns of community similarities between rivers, revealing ecological relationships among sites based on habitat characteristics or geological factors (Gansfort & Traunspurger. 2019). Using the *metaMDS* function from the vegan package in R (Oksanen et al. 2015), the species-by-river matrix reduced multidimensional data into two axes while preserving the rank order (Bray-Curtis dissimilarities) between sites, allowing similar community compositions to cluster together on a single plane. Ellipses were drawn around rivers delineating DUs at a 95% confidence interval, indicating potential patterns in community structure between geographical regions. To ratify the visual interpretation of the NMDS plot, a nonparametric permutated multivariate analyses of variance (perMANOVA) analysis tested the null hypothesis that there was no difference in species assemblage between DU's. Similar analyses comparing community assemblages have been successful in designating spatially separated habitats in freshwater systems. Bliss et al. (2017) demonstrated different species assemblages within the same urban watershed associated with runoff, temperature and habitat heterogeneity. Using NMDS analyses, their study found that anthropogenic impact to drainages into the main watershed had a substantial effect on the structure and diversity of the species within each reach of the river (Bliss et al. 2017). More recent studies comparing freshwater ecosystems have demonstrated the effectiveness of NMDS to correlate species assemblages by habitat type (Ludwig et al. 2024).

To compare the abundance of salmon caught between DUs, we used a Generalized Additive Model (GAM) with a Poisson distribution and log link function, using abundance as the response variable. The model included a random effect for river name to account for variation among individual rivers and smooth out spatial effects. The model included transect number, species, and DU as fixed effects. The model was fit using the gam() function from the *mgcv* package (Wood, 2017) in R, according to the following equation:

$$\text{Abundance}_i \sim \text{Poisson}(\mu_i)$$
$$E(\text{Abundance}_i) = \mu_i$$
$$\log(\mu_i) = \text{Intercept} + \text{Transect} + s(\text{River Name}) + (\text{Species} \times \text{Side})$$

The same GAM was used to identify environmental predictors of salmon habitat suitability between DUs in the Cape Breton Highlands. The incentive for this approach was to determine habitat characteristics correlated with salmon presence, which could indicate the suitability of rivers outside the scope of this study. The model incorporated both variables collected in-situ (river pH temperature) and the average river gradient of the sampled transects extracted from Geographic Information System (GIS) software. Using the stepwise variable selection process (Murtaugh. 2009) model selection was conducted with the Akaike Information Criterion (AIC) yielding most robust model with the following equation:

$$\text{Abundance}_i \sim \text{Poisson}(\mu_i)$$
$$E(\text{Abundance}_i) = \mu_i$$
$$\log(\mu_i) = \text{Intercept} + \text{Transect} + s(\text{River Name}) + (\text{Species} \times \text{Side}) + \text{Temperature} + \text{pH} + \text{Gradient}$$

An ANOVA test was used to determine the significance of the main effects in the model. If significant, post-hoc testing would be applied. This modeling approach has been successfully applied to various spatial studies on Atlantic salmon, providing insights into factors influencing abundance, migration timing, and survival (Sortland et al. 2024).

Results

Across the 24 systems surveyed, a total of 597 fish were captured and identified, representing six different species (Figure 2); Atlantic salmon were present in 13 of the surveyed systems (Figure 3), generally in substantially lower abundance in each system compared to brook trout. Atlantic salmon were the most abundant in Fiset Brook, which represented a significant outlier in the region. Species diversity was considerably low across all surveyed systems, with stickleback (*Gasterosteus aculeatus*), brown trout (*Salmo trutta*) and "Gaspereau" being seldomly caught. Anadromous spawning *Alosidae* were recorded as "Gaspereau," a name encompassing both alewife (*Alosa pseudoharengus*), and blueback herring (*Alosa aestivalis*) due to their difficulty to differentiate in-field (Brown et al. 2024). Brook trout (*Salvelinus fontinalis*) were the dominant species across both DUs (relative abundance = 62.8%) as they were present in every river surveyed.

The NMDS and corresponding perMANOVA analyses indicated that species community assemblages between DUs were not significantly different (perMANOVA; pseudo-$F_{23} = 0.951$, $p = 0.431$). Given the low species diversity of the Highlands, many systems had similar assemblages, or were comprised exclusively of brook trout. Our results indicate that despite the environmental differences between DUs (e.g. gradient), and geographic separation, the same resident fish species are ubiquitous across the Highlands (Figure 4).

Among the candidate models, the lowest AIC model included all of the parameters from the initial model; the transect number, DU, river temperature, pH, gradient and river name as a random effect,(AIC = 617.04). This model outperformed alternative models that omitted certain parameters, which had larger AIC values (AIC > 698.75), indicating that all metrics contributed to the accuracy of the model's prediction.

