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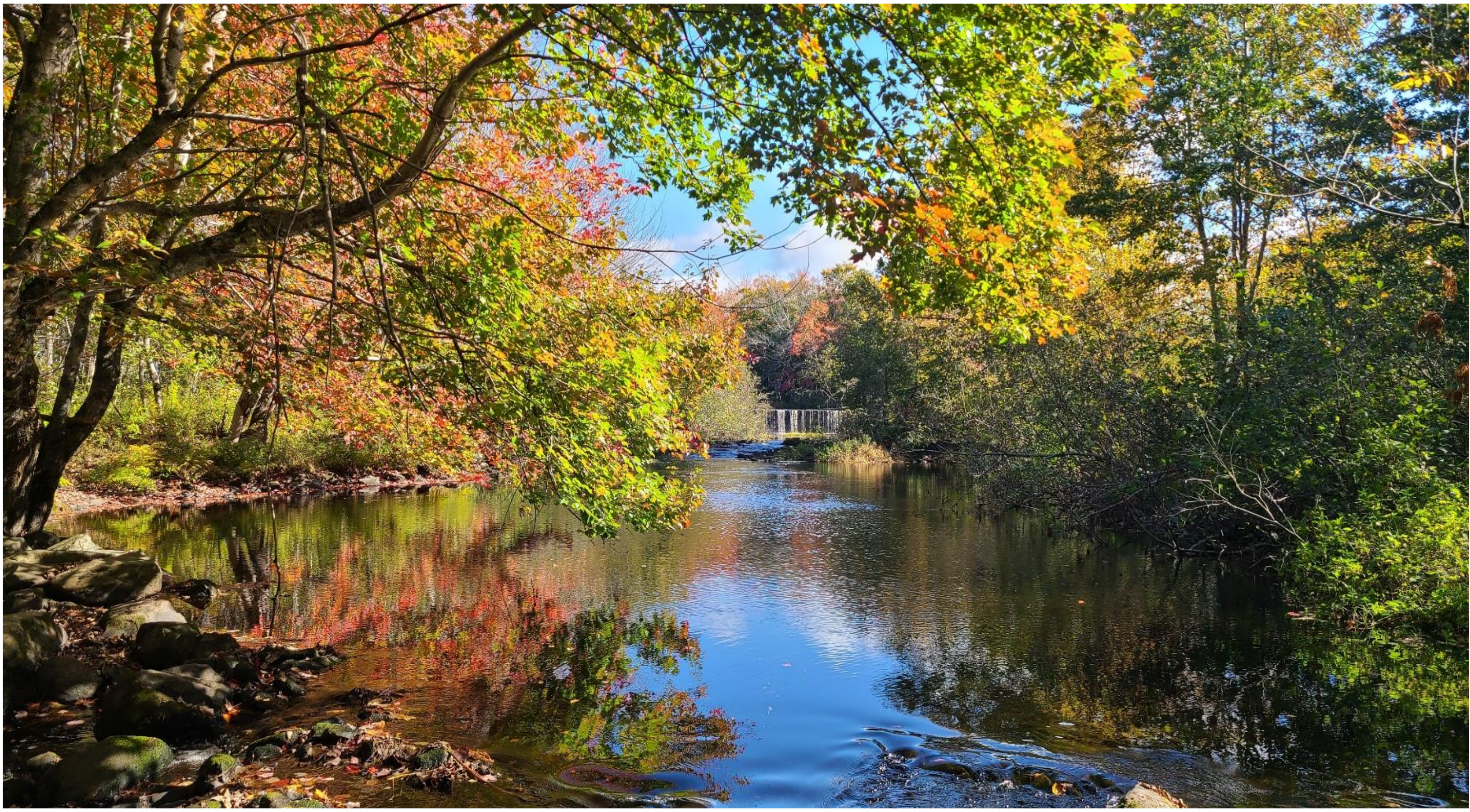

Evaluating river significance for wild Atlantic salmon (*Salmo salar*) in Nova Scotia

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Table of Contents

1 Introduction

1.1 Status of wild Atlantic salmon in Nova Scotia

Across Atlantic Canada, wild Atlantic salmon (*Salmo salar*) populations have declined, and recovery has been challenging. Continued efforts to maintain healthy ecosystems and re-establish wild populations are priorities under *Canada's Wild Atlantic Salmon Conservation Policy* (Fisheries and Oceans Canada, 2018), which recognizes the multiple threats facing the survival and restoration of wild populations in Eastern Canada. While the mechanisms driving population declines are not fully understood, multiple threats exist across the marine and freshwater stages of the wild salmon lifecycle. These threats include, but are not limited to: changes in freshwater habitat from damming or industrial development (Clarke et al., 2014), fishing mortality, including illegal fishing (Dempson et al., 2004; Dadswell et al., 2021), acidification (Gibson et al., 2011), climate change-related impacts on survival (Mills et al., 2013), and potential negative interactions with farmed salmon (Keyser et al., 2018).

1.2 The importance of rivers for wild salmon

Freshwater rivers serve as the primary habitat for the crucial life reproductive processes, such as spawning and juvenile rearing. Monitoring rivers can provide insights into habitat health, population abundance, and potential threats; supporting targeted conservation and management efforts. River-specific information can also inform sustainable development planning in areas near river ecosystems, to help guide effective mitigation or management measures to preserve wild Atlantic salmon populations.

Despite the recognized importance of evaluating and monitoring salmon rivers, what constitutes a 'wild salmon river' is not clearly defined. There is no widely accepted definition of a 'wild salmon river' and this, in part, may explain the inconsistency in the location and number of wild salmon rivers identified for Nova Scotia. Only a handful of over two hundred rivers in Nova Scotia are monitored with established and consistent monitoring programs in place, with many rivers that historically sustained wild salmon populations now assumed to be extirpated. Providing a consistent measure of the status and definition of a wild salmon river is technically challenging, complicated by a lack of empirical data for many rivers, reliance on historical or potentially outdated data, and variable methodologies and metrics for assessment. These definitions are further complicated by the various factors that make a river significant for wild Atlantic salmon, particularly considering future potential recovery and wider conservation goals.

1.3 What makes rivers significant for wild salmon?

Rivers are significant ecosystems to support Atlantic salmon populations. When using rivers to understand and prioritize efforts for conservation and research, a river's significance can refer to its overall importance, value, or relevance within a wider ecological, cultural, and socio-economic context. In the context of informing the sustainability of wild Atlantic salmon, we define significance as the role of the river in supporting the long-term viability of salmon populations and the broader sustainability goals associated with their conservation and management. Some rivers, such as the Margaree River may be significant as it is known to have a relatively healthy population of returning salmonids. Alternatively, rivers such as the LaHave River, may be significant as a DFO-recognized Index River that is critical for understanding the larger presence of salmon in an area. Similarly, rivers such as the Stewiacke River may be significant as it is an Inner Bay of Fundy River, which is protected under the Species at Risk Act. Significance is thus a complex, multi-faceted concept that is reflective and embodies the multi-criteria approach of the framework.

1.4 Objectives

The overall goal of this research was to assess the significance of rivers for wild Atlantic salmon in Nova Scotia. The objectives of this project were to:

- Develop an assessment framework to evaluate the significance of wild Atlantic salmon rivers in Nova Scotia; and
- Collate diverse available data and information on salmon population and habitat monitoring across the province

2 Methods

2.1 General approach / framework

To assess the significance of rivers for wild Atlantic salmon populations across Nova Scotia, this project developed and applied a **River Significance Index (SI Index)**. The SI Index is a composite metric designed to integrate multiple criteria relevant to the evaluation of significance for wild Atlantic salmon into a single semi-quantitative assessment framework. This semi-quantitative assessment framework will combine an evidence-based scoring of criteria indicators with quantitative methods of aggregation, providing a numeric metric to classify and compare rivers. The outputs of the SI Index are categorized into broad river significance ratings, identifying rivers with either low significance, medium significance, or high significance. To acknowledge data gaps and uncertainties, some rivers may also remain unclassified.

The SI index was developed as a general framework (**Figure 1**) to provide a standardized and replicable approach for evaluating the relative significance of rivers in supporting the long-term viability of wild Atlantic salmon populations. The SI Index builds off data collected across a set of carefully selected criteria and indicators to evaluate the significance of wild salmon rivers. Data collection for the framework will involve compiling and combining information from multiple sources into a comprehensive Data Inventory that compiles data from various sources such as scientific literature, monitoring and evaluation efforts, and government and community-led research activities.

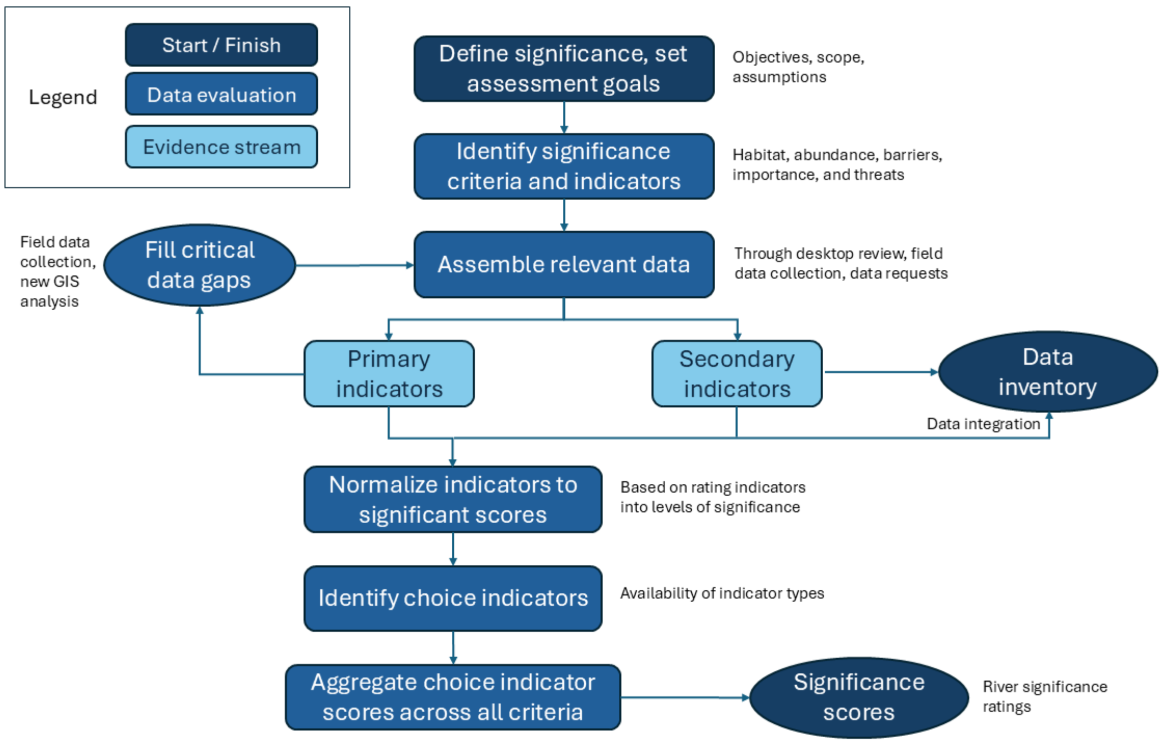

Figure 1. Framework for the assessment and scoring of river significance for Atlantic salmon in Nova Scotia.

