THE SECOND GENERATION COASTAL INFRASTRUCTURE VULNERABILITY INDEX (CIVI 2.0) FOR DFO SMALL CRAFT HARBOURS

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THE SECOND GENERATION COASTAL INFRASTRUCTURE VULNERABILITY INDEX (CIVI 2.0) FOR DFO SMALL CRAFT HARBOURS

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LIST OF ABBREVIATIONS

ACCASP	Aquatic Climate Change Adaptation Services Program
AR5	IPCC Fifth Assessment Report
AR6	IPCC Sixth Assessment Report
CAN-EWLAT	Canadian Extreme Water Level Adaptation Tool
CIVI	Coastal Infrastructure Vulnerability Index
CSI	Coastal Sensitivity Index
CSD	Census subdivision
DFO	Fisheries and Oceans Canada
DFP	Degree of Facility Protection
EOS	DFO Ecosystem and Oceans Science sector
HC	Harbour Condition
HU	Harbour Utilization
IDC	Ice Days Change
IPCC	Intergovernmental Panel on Climate Change
PRX	Proximity
RC	Replacement Cost
RSLC	Relative Sea Level Change
SCH	DFO's Small Craft Harbours program
SCHMIR	Small Craft Harbours - Management Information Retriever

ABSTRACT

Greenan, B. J. W., Shackell, N. L., Daigle, R., Harbin, J., Ferguson, K., Brickman, D., Boyce, D. G. 2026. The Second Generation Coastal Infrastructure Vulnerability Index (CIVI 2.0) for DFO Small Craft Harbours. Can. Tech. Rep. Fish. Aquat. Sci. 3794: x + 40 p. https://doi.org/10.60825/0vfb-8s28

The Coastal Infrastructure Vulnerability Index (CIVI) was developed by Fisheries and Oceans Canada (DFO) to provide a standardized, evidence-based approach for assessing the relative vulnerability of Small Craft Harbours (SCH) infrastructure to climate change. Building on the first-generation CIVI released in 2018, this report presents the second-generation framework, CIVI 2.0, which incorporates updated climate projections and additional engineering information. CIVI 2.0 adopts a broadly supported vulnerability assessment structure, including indices of sensitivity, exposure, and adaptive capacity, enabling greater alignment with current climate-risk science and enhancing interpretability for decision-makers.

The methodology integrates national datasets on coastal geomorphology, relative sea-level change, ice-climate projections, harbour condition, facility protection, replacement cost, harbour utilization, and geographic proximity. Indicators are normalized and combined using a geometric-mean approach to reduce the influence of outliers while preserving regional variability. CIVI 2.0 also incorporates contextual information—including census subdivision population and harbour-level climate vulnerability of the commercial fisheries—to support more holistic decision-making, while maintaining a strictly indicator-based vulnerability scoring approach.

Results highlight substantial regional variation in infrastructure vulnerability across Canada. Marine sites in the southern Gulf of St. Lawrence generally exhibit high exposure due to projected increases in relative sea level and reductions in ice days, whereas many British Columbia and inland sites exhibit lower overall vulnerability. The updated framework improves national consistency, enhances transparency, and provides a reproducible methodology to support adaptive planning and prioritization in the management of SCH under changing climate conditions.

CIVI 2.0 is intended as an operational tool for SCH program managers, engineers, and policy analysts, guiding capital planning, risk reduction, and long-term climate-resilience strategies across Canada’s fishing harbour network.

RÉSUMÉ

Greenan, B. J. W., Shackell, N. L., Daigle, R., Harbin, J., Ferguson, K., Brickman, D., Boyce, D. G. 2026. The Second Generation Coastal Infrastructure Vulnerability Index (CIVI 2.0) for DFO Small Craft Harbours. Can. Tech. Rep. Fish. Aquat. Sci. 3794: x + 40 p. https://doi.org/10.60825/0vfb-8s28

L'indice de vulnérabilité des infrastructures côtières (IVIC) a été élaboré par Pêches et Océans Canada (MPO) afin de fournir une approche normalisée et fondée sur des données probantes pour évaluer la vulnérabilité relative des infrastructures des ports pour petits bateaux (PPB) aux changements climatiques. S'appuyant sur l'IVIC de première génération publié en 2018, le présent rapport présente le cadre de deuxième génération, l'IVIC 2.0, qui intègre des projections climatiques actualisées et des informations techniques supplémentaires. L'IVIC 2.0 adopte une structure d'évaluation de la vulnérabilité largement soutenue, y compris des indices de sensibilité, d'exposition et de capacité d'adaptation, ce qui permet une meilleure harmonisation avec la science actuelle des risques climatiques et améliore l'interprétabilité pour les décideurs.

La méthodologie intègre des ensembles de données nationales sur la géomorphologie côtière, le changement relatif du niveau de la mer, les projections du climat des glaces, l'état des ports, la protection des installations, le coût de remplacement, l'utilisation des ports et la proximité géographique. Les indicateurs sont normalisés et combinés à l'aide d'une approche géométrique-moyenne afin de réduire l'influence des valeurs aberrantes tout en préservant la variabilité régionale. L'IVIC 2.0 intègre également des informations contextuelles, y compris la population des subdivisions de recensement et la vulnérabilité climatique des pêches commerciales au niveau des ports, afin de soutenir une prise de décision plus globale, tout en maintenant une approche de notation de la vulnérabilité strictement basée sur des indicateurs.

Les résultats mettent en évidence les variations régionales importantes de la vulnérabilité des infrastructures au Canada. Les sites marins du sud du golfe du Saint-Laurent présentent généralement une exposition élevée en raison de l'augmentation prévue du niveau relatif de la mer et de la réduction du nombre de jours de glace, tandis que de nombreux sites de la Colombie-Britannique et de l'intérieur des terres présentent une vulnérabilité globale plus faible. Le cadre actualisé améliore l'uniformité nationale, accroît la transparence et fournit une méthodologie reproductible pour soutenir la planification adaptative et l'établissement des priorités dans la gestion des PPB dans des conditions climatiques changeantes.

L'IVIC 2.0 se veut un outil opérationnel pour les gestionnaires de programme des PPB, les ingénieurs et les analystes des politiques, guidant la planification des immobilisations, la réduction des risques et les stratégies de résilience climatique à long terme dans l'ensemble du réseau de ports de pêche du Canada.

1 INTRODUCTION

Canada, with the world's longest coastline, is increasingly vulnerable to the impacts of climate change. Rising sea levels, increasing ocean temperatures and acidity, and the loss of sea ice and permafrost are already affecting coastal regions (Bush & Lemmen, 2019). These changes pose significant risks to coastal infrastructure, ecosystems, communities, and the economy. These risks associated with climate change are expected to lead to significant losses, damages, and disruptions in the coming decades with the six most critical areas of climate-related risk including: physical infrastructure; coastal communities; northern communities; human health and wellness; ecosystems; and fisheries (Council of Canadian Academies, 2019). Many of these areas fall under the mandate of Fisheries and Oceans Canada (DFO), which plays a central role in developing and implementing adaptation strategies to enhance the climate resilience of coastal communities in Canada.

Canada's coastal resource projections (including the key sectors of fisheries, aquaculture, and ocean energy) are mixed, ranging from −7 % to + 38 % in resource potential, depending on the region and emissions scenario (González-Espinosa et al., 2026). These national averages obscure potential severe localized resource availability declines of up to 50 %, particularly in the Arctic and East Coast, which could impact vulnerable sectors, including Indigenous communities and resource-dependent stakeholders with limited adaptive capacity. This emphasizes the need for local, regional, and national adaptive climate-resilient policy frameworks that prioritize support for coastal communities, and ensure the long-term sustainability of ocean-dependent livelihoods and ecosystems (González-Espinosa et al., 2026).

As of Spring 2026, the DFO Small Craft Harbours (SCH) program manages a portfolio of 935 harbours (655 core fishing, 280 non-core) with approximately 22,500 harbour users, nationally. The core harbours provide critical infrastructure for the commercial fishing industry, while the non-core facilities support recreational activities that can include fishing. This portfolio is comprised of over 10,000 engineering assets (wharves, breakwaters, etc.) with a replacement value of over $7.1 billion. These harbours are essential to the commercial fishing industry and the economic vitality of rural and Indigenous coastal communities, with annual commercial landings in excess of $2.5 billion. While day-to-day operations are carried out by local non-profit Harbour Authorities with over 5,000 volunteers, DFO provides the infrastructure, property, and funding for major repairs and maintenance. In addition to addressing the impacts of climate change on SCH infrastructure, the program faces a number of other challenges that include: limited permanent funding to address long-term infrastructure needs; frequent short-term injections of supplemental funding making project planning difficult; increasing vessel size and harbour overcrowding; construction difficulties in the Arctic; increasing needs for dredging; and hazardous, abandoned and wrecked vessels.

The importance of proactive adaptation was underscored in the 2017 Fall Report of the Commissioner of the Environment and Sustainable Development (OAG, 2017), which highlighted the vulnerability of Canada's infrastructure and the need for federal departments to respond effectively. The report specifically recognized DFO's Small Craft Harbours (SCH) program for its efforts to address climate risks through the collaborative development of adaptation tools with DFO's Ecosystem and Oceans Science (EOS) sector. These tools included the Canadian Extreme

Water Level Adaptation Tool (CAN-EWLAT) (Zhai et al., 2023), which provides sea-level rise projections, and the Coastal Infrastructure Vulnerability Index (CIVI) (Greenan et al., 2018), which integrates environmental, engineering, and socio-economic data to assess the relative vulnerability of harbour infrastructure to climate change impacts (OAG, 2017).

This commitment to climate change adaptation is reflected in DFO's 2023–24 Departmental Results Report (DFO, 2024a), which emphasized the use of CAN-EWLAT and CIVI to assess the vulnerability of infrastructure assets such as wharves and breakwaters. These tools were used to inform portfolio planning and support the integration of climate change criteria into infrastructure programs and policies. Similarly, recent DFO Departmental Plans (DFO, 2024b, 2025b, 2026) reaffirm DFO's focus on climate-resilient infrastructure. Through these plans, the Department has committed to ensuring that future modifications to SCH assets incorporate the best available climate resilience information, including projections from CAN-EWLAT and vulnerability assessments from CIVI. These tools are used to guide the design and construction of infrastructure that is higher, stronger, and more resilient, often incorporating nature-based solutions. The plans also highlight the Department's continued investment in harbour repairs, particularly in response to damage from extreme weather events such as Hurricane Fiona in 2022, which affected 142 harbours in Atlantic Canada and Eastern Québec.

The DFO 2024–25 Departmental Risk Profile (DFO, 2025a) further identifies climate change and extreme weather as key risk drivers affecting DFO's ability to maintain and upgrade its infrastructure. It explicitly references the use of CIVI to prioritize climate-related risk reduction measures across the SCH portfolio to ensure that financial resources are directed to the highest priorities. This strategic use of data-driven tools supports the Department's broader goals under the Greening Government Strategy, which aims to transition federal operations to net-zero carbon and climate-resilient standards.

In response to these challenges and policy commitments, EOS and SCH have undertaken work to develop an improved version of CIVI (hereafter CIVI 2.0) to provide a standardized, evidence-based approach to evaluating the relative vulnerability of SCH locations to climate change. This will enhance the ability of engineers, policymakers, and managers within the SCH program to make informed decisions about where and how to invest in infrastructure upgrades and resilience measures. In addition to supporting the operational needs of DFO SCH, CIVI has also underpinned a scientific research on climate change impacts on lobster fishing communities in Atlantic Canada (Greenan, Shackell, et al., 2019), and will continue to support similar research initiatives.

This technical report will firstly summarize the original development of the CIVI in Section 2.1. This will be followed in Section 2.2 by a description of the revised approach to the vulnerability assessment and of each of its indicators. As well as the computation of the vulnerability index, additional information is included to provide broader context for SCH decision makers but this information is not explicitly incorporated in the CIVI 2.0 calculation (Section 2.2). Section 3 will present some representative examples of results of the analysis to provide the reader with insights on the application of this tool. Conclusions from this research and development will be provided in Section 4.

2 DATA AND METHODS

2.1 FIRST GENERATION OF THE COASTAL INFRASTRUCTURE VULNERABILITY INDEX (CIVI)

The original development of CIVI was initiated in 2016 and supported by the DFO Aquatic Climate Change Adaptation Services Program (ACCASP) with the intent of providing an adaptation tool which supported the incorporation of climate change information in decision making for SCH. This resulted in an interactive GIS-based application which allowed the user to visually explore the vulnerability assessment along with the underlying data.

CIVI incorporates three sub-indices that represent components of vulnerability for the SCH program: environmental exposure, infrastructure, and socio-economics (Greenan et al., 2018). The exposure sub-index (ESI) is comprised of five indicators: relative sea level change (from present to 2100), mean annual maximum significant wave height (1990 – 2014), mean annual maximum wind speed (1990 – 2014), change in sea ice coverage (1970s – 2000s), and coastal materials (i.e., geology). The infrastructure sub-index (ISI) is represented by three indicators: harbour condition, degree of protection, and total replacement cost. The socio-economic sub-index (SESI) is comprised of three indicators: percent income from fishing, value landed per vessel, and harbour population. Further details about the data and methods used to quantify the CIVI indicators are provided in Greenan et al. (2018).

Each one of the SCH vulnerability indicators were scored on a scale of 1 to 5 (low vulnerability to high vulnerability). The probability distributions of some of these indicators were not Gaussian (normal) and, therefore, transformations of these data was sometimes required to facilitate scoring of 1 to 5. Importantly, to maintain the proportional relationships among component indicators and comparability across CIVI values, the geometric mean (instead of the arithmetic mean) was used when computing summary statistics for these non-Gaussian data (Cogswell et al., 2018), which is represented as:

$$\mathbf{CIVI} = \sqrt[3]{\boldsymbol{ESI * ISI * SESI}}$$

The sub-indices were calculated from their respective indicator scores using a geometric mean method, and were subsequently aggregated into an overall vulnerability index (CIVI) for each SCH site, which provides a relative measure of harbour vulnerability in comparison to other harbours in the same region. Because there were some indicators that differed between the Atlantic and Pacific regions (e.g. there were no socio-economic data available for the Pacific SCH) index comparisons were more informative at regional scales.

2.2 SECOND GENERATION OF THE COASTAL INFRASTRUCTURE VULNERABILITY INDEX (CIVI 2.0)

Climate change vulnerability assessments commonly organize indicators into three core components: sensitivity, exposure, and adaptive capacity (Foden et al., 2019). This framework originates from the Intergovernmental Panel on Climate Change (IPCC, 2007), which defined vulnerability as a function of the degree to which a system is sensitive to, exposed to, and able to adapt to the adverse effects of climate change (Figure 1). Exposure refers to the extent to which a system experiences climate-related hazards, sensitivity captures the degree to which a system is affected by those hazards, and adaptive capacity reflects the system's ability to adjust, cope, or recover. To leverage its familiarity and promote interpretability, we have decided to follow this more common framework for the second generation of our climate change vulnerability assessment (CIVI 2.0), which represents a significant change in approach from the first generation CIVI. One significant advantage of this change is that it will better align with research recently published on climate risk for marine species (Boyce et al., 2022, 2024), which we will be using to provide contextual information to end users for SCH sites in Atlantic Canada.