The model (poisson distribution) revealed a significant negative effect of transect number on abundance ($\beta = -0.1682$, $p < 0.005$; Figure 5), indicating lower abundance in upstream transects. Trout (*Salvelinus fontinalis, Salmo trutta*) exhibited significantly higher abundance than Salmon parr ($\beta = 2.3486$, $p < 0.001$; Figure 5). The effect of DU did not significantly influence the abundance of either trout species or salmon ($p = 0.0605$; Figure 5), however fish abundance was marginally higher in the Maritimes ($\beta = 0.9772$). Although we recognize a statistical significance of $p < 0.05$, it has been appreciated that p-value alone is not an all-encompassing marker of effect and further context in instances of a near-significant p-value is valuable when interpreting conclusions (Wasserstein & Lazar, 2019; e.g., Etherington et al. 2023). According to the model, the environmental metrics recorded were not significant predictors for salmon abundance. The model indicated that the effects of temperature ($p = 0.532$), pH ($p = 0.467$) and river gradient ($p = 0.527$) did not impact the likelihood of salmon residence, likely due to the low variability between sites.

Discussion

This study aimed to establish the contemporary distribution of Atlantic salmon in the Cape Breton Highlands, where previous biogeographical information was outdated and not comprehensive. This study adds new rivers to the scientific knowledge of where salmon are currently found in these relatively pristine habitats where salmon should be able to thrive

(Gibson et al. 2014). We identified four systems that held no records of salmon occupancy, as well as four systems where salmon had been previously recorded but were not present at the time of our survey. We sought to determine whether the abundance of salmon in either DU was significantly different, to either reinforce or contest the 2010 COSEWIC conservation listings of salmon in the Highlands and offer insight for a proposed designation. We found that the difference in salmon abundance between DUs was not significant, reinforcing the existing evidence for a new COSEWIC status designation (Lehnert et al. 2024). We finally set out to identify environmental predictors for salmon as well as community assemblage differences between DUs and found none. Despite the considerable variation in habitat between the two regions (DFO & MNRF. 2008), species assemblages are not different, and salmon residency cannot be predicted by basic water quality and landscape metrics in Highlands habitats.

We identified salmon populations within ECB in rivers where there have been no previously published data: MacLeods Brook, Power Brook, French River and Little River. In contrast to previous reports from ECB (Appendix Table 1; Levy & Gibson. 2014; Gibson et al. 2014; NASCO. 2022), we did not find salmon in Wilkie Brook, which was repeatedly listed as a "known salmon river" or MacAskill's Brook, where salmon had been reported in 1990 (Levy & Gibson. 2014). All other rivers surveyed were consistent with previous reports for this DU. It is likely that some of the rivers we surveyed had never been accessed with an electrofisher –Smelt Brook (46.870301N 60.398340W), Halfway Brook (46.80684N 60.34817W), MacInnis Brook (46.49656N 60.44001W)– due to their small size and remoteness in the Highlands. Although we did not find salmon in these systems, all three rivers had ample habitat for spawning and should be considered as future candidates for monitoring or restoration. It is important to note that there are several other well-known salmon rivers in the ECB DU that we did not survey and that have not been mentioned here (e.g. Clyburn Brook, Ingonish River, Indian Brook) because they have well-documented salmon populations from more recent surveys than our focal streams.

We compared our findings in the Gulf of St. Lawrence to the comprehensive report of Daigle (2023), who compiled the data from the initial investigation of Breau (2009), and all subsequent data available. None of the systems that we surveyed from Daigle (2023) had data available since 2009 (15 years). We found salmon parr in the southern branch of the Pollett's Cove river system (n = 4; Appendix Table 2a), connected to which is the Blair River. In contrast to previous reports, we did not find salmon in Red River or Mackenzie's River, where they had previously been recorded. In the Gulf of St. Lawrence DU, we surveyed three systems that we did not find any previous reference to in other publications; Ruisseau des Basiles (46.50209N 61.05819W) and Otter Brook (46.89101N 60.71745W), neither of which held salmon parr. Meat Cove Brook (47.01992N 60.56318W), which is not formally listed as a salmon river, had anecdotal evidence of a historical salmon stock that was lost after flash flooding in 2010 (CBC. 2011); we did not find any evidence that salmon have since returned. Again, we did not survey the well-known salmon rivers in this region (Margaree River, Chéticamp River, Grand Anse River).

The Cape Breton Highlands exhibit significant topographic variability between the eastern and western shores, with the eastern coast being generally characterised by higher gradient rivers (Gulf mean gradient = 1.00°; ECB mean gradient = 1.74°) and steeper cliffs descending towards the ocean (Lehnert et al. 2024). Given these geomorphological differences, we assumed that species assemblages would differ between designatable units, in both anadromous and resident fish. However, our NMDS analysis found that community assemblages were similar between DUs, despite the substantial differences in river gradients, suggesting that most highland species are broadly distributed throughout the region (Figure 4). This finding is likely attributable to the inherently low species diversity within the Highlands, where only a limited number of specialists are adapted to the riverine environment. Additionally, our study did not encompass non-riverine habitats such as wetlands and ponds, where more generalist species occur, which could have added more regionally-specific differentiation between species.

