SMALL CRAFT HARBOURS COASTAL INFRASTRUCTURE VULNERABILITY INDEX PILOT PROJECT

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LIST OF ABBREVIATIONS

ACCASP	Aquatic Climate Change Adaptation Services Program
AFI	Average Fishing Income
AFIAEI	Average Fishing Income to Average Employment Income
ALQ	Average Landed Quantity
ALQVAPL	Average Landed Quantity per Vessel Port of Landing
ALV	Average Landed Value
AR5	Fifth Assessment Report
ATITF	Average Total Income with Tax Filers
CAN-EWLAT	Canadian Extreme Water Level Adaptation Tool
CIVI	Coastal Infrastructure Vulnerability Index
CM	Coastal Materials
CRA	Canada Revenue Agency
CSD	census sub-division
CTLQ	Change in Total Landed Quantity
DFO	Fisheries and Oceans Canada
DFP	Degree of Facility Protection
EEZ	Economic Exclusion Zone
ESI	Exposure Sub-Index
gm	geometric mean
HC	Harbour Condition
ICERS	Integrated Catch and Effort System
IPCC	Intergovernmental Panel on Climate Change
ISI	Infrastructure Sub-Index
ISI	Infrastructure Sub-Index
LTS	Long Term Strategy
MMWH	Mean Maximum Wave Height
MMWS	Mean Maximum Wind Speed
NA	not available
NAVPL	Number of Active Vessels Port of Landing
NEC	National Engineering Committee
NMC	National Management Committee
NRCAN	Natural Resources Canada
NTS	National Topographic System
RC	Recoded
SCH	small craft harbour
SESI	Socio-Economic Sub-Index
SIC	Sea Ice Change
SLC	Sea Level Change
TP	Total Population
TRC	Total Replacement Cost

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ABSTRACT

As part of the Aquatic Climate Change Adaptation Services Program (ACCASP) established by the Government of Canada in 2011, Fisheries and Oceans Canada (DFO) Small Craft Harbours (SCH), DFO Science, Maritimes Region, and DFO Economic Analysis and Statistics Directorate developed a Coastal Infrastructure Vulnerability Index (CIVI). The CIVI provides a numerical indication of the relative vulnerability of an SCH to the effects of climate change. Based on a benchmarking exercise conducted for vulnerability indices used for similar purposes, the CIVI was designed with three component sub-indices: Exposure (natural forces), Infrastructure, and Socio-economic. Each of the sub-indices incorporates three to five component variables which were scored on a scale of 1 to 5 (not vulnerable to highly vulnerable) depending on the harbour's vulnerability to that particular variable. These scores were then rolled up at the sub-index level, and subsequently aggregated into a final Coastal Infrastructure Vulnerability Index (CIVI) for each of the pilot harbours.

The Exposure Sub-Index (ESI) includes five component variables: relative sea level change, maximum wind speed, maximum significant wave height, coastal materials (shoreline type/susceptibility to erosion), and change in sea ice duration. The Infrastructure Sub-Index (ISI) is composed of three variables: harbour condition, total harbour replacement cost and degree of facility protection. The Socio-Economic Sub-Index (SESI) is composed of three variables: average landed quantity per average number of vessels at harbour, average fishing income to average employment income, and total population.

This report details the methods and results of the pilot study conducted between November 2014 and March 2016. Twenty-four core small craft harbours were selected from the five SCH Regions for analysis as part of the pilot project. Of the 24 pilot harbours, the three pilot harbours in Central and Arctic Region had to be removed from the analysis due to the lack of Exposure and Socio-Economic data. The four pilot harbours in the Pacific Region had the CIVI calculated with only the Exposure and Infrastructure sub-indices since socio-economic data was unreliable or unavailable. The remaining 17 harbours from the Maritimes & Gulf of St. Lawrence, Newfoundland and Labrador, and Québec Regions had the complete CIVI calculated with all three component sub-indices. These 17 harbours are collectively referred to as the Atlantic Region pilot sites throughout this report.