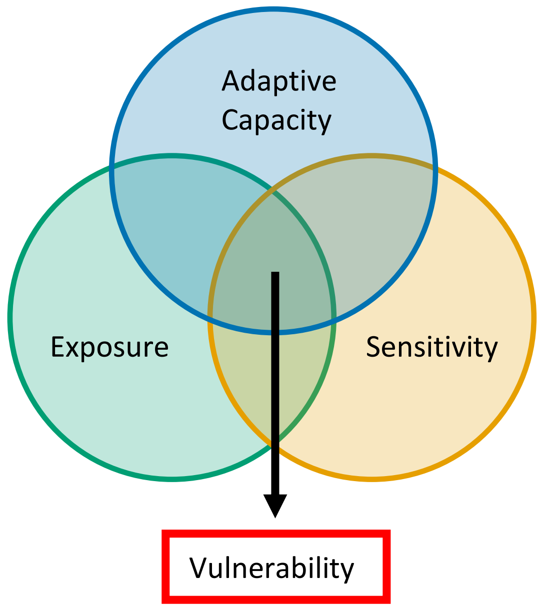

Figure 1: According to the IPCC Fourth Assessment Framework (IPCC, 2007) and common usage in the field of climate change vulnerability assessments, the estimate of the vulnerability of a system results from the interaction of exposure and sensitivity with adaptive capacity.

While the DFO SCH program is national in scope and mandate, regional differences in the availability of data pose challenges in defining common indicators for the vulnerability components. We address this by creating two categories of SCH sites with "Marine" being defined as any location within 20 km of the CanCoast Marine Shoreline (Manson et al., 2019), and the remainder of the sites being designated as "Inland".

A summary of the changes in indicators from the first to second generation of CIVI is provided in Table 1. In the second generation, the Exposure component focuses on future environmental changes that may impact SCH infrastructure. As a result, several indicators used in the first generation—those based on historical trends or climatologies—have been removed. A new Exposure indicator, Ice days change, has been added to reflect future projections. The Coastal materials Exposure indicator has been replaced by a related Coastal sensitivity indicator and moved to the Sensitivity component.

The inclusion of socio-economic indicators in the first-generation CIVI assessment was challenging due to a lack of income and fishery landing data for SCH facilities in the DFO Pacific region;

consequently, CIVI values could not be computed for the west coast. In addition, calculating the percentage of income derived from commercial fisheries at the census subdivision level was complex and required data requests from Statistics Canada and the Canada Revenue Agency (CRA). In small coastal communities where data were available, CRA often could not release fishery income data due to privacy regulations.

Given these challenges, CIVI 2.0 will not include an assessment of community reliance on fisheries, as represented by the percentage of income from fishing indicator used in the first generation. The two other socio-economic indicators from the first generation will also be excluded. Consultation with the SCH management team determined that other indicators—such as harbour utilization and proximity to a neighbouring SCH site—are more important for assessing adaptive capacity.

Table 1: Summary of indicators used in computation CIVI 1.0 and CIVI 2.0. The CIVI 1.0 indicators which are underlined have been removed from the CIVI 2.0 analysis and new indicators (italicized) have been added in the second generation.

CIVI 1.0	CIVI 2.0 (Marine)	CIVI 2.0 (Inland)
Infrastructure	**Sensitivity**	**Sensitivity**
Harbour condition	Harbour condition	Harbour condition
Degree of facility protection	Degree of facility protection	Degree of facility protection
Total replacement cost	*Coastal sensitivity*	
Exposure	**Exposure**	**Exposure**
Relative sea level change	Relative sea level change	
<u>Mean annual maximum significant wave height</u>	*Ice days change*	*Ice days change*
<u>Mean annual maximum wind speed</u>		
<u>Change in sea ice coverage</u>		
<u>Coastal materials</u>		
Socio-economics	**Adaptive Capacity**	**Adaptive Capacity**
<u>Percent income from fishing</u>	Total replacement cost	Total replacement cost
<u>Value lander per vessel</u>	*Harbour utilization*	*Harbour utilization*
<u>Population</u>	*Proximity*	*Proximity*

For each of the indicators used in this analysis, an assessment of the skewness of the distribution of the data is carried out. Those with highly skewed distributions are transformed to achieve roughly normal distributions prior to reclassifying the dataset as scores from 1 to 5 using the R cut function, with 1 being the least vulnerable and 5 being the most vulnerable (Cogswell et al., 2018; Greenan et al., 2018).

2.2.1 SENSITVITY COMPONENT

For the CIVI 2.0 application, we define the Sensitivity component as a measure of how strongly

DFO SCH infrastructure is affected by climate hazards. This assessment is based on the current state of the infrastructure and, therefore, is an indicator of the present day vulnerability to climate change impacts. In the overall assessment of vulnerability, a higher sensitivity will result in higher vulnerability. For this component, all indicators have been assigned equal weighting in the calculation.

2.2.1.1 COASTAL SENSITIVITY INDEX (CSI)

The Coastal Sensitivity Index (CSI, Figure 2) is an indicator of sensitivity derived from a Natural Resources Canada product entitled CanCoast (Manson et al., 2019). CanCoast is a collection of datasets that describe the physical characteristics of Canada's marine coasts. It includes datasets that are not expected to change through time (such as coastal materials and backshore slope), and some that may change as the climate changes (such as wave height and mean sea level). CanCoast includes: sea-level change (early and late 21st century); wave-heights including the effects of sea ice (early and late 21st century); ground ice content; coastal materials; tidal range; and backshore slope. These are mapped to a common high-resolution shoreline and used to calculate an index of the generalised coastal sensitivity of Canada's marine coasts in early and late 21st century climates, and the spatially-variable change in sensitivity between the early and the late 21st century.

For our application, we focus on the CSI calculations for the early 21st century (Figure 2) because our CIVI 2.0 Sensitivity component is focused on the present day state of the SCH infrastructure. While the CSI does include data related to sea level change over the recent past (change between 2006 and 2020), this is considered to contribute to the present-day sensitivity of the marine coastline. The relative sea level change indicator that will be presented as part of the Exposure component (Section 2.2.2.1) is forward-looking as a forcing on coastal infrastructure over the remainder of this century.

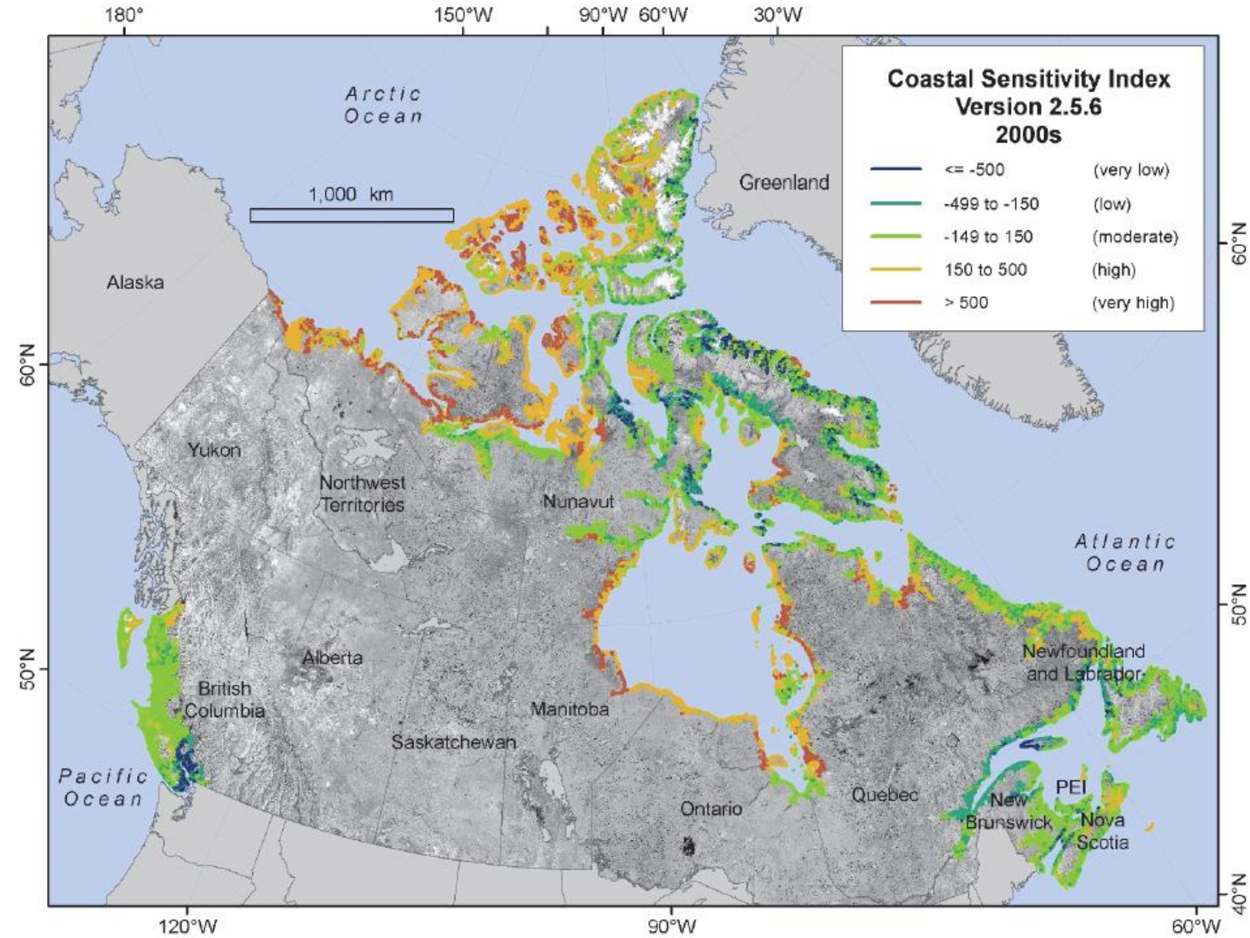

Figure 2: Map of the Coastal Sensitivity Index for the early 21st century in the CanCoast geodatabase (Manson et al., 2019).

In CanCoast, the CSI results are classified into five categories indicating areas of very low sensitivity, low sensitivity, medium sensitivity, high sensitivity and very high sensitivity. We assign these categories with a score of 1 to 5 representing increasing sensitivity with a higher score. These results are shown for the DFO SCH sites in Figure 3.

One note of caution for the use of the CSI in CIVI 2.0 is that because the scales of the various input datasets in CanCoast differ from one another, the generalised categories or scores are best used to compare the relative sensitivity of the coastline to the changing climate, rather than local properties with specific characteristics that cannot be resolved in this national-scale approach. However, our assumption is that the use of the CSI as one of three indicators in the Sensitivity component provides important additional information to the overall site assessment which is independent of the facility infrastructure but important for engineering design considerations.

It is important to note that the CSI is only available for Canada's marine coastline (as defined in CanCoast) and, therefore, it is not available as an indicator in the CIVI 2.0 for SCH facilities at inland locations (Figure 3).

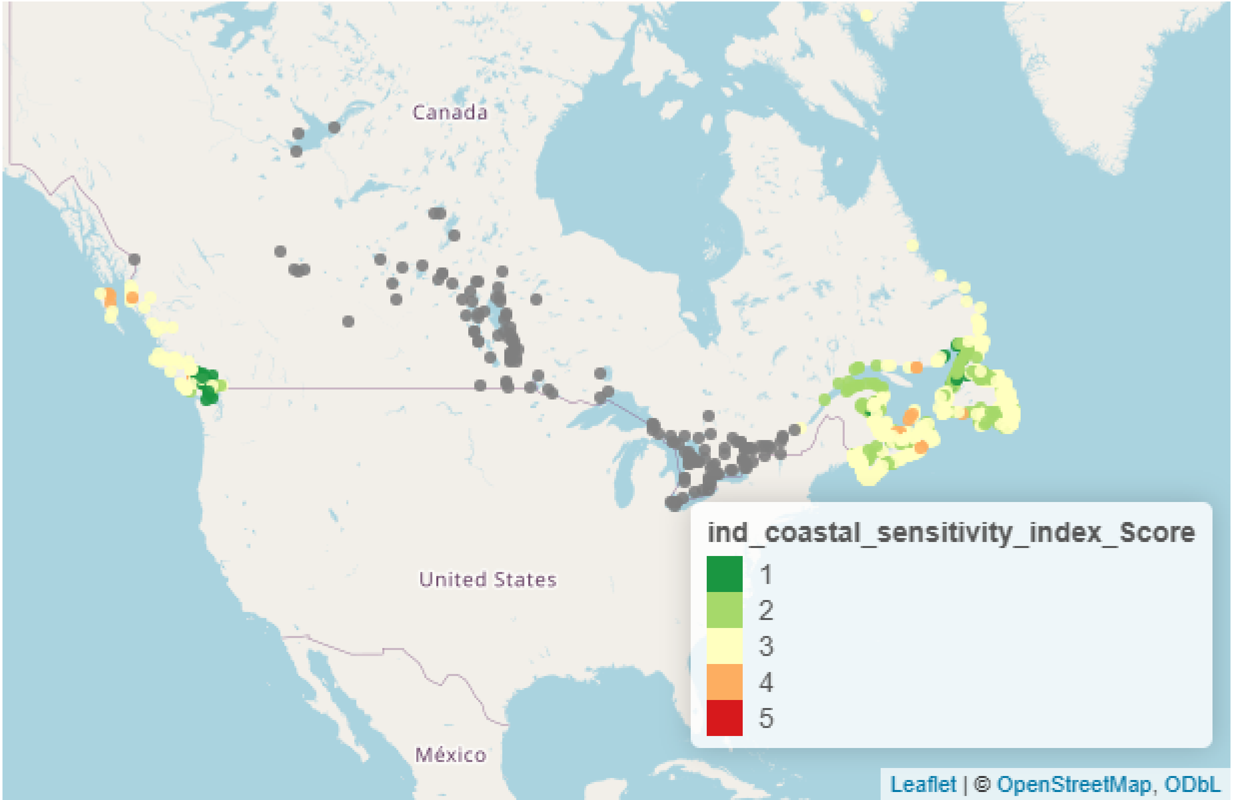

Figure 3: Map of the Coastal Sensitivity Index (CSI) score at DFO SCH facilities derived from CanCoast for the early 21st century. The higher scores represent higher sensitivity. This indicator is only available for the marine coastline, so inland sites are colored grey since this is not relevant for those locations.

2.2.1.2 HARBOUR CONDITION (HC)

The physical condition of SCH harbour infrastructure affects its ability to withstand the forces of climate change. For example, a breach in a breakwater or steel sheet pile wharf would impact its ability to withstand wave and ocean current forces which would leave it vulnerable to premature deterioration or in the most severe circumstances, structural failure.