Our model incorporated various landscape metrics to assess the utility of specific environmental characteristics for predicting salmon residence. The model revealed that none of the variables that we incorporated were significant, indicating that the variability in pH, temperature and gradient between rivers is not high enough to sufficiently indicate areas preferred by salmon. A larger study area incorporating more systems may have added higher resolution to our model, as we operated at a relatively small spatial scale, where environmental patterns were somewhat consistent across the region. Future efforts to refine predictive models for salmon residence in the Highlands should incorporate additional habitat variables, such as current velocity, depth, and substrate composition, to enhance model reliability (Jelovica et al. 2024).

In 2010, COSEWIC bisected the Cape Breton Highlands, with Salmon River (46.99881N 60.49492W) delineating the boundary between the two DUs (COSEWIC. 2010). Despite the habitat differences between the eastern and western coastlines of the Highlands, genetic distinctions between salmon populations in the Gulf of St. Lawrence and ECB DUs were not identified, suggesting that these salmon may belong to the same population (Moore et al. 2014). Life history data further indicate that ECB salmon populations share similarities with those in the southern Gulf, with smolts predominantly aged two or three years, contrasting with the older smolts in the adjacent Gaspé DU (Daigle. 2023; Douglas et al. 2023). ECB and southern Gulf populations also exhibit a higher proportion of multi-sea-winter fish compared to the Southern Upland populations; these similarities suggest a comparable generation time for both Highlands DUs. (Daigle 2023; Douglas et al. 2023). Based on these data it has been proposed that part of the Gulf of St. Lawrence unit should be merged with the ECB DU, forming the new Southern Gulf of St. Lawrence-Cape Breton DU (Lehnert et al. 2024). According to the current COSEWIC listing, the conservation statuses for salmon in the two DUs are “Special Concern” and “Endangered” for the Gulf and ECB units respectively (COSEWIC. 2010). Our data aligns with the literature that has been produced since the last conservation status designations in these DUs, indicating that the distribution and abundance of salmon between these two regions are not in fact different. Our findings substantiate the newly proposed merger of the southern Gulf and ECB DUs, and support the notion that this listing better represents the ecological, evolutionary and conservation statuses of the salmon populations in this region.

We recorded multiple instances of large salmon parr inhabiting rivers in low abundance, potentially representing instances of precocious parr. (e.g. Salmon River: n = 1, length = 19cm; Polletts Cove River: n = 4, average length = 16.25cm; Appendix Tables 2a, b). These systems were not characterised by an otherwise low abundance of other species, suggesting that nutrient availability was not the limiting factor for salmon abundance. We therefore suggest that these rivers were occupied by small populations of precocious parr, which opportunistically remain year-around in freshwater to fertilize a very low number of annually returning females, or perhaps females who have strayed from their natal rivers (Thorpe 1994). Previous studies have indicated that these morphologically juvenile but sexually mature salmon exert a substantial influence in the overall paternal pool, siring up to 60% of the population (Saura et al. 2008). The inclusion of precocious parr in rivers has been suggested to increase effective population size to some extent, whether negligible (Jones & Hutchings. 2002) or substantial (two-to threefold; Saura et al. 2008) by reducing the variance in male reproductive success (Saura et al. 2008). Although it has been demonstrated that anadromous males exhibit higher individual reproductive success than precocious parr (Hutchings & Myers. 1998; Jones & Hutchings. 2002), instances where at least six precocious parr fertilize one redd have been documented (Morán & Garcıá-Vázquez. 1998), mitigating the risk of inbreeding, which is especially high in small populations. Further, in the absence or exhaustion of anadromous males, precocious parr gametes are able to fertilize up to 80% of a redd (Morán et al. 1996). Despite their low abundance in some Highlands rivers, these precocious parr may be key to the river's legacy by increasing genetic diversity and acting as safeguards if male anadromous salmon do not return to spawn.

Fiset Brook represented a notable outlier in this study, with a significantly higher abundance of salmon than any other river surveyed (n = 53, other rivers mean = 6.5; Appendix Tables 2a, b). Not only was the habitat in Fiset Brook marginal compared to systems elsewhere in the Highlands where salmon were vacant, but it was also likely subject to higher anthropogenic influence, given that it ran through the town of Chéticamp. Fiset Brook was the only system that we surveyed with resident brown trout, factoring an additional degree of competition for juvenile salmon (Van Zwol et al. 2012). Brown trout have been present in the Gulf DU since the early 1900s, although there are no previous records of brown trout occupying Fiset Brook or any of its neighboring systems (Daigle. 2023). However, the impact of brown trout on Atlantic salmon in the gulf region is considered low (Breau et al. 2009). The region surrounding Fiset brook had no evident source of terrestrial farmland, the runoff of which is capable of bolstering an eutrophic system which could boost system productivity and therefore salmon abundance (Bernthal et al. 2022). We therefore infer that this system supported a high rate of juvenile survival, which may vary year by year. Future surveying is necessary to substantiate this hypothesis.