For the Atlantic Region, ESI scores ranged from 3.4 to 1.9, with Étang-du-Nord (QC) being the most vulnerable and North Head (NB) being the least vulnerable. The ISI scores ranged from 4.2 to 1.8, with Bartlett's Harbour (NL) being the most vulnerable harbour and Twillingate (NL) being the least vulnerable of the pilot harbours. The SESI ranged from 3.3 to 1.3, with Mont-Louis Ouest (QC) being the most vulnerable harbour and Seal Cove (PEI) being the least vulnerable harbour. When aggregated into the final CIVI the scores ranged from 3.14 to 1.99, with Bartlett's Harbour being the most vulnerable harbour and Seal Cove being the least vulnerable harbour.

In the Pacific Region the Exposure sub-index ranged from 3.41 to 3.00, with Ucluelet

West being the most vulnerable and Fanny Bay being the least vulnerable. The Infrastructure sub-index ranged from 3.63 to 2.88, with Cowichan Bay being the most vulnerable and Fanny Bay being the least vulnerable. The lack in variability of these scores is likely due to all of the harbours being located on Vancouver Island, with relatively similar exposure levels.

A progress update and presentation of preliminary results for the CIVI project were provided to the SCH National Management Committee (NMC) on February 18, 2016. NMC supported a continued effort on this work and recommended a roll-out to all remaining SCH locations for which complete datasets exist. Based on the endorsement of NMC, in the following year the Project Steering Committee aims to complete the Degree of Infrastructure Protection variable for all Atlantic and Pacific harbours, explore improving socio-economic data for Atlantic and Pacific Regions, and investigate the feasibility of extending the tool to freshwater SCH sites.

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RÉSUMÉ

Dans le cadre du Programme des services d'adaptation aux changements climatiques en milieu aquatique (PSACCMA) établi par le gouvernement du Canada en 2011, Ports pour petits bateaux (PPB), le Secteur des sciences, la Région des Maritimes et la Direction des analyses économiques et statistiques de Pêches et Océans Canada (MPO) ont élaboré un indice de vulnérabilité des infrastructures côtières (IVIC). L'IVIC donne une indication numérique de la vulnérabilité relative d'un port pour petits bateaux aux effets des changements climatiques. D'après un exercice d'analyse comparative mené pour des indices de vulnérabilité utilisés à des fins similaires, l'IVIC a été conçu au moyen de trois sous-indices : exposition (forces de la nature), infrastructures et contexte socio-économique. Chaque sous-indice compte de trois à cinq variables qui ont été cotées sur une échelle de 1 (non vulnérable) à 5 (très vulnérable) selon la vulnérabilité du port à une variable donnée. Les cotes ont ensuite été cumulées au niveau des sous-indices, puis regroupées en un indice de vulnérabilité des infrastructures côtières (IVIC) final pour chacun des ports participant au projet pilote.

Le sous-indice de l'exposition (SIE) se compose de cinq variables : le changement relatif du niveau de la mer, la moyenne de la vitesse maximale du vent, la hauteur moyenne significative des vagues, les matériaux côtiers (le type de littoral et la vulnérabilité à l'érosion) et le changement de la durée de la glace de mer. Le sous-indice des infrastructures (SII) se compose de trois variables : l'état du port, le coût total de remplacement du port et le degré de protection des installations. Le sous-indice socio-économique (SISE) se compose de trois variables : la quantité débarquée moyenne par d’emploi moyens et la population totale.

Le présent rapport décrit en détail la méthode et les résultats de l'étude pilote menée entre novembre 2014 et mars 2016. Vingt-quatre ports essentiels pour petits bateaux ont été choisis dans les cinq régions de PPB aux fins d'analyse dans le cadre du projet pilote. Sur les 24 ports participant au projet pilote, les trois ports de la Région du Centre et de l'Arctique ont dû être retirés de l'analyse en raison du manque de données sur l'exposition et le contexte socio-économique. Pour les quatre ports de la Région du Pacifique, l'IVIC n'a été calculé que pour les sous-indices de l'exposition et des infrastructures, car les données sur le contexte socio-économique n'étaient pas fiables. Pour les 17 autres ports des Régions des Maritimes (golfe du Saint-Laurent), de Terre-Neuve-et-Labrador et du Québec, l'IVIC a été calculé au moyen des trois sous-indices. Dans le rapport, ces 17 ports sont collectivement nommés les sites pilotes de la Région de l'Atlantique.