DFO SCH has developed a Long Term Strategy (LTS) project, which assembles data related to its operations and maintenance of coastal infrastructure with the objective of informing management decisions and capital investments. One component of the LTS is the physical condition of SCH infrastructure, which is referred to as the Harbour Condition (HC) indicator. To compute the HC indicator, each component of the facility (i.e., breakwater, wharf, etc.) is evaluated and assigned a numerical score between 0 (very poor condition) and 5 (very good condition). For each harbour the average of all the individual facility conditions are weighted against the harbour's replacement cost (see Total Replacement Cost indicator in Section 2.2.3.1). The Harbour Condition is assessed for 1/3 of the SCH facilities each year, so on a rotating basis this indicator if fully updated over a 3-year period. The HC data used in the CIVI analysis has been accessed from the Small Craft Harbours - Management Information Retriever (SCHMIR) database system and a visualization is shown in Figure 4.

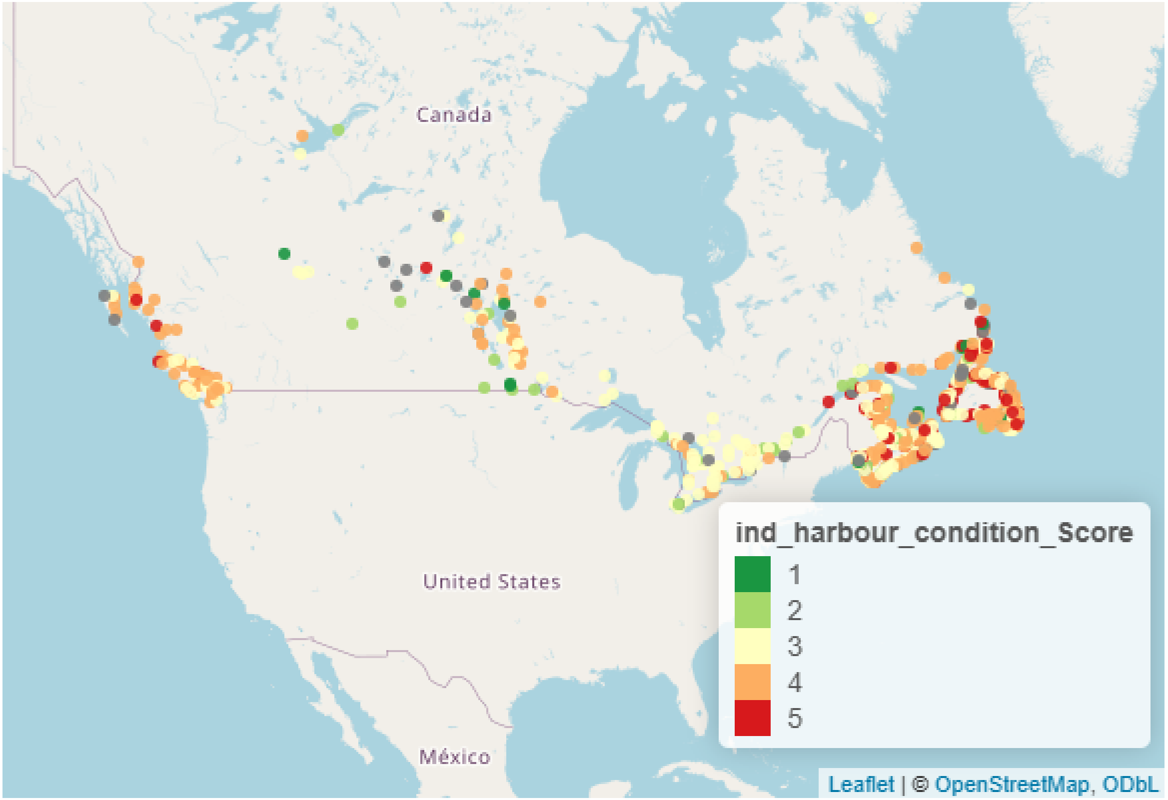

Figure 4: Map of the Harbour Condition (HC) score at DFO SCH facilities based on entries in the SCHMIR database. The higher scores represent higher HC (better condition, lower sensitivity). Sites that are colored grey indicate that data for the location is not available.

2.2.1.3 DEGREE OF FACILITY PROTECTION (DFP)

The Degree of Facility Protection (DFP) is an indicator of the degree to which a harbour is naturally protected or has manufactured protection from storm surge, waves, wind, and other natural forces. To assess the DFP indicator a five-point qualitative scale was developed by the DFO SCH national engineering committee. The outcome of the assessment is an indicator scaled 1 to 5 where 1 represents a completely exposed harbour (very high sensitivity) and 5 represents a fully enclosed harbour (very low sensitivity). Since this indicator was developed for the original CIVI project, only elements of a harbour relevant to CIVI were included in the development of the scale. This includes the basin, wharves, floats, shore protection, slipways and breakwaters, but not buildings, roads or parking lots.

The DFP score was assigned to each of the harbours by the SCH Regional Engineer in each DFO Region. This score is a function of the presence or absence of protective assets (such as breakwaters or natural topographical features) and their orientation (i.e. positioned such to withstand primary wave direction). The matrix used to assign degree of facility protection scores is presented in Table 2.

Table 2: Summary of the criteria used to assess the Degree of Facility Protection (DFP) for each SCH facility.

1 – Completely Exposed	**2 – Predominantly Exposed**	**3 – Moderately Exposed/Enclosed**	**4 – Predominantly Enclosed**	**5 – Completely Enclosed**
Basin: Structures are not located in a basin and/or not enclosed by breakwaters.ie. Harbour is located on exposed shoreline with no protection from wave and wind climate. Harbour Entrance: No channel Breakwaters: No breakwaters	Basin: Structures are located in shallow basin and/or partially protected by floating breakwaters or insufficient fixed breakwaters. Harbour Entrance: Entrance not well defined from open water, prevailing winds and/or beam waves. Subject to extensive sediment deposition (i.e. maintenance dredging on annual basis) Breakwaters: Harbour has only floating breakwaters or fixed structures that are often breached during storm events. Fixed structures may also be frequently overlapped during storms of only moderate intensity. Harbour has no breakwaters in secondary wind/wave direction.	Basin: Structures may be located in shallow basin and partially protected by fixed breakwaters but are still exposed to strong weather forces. Harbour Entrance: Entrance not protected from prevailing winds and/or beam waves. Subject to significant sedimentation. (i.e. maintenance dredging every 2-4 years). Breakwaters: Fixed breakwaters may not be built to proper standards for wave and wind climate. Do not adequately protect harbour from 5-10 year storms. Insufficient protection from secondary wind/wave direction.	Basin: Structures are largely located within small natural harbour, enclosed by fixed breakwaters. Harbour Entrance: Entrance may not be protected from prevailing winds and/or beam waves. Subject to moderate sediment deposition (i.e. maintenance dredging every 5+ years). Breakwaters: Fixed breakwaters built to appropriate height and slope for wave and wind climate. Situated to completely protect basin from 10-20 year storms, prevailing winds and beam waves.	Basin: Structures located within natural harbour or completely enclosed by fixed breakwaters. Basin is completely sheltered from severe weather events. Harbour Entrance: Entrance away from prevailing winds and/or beam waves. Subject to little or no sediment deposition. Breakwaters: Fixed breakwaters built to appropriate height and slope for wave and wind climate. Situated to completely protect basin from 20+ year storms, prevailing winds and beam waves.

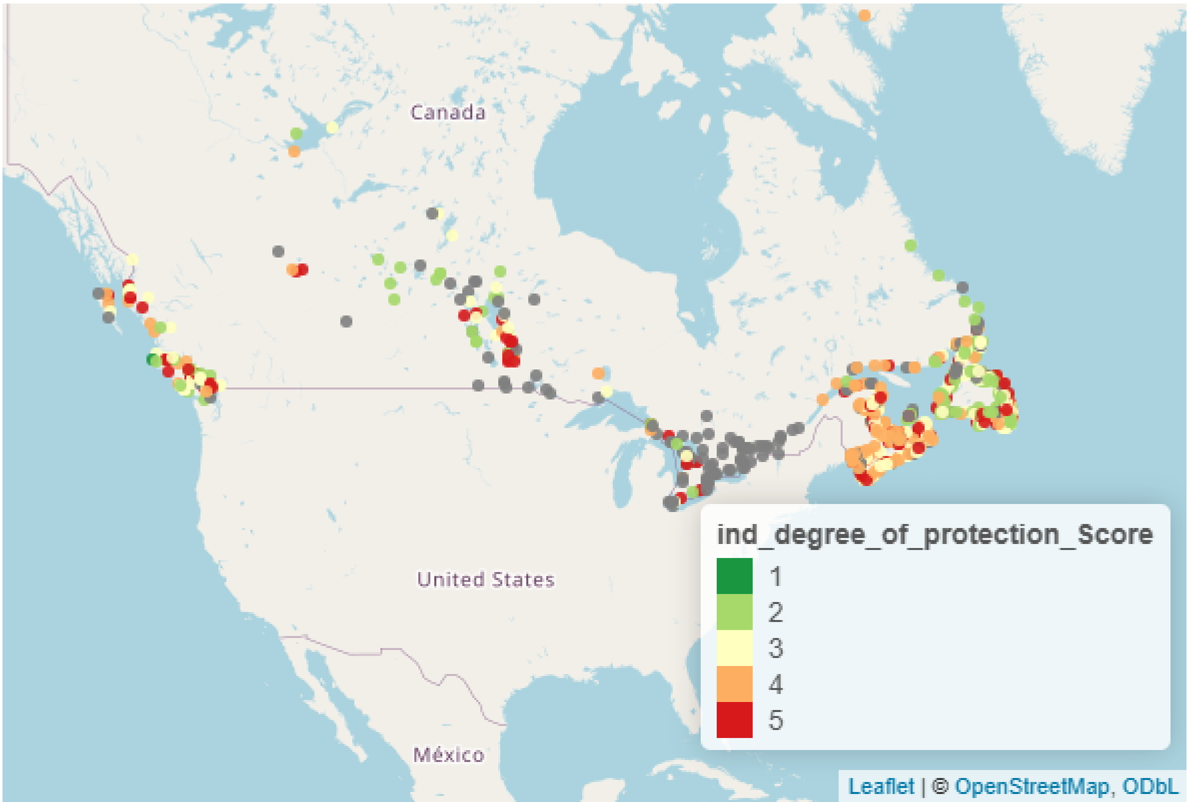

Figure 5: Map of the Degree of Facility Protection (DFP) score at DFO SCH facilities based on the criteria listed in Table 2. The higher scores represent higher level of protection (lower sensitivity). Sites that are colored grey indicate that data for the location is not available.

2.2.2 EXPOSURE COMPONENT

For the CIVI 2.0 application, we define the Exposure component as a measure of how strongly DFO SCH infrastructure will be subject to future climate hazards. This component is calculated as the average of indices based on computer model projections generated in support of the IPCC Assessment Report 6. In the overall assessment of vulnerability, a higher exposure will result in higher vulnerability.

2.2.2.1 RELATIVE SEA LEVEL CHANGE (RSLC)

Climate change is driving global mean sea-level rise, creating significant adaptation challenges for coastal communities in Canada. Projections indicate that global mean sea level could increase by more than one metre by the end of the century (Fox-Kemper et al., 2021). Local sea-level change, however, can differ markedly from the global mean trend due to processes such as vertical land motion—including subsidence and post-glacial rebound. These regional differences highlight the importance of high-resolution sea-level projections to guide adaptation planning, strengthen the resilience of Canada's varied coastal environments, and support community safety.

Relative sea-level change—the change in ocean height relative to the land—integrates both global sea-level rise and regional factors such as vertical land motion, oceanographic conditions, and gravitational effects (Fox-Kemper et al., 2021; Greenan, James, et al., 2019). Because these influences vary across the country, projected relative sea-level change is highly spatially heterogeneous (see Figure 6). Over the coming century, some coastal regions in Canada are expected to face relative sea-level rise that exceeds the global average, while others may experience relative sea-level fall where uplift outpaces climate-driven sea-level rise (Greenan, James, et al., 2019). This variability is central to understanding local flooding risks and planning for the protection of infrastructure, ecosystems, and communities.

For CIVI 2.0, we focused on a scenario roughly consistent with current implemented global climate policies (IPCC, 2023), in which global greenhouse gas emissions remain relatively constant until about 2050 (SSP2-4.5). This approach is further supported by the 2023 and 2024 UNEP Emissions Gap Reports (United Nations Environment Programme, 2023, 2024), which project almost constant global greenhouse gas emissions out to 2050 under current adopted and implemented policies. The projection under SSP2-4.5 at 2100 was used to create a nationally consistent RSLC indicator scored from 1 to 5, where 1 represents smaller changes and 5 representing larger changes requiring adaptation of coastal infrastructure heights. As is evident in Figure 6, there are regions where RSLC is projected to be positive (i.e., an increase in sea level relative to land) and regions where it is projected to be negative (i.e., a decrease in sea level relative to land) (James & Brierley-Green, 2026). Since both positive and negative changes in relative sea level pose risks for coastal communities (Hague et al., 2023; Lewright et al., 2026; Taherkhani et al., 2020), we will take the absolute value of the RSLC when calculating the indicator score (Figure 7). Therefore, the same positive and negative RSLC values will result in the same indicator score. In summary, regions of Canada where the projections of relative sea level change are small (e.g., northern Gulf of St. Lawrence) will be scored 1 and regions where projected changes are largest (e.g., coast of Cape Breton) will be scored 5.

It is important to note that RSLC is not relevant for inland SCH facilities and, therefore, will not be part of the Exposure component calculation for those locations.