The assessment framework was developed through an evidence-based process, drawing from key scientific literature and expert advice. The development of the overall framework for assessment, including the selection of significance criteria was informed through consultation with experts convened as part of the Government of Nova Scotia's aquaculture Coastal Classification System (CCS)[1]. Experts also provided advice throughout the framework's application, including the selection and scoring of indicators and review of final project outputs.

[1] For more information about the CCS and the involvement of experts and Data Committees, visit https://novascotia.ca/aquaculture-coastal-classification-system/

2.2 Study area and river selection

To provide a province-wide assessment of the significance of rivers to wild Atlantic salmon, this study evaluated 287 identified rivers across Nova Scotia (**Figure 2**). Rivers sampled in this study span all four COSEWIC-recognized Designatable Units (DU) within the province and represent diverse geographic regions, ensuring representation of the full suite of habitat conditions, anthropogenic pressures, and recovery priorities present within Nova Scotia's wild salmon populations.

Here, a "river" was identified by pour points – the location where a river system discharges into the coastal environment. Here, we focus on the pour points of river systems, since they are critical junctures, often serving as key migratory routes for salmon. While recognizing that river systems often consist of interconnected streams, tributaries, and lakes within nested watersheds, our analysis is centered on individual rivers as distinct units. Data from both watershed-scale assessments and specific point data within a river's catchment (that includes connected tributaries and streams) was included in the assessment. To ensure consistency and recognizability, rivers were identified and referenced by their commonly used names.

The rivers included were inclusive of previously recognized rivers, such as designated Index Rivers[2] (e.g. The LaHave River, and Margaree River), and major named rivers with a coastal pour point (e.g. Little Bass River and Glasgow Brook).

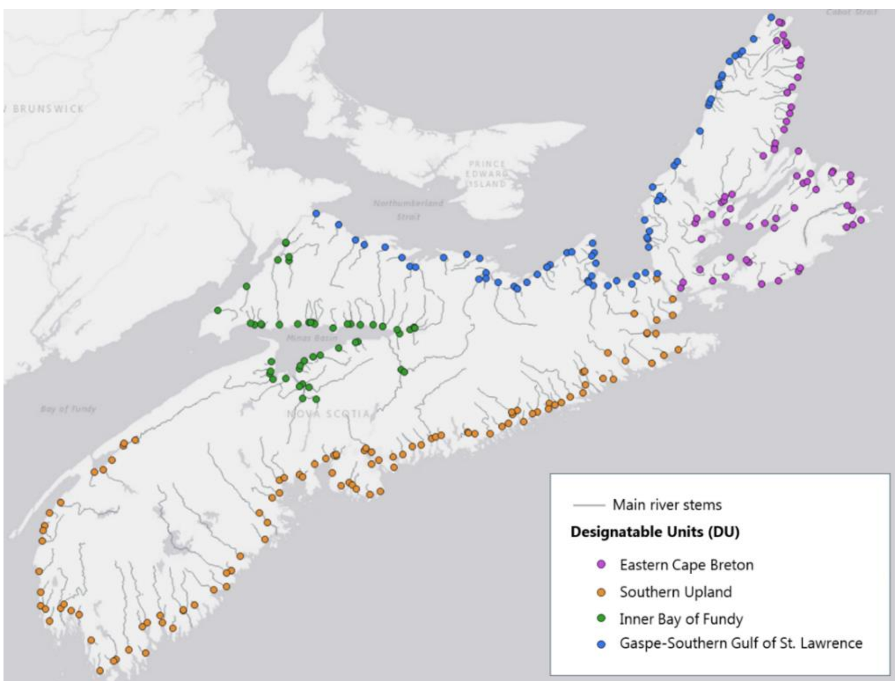

Figure 2. Map of the 287 rivers to be included in the wild Atlantic salmon river assessment, categorized by Designatable Units (DU). Rivers are marked at the river mouth.

[2] DFO regularly monitors Index rivers to asses the status of Atlantic salmon stocks, to be roughly indicative of regional trends (Amiro, 2000) .

2.3 Significance criteria and factors

The significance of rivers for wild Atlantic salmon in Nova Scotia was evaluated based on scoring and combining five overarching significance criteria - collectively referred to by the acronym HABIT - which capture key dimensions of river significance: Habitat (habitat quality), Abundance (population abundance), Barriers (freshwater connectivity), Importance (conservation value), and Threats (existing stressors) (**Figure 3**).

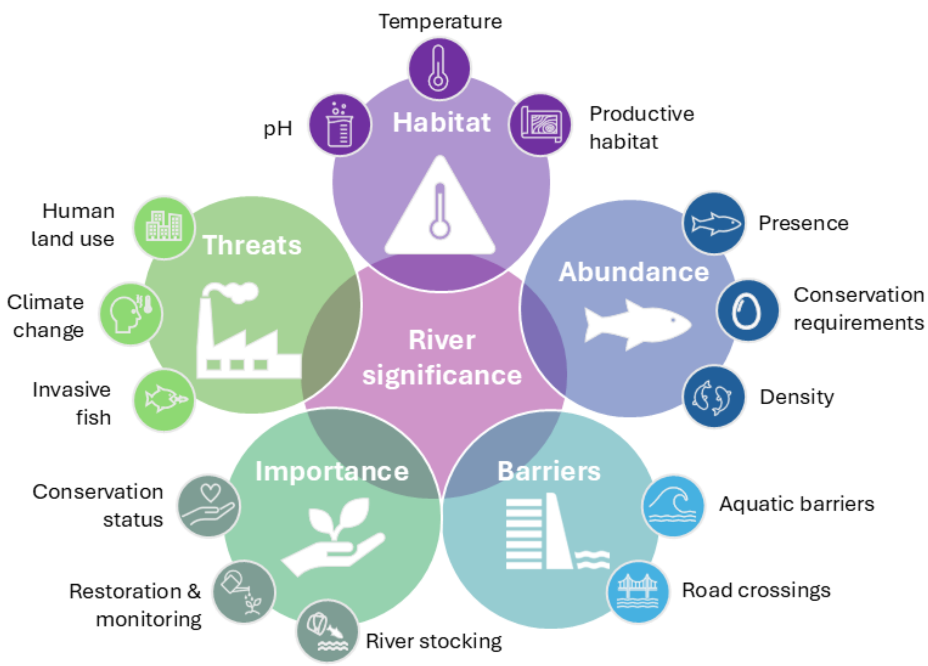

Figure 3. Calculation of river significance for wild Atlantic Salmon, based on an assessment of five criteria: Habitat, Abundance, Barriers, Importance, and Threats, and their respective factors.

Each HABIT criterion is subdivided into several factors that represent major considerations used to evaluate the significance of each criterion (**Table 1**). The selected factors do not represent a comprehensive, exhaustive list of all potential factors relevant to understanding each criterion but aim to identify the critical considerations that can be used to indicate general significance of the criteria at a whole-river level. For example, other Habitat factors are often used to assess habitat quality for Atlantic salmon. Furthermore, other aspects of importance are recognized, such as the socio-cultural importance rivers have for communities and Indigenous Peoples. These types of factors are important to understanding the river's overall significance at a local scale but were beyond the scope of this assessment.

Table 1. Description of significance criteria, their relevance to the assessment of significance, and their associated factors.

Criteria	Definition	Significance	Factors	Definition
Habitat	The quality and availability of salmon aquatic and riparian habitat, which are essential for supporting all life stages of salmon.	Favourable habitat characteristics may support salmon growth and population recovery.	pH	The acidity and alkalinity of water, which influence the quality of aquatic habitats for salmon.
			Temperature	The thermal conditions of aquatic habitat, which influences metabolic rates, oxygen availability, and survival of salmon.
			Productive rearing habitat	The availability of productive freshwater habitats that are essential to supporting key life stages for salmon.
Abundance	The abundance of populations in rivers is suggestive of overall health and reproductive success of populations.	Rivers with very low population sizes face more challenges for recovery and are more vulnerable to additional stressors.	Conservation requirement	The extent to which salmon populations are meeting the necessary egg deposition levels required to sustain populations.
			Density	Density estimates (number of salmon per area), which may indicate reproductive success and recruitment potential.
			Presence	Overall presence or absence of Atlantic salmon detected in a river system, which can provide foundational information on reported abundance of salmon.
Barriers	Physical barriers such as dams, culverts, and other obstacles that can impede salmon migration and access to habitats, potentially affecting population connectivity.	Rivers with low number of barriers and higher connectivity can support salmon populations.	Aquatic barriers	Physical barriers that can impede salmon migration and access to habitats, potentially affecting population connectivity.
			Watercourse crossings	Locations where roads intersect with streams or rivers, typically culverts or bridges that can act as a barrier to fish movement.
Importance	Salmon rivers have significance based on their contribution to meeting conservation goals.	River identified as priorities for monitoring and/or recovery contribute to conservation goals for wild salmon.	Conservation Status	Formal classifications assigned to a population based on their risk of extinction or extirpation, as recognized under legislation or designated by scientific bodies.
			Restoration and monitoring	Evidence of targeted actions aimed at improving habitat quality, connectivity, or population health, such as barrier removals or liming.
			River stocking	Evidence of river stocking efforts (i.e., releasing hatchery-raised fish into a river system) which can provide indication of the river's significance for wild salmon conservation.