Limitations to the electrofishing survey technique used in this study are accounted for by both the technology itself and the hydromorphological complexity of the region. Many Highlands rivers contain deep pools and channels that were inaccessible with the electrofisher due to its limited electrical output. Additionally, deadfall and debris presented a challenge, both by providing refuge for evasive fish and by disrupting the electrical field of the electrofisher. These factors may have influenced species detection and relative abundance estimates, as has been observed in previous studies (e.g. Meador et al. 2003). This study adopted a distinct methodological approach compared to prior assessments in the Highlands, incorporating more sampled rivers and describing both DUs in the Highlands. In comparison, previous electrofishing efforts in the ECB unit encompassed eight rivers with 2–6 sites (1998–2002; Robichaud-LeBlanc & Amiro. 2004), 11 rivers with 1–5 sites (2006–2007; Bowlby & Gibson, 2009), and, most recently, eight rivers with three sites (2016; Taylor et al. 2024). Our approach of sampling as many rivers within our means as possible enabled us to sample systems between DUs and ones that had not previously been explored.

Conclusion

Owing to the remoteness and topographical complexity of the Cape Breton Highlands, comprehensive characterization of the region remains challenging. Consequently, few studies have attempted a broad-scale assessment of multiple rivers within a single investigation, with Breau (2009) being a notable exception. Instead, both the ECB and Gulf of St. Lawrence DUs are typically represented by a subset of index rivers which have known salmon populations that are repeatedly surveyed for health and abundance trends that are used for reference for the rest of the DU. In the ECB unit, these rivers are the Middle, North, Grand, Miramachie and Clyburn systems and in the Gulf they are the The Margaree, West Antigonish, East Pictou, and River Philip (Taylor et al. 2024; Daigle. 2023). Only one of each of these index systems is in each DU of the Highlands (Gulf; Margaree, ECB; Cylburn), meaning that for the most part, the status of the region continues to lack description. We suggest that this framework does not permit a thorough understanding of the status of the entire DU, nor does it account for smaller populations if they become extirpated. As remarked by Taylor (2024), the distribution of Atlantic salmon varies temporally depending on environmental factors, which can impact annual occupancy. We emphasise that ongoing monitoring in an increased subset of systems in the newly proposed DU is necessary to understand the status of the population as marine and freshwater conditions continue to change (Lehnert et al. 2023). It is our hope that this study shed light on the distribution and abundance of salmon in the Cape Breton Highlands, and that our data is insightful to managers considering the re-designation of the Gulf and ECB DUs. Future studies should incorporate environmental DNA sampling to complement and enhance the accuracy of electrofishing data, to further confirm the presence or absence of salmon in each river. Given that some Highlands systems are difficult to survey using traditional electrofishing techniques, environmental DNA sampling holds potential to assess the far upstream reaches of many systems (Penaluna et al. 2024), adding further precision to our assessment of this region.

Acknowledgments

We would like to thank Parks Canada for their equipment contributions and local expertise, as well as Emma Cooke, Hugo Flávio and Alex Bevilacqua for their invaluable feedback and analytical support. This research was made possible by the generous contributions from the Nova Scotia Freshwater Fisheries Research Commission, and the Nancy Witherspoon research award.

Conflict of Interest State
The authors have no conflicts to disclose.

Data Statement
The data will be supplied upon reasonable request.

Author Contributions Statement
O.D.P.N.G: Conceptualization, methodology, formal analysis, investigation, data curation, visualisation, original draft; J.R: Conceptualization, investigation, review and editing; K.O: Resources; M.L.P: Investigation, data curation, review and editing, visualization, supervision; R.J.L: Conceptualization, methodology, investigation, visualisation, supervision, project administration, funding acquisition. O.D.P.N.G wrote the paper, which received input from all co-authors.

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Tables

Table 1 2024 survey results compared to previous reports from Daigle (2023), Levy & Gibson (2014), and unpublished Parks Canada data. (P) indicates salmon rivers where salmon were present, (A) indicates salmon absence and (.) represent rivers where data was not available.

River	**2024**	**Previous Reports**
Ruisseau des Basile	A	.
Farm Brook	P	P
Fiset Brook	P	P
Corney Brook	A	A
MacKenzies River	A	P
Red River	A	P
Otter Brook	A	.
Polletts's Cove River	P	P
Meat Cove Brook	A	.
Salmon River	P	P
Wilkie Brook	A	P
Middle Aspy River	P	P
South Aspy River	P	P
Glasgow Brook	P	P
Smelt Brook	A	.
Halfway Brook	A	A
Dundas Brook	P	P
Power Brook	P	.
MacLeods Brook	P	.
MacInnis Brook	A	.
French River	P	.
Little River	P	.