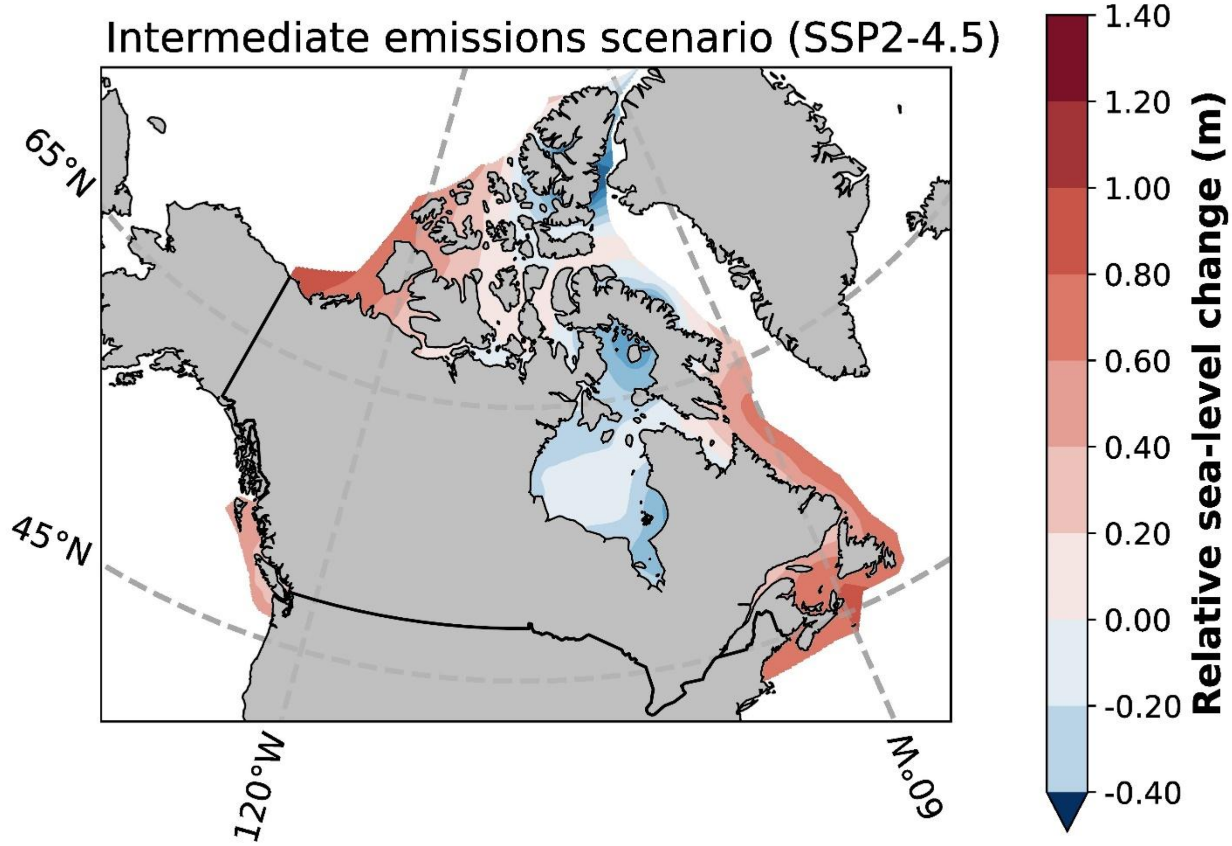

Figure 6: **Projected median (50th percentile) relative sea-level change across Canada at 2100, from a baseline of mean sea level from 1995 to 2014, for the emissions scenario SSP2-4.5 *(James & Brierley-Green, 2026)*.**

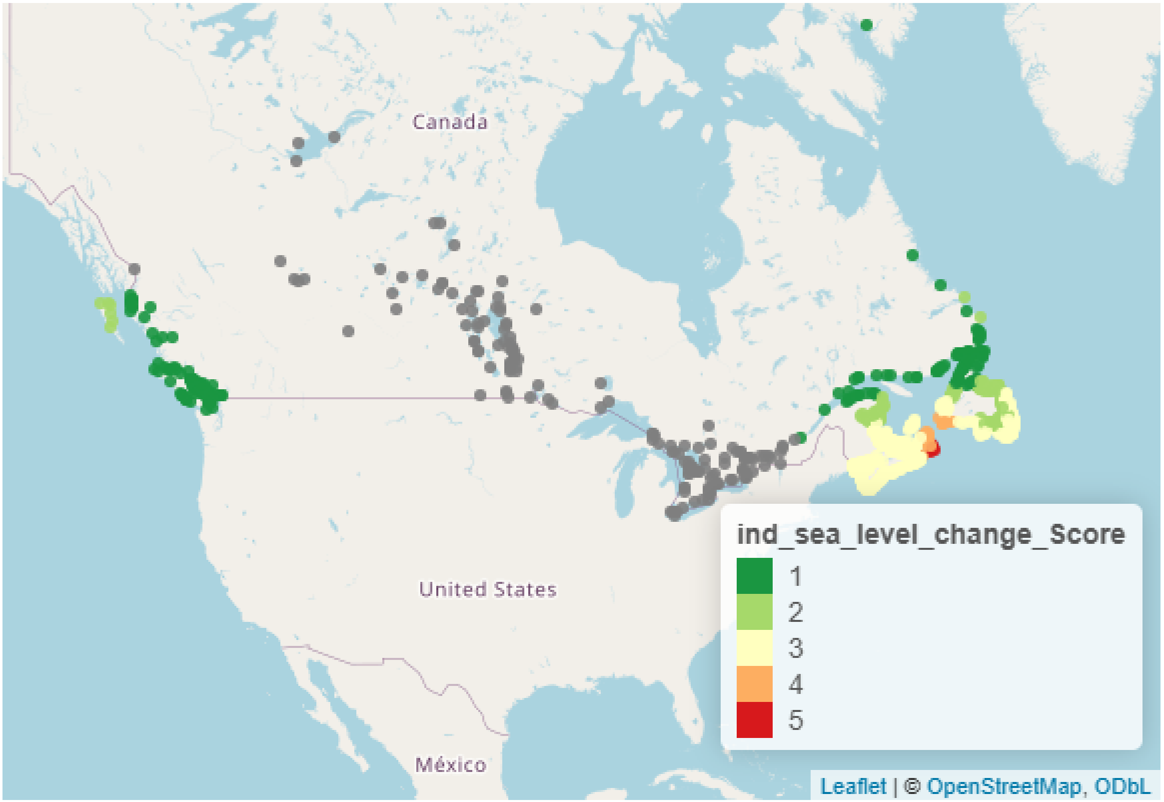

Figure 7: Map of the Relative Sea Level Change (RSLC) score at DFO SCH facilities. The higher scores represent higher exposure. Inland sites are colored grey to indicate that no value is assigned since RLSC is not relevant for those locations.

2.2.2.2 ICE DAYS CHANGE (IDC)

Ice Days describe the number of days in a year where the warmest temperature of the day is not above 0°C. In other words, this indicates the number of days when temperatures have remained below freezing for the entire 24-hour period and is an indicator of the length and severity of the winter season.

For CIVI 2.0, we calculate the Ice Days Change (IDC) as the number of annual ice days averaged over the period 2071-2100 referenced to the baseline period of 1971-2000 (see Figure 8). The data for this analysis were accessed via the data portal maintained by the Canadian Centre for Climate Services (2025). As discussed in the section above for RSLC, we chose to use the SSP2-4.5 emissions scenario for the calculation of the IDC indicator. The projection under SSP2-4.5 was used to create a nationally consistent IDC indicator scored from 1 to 5, where 1 represents smaller changes and 5 representing larger changes with larger changes signifying more exposure to climate change (Figure 9).

Seasonal sea ice severity metrics in the Gulf of St. Lawrence (duration, maximum area and estimated volume) have been shown to be related to winter air temperatures (Galbraith et al., 2024). Hence, ice days change can serve as a potential indicator for future changes in sea ice conditions in Atlantic Canada. The relationship of the IDC indicator to SCH infrastructure is less direct than the RSLC indicator, but does provide insight into the regional differences that are expected in winter climate conditions over the coming century. A larger negative IDC should result in more reductions in the sea ice presence which in turn can have impacts on sediment transport and the requirements for expensive dredging operations.

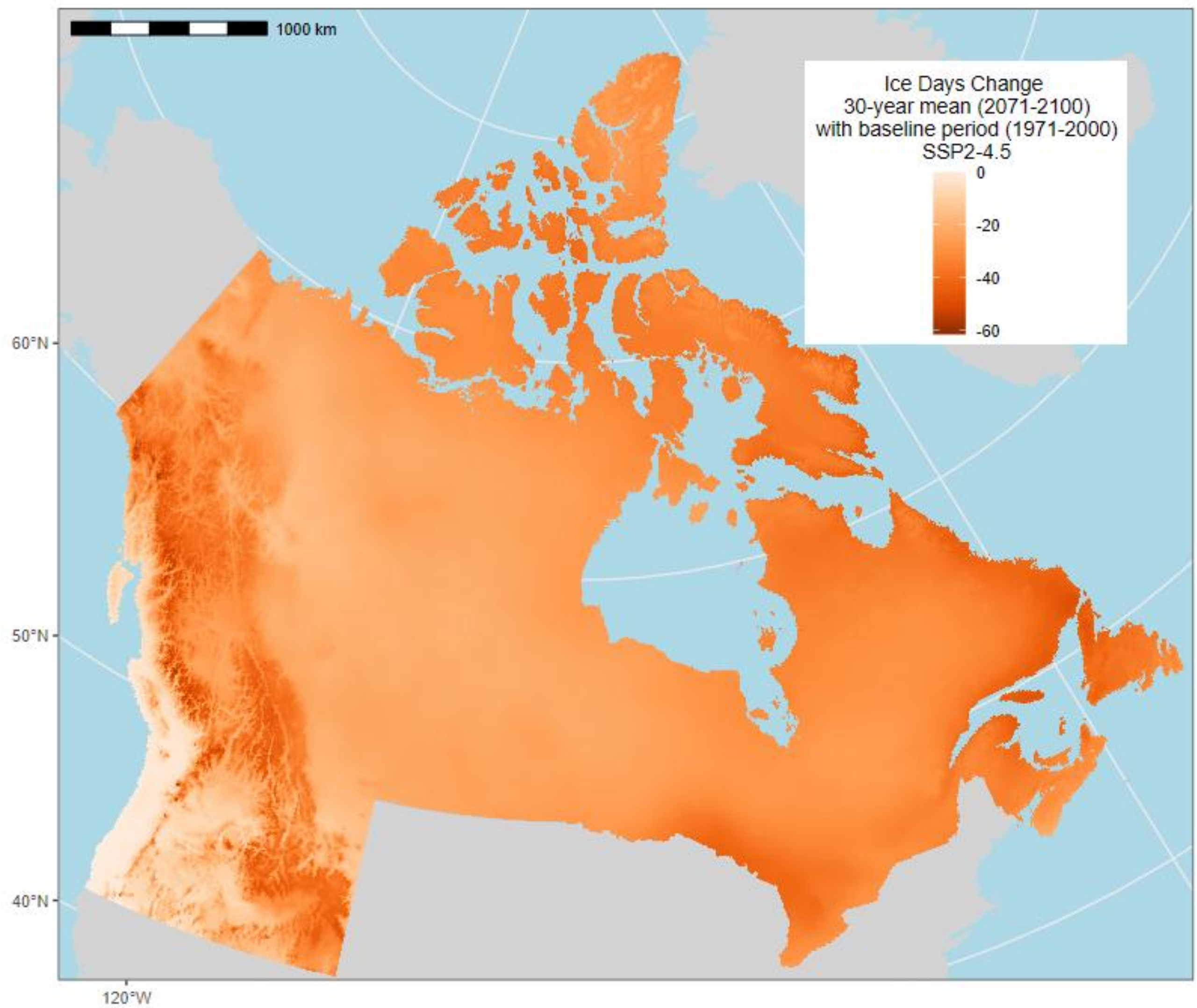

Figure 8: Map of Ice Days Change (IDC) for the period of 2071-2100 referenced to the baseline period of 1971-2000 (Canadian Centre for Climate Services, 2025).

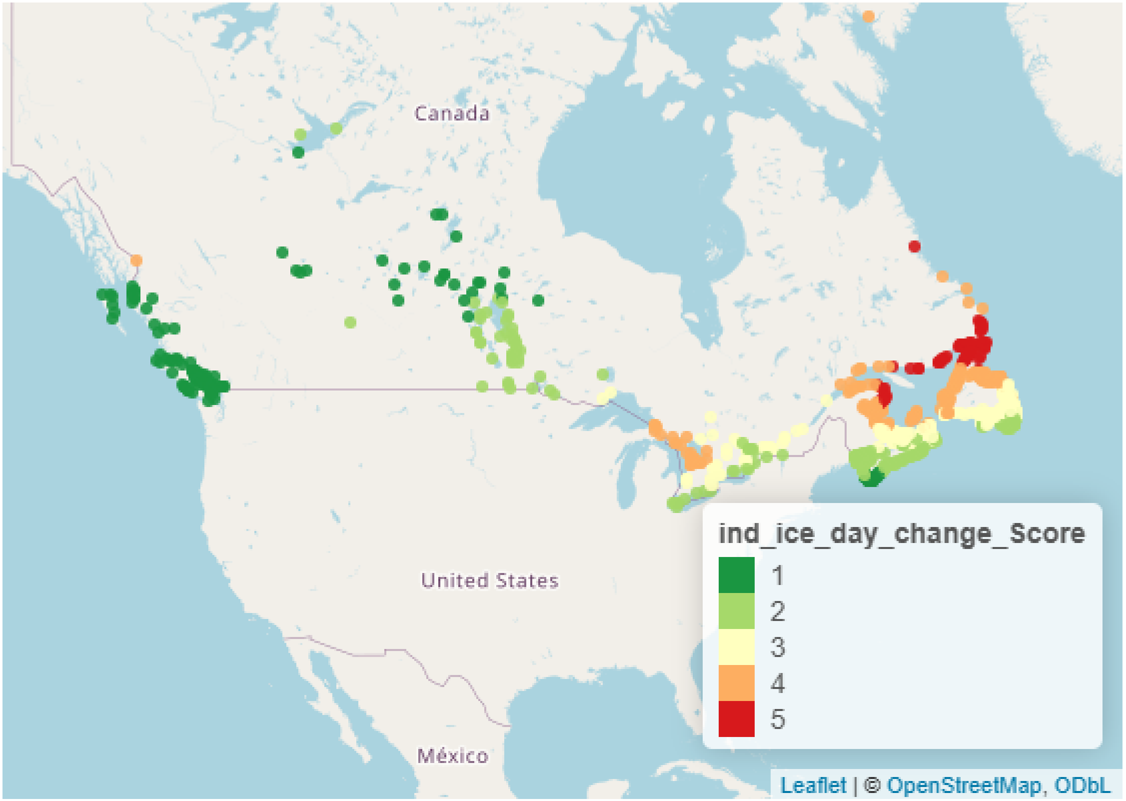

Figure 9: Map of the Ice Days Change (IDC) score at DFO SCH facilities. The higher scores represent higher exposure (more projected change (decline) in ice days).

2.2.3 ADAPTIVE CAPACITY COMPONENT

For the CIVI 2.0 application, we define the Adaptive Capacity component as a measure of the ability of DFO SCH to cope, respond, and adapt to climate change with limited resources. In the overall assessment of vulnerability, a lower adaptive capacity will result in higher vulnerability.

2.2.3.1 REPLACEMENT COST (RC)

The Replacement Cost (RC) of infrastructure owned by DFO at a harbour is an indicator of a facility's vulnerability to the impacts of climate change. The larger the department's asset holdings at a harbour, the greater the opportunity for financial losses in the event of a major weather event associated with the exposure-related impacts of climate change. While the degree of facility protection provides an indication of the harbour's ability to protect users and facilities from the impacts of climate change, harbour facility replacement cost provides only an indication of the department's potential liabilities related to major financial losses. RC has been extracted from the SCHMIR database system for this analysis.

A higher RC is an indicator of lower adaptive capacity (higher vulnerability). The RC values have been scored from 1 representing very low RC (high adaptive capacity) to 5 portraying very high RC (low adaptive capacity) across all sites in the SCH portfolio. (Figure 10).