Criteria	Definition	Significance	Factors	Definition
Threats	Various human activities and industries may introduce additional stressors to salmon populations and their habitats.	Avoid introduction of additional stressors to rivers with high levels of existing threats.	Human land use	The modification of natural landscapes for purposes such as agriculture, forestry, urban development, and infrastructure, which can impose additional stressors to salmon populations and their habitats.
			Climate change	Climate change may introduce additional stressors to salmon populations and habitats directly through habitat alterations and indirectly by altering ecosystem function.
			Aquatic Invasive Species (AIS)	The presence of AIS, which can pose additional stressors to salmon by reducing the availability of essential resources and increasing predation of salmon populations.

2.3.1 Habitat

The quality and availability of aquatic and riparian habitat are essential for supporting all life stages of Atlantic salmon, and physical and chemical habitat characteristics can significantly influence the population success of wild Atlantic salmon (Amiro, 2006). Elevated water temperatures and alterations to the availability and access to thermal refuges[3], resulting from climate change and disruptions in forest cover shading, can lead to physiological stress and alteration of behaviour (Breau et al., 2011; Millar et al., 2019a). Wild salmon are sensitive to elevated temperatures, showing metabolic stress and behavioral alteration when waters warm to 22-24°C, and have limited tolerance of temperatures above 28°C (Elliott, 1991; Breau et al., 2011). From a chemical standpoint, habitat quality can also be impacted by acidification (lowered pH) in freshwater ecosystems. Acidification is a stressor for wild Atlantic salmon, which are sensitive to pH levels below 5.3 (Amiro, 2006), with mean annual pH levels below 5.0 considered insufficient for maintaining salmon populations (Watt et al., 1983). River habitat quality can also be influenced by the availability and accessibility of productive freshwater habitats that are essential to supporting key life stages for wild Atlantic salmon, including spawning and rearing. These habitats provide essential conditions like clear, cold, fast-moving water with a gravel bottom for spawning and rocky areas for juvenile fish (Fisheries and Oceans Canada, 2018a).

2.3.2 Abundance

Abundance and population metrics are critical to the assessment of the health and sustainability of wild salmon ecosystems. Various metrics are employed to assess wild salmon population abundance, including specific conservation-based metrics such as Conservation Egg Requirements (Fisheries and Oceans Canada, 2017). These metrics, along with data on juvenile survival, adult abundance relative to reference levels, and adult returns, offer critical insights into the resilience and reproductive success of wild salmon populations (Lacroix, 1989; Fisheries and Oceans Canada, 2017; Atlantic Salmon Federation, 2019). Salmon populations with low abundance metrics are particularly vulnerable (Milner and de Leaniz, 2023). Smaller populations are suggested to be less stable as they often have reduced genetic diversity, fewer age classes, and a lower intrinsic growth rate, resulting in increased susceptibility to environmental changes and local extinctions (Einum et al., 2003; Moore et al., 2010; Milner and de Leaniz, 2023).

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[3] Thermal refuges can be described as patches of colder water within the river which provide thermal relief for salmon during times of elevated temperatures.

2.3.3 Barriers

Human developments can lead to the introduction of various river obstructions, including dams, culverts, or watercourse crossings. River obstructions without functional fish passageways can result in the loss of connectivity within the freshwater ecosystem, thus impeding migration and access to important habitat throughout the system. Dams and other aquatic barriers are a major threat to freshwater biodiversity, impacting sedimentation, flow, temperature regimes, and habitat connectivity (Angermeier et al., 2004; Fielding, 2011; Liermann et al., 2012; Millar et al., 2019a). By physically blocking the river, barriers can alter the flow regime of a river and sediment transport patterns, potentially leading to habitat changes both upstream and downstream (Bednarek, 2001; Graf, 2006). Furthermore, road crossings can also impact the freshwater habitat of Atlantic salmon, potentially acting as a barrier to fish movement, leading to habitat fragmentation and impeding salmon access to important habitat (Angermeier et al., 2004; Fielding, 2011; Bowlby et al., 2013b; Millar et al., 2019).

2.3.4 Importance

Salmon rivers have significance based on their contribution to meeting wider conservation goals connected to wild Atlantic salmon. The conservation status, as determined by the regulatory mechanisms, like the *Species at Risk Act* and other bodies such as The Committee on the Status of Endangered Wildlife in Canada (COSEWIC), can indicate the direct recognition of rivers for broader conservation. Furthermore, Research, monitoring, and conservation efforts in Nova Scotia’s salmon rivers are extensive and diverse, involving various individuals and organizations including, government, Indigenous groups, universities, and conservation organizations. These efforts, which have ranged widely in scale, include but are not limited to habitat identification and restoration, population monitoring, and stocking efforts (Fisheries and Oceans Canada, 2010; Daigle, 2023; Nova Scotia Salmon Association, n.d.). Rivers identified as important for conservation purposes (including research, monitoring, and stocking) are likely more significant in achieving sustainability goals, as their recognition may lead to their prioritization for restoration or conservation efforts.

2.3.5 Threats

Nova Scotia's wild salmon populations currently face a myriad of threats that pose significant challenges to their survival and proliferation (Dadswell et al., 2021). Many stressors to salmon habitat come from nearby human development and land use, including industrial and agricultural activities both on land and in adjacent coastal areas. Increased sedimentation to rivers from forestry, agriculture, vehicle travel, or damming activities can influence river water quality and spawning habitat (Soulsby et al., 2001) and may lead to physiological and behavioural changes in many fish species, including Atlantic salmon (Robertson et al., 2007; Kjelland et al., 2015). Freshwater contaminants from intensive industrial development or runoff from agriculture and forestry can also have damaging impacts on Atlantic salmon by causing eutrophication and reduced oxygen concentrations (Rosseland and Kroglund, 2011). The introduction and spread of non-native (i.e., invasive) species can also have dramatic and damaging effects on ecosystem structure and function (Mitchell et al., 2010; Feener, 2017; Government of Nova Scotia, 2017; Walsh, 2022). In Nova Scotia's freshwater ecosystems, smallmouth bass (*Micropterus dolomieu*) and chain pickerel (*Esox niger*), are both highly predatory and can compete for habitat and food with native fish, like salmon (Walsh, 2022; DEEHR, n.d.). Climate change may also introduce additional stressors to salmon populations and their habitats, directly through habitat alterations, such as shifts in temperature and water flow, and indirectly by altering ecosystem functions, including food availability and predator-prey relationships (Thorstad et al., 2021). Together, these threats can have compounding impacts on wild salmon population success.

2.4 Indicator selection

The measurement of significance was based on a composite index consisting of various indicators across all criteria factors. Indicators represent the measurable metrics for evaluating each factor. Indicators were identified based on previously assessed or considered metrics for evaluating factors, as guided through a review of relevant scientific literature and in consultation with subject matter experts. The list of indicators was refined based on availability, resolution, and quality of available data within Nova Scotia. Indicators selected were restricted to those able to be easily quantified and interpreted, while removing potentially redundant or highly correlated indicators. Since the multi-faceted interpretation of significance defined by this project is novel in this context, some factors did not have well-established indicators. In those cases, novel indicators were developed and populated in-house. These are further described in **Section 3.1 – Indicators**.

To prioritize the most recent, river-specific data, while also recognizing the relevance of historical or coarse datasets, the identified indicators were categorized into two levels of relevance:

- **Primary indicators** represented fundamental metrics directly linked to the key criteria defining the high-level significance of salmon rivers. They served as the backbone of assessment, offering quantitative and foundational insights into river significance. Each factor had at least one primary indicator representing the most relevant metric.

- **Secondary indicators** provided supplementary information that contributed to the understanding of the criteria but typically offered less detail (such as information from broader primary watershed-level assessments) or provided more qualitative insights (compared to quantitative information).

Some indicators had both primary and secondary indicator options, depending on the recency and scale of data. Primary indicators may be downgraded to secondary if:

- Data could be considered outdated based on the specific indicator[4]; and/or
- Data available was generalized from a larger watershed area[5].

This hierarchical approach prioritized the most critical factors influencing the overall assessment of river significance, while also considering additional layers of complexity and nuance. While primary indicators are the preferred indicators for evaluation of rivers, where data is not available, assessment using secondary indicators enables a more complete assessment of all rivers through a triangulation of datasets. **Section 2.7 – Calculating the Significance Index** further describes how each type of indicator is used to inform the calculation of the final significance index.

2.5 Data collection and sources

Data collation efforts took place between July 1, 2023 to December 31, 2024. Data used in this assessment were collated largely from publicly available data sources through an extensive internet search. Data was identified from a wide range of sources, including government and non-government reports, peer-reviewed journal articles, online databases, institutional websites, and academic theses. Consultations with subject-matter experts and researchers within Nova Scotia also identified several sources of data. Finally, the Centre for Marine Applied Research (CMAR) collected some temperature and abundance data on select rivers to support this initiative[6]. While every effort was made to identify and incorporate the most relevant and available data, it is acknowledged that additional sources may exist. This assessment included only data available up to December 31, 2024, when collation efforts concluded, as determined by the point at which further efforts were not yielding substantial new insights. The assessment framework is designed to be iterative and can be updated as new information is identified or becomes available.

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[4] For some indicators, this was when data available was from before 2014 (10 years), and for others, it was when data was from before 2019 (5 years).

[5] For example, pH data for a river may only be available from watershed-level estimations of pH (secondary indicator), while other rivers may have river-level specific pH measurements (primary indicator).

[6] Findings from these 'in-house' data collection efforts are available on CMAR's website.

Searches for river-specific data were guided primarily by the river's common name. Where possible, identification through a common name was verified using latitude and longitude. In some cases, data was collected at the watershed scale, including primary and secondary watersheds, and then assigned to individual rivers based on their corresponding watershed boundaries. Some data was also collected directly through field-based methods, including the use of sensors deployed in rivers to capture temperature parameters. In some instances, data obtained from external sources required in-house re-analysis within GIS to extract river-specific characteristics or refine the spatial scale.

All collected data were compiled into a centralized data inventory, bringing together a wide range of available data and information on salmon population and habitat monitoring across the province. The Data Inventory not only supported the calculation of river significance scores, but also provides a valuable resource for researchers, conservation practitioners, and policymakers. To ensure transparency and promote collaboration, the Data Inventory will be made publicly available through the Nova Scotia Open Data Portal.