Pour la Région de l'Atlantique, les cotes attribuées au SIE allaient de 3,4 à 1,9, North Head (au Nouveau-brunswick) étant le port le moins vulnérable et Étang-du-Nord (au Québec) étant le port le plus vulnérable parmi les ports participant au projet pilote. Les cotes attribuées au SII oscillaient entre 4,2 et 1,8, Bartlett’s Harbour (à Terre-Neuve-et-Labrador) étant le port le plus vulnérable et Twillingate (également à Terre-Neuve-et-Labrador) étant le moins vulnérable parmi les ports participant au projet pilote. Le SISE avait une cote oscillant entre 3,3 et 1,3, Mont-Louis Ouest (au Québec) étant le port le plus vulnérable et Seal Cove (à l'Île-du-Prince-Édouard) étant le port le moins vulnérable.

Intégrées à l'IVIC final, les cotes allaient de 3,14 à 1,99, Bartlett's Harbour étant le port le plus vulnérable et Seal Cove, le port le moins vulnérable.

Dans la Région du Pacifique, le sous-indice de l'exposition variait de 3,41 à 3, Ucluelet West étant le port le plus vulnérable et Fanny Bay, le port le moins vulnérable. Le sous-indice des infrastructures variait de 3,63 à 2,88, le port de Cowichan Bay étant le plus vulnérable et le port de Fanny Bay, le moins vulnérable. Le manque de variabilité de ces cotes est probablement attribuable au fait que tous les ports sont situés sur l'île de Vancouver et que les niveaux d'exposition sont relativement semblables. L'indice agrégé n'a pas été calculé pour la Région du Pacifique de PPB, car les données socio-économiques pour cette région n'étaient pas disponibles.

Une mise à jour de l'avancement et une présentation des résultats préliminaires du projet d'IVIC ont été fournies au Comité national de gestion (CNG) de PPB le 18 février 2016. Le CNG était en faveur de la poursuite de ce travail et a recommandé d'inclure tous les autres emplacements de PPB pour lesquels il existe des ensembles de données complets. Compte tenu de l'appui du CNG, le Comité directeur du projet songe à achever dans l'année qui vient la variable du degré de protection des infrastructures pour tous les ports de l'Atlantique et du Pacifique, à envisager d'améliorer les données socio-économiques pour les Régions de l'Atlantique et du Pacifique, et à étudier la possibilité d'utiliser l'outil pour les sites de PPB en eau douce.

1 INTRODUCTION

> “Global mean sea level will continue to rise during the 21st century. Under all RCP scenarios, the rate of sea level rise will very likely exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets.” – Intergovernmental Panel on Climate Change Assessment Report 5 (2013).

As part of a five-year climate change adaptation initiative started in 2011 by the Government of Canada, Fisheries and Oceans Canada (DFO) established the Aquatic Climate Change Adaptation Services Program (ACCASP). The program is developing knowledge about climate change to integrate it into the delivery of departmental programs. ACCASP has three components: 1) assessment of climate change risks and vulnerabilities in four large basins, 2) research to understand the impacts of climate change and 3) research to create applied science to adapt to climate change.

The Coastal Infrastructure Vulnerability Index (CIVI) project received funding in June 2014 following a successful ACCASP project proposal. The primary objectives of this project are to develop a national vulnerability index for small craft harbours, and to provide an updated version of the Natural Resources Canada CanCoast GIS database based on the latest scientific information available.

The CIVI is an index that incorporates variables measuring exposure, infrastructure and socio-economic aspects that contribute to the viability or vulnerability of a harbor. Combining measures of environmental exposure with socio-economic and infrastructure variables, the final index gives a relative measure of vulnerability in comparison to other harbours in the same region.