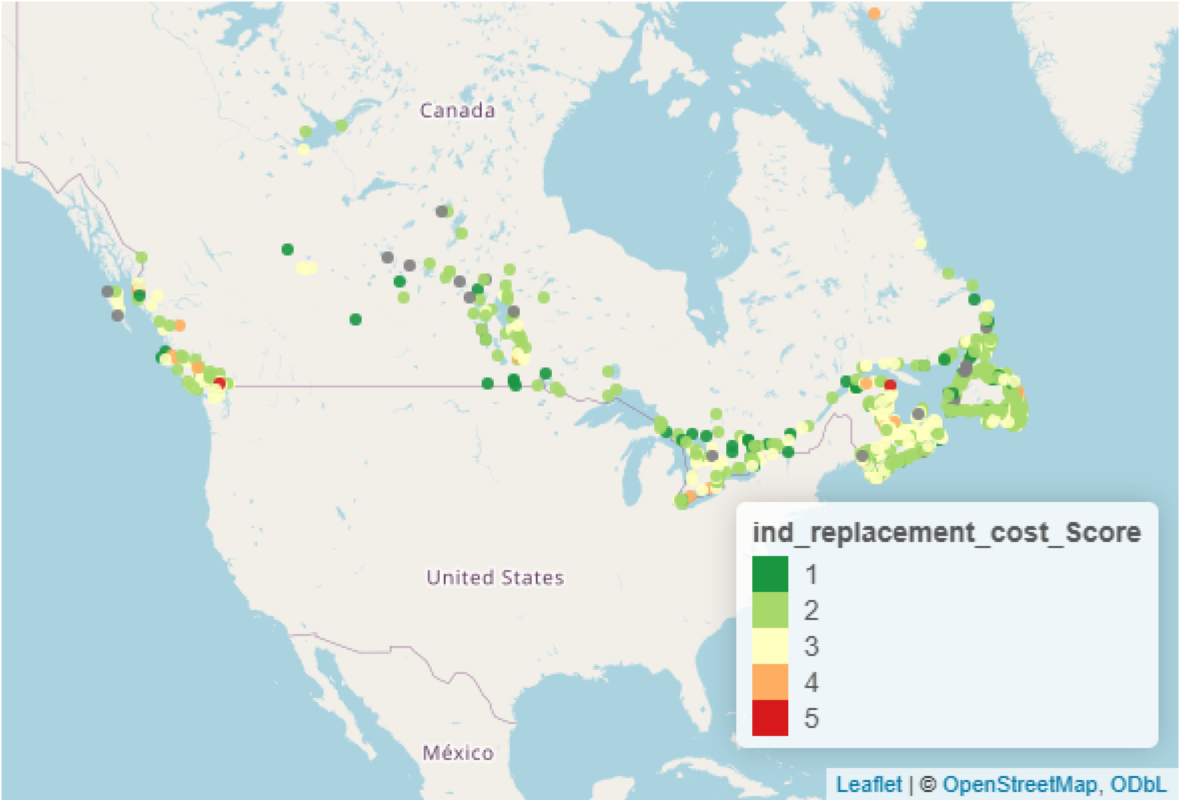

Figure 10: Map of the Replacement Cost (RC) score at DFO SCH facilities. The higher scores represent lower adaptive capacity. Sites that are colored grey indicate there is no data available for the SCH facility.

2.2.3.2 HARBOUR UTILIZATION (HU)

The Harbour Utilization (HU) indicator is a quantitative measure related to the size of a SCH facility. The units of HU are vessel metres, which is the cumulative length of all vessels registered with the SCH facility as their home port. HU data were extracted from the SCHMIR database system for this analysis.

A higher HU is an indicator of lower adaptive capacity (higher vulnerability) because it would be more difficult to accommodate the harbour users at other nearby facilities in the event of a climate-related damage. The HU values are scored from 1 showing very low HU (high adaptive capacity) to 5 depicting very high HU (low adaptive capacity) across all sites in the SCH portfolio (Figure 11).

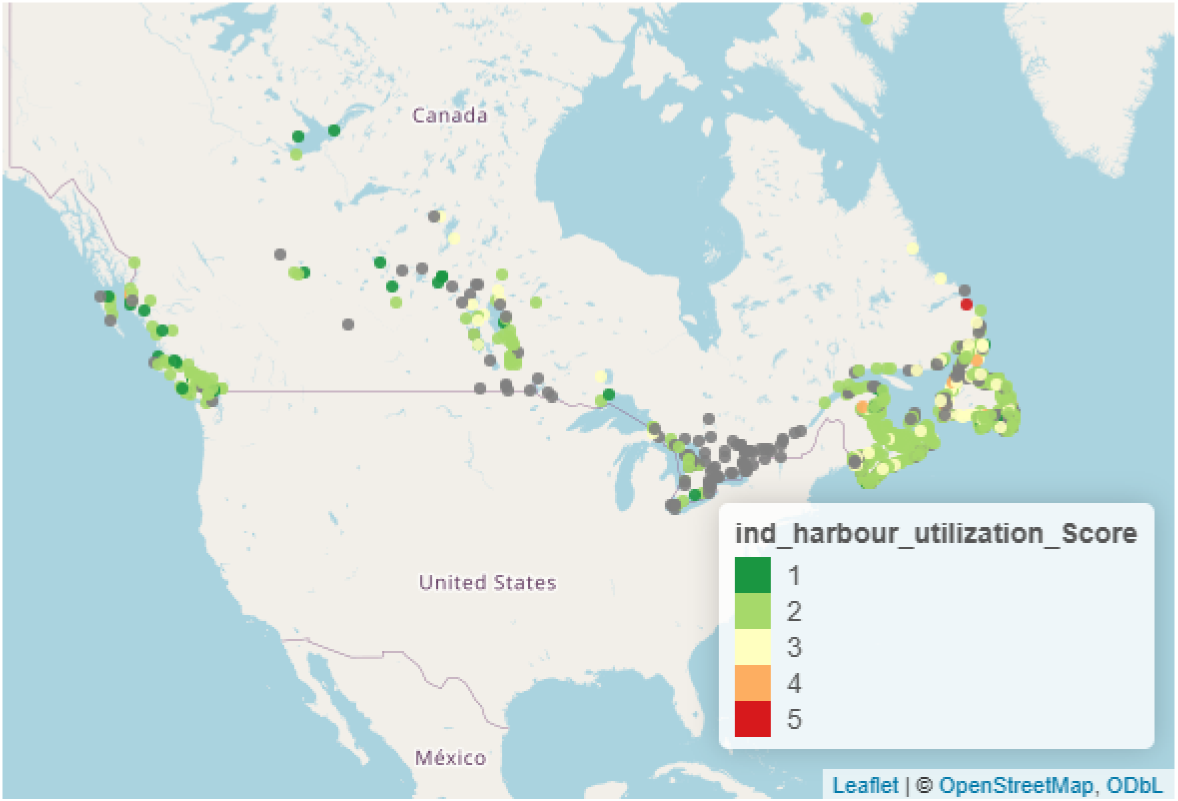

Figure 11: Map of the Harbour Utilization (HU) score at DFO SCH facilities. The higher scores represent lower adaptive capacity. Sites that are colored grey indicate there is no data available for the SCH facility.

2.2.3.3 PROXIMITY (PRX)

The Proximity (PRX) indicator is a measure of the remoteness of a SCH facility (i.e., low (high) PRX reflects that access to the nearest SCH site is relatively difficult (easy) in terms of time commitment). This has been estimated through two computations: firstly, the time required to drive to the nearest neighbouring SCH facility has been calculated using GIS analysis with route mapping and, secondly, the time for a vessel to transit at 10 knots to the nearest neighbouring harbour has been estimated using a least-cost path analysis. The larger of the two times in units of hours is used to calculate the PRX indicator for the SCH facility.

A low PRX is an indicator of lower adaptive capacity (higher vulnerability) because it means that it would require a significant loss of time for the vessel owners to operate from the nearest neighbouring SCH facility. The PRX values based on the time required are scored from 1 representing very low PRX (low adaptive capacity) to 5 depicting very high PRX (high adaptative capacity) across all sites in the SCH portfolio (Figure 12). The resulting estimates of proximity were highly variable along Atlantic and Pacific coast, but in some regions, like the northern Gulf of St. Lawrence and Labrador coast, scores were predominantly low. Many of the inland sites have low proximity scores because they are located on lakes with no other SCH facilities.

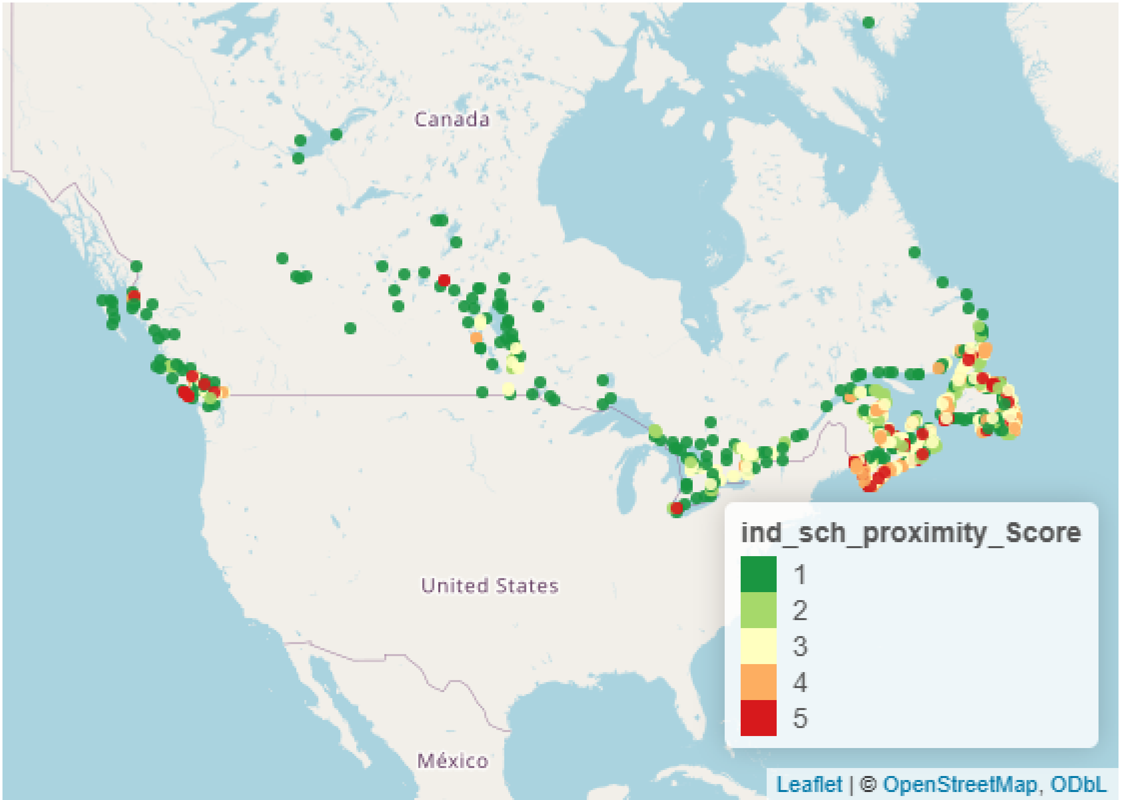

Figure 12: Map of the Proximity (PRX) score at DFO SCH facilities. The higher scores represent higher adaptive capacity.

2.2.4 CALCULATION METHODS

For each of the three components of CIVI 2.0 (Sensitivity, Exposure, Adaptive Capacity), a score was calculated using the geometric mean of the contributing indicators which is defined as the nth root of the product of the indicators:

$$\text{Component Score} = \sqrt[n]{I_1 * I_2 * I_3 * \ldots I_n}$$

This method was selected because it minimizes the influence of outliers and retains a similar range and distributional shape of the input variables (Cogswell et al., 2018). While it is possible to assign weightings to the indicators, this was not done in the analysis. If a SCH site was expected to have a value for an indicator but data were not available to compute a value for this indicator, this resulted in the component score being assigned a NULL value.

Sensitivity is calculated as the geometric mean of CSI, HC, and DFP for each Marine SCH location, and with HC and DFP for each Inland SCH location. Harbour Condition (HC) and Degree of Protection (DFP) are inverted prior to index calculation because higher values for these indicators reflect lower sensitivity. This inversion ensures that all indicators are aligned so higher values consistently indicate greater sensitivity. Consequently, lower Sensitivity index values indicate sites that are less sensitive to climate change.

Exposure is calculated as the geometric mean of the RSLC and IDC for each SCH location. A lower value of this index relative to other SCH locations indicates that site is less exposed to the forces of climate change. Therefore, a lower exposure index value is better. For Inland SCH locations, the RSLC indicator is not available and, therefore, Exposure is only based on the IDC value.

Adaptive capacity is calculated as the geometric mean of the RC, HU and PRX for each SCH location. RC and HU are inverted prior to index calculation because higher values for these indicators reflect lower adaptive capacity. This inversion ensures that all indicators are aligned such that higher indicator values consistently represent higher adaptive capacity. A lower value relative to other SCH locations indicates that site has less capacity/resources to address the potential impacts of climate change. Therefore, a higher adaptive capacity value is better.

The overall vulnerability index CIVI 2.0 is then computed as:

$$\text{CIVI 2.0} = \sqrt[3]{Sensitivity * Exposure * Adaptive\ Capacity\ (inverted)}$$

In cases where any of the three component scores was NULL, this resulted in the CIVI for the site being assigned as NULL overall. The adaptive capacity component score was inverted in the CIVI computation to represent it in terms of vulnerability (i.e., high adaptive capacity (inverted) represents high vulnerability).

The analysis for this project was carried out using R Statistical Computing Software (R Core Team, 2025). The code for this project is maintained in a GitHub repository (https://github.com/AtlanticR/civi2) to maintain transparency in the analysis methodology and ensure version control is in place. Note that the GitHub repository only hosts the R code for the project and not the data files due to privacy policies.

We have limited the number of indicators included in this analysis to ensure each indicator represented an independent variable contributing to the vulnerability of SCH infrastructure with the consideration that they are broadly available for most locations. In addition, the distribution of indices calculated in such an analysis becomes constrained and compressed as more variables are added. Ultimately, the absolute values of the resulting index calculations are less important than their relation to all other values calculated the same way and within a similar extent. What matters most is how the index values compare with each other, not the exact numbers themselves, as long as they are calculated the same way and over the same area.

The results of these computations will be presented in Section 3 of this report.

2.3 CONTEXTUAL INFORMATION

The indicators included in the calculation of CIVI 2.0 were selected to represent the vulnerability of SCH facilities to climate change. However, additional contextual information about the communities and fishing industries that rely on these facilities is also important for understanding their broader socio-economic role. Although this information is not directly incorporated into CIVI 2.0, it can help inform decision-making regarding the allocation of limited capital investments across SCH facilities.

A key limitation is that this contextual information is not consistently available at the national level, resulting in uneven data coverage across regions, with some areas being more data-sparse than others.