MacAskill Brook	A	P
Barrachois River	P	P

Table 2(a) Number of each species captured at each site with an electrofisher in June 2024 in the Gulf of St. Lawrence Designatable Unit

DU	River	Coordinates	Date	Species	Abundance
Gulf	Ruisseau des Basile	46.50209N 61.05819W	2024-06-18	Brook trout	44
Gulf	Farm Brook	46.58525N 60.02165W	2024-06-16	American eel	1
				Brook trout	12
				Salmon parr	12
Gulf	Fiset Brook	46.60222N 61.00599W	2024-06-16	Brook trout	7
				Brown trout	23
				Salmon parr	53
				Threespine stickleback	1
Gulf	Corney Brook	46.72528N 60.92568W	2024-06-08	American eel	2
				Brook trout	23
Gulf	MacKenzies River	46.82120N 60.82846W	2024-06-08	Brook trout	8
				Gaspereau	1
Gulf	Red River	46.84920N 60.76685W	2024-06-18	American eel	1
				Brook trout	16
Gulf	Otter Brook	46.89101N 60.71745W	2024-06-22	Brook trout	26
Gulf	Polletts Cove River	46.91151N 60.69161W	2024-06-22	American eel	2
				Brook trout	14
				Salmon parr	4
Gulf	Meat Cove Brook	47.01992N 60.56318W	2024-06-15	American eel	2
				Brook trout	25
Gulf	Salmon River	46.99881N 60.49492W	2024-06-15	American eel	2
				Brook trout	10
				Salmon parr	1

Table 2(b) Number of each species captured at each site with an electrofisher in June 2024 in the Eastern Cape Breton Designatable Unit

DU	River	Coordinates	Date	Species	Abundance
ECB	Wilkie Brook	46.94310N 60.46703W	2024-06-09	Brook trout	20
ECB	Middle Aspy River	46.88321N 60.48964W	2024-06-07	American eel	17
				Brook trout	2
				Salmon parr	13
ECB	South Aspy River	46.87201N 60.50145W	2024-06-07	Brook trout	3
				Salmon parr	7
ECB	Glasgow Brook	46.867510N 60.468957W	2024-06-09	American eel	1
				Brook trout	5
				Gaspereau	1
				Salmon parr	13
ECB	Smelt Brook	46.870301N 60.398340W	2024-06-09	American eel	1
				Brook trout	12
ECB	Halfway Brook	46.80684N 60.34817W	2024-06-11	Brook trout	1
ECB	Dundas Brook	46.68975N 60.40243W	2024-06-11	American eel	22
				Brook trout	10
				Salmon parr	8
ECB	Power Brook	46.631937N 60.439668W	2024-06-08	Brook trout	7
				Salmon parr	6
ECB	MacLeods Brook	46.560042N 60.403996W	2024-06-08	American eel	1
				Brook trout	13
				Salmon parr	7
ECB	MacInnis Brook	46.49656N 60.44001W	2024-06-06	Brook trout	21
ECB	French River	46.48767N 60.44945W	2024-06-06	American eel	1
				Brook trout	19
				Salmon parr	3
ECB	Little River	46.43859N 60.47049W	2024-06-05	American eel	2
				Brook trout	13
				Salmon parr	2
ECB	MacAskill Brook	46.40259N 60.48431W	2024-06-05	American eel	2
				Brook trout	59
ECB	Barachois River	46.34991N 60.55472W	2024-06-04	American eel	6
				Brook trout	5
				Salmon parr	2