The exposure layers used from the Natural Resources CanCoast GIS database were: projected sea level change for 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.

CIVI will enable Small Craft Harbours (SCH) to carry out scoping and first-look assessments of vulnerability to climate change using a nationally-consistent geodatabase platform.

A CIVI project steering committee was formed and a terms of reference document was developed in November 2014 (see Appendix A). The Committee met via teleconference on approximately a quarterly basis and has held two one-day face-to-face workshops (13 January 2015 and 1 February 2016) to advance the development of a coastal vulnerability index for Small Craft Harbours (SCH) harbours.

At the January 2015 workshop, the Project Steering Committee developed a project concept consisting of three sub-indices that would be developed for a harbour (exposure, infrastructure vulnerability and socio-economics). The Committee also established preliminary variables that could be included in these sub-indices. This is consistent with approaches used in other jurisdictions. This concept was presented to the SCH National Engineering Committee (NEC) on January 14, 2015, who endorsed continued work on the concept.

The second workshop took place on 1 February 2016 in Quebec City at the SCH Regional Office. A review of the methodology took place as well as discussions for improvements and limitations. Preliminary project findings were presented to the SCH National Management Committee (NMC) on February 18, 2016. NMC supported a continued effort on this work and recommended a roll-out to all SCH locations for which accurate data exist.

2 PILOT HARBOURS

The committee, with the approval of SCH-NMC, developed a list of 24 SCH pilot harbours on which to advance the development of the three sub-indices. These harbours were chosen as they represent all SCH regions and were previously part of a pilot project for the SCH Long Term Strategy Exercise. All of the sites are core harbours.

Table 1 - CIVI pilot study harbours

* harbours not used in final pilot project

Pilot Harbour Name	Province	Region
Bayfield*	ON	C&A
Rondeau (Erieau)*	ON	C&A
Wheatley*	ON	C&A
Auld's Cove	NS	M&G
Centreville (Trout Cove)	NS	M&G
Ingalls Head	NB	M&G
Machons Point	PEI	M&G
Meteghan	NS	M&G
North Head - Fishermen's Wharf	NB	M&G
Pinkney's Point	NS	M&G
Sainte-Marie-Sur-Mer	NB	M&G
Seal Cove - Fisherman's Wharves	NB	M&G
Bartletts Harbour	NFLD	NFLD
Bauline Harbour	NFLD	NFLD
Pool's Cove	NFLD	NFLD
Twillingate (Shoal Tickle)	NFLD	NFLD
Bamfield West	BC	PAC
Cowichan Bay	BC	PAC
Fanny Bay	BC	PAC
Ucluelet West	BC	PAC
Etang-du-Nord	QUE	QC

Pilot Harbour Name	Province	Region
Les Escoumins (Basques)	QUE	QC
Mont-Louis Ouest	QUE	QC
Tourelles (St-Joachim)	QUE	QC

3 SUB-INDEX DEVELOPMENT

A DFO lead was identified for each of the three sub-indices. This lead developed a sub-index and its sub-variables and calculated the values for each of the variables. Each of the sub-indices, along with component variables, are explained in detail below.

3.1 EXPOSURE SUB-INDEX (ESI)

The coastline layer used for this process is based upon the 1:50,000 National Topographic System (NTS) coastline (CanVec version 9.0) as used in the original NRCAN Shaw et al. (1998) sensitivity analysis.

For all variables, this coastline was first broken into individual line segments, the data attached to each segment and then the lines dissolved once again into NTS sheets extents.

3.1.1 <u>Sea level change</u>

Data for relative sea level change (SLC) were derived from the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC 2014, AR5). A 1 degree resolution grid of relative sea level change was calculated for all years between 2006 and 2100. Projected sea level change for the years 2020, 2030, 2040, 2050, 2060, 2070, 2080, 2090, and 2100 were used. The modeled grid did not touch the coastal line layer in all areas and so the grid was extended into the gaps using the Focal Statistics (MEAN) function. To extend the grid into areas not covered by the model it was necessary to first subtract out the value of isostatic adjustment, extend the raw sea level rise into those blank areas and then add the isostatic adjustment back in. SLC change values were then joined to the coastline using the Intersect Lines With Raster tool from Geospatial Modelling Environment (http://www.spatialecology.com/gme/).