2.3.1 POPULATION (CENSUS SUBDIVISION)

In this assessment, each DFO Small Craft Harbour (SCH) was assigned to a 2021 Census Subdivision (CSD), a Statistics Canada unit representing municipalities or municipal equivalents, including reserves and unorganized territories. The latitude–longitude coordinates provided by SCH sometimes fall tens of metres from the coastline (e.g., at wharf or breakwater locations), which can result in misclassification of facilities into incorrect CSDs.

To assign SCH facilities to CSDs, a standard spatial intersection approach was used to identify which CSD polygon contained each SCH location. However, issues arose in cases where small CSD polygons are nested within larger ones. In these situations, some SCH facilities were incorrectly assigned to the larger surrounding polygon, despite being more appropriately associated with the smaller embedded polygon.

To address this, an additional set of conditions was applied:

1. The centroid of an alternative CSD polygon had to be closer to the SCH location than the centroid of the intersecting polygon;
2. The alternative polygon had to be fully contained within the intersecting polygon; and
3. The SCH location had to be within 1 km of the alternative polygon.

When all three conditions were met, the SCH location was reassigned to the nearer, embedded CSD polygon rather than the one identified through the initial intersection. The population of the reassigned CSD was then attributed to the SCH facility (e.g., Figure 13).

This approach results in all SCH facilities located within the same CSD being assigned the same population value.

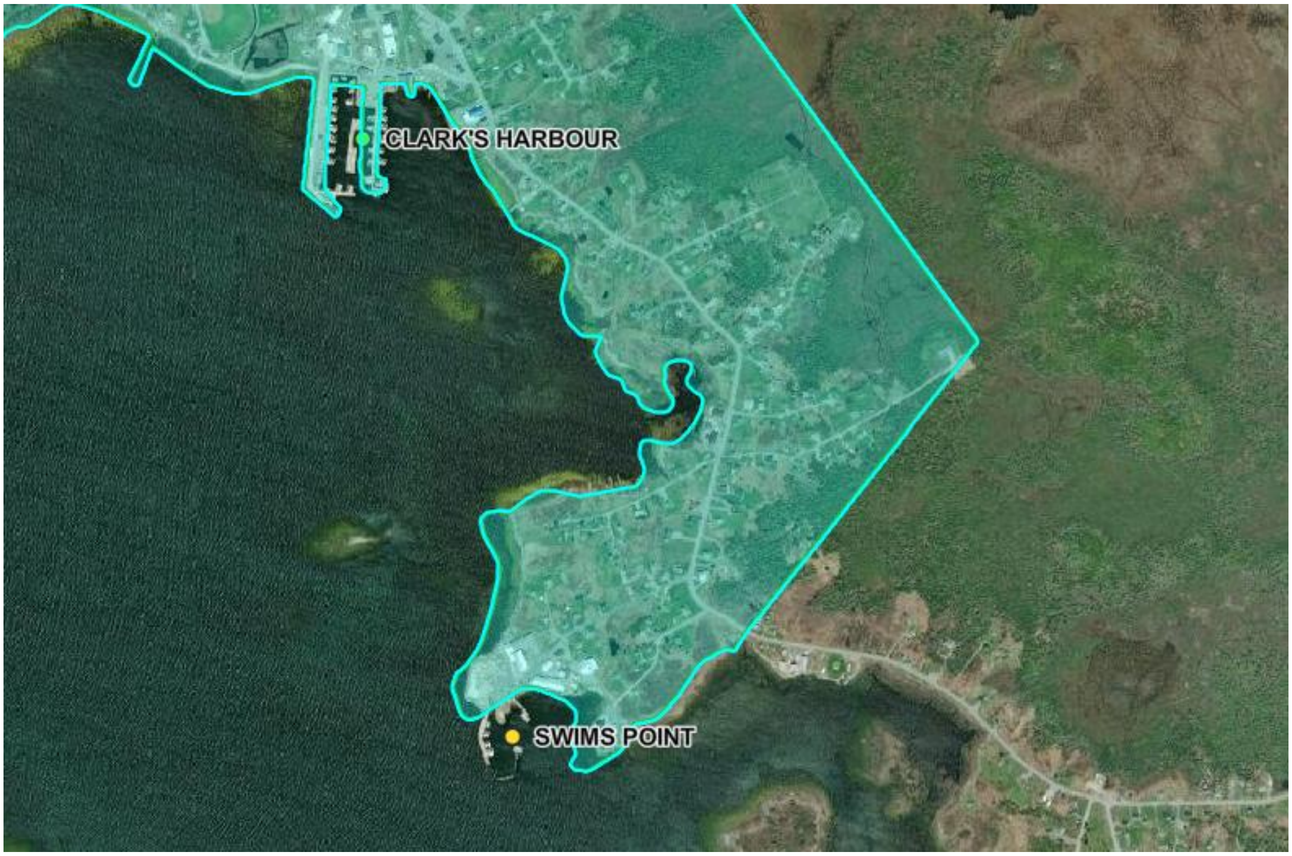

Figure 13: Example of the Swims Point SCH facility in southwest Nova Scotia in which the latitude-longitude position (indicated by the green dot) is assigned to the larger Barrington CSD polygon. However, given the spatial context provided this facility should be assigned to the Clark's Harbour CSD polygon, highlighted by the shaded area, which is nested within the larger Barrington CSD.

2.3.2 CATCH VULNERABILITY

2.3.2.1 FISHERIES LANDINGS

Geolocated commercial fisheries landings data between 2010 and 2020 were obtained from DFOs Integrated Catch and Effort Reporting System (ICERS). ICERS is a comprehensive database aggregating landings from the four DFO Atlantic Regions (Quebec, Maritimes, Gulf, Newfoundland and Labrador) (Figure 14). Each record in the database represents a landing by an individual licence holder. Regardless of the number of sets or tows (individual catch events while at sea), a record represents the catch of each species landed when the harvester returns to port. For example, if a larger boat is at sea for several days and catches four different species that are permitted under the licence conditions, the landed weight and value of each of those species is indicated with a separate record in the ZIFF database, along with other particulars like catch date, vessel ID, geographic region, gear used, species, etc. Similarly, smaller boats that make daily trips for one species (e.g. lobster) have a record in the ZIFF database for each time they return to port with their catch. ICERS data were retrieved by Todd Crawford and Robert Durofil from the DFO Economic Analysis and Statistics group in DFO's National Headquarters.

It should be noted that this analysis was only possible for Atlantic Canada where tracking of commercial fishery landings is available at the scale of DFO SCH facilities. Therefore, this contextual information is not available for other regions of Canada.

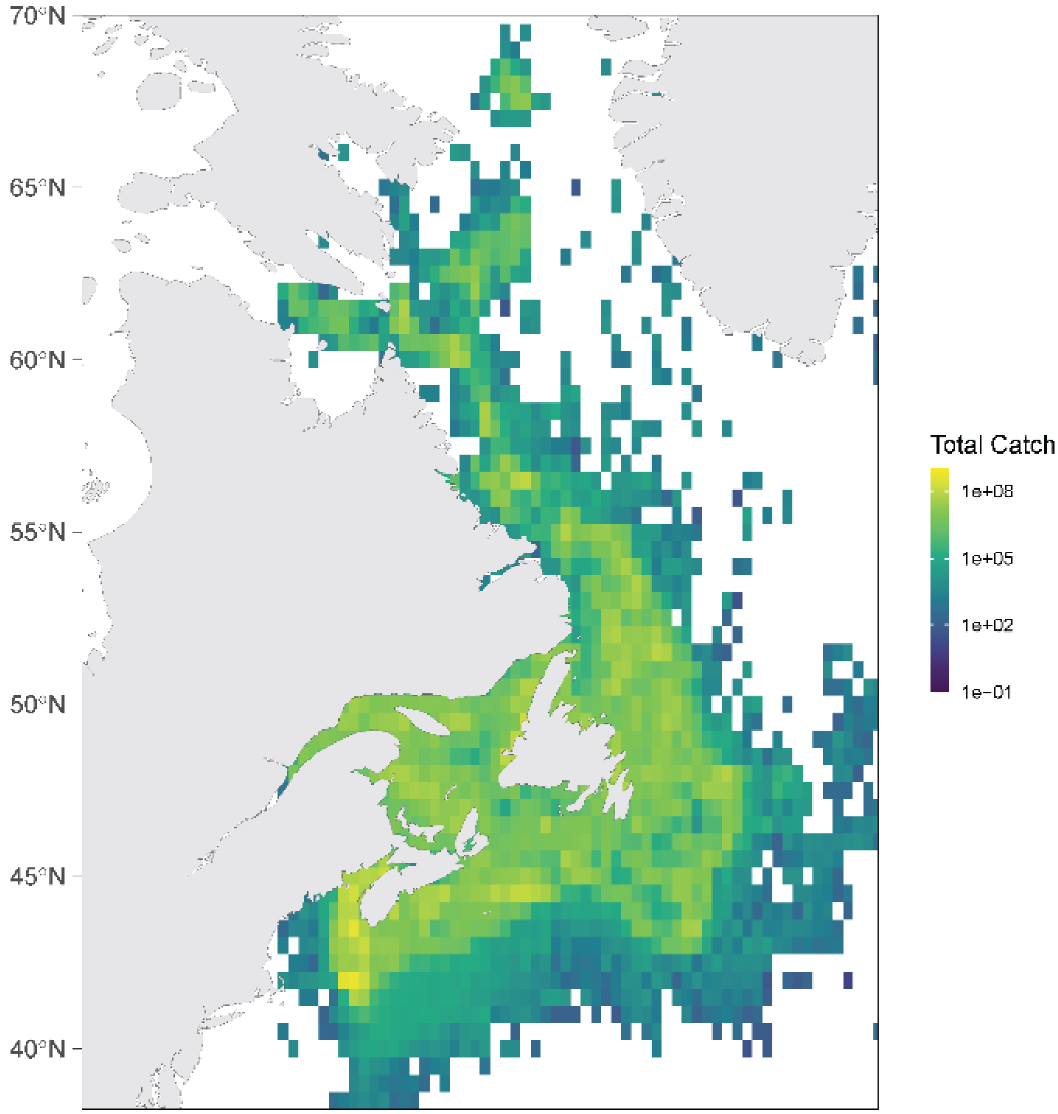

Figure 14: **Geographic distribution of fisheries catch from the ICERS database between 2010 and 2020.**

2.3.2.2 CLIMATE VULNERABILITY AND RISK

Spatially resolved estimates of climate vulnerability and risk for commercial species in Atlantic Canada were derived from the Climate Risk Index for Biodiversity (Figure 15) (Boyce et al., 2022, 2024).

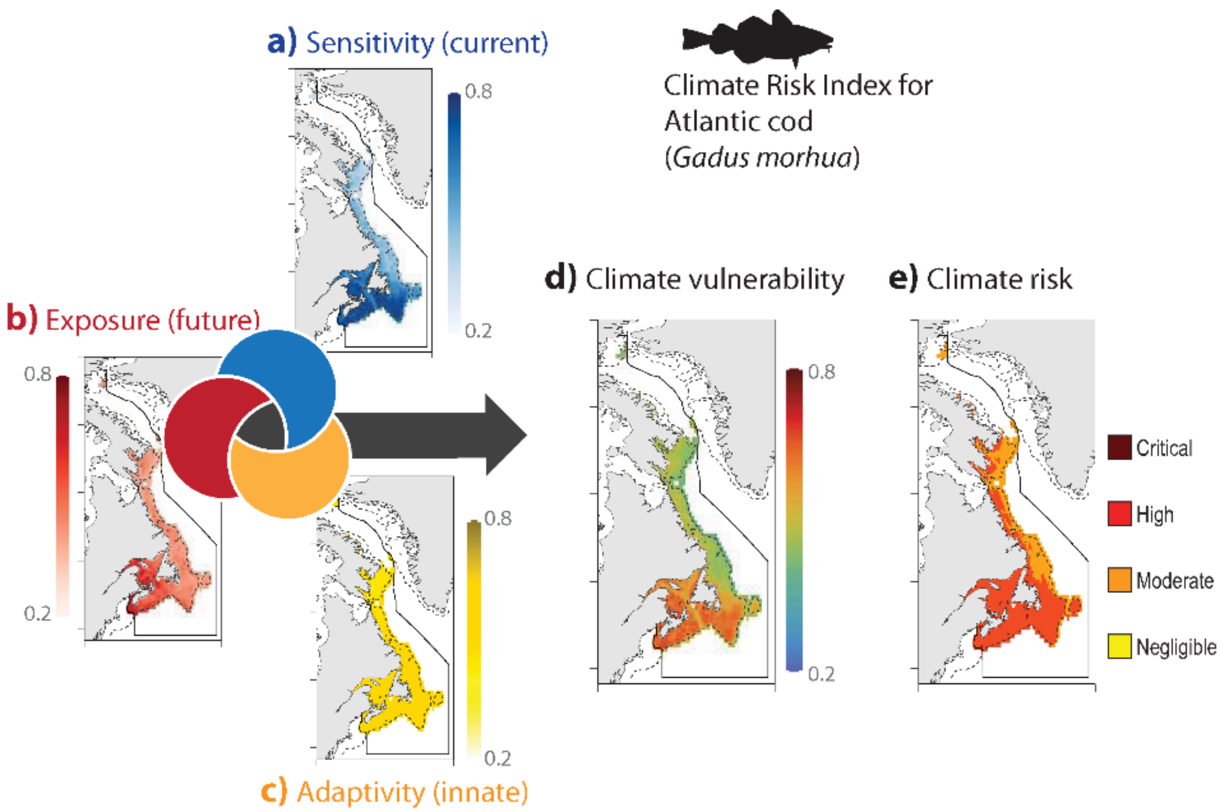

Figure 15: **Spatially explicit CRIB assessment of climate vulnerability and risk for a single species, Atlantic cod (*Gadus morhua*). Within each 0.25° grid cell across the native geographic distribution of cod within the study area, 12 standardized climate indices are calculated and used to define the three dimensions of climate vulnerability, presented here as a conceptual Venn diagram: present-day sensitivity (a; blue), projected future exposure (b; red), and innate adaptivity (c; yellow). The dimensions are used to calculate cod's climate vulnerability (d), and the relative vulnerability scores are translated into absolute climate risk categories for cod at all locations across its distribution (e). Reproduced from *(Boyce et al., 2022)*.**

Given a user-defined spatial domain, species pool, climate projection horizon, and set of emission scenarios, the CRIB produces spatially explicit estimates of relative climate vulnerability and absolute climate risk for each species in the species pool. CRIB operates hierarchically: 12 standardized climate indices capture unique information about the different ways climate can affect marine species and are used to calculate three unique dimensions of risk (sensitivity, exposure, adaptivity), which are finally used to calculate vulnerability. Vulnerability is then translated into risk using pre-defined thresholds informed by the scientific literature; this approach is akin to that used by the International Union for Conservation of Nature (IUCN) Red List to define species extinction risk. A full description of the CRIB framework for estimating climate vulnerability and risk is in Boyce et al. (2022a), and the data and methodology used to implement them in this analysis are in Boyce et al. (2024) and in Table 3.