Figures

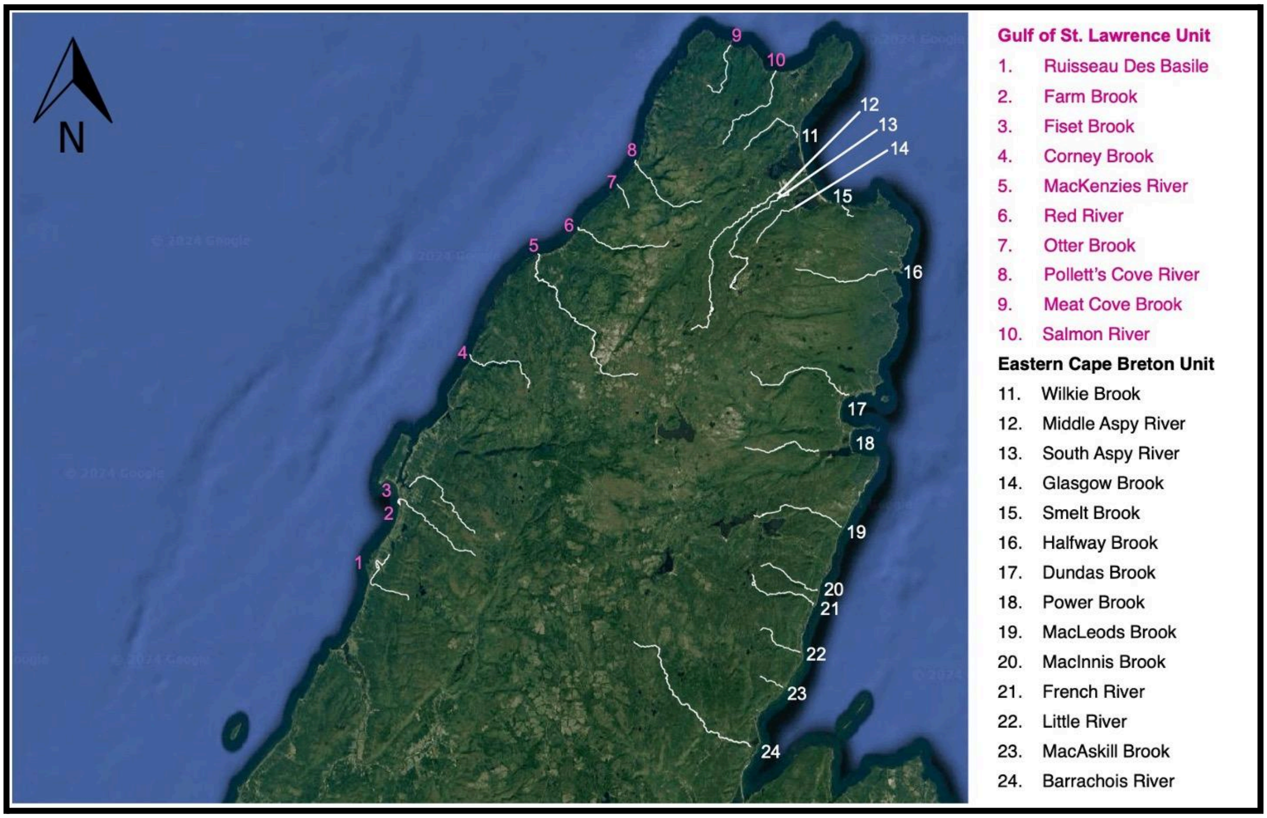

Figure 1 Map of the Cape Breton Highlands including all of the rivers surveyed in June 2024, highlighted in white. The associated legend indicates the Designatable Unit in which each river belongs.

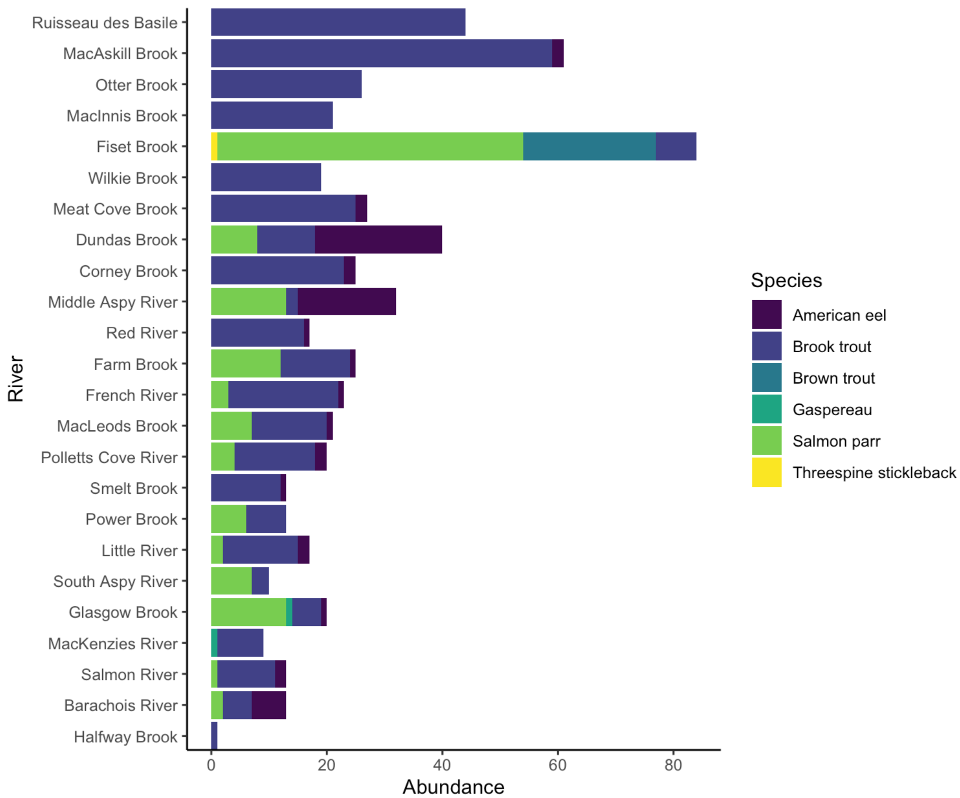

Figure 2 Species composition and abundance of each system surveyed by backpack electrofisher in June 2024 in the Gulf of St. Lawrence and Eastern Cape Breton Designatable Units of the Cape Breton Highlands.