2.6 Indicator scoring

To enable an overall calculation of significance, indicators were reclassified to a common scale. Scoring involved assigning numerical values and ratings to the possible values within each indicator, based on how that indicator relates to the significance of each factor. This was done by applying a scoring system whereby indicator data were classified into: Low (score = 1), Medium (score = 2), or High (score =3) significance.

Indicator scores were established, where possible, based on pre-established thresholds from the scientific literature or pre-existing assessments. For example, habitats are considered largely inhabitable for wild salmon when pH values are below 4.7, which would make it appropriate to be scored as Low (1). In some cases, no pre-existing thresholds or guidance was provided, and indicators were based on the distribution of data to identify worst and highest performing scores, based on the data available. Indicator scores were reviewed and developed in consultation with subject-matter experts as part of the established CCS Wild Salmon Data Committee.

2.7 Calculating the Significance Index

The final River Significance Index (SI Index) represents the hierarchical aggregation of numerical scores across all five criteria, their nested factors, and their relevant indicators.

First, a single indicator score was determined per river, based on the average score across all observations for a given indicator[7]. Second, all indicator scores for a given factor were averaged to produce a single significance score for each factor. However, due to variable data availability across the study area, not all rivers had complete data for every indicator. To account for this, a flexible approach was used in which the factor score was determined through a set of **choice indicators**, identified during this step based on the availability of collected data across primary and secondary indicators (**Figure 4**). When data was available, primary indicators were used as choice indicators. However, when primary indicator data was unavailable, the average across all secondary indicators was used to score rivers, although added uncertainty was acknowledged (see **Section 2.8 - Uncertainty, validation, and reliability**).

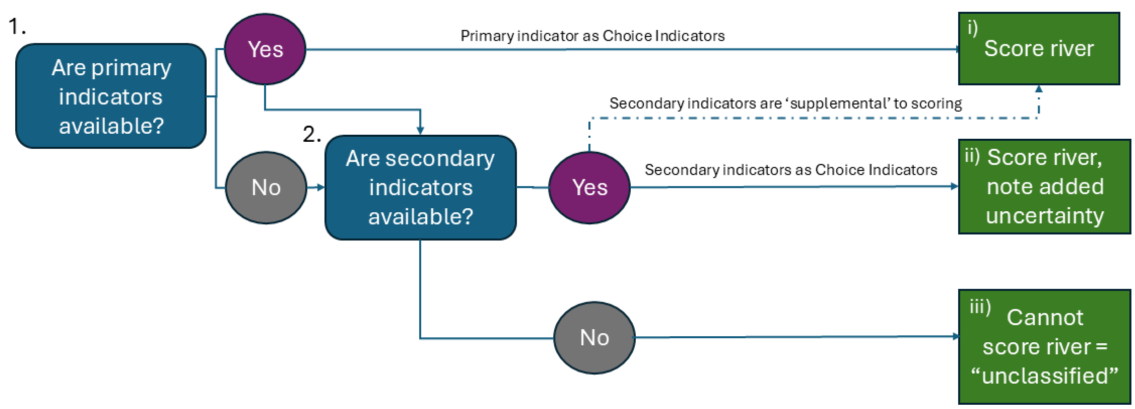

Figure 4. Decision flowchart describing how rivers (factors) were scored (green boxes), which depended on three questions related to the availability of data enabling the measurement of indicators. Dashed arrows represent where indicators may be used to support validation of scoring but not used as a main indicator for scoring a river.

In the third step, each HABIT criteria score was calculated based on the average of the aggregated factor scores. Finally, to calculate the overall SI Index of each river, the average across all criteria scores was calculated.

For this assessment, we assume that each of the five criteria has equal importance to the overall calculation of significance. Similarly, each factor can be presumed to have equal importance to the criterion and weighted equally. To ensure proper consideration of this

[7] Rivers may have multiple indicator observations since indicator data may be available from multiple sources or years

equal weighting, scores were reclassified after each aggregation step (**Table 2**)[8]. The final calculated SI Index (with values ranging from 1-3) was reclassified to identify the final significance ratings, which are represented by descriptive classes, including "Low", "Medium", and "High".

Table 2. Description and values of reclassified scores.

Significance score	Significance rating	Reclassified score
1.0 to 1.67	Low	1
1.67 to 2.33	Medium	2
2.33 to 3.0	High	3

The significance ratings of rivers and their aggregated criteria can provide useful information to understanding the relative significance of different rivers and clarity in communicating a nuanced understanding of river significance. **Table 3** provides a general interpretation for each level of significance for each criterion. As significance is a complex and multifaceted construct, clarification on the interpretation of significance for each criterion is arguably more relevant than an overall river-level interpretation.

Table 3. Proposed high-level interpretation of river significance ratings, as they apply to the overall Significance Index and to each criterion.

	Low Significance	Medium Significance	High Significance
Overall SI rating	*Rivers that poorly support salmon populations, with minimal role in supporting sustainability goals for salmon.*	*Rivers that may support salmon populations but may require substantial proactive management and conservation.*	*Rivers with a high likelihood of supporting salmon populations and are considered critical for salmon conservation and management.*
Habitat	Rivers where habitat is considered poor for salmon growth, either through degraded habitats, poor water quality, or limited suitable areas.	Rivers with moderate habitat quality, featuring some areas that may be suitable for spawning and rearing, but where improvements could be beneficial.	Rivers with generally good-quality habitat, within suitable ranges to support salmon.

[8] For example, averaged indicator scores were reclassified to 1,2, or 3, before being aggregated to produce factor scores. Similarly, averaged factor scores were reclassified before being aggregated to produce criterion scores.

Abundance	Rivers that do not appear to support salmon populations or are generally considered lost or extirpated.	Rivers where salmon are reported but populations considered critically low.	Rivers where sustained salmon populations are reported.
Barriers	Rivers with substantial portion of habitat impeded by barriers to salmon passage.	Rivers with moderate barriers, featuring some obstacles that partially hinder salmon passage.	Rivers with few or no barriers to salmon migration, allowing for unimpeded movement between habitats.
Importance	Rivers lacking significant evidence of monitoring, conservation, or research efforts.	Rivers with moderate importance, demonstrating some conservation research efforts	Rivers with high overall importance, with extensive evidence of conservation, monitoring, or research
Threats	Rivers under significant threats, experiencing numerous anthropogenic or introduced pressures posing substantial risk to salmon population and ecosystem health.	Rivers facing moderate threats, experiencing some level of pressures that could negatively affect salmon populations.	Rivers with minimal threats, characterized by low anthropogenic impacts and vulnerability to environmental stressors.

2.8 Uncertainty, validation, and reliability

To account for rivers with high uncertainty, this assessment also included an "unclassified" category, representing rivers that could not be scored due to data limitations or high uncertainties. We identified rivers with high uncertainty when a river had one factor with no data (for primary or secondary indicators) and at least one factor scored with secondary choice indicators.

To enhance the validity and reliability of the assessment framework, triangulation of data sources, member-checking, and inter-rater reliability checks were employed. To further enhance the validity and value of the framework, the development and application of the framework was reviewed and discussed by a committee formed of external experts. This process ensures that the indicators selected, scores applied, and significance ratings are reviewed and scrutinized.

3 Results

3.1 Indicators

A total of 33 indicators were identified across the five HABIT criteria (**Table 4**). This included 18 primary indicators and 15 secondary indicators. Some (9) primary indicators may also be secondary indicators, if the data available was at a broader scale (e.g.

watershed level) or if data was outdated. Three indicators were developed in-house by CMAR, for the purposes of this assessment: *Presence Rating*, *Evidence of Restoration and Monitoring Efforts*, and *River Stocking Status*. In these cases, existing province-wide metrics were not available. Indicators were thus developed to aggregate information into a single metric. For a full description of all indicators, their data sources, and how they were processed, see the accompanying **Indicator Description Report** available on the CMAR website.

Table 4. Indicators identified for each factor. Bolded indicators are primary indicators. * Identified indicators that may be primary or secondary, depending on the data available. ǂ Indicates indicators where data from the Nature Conservancy of Canada's Freshwater Stream Classification (Millar et al., 2019b) was analyzed in house with GIS to produce river-level outputs.

	Factor	Indicator	Description
HABITAT	pH	**pH***	pH based on values measured within the last 15 years *Secondary if values only available at watershed scale
		Alkalinityǂ	Proportion of total stream length (km) within river watershed with low alkalinity (≤20 mg/L of $CaCO_3$)
		Acid rock drainage (ARD) potential	Area of potentially exposed acid rock (km^2)/watershed area (km^2)
		Acidification stressor rank	The rank of acid deposition as a primary stressor (within top 3) within the watershed
	Temperature	**Proportion of summer period >20°C**	Proportion of the summer period (June-Sept) where maximum temperatures are above 20 °C, based on data since 2019 *Secondary if data is older than 2019
		Maximum temperature of warmest month	Maximum temperature (in °C) reported in the warmest month, based on data since 2019
		Average cool summer temperaturesǂ	Proportion of total stream length (km) within river watershed with average temperatures <21 °C ('cool' and 'cold')
	Productive rearing habitat	Rearing area	The number of habitat units (100 m^2) in a watershed with gradients 0.12 -25 %
		Stream gradientǂ	Proportion of total stream length (in km) with gradients between 0.1 % and 2 %
ABUN	Conservation requirement	**Conservation requirements***	Most recent value of percent attainment of conservation egg requirements (CR) within the last 10 years *Secondary if values are from before 2014