We harmonized the taxonomic hierarchies using the World Register of Marine Species (WoRMS) to associate species in the CRIB database with those in ICERS.

Table 3: **Data sources used to calculate climate risk using the CRIB framework.**

Type	Variable	Source	Temporal	Spatial	References
Taxonomic, spatial	Species native geographic distribution	AquaMaps	2000-2014	0.5°	(Kaschner et al., 2019)
Taxonomic	Conservation status	Wild Species, IUCN Red List	-	-	(IUCN, 2021)
Taxonomic, spatial	Vertical habitat variability and use	FishBase, SeaLifeBase, AquaMaps	-	-	(Froese & Pauly, 2000; Kaschner et al., 2019; Palomares & Pauly, 2022)
Taxonomic	Maximum body length	FishBase, SeaLifeBase	-	-	(Froese & Pauly, 2000; Palomares & Pauly, 2022)
Taxonomic	Thermal niche	AquaMaps	2000-2014	-	(Kaschner et al., 2019)
Spatial	Cumulative impacts	Cumulative human impact index	-	$1km^2$	(Halpern et al., 2008, 2012, 2015)
Spatial	Bathymetry	General Bathymetric Chart of the Oceans (GEBCO)	-	$4km^2$	(GEBCO, 2009)
Spatiotemporal	Sea surface temperature	NOAA daily Optimum Interpolation Sea Surface Temperature	1981-2020	0.25°	(Reynolds et al., 2007)
Spatiotemporal	Projected sea surface temperature	Coupled model intercomparison project phase 6 (CMIP6)	1850-2100	0.25°	(Eyring et al., 2016)

2.3.2.3 PORT-LEVEL FISHING FOOTPRINTS

The ICERS database was used to create a list of all commercially harvested species (n=52) landed at each unique small craft fishing harbour port (1,233) between 2010 and 2020. We used the homeport of fishing instead of the port of landing because fishers may occasionally offload catch at the port of landing but use their home port more frequently. For each unique species and port combination (n=6,810), we used the catch locations to create a footprint of fishing activity. The fishing footprint represents the geographic domain where fishing from that port for that species is presently carried out; put another way, it is the geographic range of the catch. Fishing footprints were derived by creating a convex hull around the locations of the catch (Figure 16). We then added a small buffer of 0.01 degrees to the footprint as a conservative way of accounting for the possibility of catch occurring nearby or minor errors in data entry. The 6,810 unique fishing footprints were collated as spatial polygons.

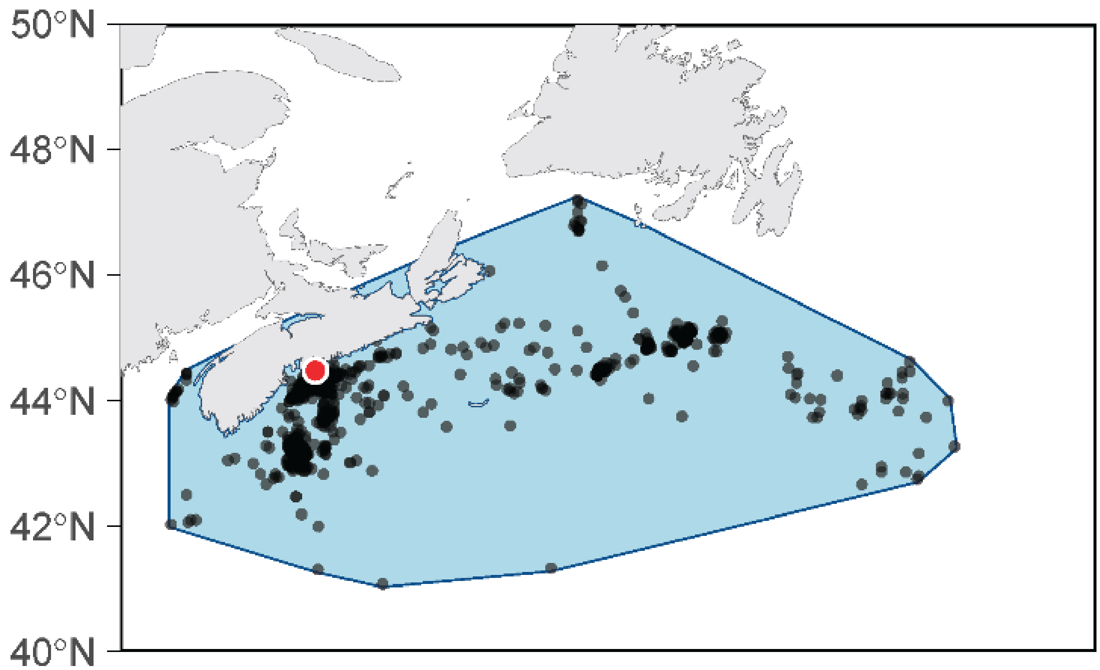

Figure 16: Example of the fishing footprint derivation for harvesting of Atlantic cod from Sambro harbour. Catches of cod are displayed as black dots, the convex hull defining the fishing footprint as light blue, and the red point is Sambro Harbour.

2.3.2.4 PORT-LEVEL CLIMATE VULNERABILITY AND RISK

Climate sensitivity, exposure, adaptivity, vulnerability and risk were estimated for each species and port combination. To achieve this, each fishing footprint was sequentially overlaid on the spatially resolved CRIB output for that particular species (Figure 17). Climate sensitivity, exposure, adaptivity, and vulnerability values, as well as their variances, were calculated across the domain of the fishing footprint. This procedure was repeated for each combination of port and species for the SSP2-4.5 emissions scenario to yield estimates of climate risk and its statistical uncertainty for each commercial species being fished from each small craft fishing harbour. We then translated relative sensitivity, exposure, adaptivity, and vulnerability to risk values using a thresholding approach (Boyce et al., 2022).

A small fraction of the catch recorded in ICERS (0.3%) was not identified to the species level and was removed from the analyses. The resulting database contained catch records and corresponding CRIB output for 68 species, fished from 1,230 harbours including both DFO SCH and private facilities. Possible reasons why estimates were unavailable for the remaining 53% of SCHs include:

1. No catch is landed in the harbours because they are non-operational for fishing activities. In this case, a fishing footprint would not exist, and vulnerability could not be calculated.
2. The catch is landed elsewhere. Harvesters may identify a particular port as their “home port” but land their catch elsewhere at a “landing port,” so there is no recorded catch at the home port. In this case, a fishing footprint would not exist, and vulnerability could not be calculated.

3. Vulnerability estimates are unavailable for the harvested species. The CRIB methodology does not calculate climate vulnerability for deep-dwelling species or those that spend significant periods of their life in freshwater (e.g., gaspereau, alewives, salmon).

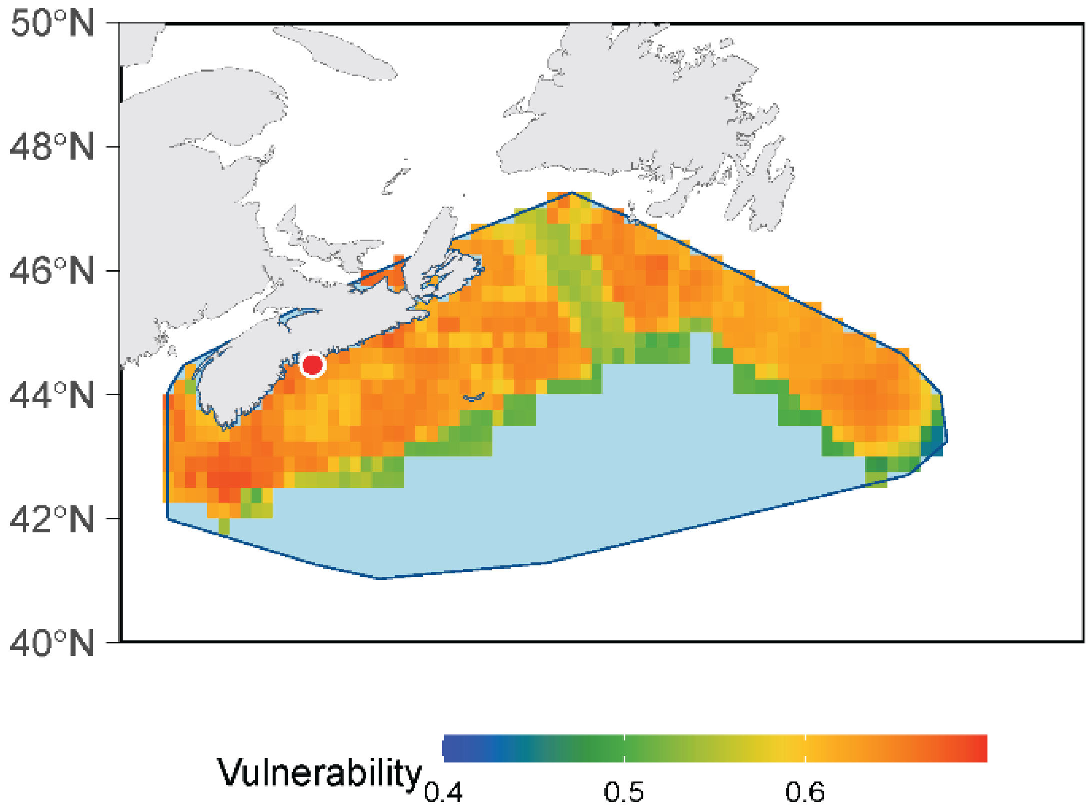

Figure 17: Example of how climate vulnerability is derived for Atlantic cod from Sambro harbour. The spatially-resolved climate vulnerability estimates for cod to 2100 under high emissions (RCP 5-8.5) are restricted to the domain of the fishing footprint for cod harvesting from Sambro harbour (blue-shaded area). The red point is Sambro Harbour (red point).

3 RESULTS

This section will provide a presentation of the components sensitivity, exposure, and adaptive capacity, as well as the overall CIVI results. As stated in Section 2.2.4, each component is computed as the geometric mean of its indicators. CIVI is then calculated as the geometric mean of the three components. It is important to note that since the SCH marine and inland sites do not have the same set of indicators that comparisons of sites should be limited to sites of the same type (marine or inland).

To aid visualization in the CIVI 2.0 application, the Sensitivity, Exposure, Adaptive Capacity and Catch Vulnerability were grouped into three categories: low, medium, and high. The data were first assessed for outliers using a 3-standard-deviation threshold. Values identified as right-side outliers were automatically assigned a score of high, while left-side outliers were assigned a score of low. The remaining observations, which fell within three standard deviations of the median, were classified using a cut function to evenly bin values into the three groups.

3.1 SENSITIVITY COMPONENT

For the sensitivity component, all three indicators are assigned equal weighting in the calculation for marine sites. As the coastal sensitivity index (CSI) is not available for inland sites, the sensitivity component score was calculated as the geometric mean of the harbour condition and degree of facility protection indicators. In other cases, if an indicator value was not available for a site, then the component score was set to NULL value for that site.

The first generation of CIVI did not include any analyses for the SCH inland sites. Although indicator data were available for a large proportion of inland sites for application of CIVI 2.0, NULL values were still more prominent for inland relative to marine sites. As the Degree of Facility Protection (DFP) data set becomes more complete, CIVI 2.0 will be updated to improve the inland coverage for the sensitivity component. There are also some marine facilities without data for either harbour condition or DFP, which needs to be addressed going forward.

The CIVI 2.0 Sensitivity component results for the marine sites were primarily in the low to moderate range (Figure 18). One factor in this pattern is that the CSI from CanCoast is in this range for most locations in Atlantic Canada and the Pacific Region. Higher values of the CSI are predominantly found in the Canadian Arctic. The sites with higher sensitivity values on the marine coastline we driven more by poor HC or low DFP.

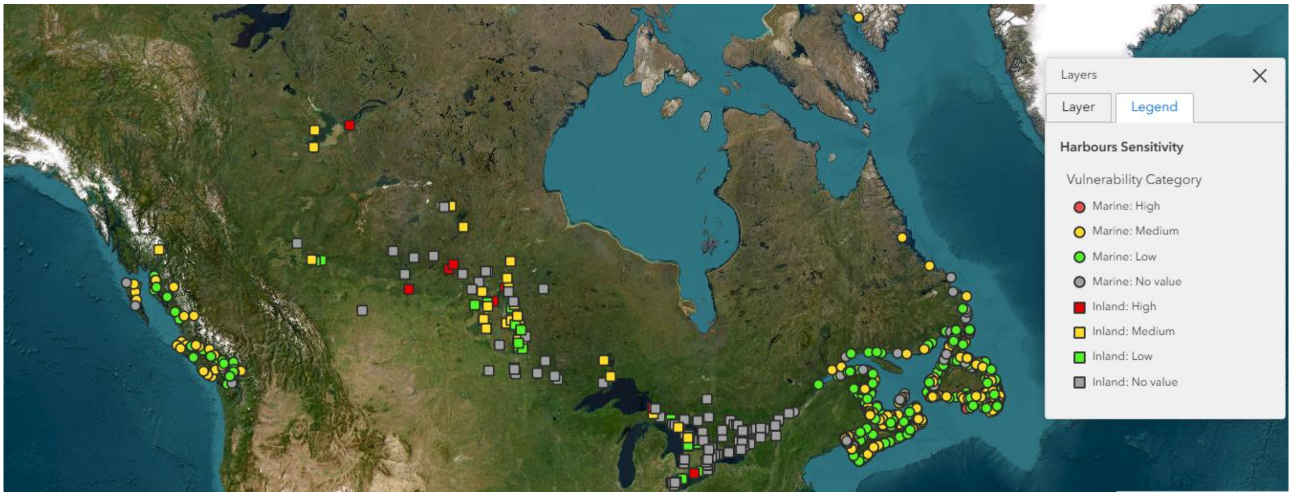

Figure 18: Map of the Sensitivity component at DFO SCH facilities. The higher values represent higher sensitivity. Sites that are colored grey indicate there is at least one missing Sensitivity indicator for the SCH facility and, therefore, the component is not calculated. It is important to note that the Sensitivity for inland sites does not include the Coastal Sensitivity Index (CSI) in the computation of the score, so it is not appropriate to compare marine and inland sites.

3.2 EXPOSURE COMPONENT

For the exposure component, both indicators were assigned equal weighting in the calculation for marine sites. Since sea level change is not applicable to inland sites, Exposure for these sites was determined solely by the ice days change indicator.

The relative sea level change indicator for marine sites was scored highest in southern Atlantic Canada (Figure 7). This is a region where land subsidence exacerbates rising global mean sea level. Relative sea level change is positive at most SCH locations because there is little infrastructure in regions with large land uplift rates. Hence, the low score for sea level change occurs in regions of land uplift which combines with global mean sea level change to have smaller rates of relative (local) change.

The highest scores for the Ice Days Change indicator occurred at marine sites is in the Gulf of St. Lawrence, northern Newfoundland and along the coast of Labrador (Figure 9). The lowest scores were found in regions where present day conditions are relatively warm, such that little to no ice forms in these regions already and, therefore, climate change driven warming will not affect the number of ice days. This was primarily the case along the coast of British Columbia as well as the southern coasts of Nova Scotia and Newfoundland. For inland SCH sites, the highest score was observed in southern Ontario and the lowest found in the northern prairie region where climate change in the SSP2-4.5 scenario is not projected to warm this cold winter region enough to significantly reduce the number of ice days.