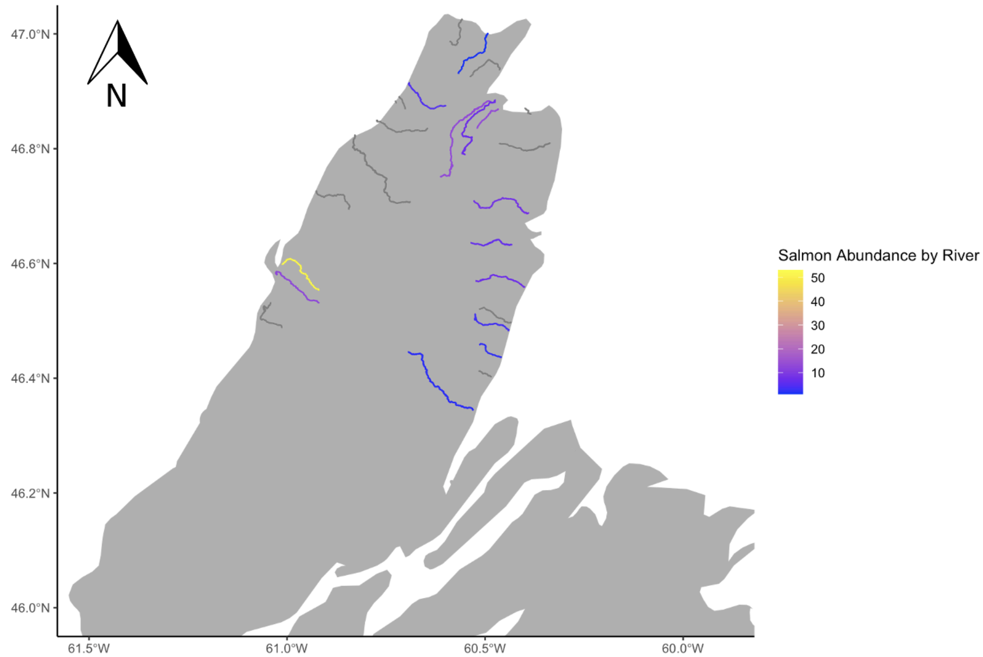

Figure 3 Outline of the Cape Breton Highlands with each system surveyed in June 2024. The associated legend designates the abundance of salmon in each system. Grey rivers indicate survey sites where Atlantic salmon were absent.