	Factor	Indicator	Description
	Density	**Juvenile density***	Average estimated juvenile salmon density calculated within the last 10 years *Secondary if values are from before 2014
	Presence	**Presence rating**	Presence of wild Atlantic salmon, based on reported evidence (and recency) into active, historical, or none observed
BARRIERS	Aquatic barriers	**Proportion of river inaccessible*†**	River length upstream of dams with no fish passage (km)/river length (km) *Secondary if data is from a primary watershed scale
		Aquatic barrier density	Number of barriers per km of the river watershed
		Aquatic barriers stressor rank	The rank of aquatic barriers as a primary stressor (within top 3) within the watershed
	Watercourse crossings	**Density of road crossings*†**	Number of crossings / km of the river watershed. *Secondary if data is from a primary watershed
		Crossings stressor rank	The rank of water crossing as a primary stressor (within top 3) within the watershed
IMPORTANCE	Conservation status	**SARA status**	Status of the river's stock, as designated by the *Species at Risk Act* (SARA)
		COSEWIC status	Status of the river's stock, as designated by the Committee on the Status of Endangered Wildlife in Canada
	Restoration and Monitoring	**Evidence of restoration/ monitoring efforts***	Presence/evidence of initiatives to restore or monitor rivers since 2014 *Secondary if data is from the primary watershed level or before 2014
	River stocking	**River stocking status**	Rating presence of river stocking efforts used to supplement existing populations. This also includes aspects of recency of stocking
THREATS	Human land use	**Human population density***	Average number of people per km^2 within the river watershed *Secondary if within the primary watershed or before 2019
		Total road density*	The total length of roads divided by the total area of the watershed *Secondary if within the primary watershed
		Impervious surfaces	Percentage of impervious surfaces estimated within the river's watershed

	Factor	Indicator	Description
		Total riparian disturbance*	Total proportion of the riparian area within the river's watershed that has been altered or disturbed due to human, forest loss, and agriculture impacts *Secondary if data is from the primary watershed
		Total watershed disturbance	Total proportion of the watershed that has been altered/disturbed due to human, forest loss, and agriculture impacts.
		Human land use stressor rank	The rank of human land use stressors as a watershed stressor (within top 3)
	Climate change	**Climate change velocity**	The mean velocity of change (km/yr) in average annual air temperature of the watershed
		Increased water temperature	Weighted average temperature increase (°C) of a watershed for rivers predicted to have warmed due to land use change
		Temperature stressor rank	The rank of water temperature as a primary stressor (within top 3) within the watershed
	Aquatic Invasive Species (AIS)	**Presence of chain pickerel and smallmouth bass**	Refers to the existence/reported evidence of non-native fish (chain pickerel and smallmouth bass) in the river or watershed
		Number of non-native fish species	Refers to the number of non-native fish species present within the watershed
		Non-native fish species stressor rank	The rank of non-native fish species as a watershed stressor (within top 3)

3.1.1 Indicator data

In total, 90 different data sources were used to catalogue indicators across the 287 assessed rivers (**Table 5**). Factors rated from a single source were those developed in-house. Multiple sources are often referenced within the development of those indicators. For example, the development of a presence rating drew from 34 different sources of abundance information to identify a general estimate of wild Atlantic salmon presence. Some data sources were applied more frequently. These sources provided province-wide information for indicators as part of larger regional-scale or province-wide assessments, such as the Nature Conservancy's Watershed Health Assessment (referenced 2860 times) and the Nova Scotia Watershed Assessment Program (NSWAP) II Database (referenced 1988 times).

Table 5. Total number of sources referenced to obtain data on primary and secondary indicators across rivers.

Criteria	Factors	Total # of sources
Habitat	pH	19
	Temperature	32
	Productive habitat	4
Abundance	Conservation requirements	19
	Juvenile density	29
	Presence	1
Barriers	Aquatic barriers	3
	Road crossings	5
Importance	Conservation status	2
	Restoration and monitoring	1
	River stocking	1
Threats	Human land use	8
	Climate change	2
	Aquatic Invasive Species	2
	TOTAL	90

While various data sources were used to score rivers, some indicators had wider coverage of data available to score all rivers across the province (**Figure 5**). Data on *Conservation requirements* were only available for twelve rivers, only six of which were considered primary indicators. Other factors where primary indicator data was sparse included *Temperature*, *Juvenile density*, and *pH*.

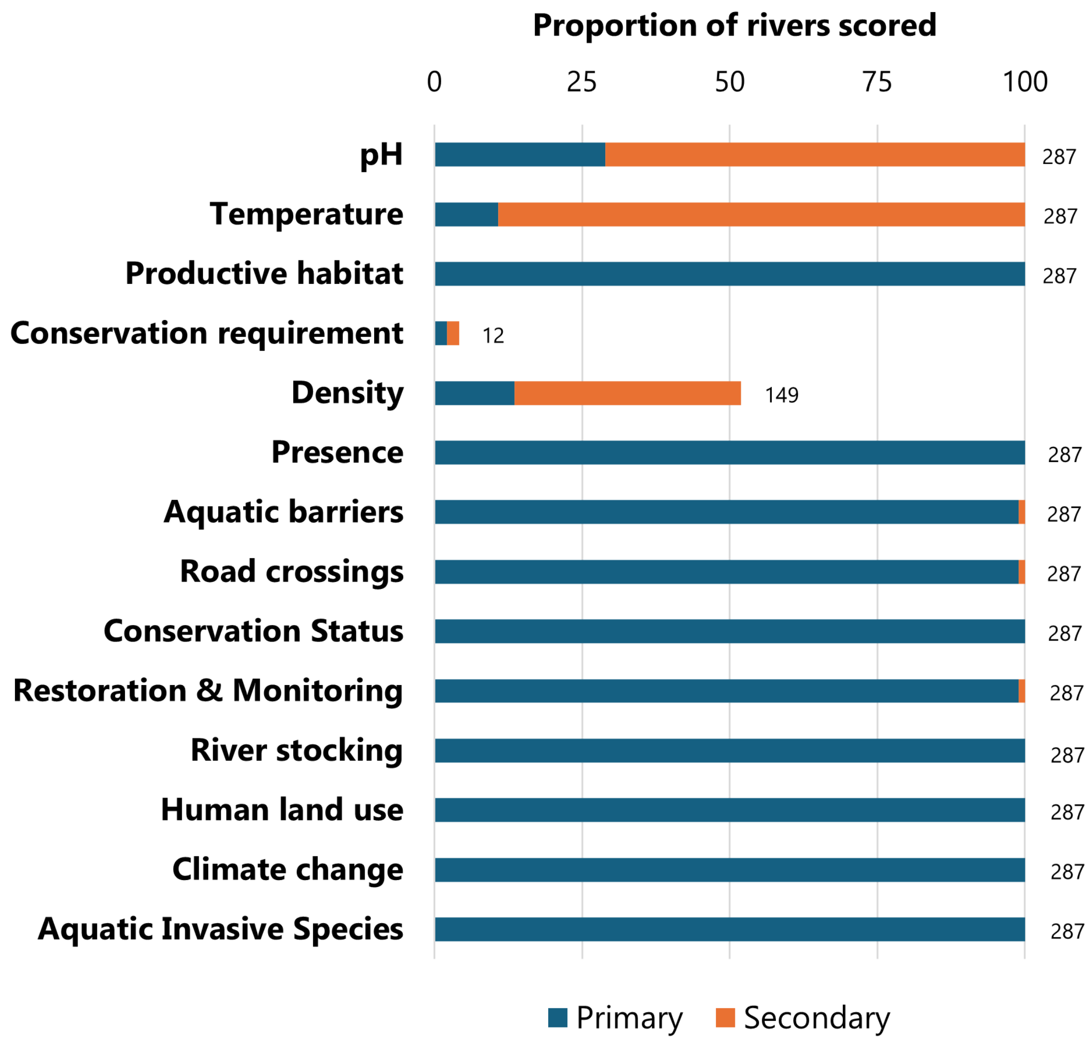

Figure 5. For each factor, the proportion of rivers scored using primary or secondary indicators as their choice indicator for scoring. Numbers at the end of bars represent the total number of rivers with available data for each factor.

3.1.2 Indicator scoring

The values of each indicator were scored on a scale of 1-3 based on how they influence the factor under consideration (**Table 6**). For rationale on how indicators were scored, see the accompanying **Indicator Description Report** available on the CMAR website.

Table 6. Indicator scores used to reclassify indicators to generate the combined significance index.

Indicator	Unit	Significance Score		
		Low = 1	Medium = 2	High = 3
pH*	pH	< 4.7	≥ 4.7 - < 5.4	≥ 5.4
Alkalinity	% of stream length (km)	> 75	75 - 50	< 50
Acid rock drainage potential	km^2/ km^2	> 0.1	> 0 - 0.1	0
Acidification stressor rank	Rank	1,2	3	None
Proportion of summer period >20°C	%	> 75	25 - 75	< 25
Maximum temperature of warmest month	°C	> 28	24 - 28	< 24
Average cool summer temperatures	% of stream length (km)	< 50	50 - 75	> 75
Stream gradient	% of stream length (km)	< 25	25 – 50	> 50
Rearing area	Habitat units	< 500	500 - 2000	> 2000
Conservation requirements*	%	< 50	50 - 100	> 100
Juvenile density*	# fish/100m^2	< 29	29 - 66	> 66
Presence rating	Rating	None observed	Historical	Active
Proportion of river inaccessible*	%	> 30	10 – 30	< 10
Aquatic barrier density	#/km	> 0.005	> 0 - 0.005	0
Aquatic barriers stressor rank	Rank	1,2	3	None
Density of road crossings*	#/km	> 1.0	0.5 - 1.0	< 0.5
Crossings stressor rank	Rank	1,2	3	None
SARA Status	Status	No status	Special Concern	Endangered or Threatened
COSEWIC Status	Status	Not at risk	Special Concern	Endangered or Threatened
Evidence of restoration/monitoring*	Rating	None	Some	Strong
River stocking status	Rating	No observations	Historical	Active
Human population density*	#/ km^2	> 50	25 - 50	< 25

Indicator	Unit	Significance Score		
		Low = 1	Medium = 2	High = 3
Total road density	km/km	> 2.0	1.0 - 2.0	< 1.0
Impervious surfaces	%	> 10	1 - 10	< 1
Total riparian disturbance*	%	> 30	20 – 30	< 20
Total watershed disturbance	%	> 30	20 – 30	< 20
Human land use stressor rank	Rank	1,2	3	None
Climate change velocity	km/year	> 15	6 - 15	< 6
Increased water temperature	°C	> 0.025	> 0 – 0.025	0
Temperature stressor rank	Rank	1,2	3	None
Presence of chain pickerel and smallmouth bass	Rating	Either or both in the river	Neither in river, but ≥1 in watershed	No observation in the river or watershed
Non-native fish species stressor rank	Rank	1,2	3	None
Number of non-native fish species	#species	> 1	1	0

3.2 River scores

Many of the rivers assessed (41.6% = 119 rivers) did not have sufficient data, such that they remain "unclassified" (**Figure 6**).