The Exposure component for the inland sites was identical to the ice days change indicator and shows the same patten (Figure 19). For the marine sites, the geometric mean of sea level change and ice days change indicator scores resulted in the southern Gulf of St. Lawrence having the highest exposure because significant change is expected in both of the exposure indicators in this region.

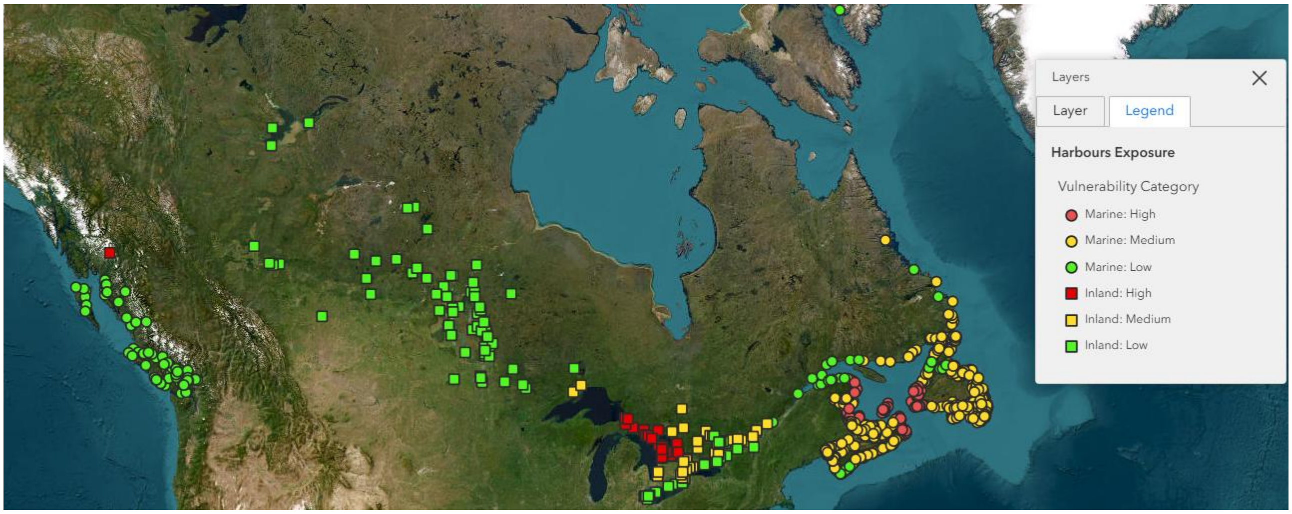

Figure 19: Map of the Exposure component at DFO SCH facilities. The higher values represent higher exposure. It is important to note that the Exposure for marine sites is comprised of sea level change and ice days change while the inland sites are only based on ice days change, so it is not appropriate to compare marine and inland sites.

3.3 ADAPTIVE CAPACITY COMPONENT

The Adaptive Capacity component was comprised of three indicators (replacement cost, harbour utilization, proximity) which were assigned equal weighting in the calculation. If an indicator value was expected but not available for a site, then the component was set to NULL for the site. While proximity was estimated for all SCH facilities, there were small number of sites for which the replacement cost was not available and a larger number (mainly inland) where harbour utilization data was not available.

As expected, the replacement cost scores were highest in areas supporting significant commercial fishery activities such as the BC coast, Gulf of St. Lawrence, Nova Scotia coast and the Bay of Fundy (Figure 10). In addition, the SCH facility in Pangnirtung, Nunavut scores high because of the high construction costs associated with Arctic facilities.

Most the of the SCH facilities, where data were available to permit calculation of the harbour utilization (HU) indicator score, fell into the low to moderate categories with very few scoring high (Figure 11). Coverage of the Adaptive Capacity component score will be improved over time as more HU data becomes available.

The proximity scores provide insight on the potential vulnerability of coastal communities in Canada due to their remoteness from nearby communities (Figure 12). While there can be strong differences in PRX within a region, there are some patterns that can be observed. Firstly, most inland facilities scored low in PRX mainly because they are the only facility on a lake and, therefore, there is no sailing distance to the nearest SCH facility and, in many cases, the nearest facility does not fall within the 25 km radius cutoff. Secondly, the highest PRX scores were mostly observed in southern BC and southern Atlantic Canada. Thirdly, in northern BC and northern Atlantic Canada almost all of the scores were 1 indicating these regions are particularly vulnerable due to their remoteness.

The general pattern of the Adaptive Capacity component (Figure 20) is similar to that of the proximity indicator because the other indicators had less spatial coherence. Therefore, the Adaptive Capacity component scores were generally highest in southern BC and southern Atlantic Canada.

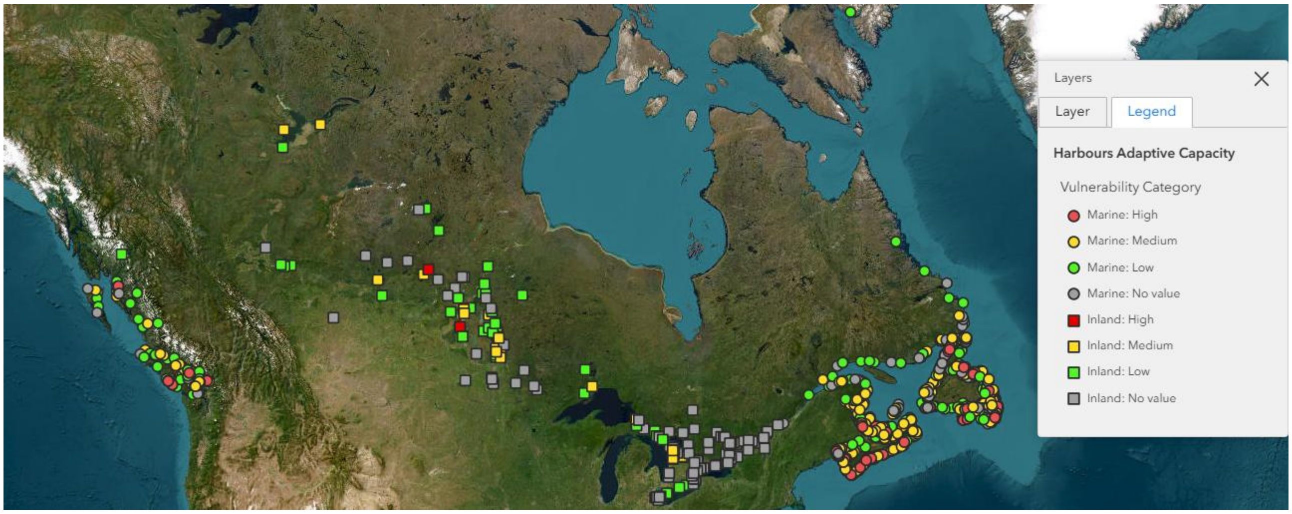

Figure 20: Map of the Adaptive Capacity component at DFO SCH facilities. The higher values represent higher adaptive capacity (lower vulnerability). Sites that are colored grey indicate there is at least one missing Adaptive Capacity indicator for the SCH facility and, therefore, the component is not calculated.

3.4 COASTAL INFRASTRUCTURE VULNERABILITY INDEX

The CIVI values for SCH facilities provide summary overview of each site incorporating the sensitivity, exposure and adaptive capacity (Figure 21). While there can be significant variability in the CIVI values between neighbouring SCH facilities, there are some regional pattens that are significant. Firstly, most of the facilities on the west coast of Canada score relatively low. Secondly, in the Atlantic region the sites in the Gulf of St. Lawrence generally have a higher CIVI score which seems to be primarily driven by the high exposure to climate change forcing that is projected for this region.

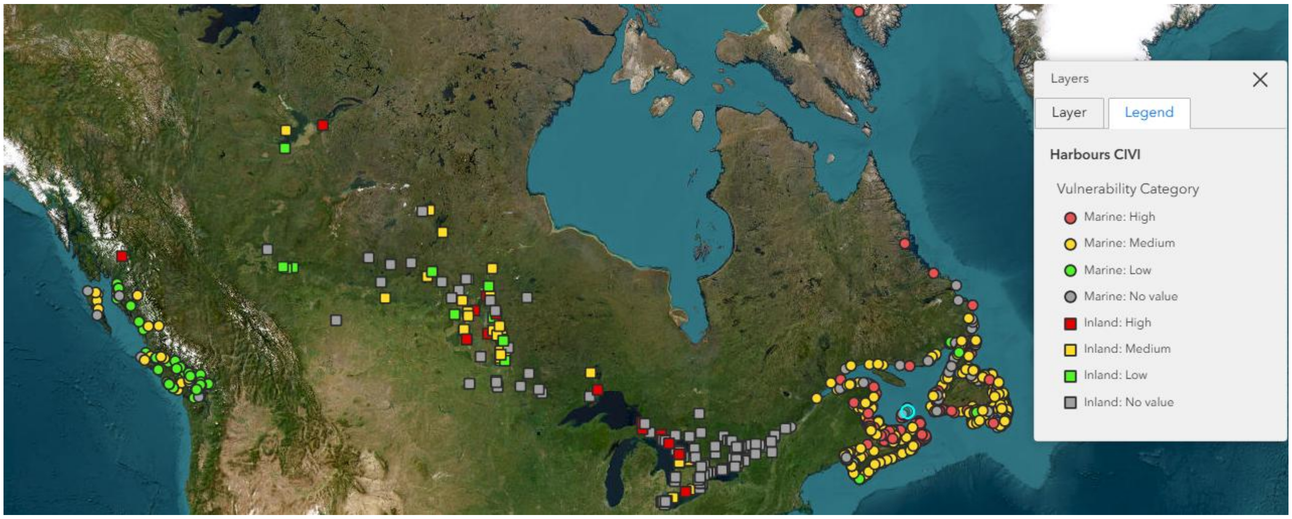

Figure 21: Map of the Coastal Infrastructure Vulnerability Index (CIVI) at DFO SCH facilities. The higher values represent higher vulnerability. Sites that are colored grey indicate there is at least one missing indicator for the SCH facility and, therefore, the index is not calculated.

3.5 CATCH VULNERABILITY

Of the 624 small craft harbours along the marine coastline of Canada with infrastructure vulnerability estimates, 473 (76%) were in Atlantic Canada and possessed corresponding estimates of Catch Vulnerability (Figure 22). The results show a general pattern of high Catch Vulnerability scores in the southern Gulf of St. Lawrence along the coasts of les Îles de la Madeleine, Prince Edward Island, western Cape Breton and eastern New Brunswick. This is a region where Snow Crab, an important component of the commercial fishery, could be impacted by the projected rise in ocean temperature in this region over the remainder of this century.

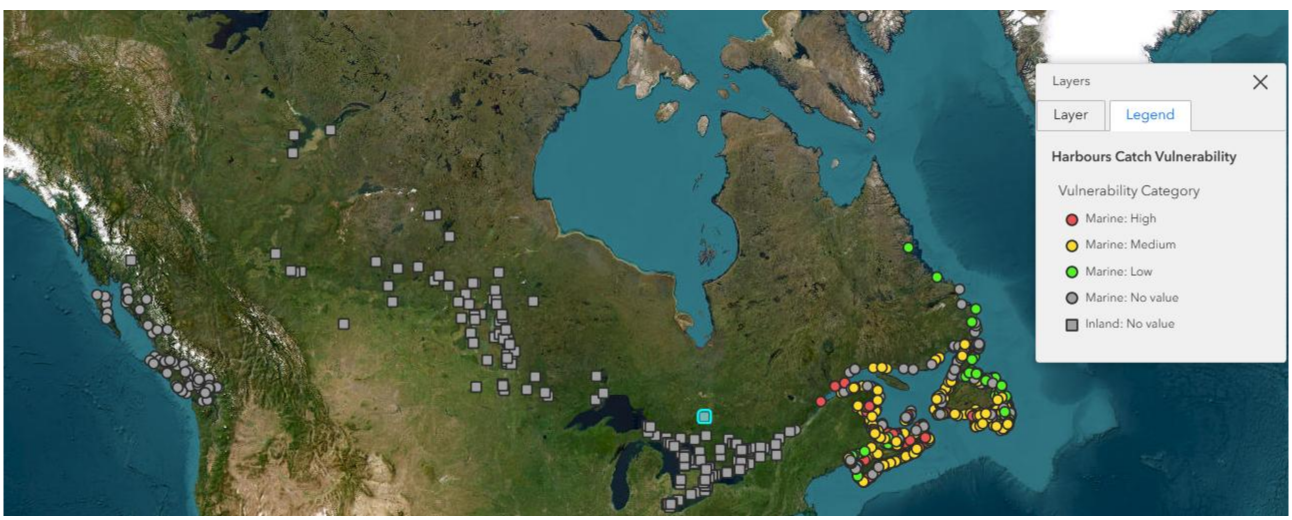

Figure 22: Map of Catch Vulnerability at DFO SCH facilities. The higher values represent higher vulnerability. Sites that are colored grey indicate that fishery landings data are not available for the SCH facility.

4 CONCLUSIONS

This report presents the development, methodology, and initial results of the Second Generation Coastal Infrastructure Vulnerability Index (CIVI 2.0). By adopting the internationally recognized vulnerability assessment framework of sensitivity, exposure, and adaptive capacity, CIVI 2.0 modernizes DFO's approach to evaluating climate-related risks to Small Craft Harbours infrastructure. This updated framework supports national consistency, increases transparency, and strengthens alignment with current scientific understanding of climate vulnerability.

Results from CIVI 2.0 underscore the diversity of climate-related risks facing SCH facilities across Canada. In particular, exposure to projected relative sea-level rise and declining ice conditions strongly elevates vulnerability in parts of Atlantic Canada, especially the Gulf of St. Lawrence. Conversely, many Pacific and inland facilities exhibit lower vulnerability scores, although data gaps—particularly related to harbour utilization and inland facility condition—highlight areas for future improvement. The adaptive capacity component provides additional insight into regional differences, emphasizing the challenges faced by remote communities and harbours with limited alternative neighbouring harbours or high replacement costs.

CIVI 2.0 also expands the suite of contextual information available to decision-makers by including commercial fishery catch vulnerability and census subdivision level population. While not incorporated directly into the index calculation, these data sets support more holistic planning and help identify where climate impacts on infrastructure may interact with community and ecological vulnerabilities.

As climate data, engineering assessments, and socio-economic conditions continue to evolve, routine updates to CIVI will be essential. The reproducible analytical workflow (https://github.com/AtlanticR/civi2) and transparent methodological choices adopted here are intended to facilitate future updates and promote ongoing collaboration between DFO SCH and Science sectors. Overall, CIVI 2.0 represents a significant advancement in DFO's efforts to build climate-resilient coastal infrastructure and to support evidence-based planning across Canada's Small Craft Harbours program.

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