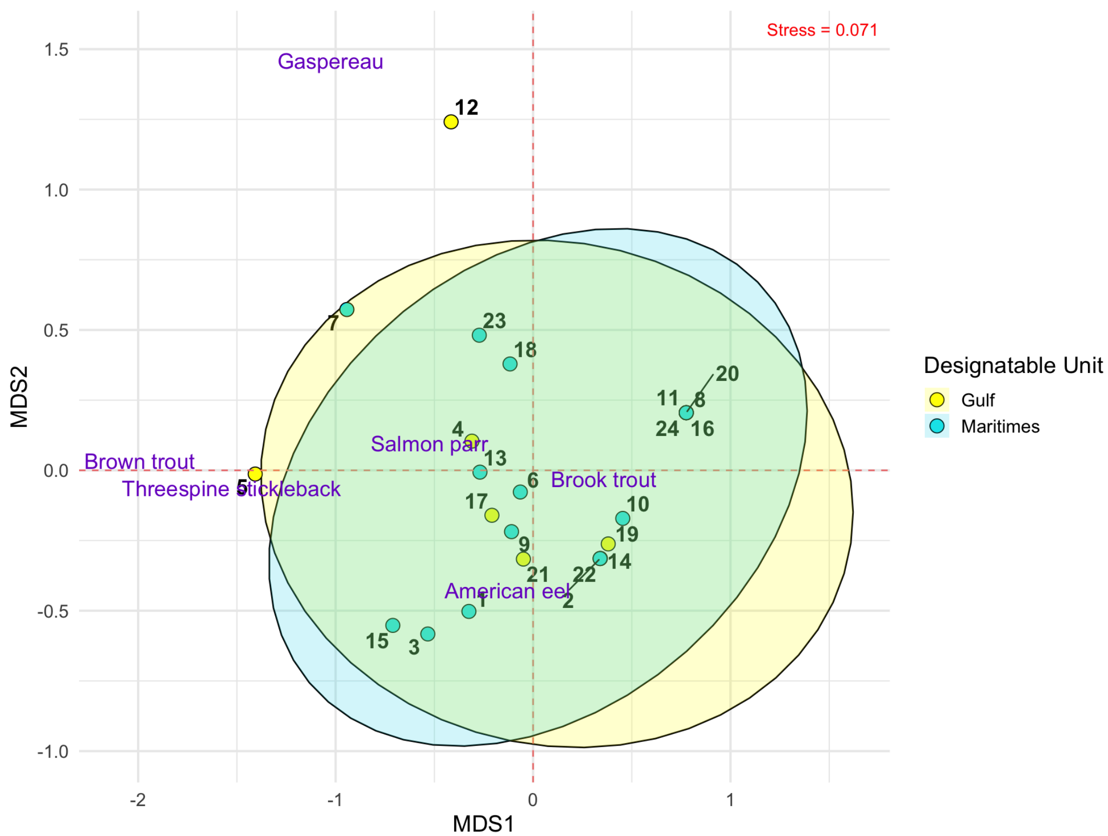

Figure 4 NMDS plot representing species assemblages and relative abundance in each surveyed system. Ellipses depict both the Gulf of St. Lawrence and Eastern Cape Breton Designatable Units at a 95% confidence interval. *1 -Barachois River, 2 -Corney Brook, 3 -Dundas Brook, 4 -Farm Brook, 5 -Fiset Brook, 6 -French River, 7 -Glasgow Brook, 8 -Halfway Brook, 9 -Little River, 10 -MacAskill Brook, 11 -Macinnis Brook, 12 -MacKenzies River, 13 -MacLeods Brook, 14 -Meat Cove Brook, 15 -Middle Aspy River, 16 -Otter Brook, 17 -Polletts Cove River, 18 -Power Brook, 19 -Red River, 20 -Ruisseau des Basile, 21 -Salmon River, 22 -Smelt Brook, 23 -South Aspy River, 24 -Wilkie Brook.*

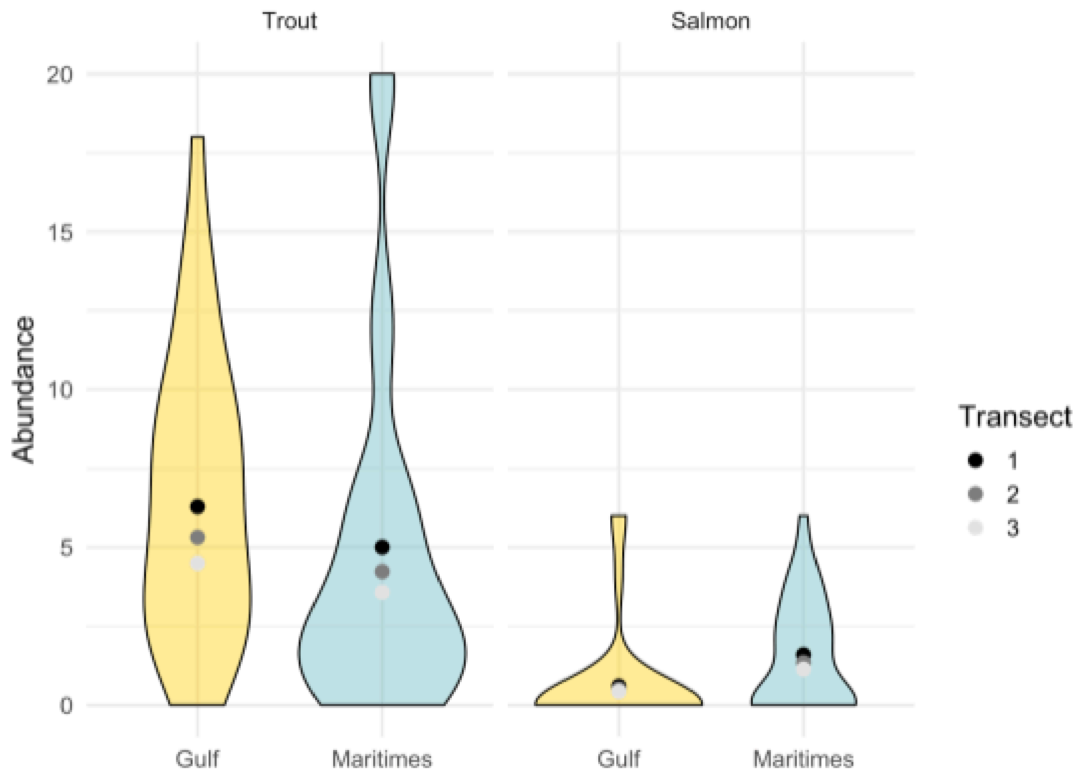

Figure 5 Generalized additive model (poisson distribution) of the predicted abundance of Atlantic salmon (*Salmo salar*) and trout (*Salvelinus fontinalis, Salmo trutta*) for each transect of the Gulf of St. Lawrence and Eastern Cape Breton Designatable Units of the Cape Breton Highlands.