Among the remaining 168 rivers that were given a significance rating, 54.2% were rated as medium significance, with 35.7% as high significance, and only 17 rivers as low significance.

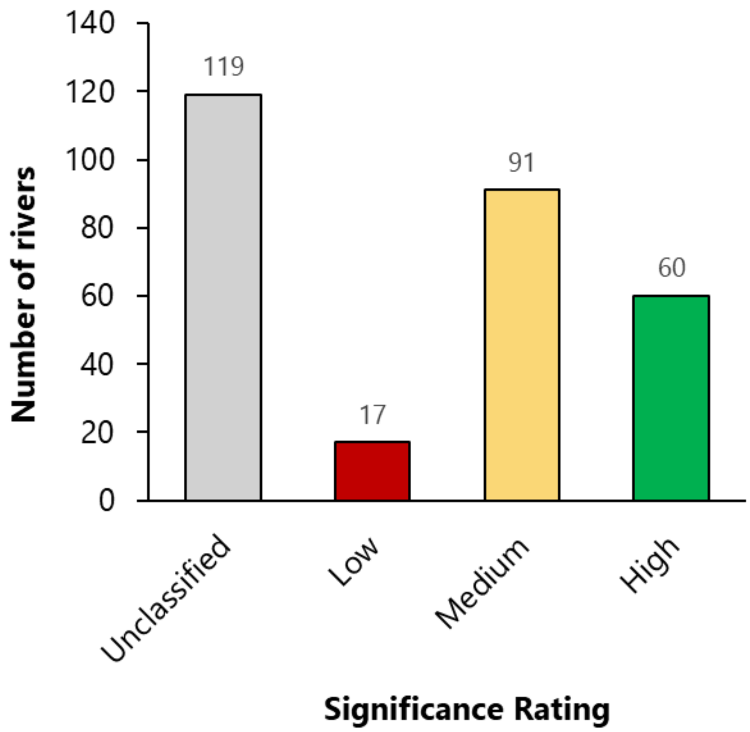

Figure 6. Total number of rivers assigned each significance rating, in addition to those 'unclassified'.

River significance varied regionally (**Figure 7**) and across Designatable Units (DU) (**Figure 8**). Just over a third (35%) of all high significance rivers were within Eastern Cape Breton, although just over half of the rivers within that DU could not be classified. Gaspe-Southern Gulf of St. Lawrence also had a high proportion of its rivers of high significance. The majority of the 17 low significance rivers (88.2%) were from Southern Uplands, which also had the lowest number of high significance rivers.

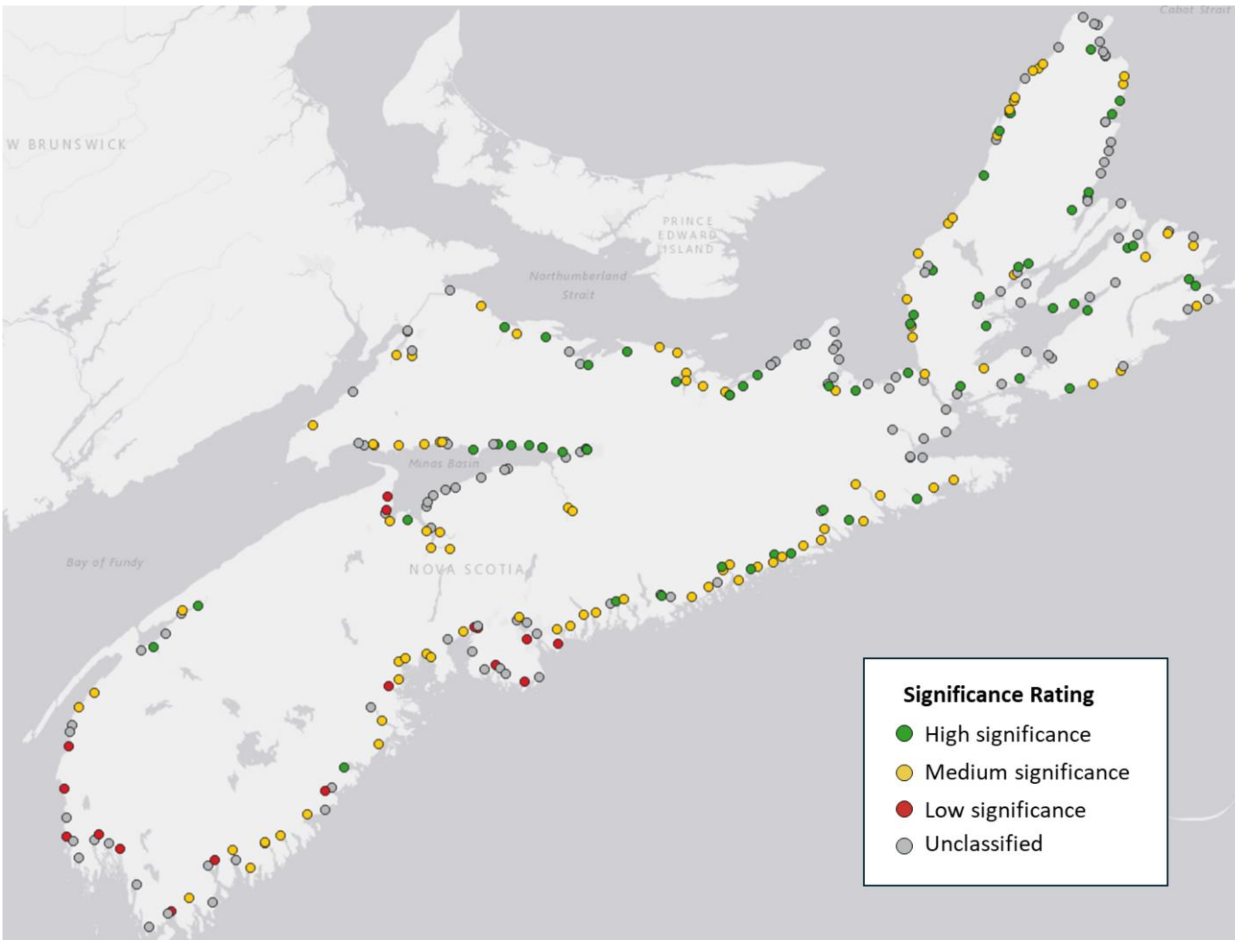

Figure 7. Map of assessed rivers in Nova Scotia with final significance ratings.

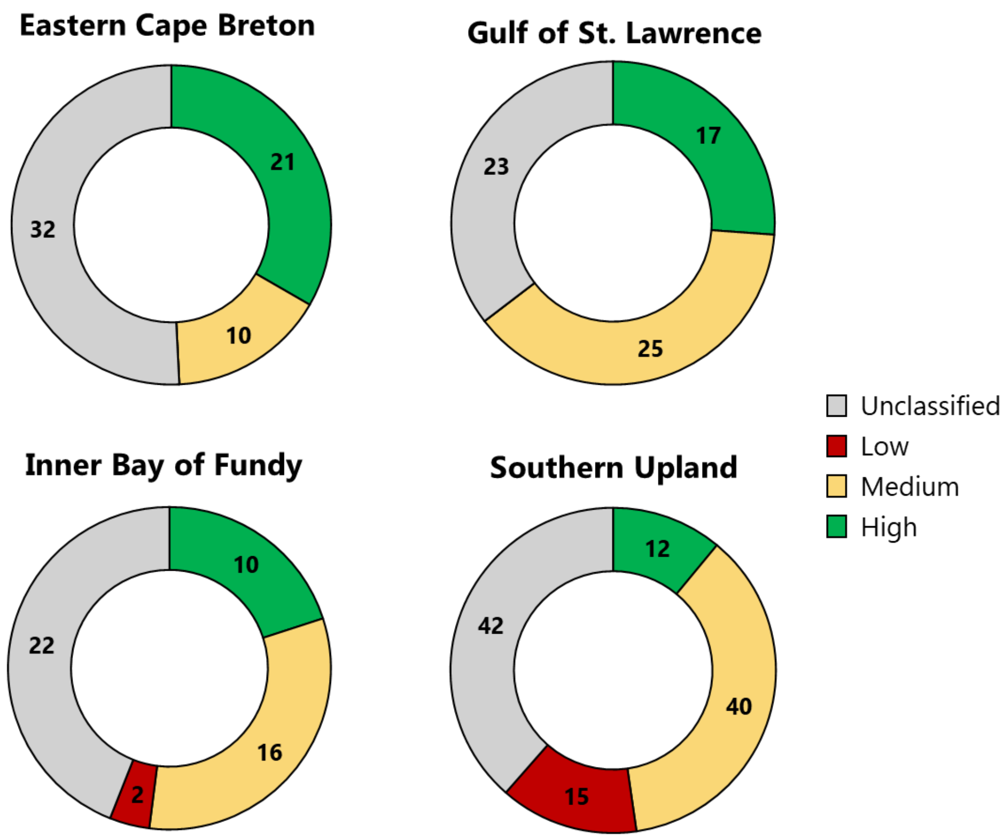

Figure 8. Distribution of significance ratings for rivers within each of the four Designatable Units (DU): Eastern Cape Breton, Inner Bay of Fundy, Gaspe-Southern Gulf of St. Lawrence, and Southern Upland.

The highest scored rivers (**Table 7**) had at least three high-scored criteria, with many having four of the five criteria rated high. Yet, no river was scored high across all five criteria. Just over half (7 rivers) of the highest scored rivers were DFO Index Rivers from the Gaspe-Southern Gulf of St. Lawrence DU and the Eastern Cape Breton DU.

Table 7. Rivers with the highest scores (2.8-3) across the four Designatable Units (DU) in Nova Scotia, and their five criteria ratings (red = 1 (Low), yellow = 2 (Medium), green = 3 (High)). *Indicates DFO Index Rivers.

River	DU	Criteria scores				
		Habitat	Abundance	Barriers	Importance	Threats
Baddeck River*	ECB	Yellow	Yellow	Green	Green	Green
Grand River*	ECB	Green	Yellow	Green	Green	Green
Great Village River	IBoF	Yellow	Yellow	Green	Green	Green
Indian Brook (Cape Breton)	ECB	Yellow	Yellow	Green	Green	Green
Mabou River	Gulf	Yellow	Green	Green	Green	Green
Margaree River*	Gulf	Red	Green	Green	Green	Green
Middle River (Victoria)*	ECB	Yellow	Yellow	Green	Green	Green
Moser River	SU	Green	Yellow	Green	Green	Green
North River (Victoria)*	ECB	Yellow	Green	Green	Green	Green
Portapique River	IBoF	Yellow	Green	Green	Green	Green
River Philip*	Gulf	Green	Green	Green	Yellow	Green
West River (Antigonish)*	Gulf	Yellow	Green	Yellow	Green	Green
West River Sheet Harbour	SU	Green	Yellow	Green	Green	Green

ECB = Eastern Cape Breton; Gulf = Gaspe-Southern Gulf of St. Lawrence; IBoF = Inner Bay of Fundy; SU = Southern Upland

The 17 lowest rated rivers (with scores between 1.4-1.6), had low scores across at least two criteria (**Table 8**). Most often, the low scores were from low scores on Abundance and on Importance criteria. It is important to note, however, that low significance rivers may still have relatively suitable conditions for Atlantic salmon, as ratings were not always low across all criteria. Scores varied widely across criteria for some rivers. For example, the Mersey River, Roseway River, Barrington River, and Argyle River each had two criteria as high (3), one criterion as medium (2), and two criteria as low (1).

Table 8. Rivers classified as low significance, based on a combined average across five criteria ratings (red = 1 (Low), yellow = 2 (Medium), green = 3 (High)).

River	Habitat	Abundance	Barriers	Importance	Threats
Argyle River	Green	Red	Yellow	Red	Green
Barrington River	Green	Red	Yellow	Red	Green
Chegoggin River	Green	Red	Yellow	Red	Red
Chocolate Lake Drainage	Yellow	Red	Green	Red	Red
Cow Bay River	Green	Red	Yellow	Red	Red
East River (Halifax)	Green	Red	Yellow	Red	Red
Habitant River	Yellow	Red	Red	Yellow	Red
Indian River (Halifax)	Yellow	Red	Red	Red	Green
Mersey River	Green	Red	Yellow	Red	Green
Meteghan River	Yellow	Yellow	Red	Red	Yellow
Mushamush River	Yellow	Red	Red	Red	Green
Nine Mile River	Yellow	Red	Green	Red	Red
Pennant River	Yellow	Red	Green	Red	Yellow
Pereaux River	Yellow	Red	Yellow	Red	Red
Roseway River	Green	Red	Yellow	Red	Green
Salmon River (Digby)	Green	Red	Yellow	Red	Yellow
Tusket River	Yellow	Red	Yellow	Red	Yellow

In general, the significance scores varied considerably across different criteria (**Figure 9**). Most rivers in Nova Scotia scored relatively well for indicators across Habitat and Threats criteria. Comparatively, rivers scored relatively poorly for Abundance and Importance indicators. There was considerable variability across scores for Barriers indicators.

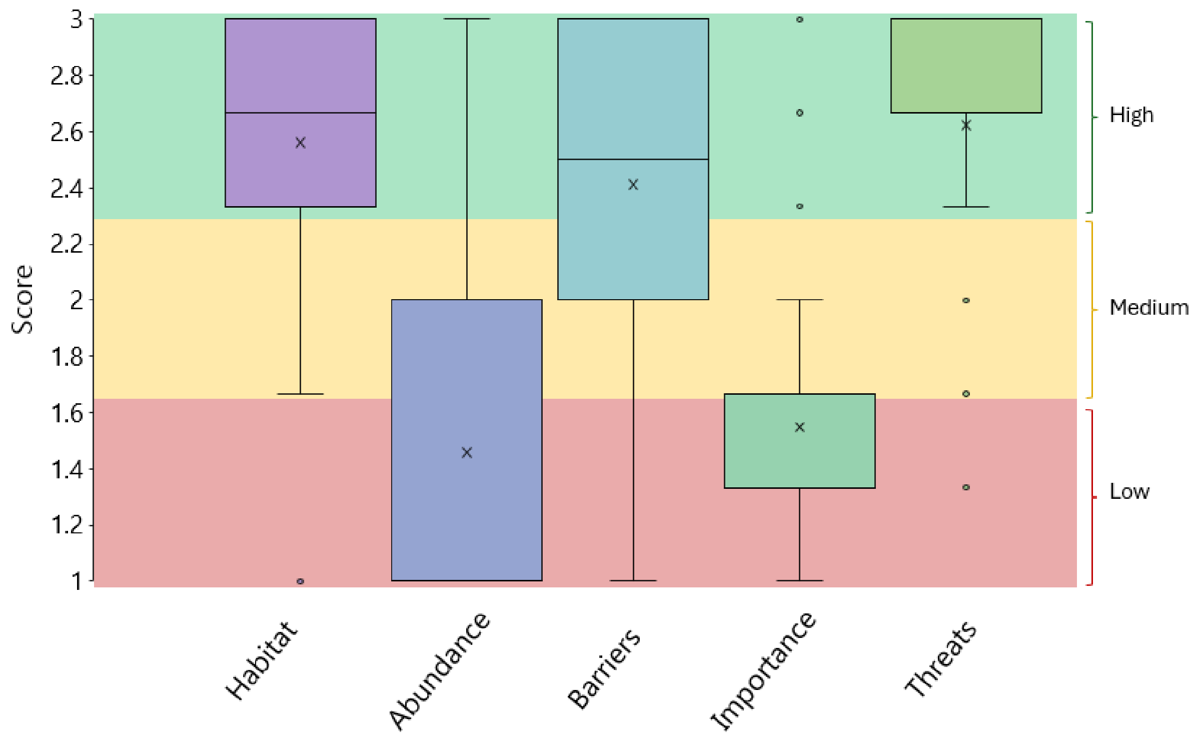

Figure 9. Distribution of average criterion scores across each of the five HABIT criteria. Each box plot shows the variability and central tendency for each criterion, displaying the mean (represented by x), interquartile range, and potential outliers, for all assessed rivers. Ranges of scores that would be considered "Low", "Medium", or "High" significance are also shown. To note, this does not include unclassified rivers.

Criterion scores also varied regionally across Designatable Units (**Figure 10**). Inner Bay of Fundy rivers had general higher scores for Importance factors, reinforcing the effort and research that has been dedicated to that region in supporting conservation goals.

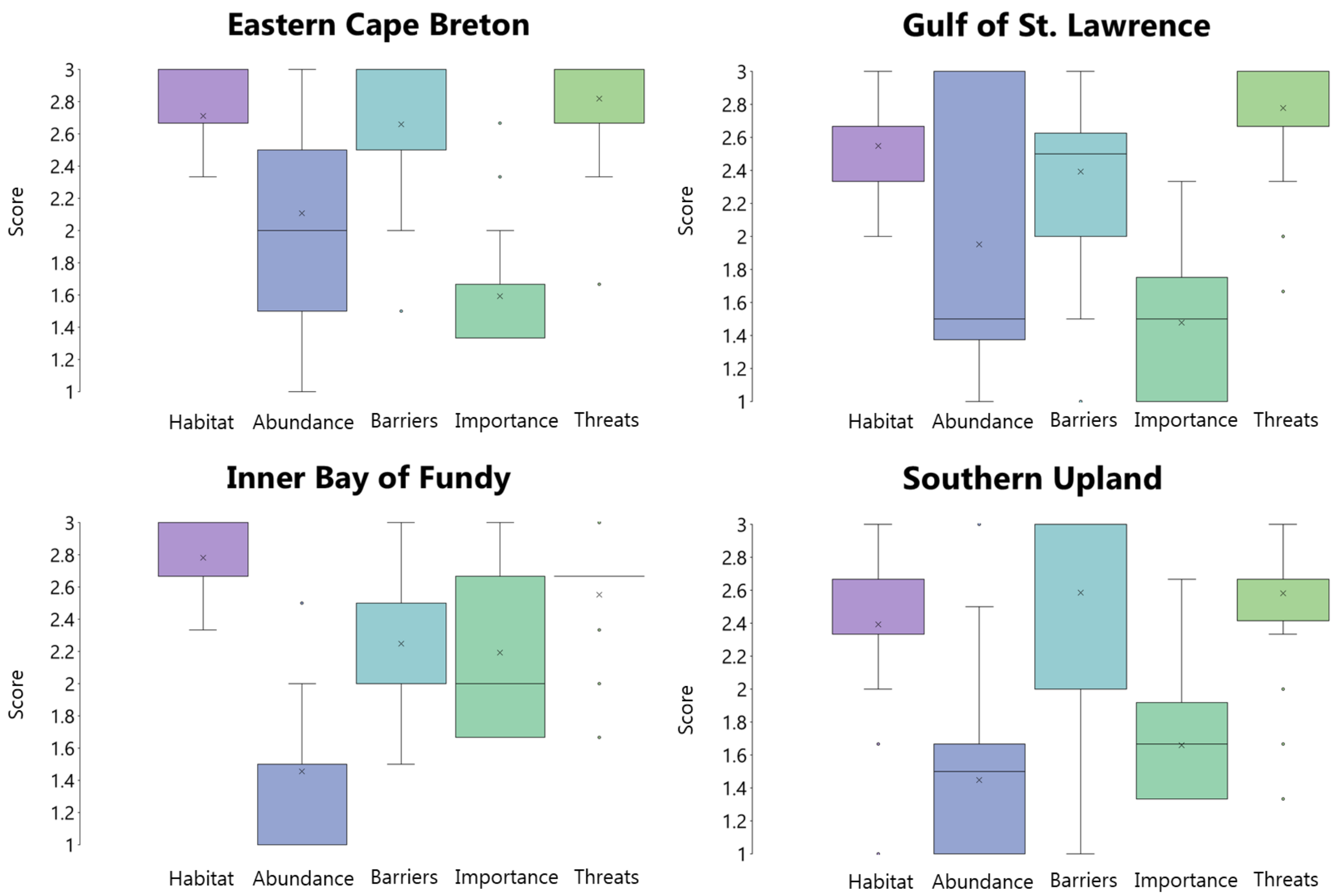

Figure 10. Distribution of average criterion scores across each of the five HABIT criteria for each of four Designatable Units (DU): Eastern Cape Breton, Inner Bay of Fundy, Gaspe-Southern Gulf of St. Lawrence, and Southern Upland. Each box plot shows the variability and central tendency for each criterion, displaying the mean (represented by x), interquartile range, and potential outliers, for all assessed rivers. To note, this also includes scores of unclassified rivers.

Furthermore, the distribution of scores for individual factors within each criterion also varied (**Figure 11**). This was most pronounced for Importance factors, where rivers had in general higher scores for *Conservation status* indicators but had predominantly lower scores for *Restoration and monitoring* and *River stocking.*

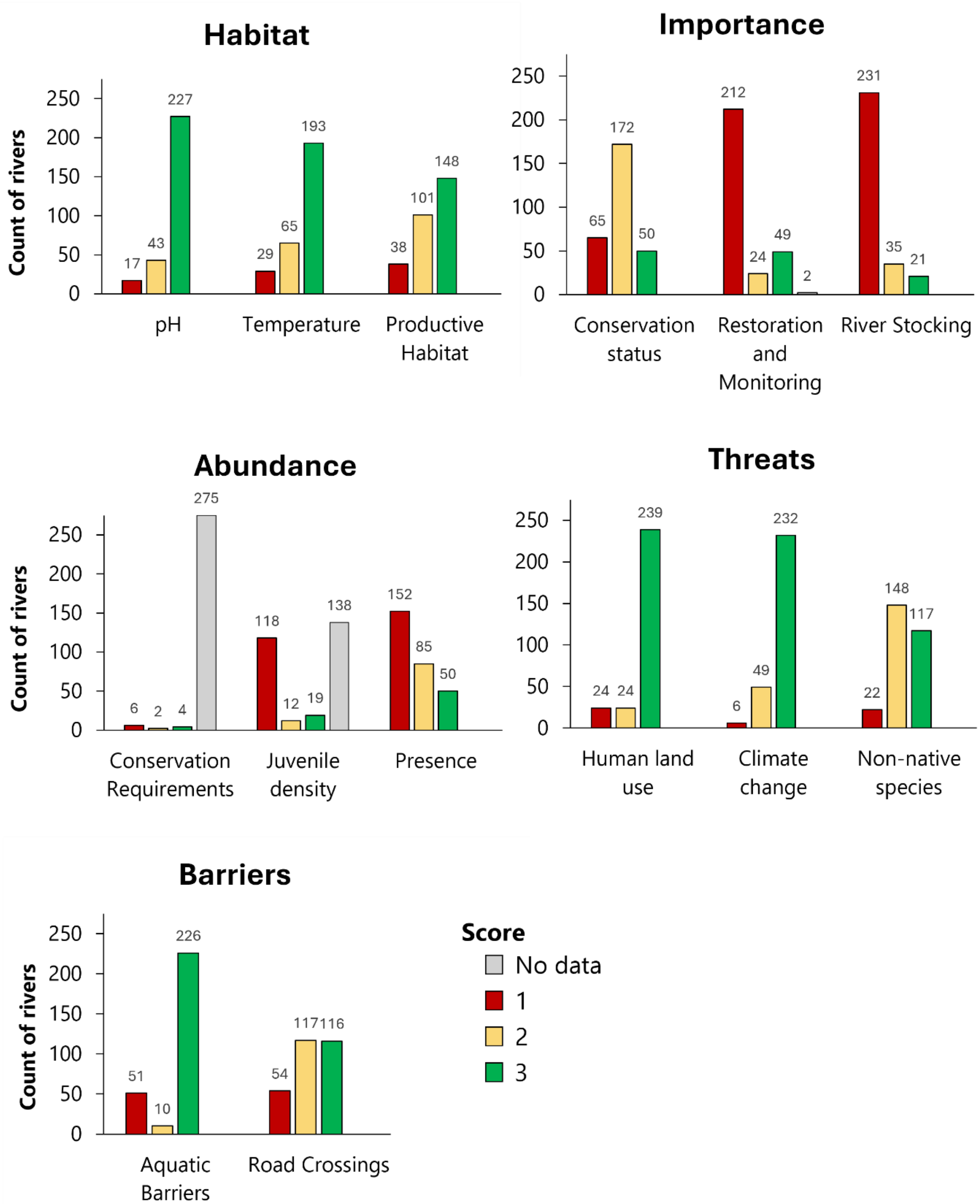

Figure 11. Number of rivers with calculated average factor scores across the five HABIT criteria. To note, this also includes scores of unclassified rivers.

3.3 Summary of key insights

- Most rivers in Nova Scotia have a combined medium significance for wild Atlantic salmon.
- Regional variation in significance ratings found many high significance rivers concentrated within the Eastern Cape Breton DU, with most low significance rivers within the Southern Uplands.
- The significance of each criterion can vary across a given river, as can the individual factors comprising of the criteria.
- In Nova Scotia, the combined significance of many rivers with a coastal outflow remains unknown, due largely to data gaps in recent river-specific habitat and abundance information.

4 Project outputs

The rating framework applied was developed for this assessment. Its purpose was to consider multiple criteria that contribute to a river's significance for wild Atlantic salmon, considering numerous goals related to its viability, environmental conditions, and conservation goals. The results of this assessment offer a high-level snapshot of Nova Scotia rivers to understand the various components that make it significant. It is the first type of assessment to offer a province-wide comparative measure.

This assessment offers a multi-faceted evaluation of the significance of rivers for supporting wild Atlantic salmon sustainability. It is meant as a broad scan of rivers incorporating multiple considerations relevant to understanding the significance of individual rivers. It can be used to foster discussions on the need to expand or build on existing efforts and can help inform where data gaps exist, and where potential recovery efforts can be highlighted. In addition, this framework can offer a set of widely applicable indicators to identify rivers for consideration in coastal planning and development to consider potential impacts to nearby wild salmon habitats and populations.

For this assessment, a comprehensive **Data Inventory** was compiled, bringing together information from 90 different sources into a single place. This catalogue can serve as a centralized place to learn about what data is available on wild Atlantic salmon in Nova Scotia for various indicators. More information related to the project output's can be found on CMAR's website.

The findings from this project can help better identify and classify which rivers in Nova Scotia may be present-day 'salmon rivers'. The Department of Fisheries and Oceans recognizes 201 rivers as potential salmon rivers[9]. While the North Atlantic Salmon Conservation Organization (NASCO)'s River Database provides stock status, which identified 139 rivers in Nova Scotia that are not 'lost', although 40% of their assessed rivers were "unknown"[10]. Similarly, our assessment found that 135 rivers had any data suggesting it currently is or was once a salmon river.

However, many rivers with a coastal outflow in Nova Scotia remain data deficient, with 41.5% of our rivers remaining unclassified. Notably, data on abundance metrics was sparse, and focused largely on Index rivers. Our presence indicator showed that 32% of our assessed rivers (92 rivers) had no information on whether wild salmon are present. Primary indicators for indicators such as temperature and river pH were also sparse. These findings highlight where data collection efforts could be optimized. Furthermore, data for unclassified rivers were still included in the Data Inventory and individual criterion scores were also calculated, where relevant. While unclassified rivers could not be assigned an overall significance rating, the scores for individual criteria may still provide important information on the river.

The framework developed in this project was designed for flexibility and adaptability, allowing for iterative updates and revisions as new data emerges or changes. It includes a robust data management system that could be adapted to easily integrate new data sources and methods. Protocols for data analysis and interpretation, as well as documenting sources and methods, can improve transparency and reproducibility. The use of a flexible selection of indicators and triangulation of data sources means that new data can easily be incorporated as needed. Thus, the framework can be not only scientifically robust but also adaptable to future needs or other areas.

4.1 Assumptions, challenges, and limitations

The outputs of this project are not meant to provide quantitative or absolute measures of habitat viability or population status across rivers. River systems are inherently complex, dynamic, and variable. There may be variability in different parts of the river system that influence its ability to support wild Atlantic salmon populations. For example, an unpassable dam may be less impactful if it is placed at a location that still allows access to tributaries and other river systems. These nuanced considerations are important for a

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[9] 72 rivers in SU (Raab et al., 2024), 46 rivers in ECB (DFO, 2014), 28 rivers within Nova Scotia in the IBoF (DFO, 2020), and 55 in the Gulf (Daigle, 2023).

[10] For an interactive map of rivers and their status, see the North Atlantic Salmon Conservation Organization (NASCO)'s River Database

more accurate understanding of the river but require more extensive local-scale data. Further, there may be local-scale variations in some indicators that could not be captured. For example, the presence of cold water refugia across the river system is important for understanding thermal stressors to salmon within a river (Breau et al., 2007; Linnansaari et al., 2023). However, there is no consistent high-level indicator nor mapped data available to apply across the province to understand where these refugia may be. While this data has been collected across various projects and programs in Nova Scotia, it requires a very in-depth understanding of a particular river system. The proposed index is not a replacement for habitat suitability assessment or population surveys.

In identifying indicators for evaluation, several metrics or measures were excluded from consideration. Indicators were selected based preferentially towards those with scientific basis (applied in previous assessment or with theoretical grounding), as well as those with data available across the entire province. Furthermore, some aspects of significance are not included as they require more extensive research and data at local scales. This assessment does not incorporate cultural or local importance of rivers or wild Atlantic salmon. Connections with salmon and salmon rivers for residents, recreational users, and Indigenous Peoples require engagement and consultation with adjacent communities and interest groups, which was beyond the scope of this assessment.

The assessment largely relied on publicly available, published data and information about salmon and salmon habitat. We acknowledge that the data inventory may not be a complete collation of existing data, and that there may be information relative to understanding salmon populations in Nova Scotia that were not included due to resource constraints of this assessment. Data that was unpublished at the time of the assessment, or that may be held privately by organizations or researchers was not included. In addition, some data may be missing due to alternative names used for rivers, where locations could not be georeferenced. Future opportunities for integrating new and updated information will improve the reliability and rigour of the assessment findings so that the assessment remains up-to-date and relevant.

5 Acknowledgements

This research was developed as a supporting initiative to contribute to the broader objectives of the aquaculture Coastal Classification System. The insights and guidance provided by experts serving on the CCS's Wild Salmon Data Committee were instrumental throughout the process. We also extend our gratitude to the researchers and data providers who engaged with us and shared data that supported the assessment and enriched the outcomes of this work.

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