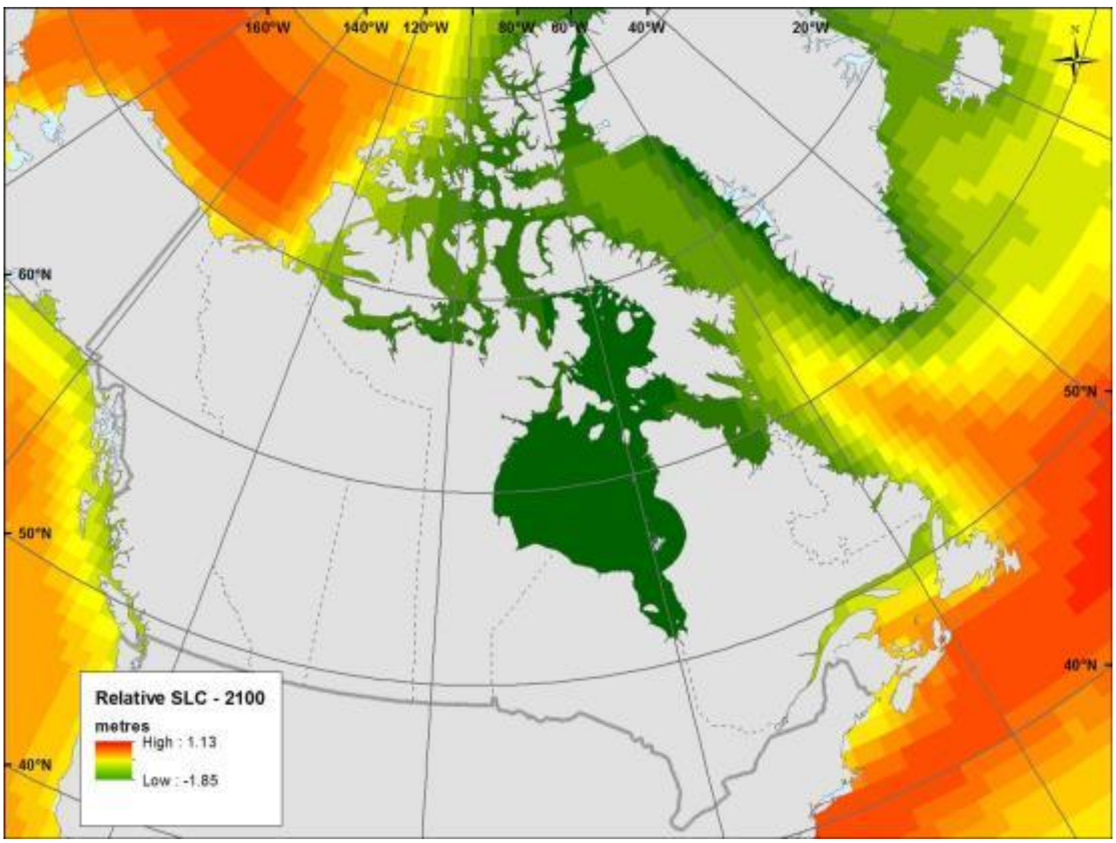


Figure 1 - Predicted relative sea level change in the year 2100.

3.1.2 Wind climate

Modelled hindcasts of yearly maximum wind speed (1990 - 2012) were used. This dataset was generated from IFREMER wave hindcasts using the WAVEWATCH III model with wind data from NCEP Climate Forecast System Reanalysis (CFSR) (Saha et al. 2010). Two high resolution (10 minute) grids of Atlantic and Pacific maximum modeled wind speeds were used for southern Canadian coastal areas while a coarser (30 minute) worldwide grid was used for the Arctic areas. From these datasets the mean annual maximum wind speed over 23 years was calculated

As with the SLC grid, areas of the grid that did not intersect with the coast were extended into the gaps with the Focal Statistics (MEAN) function.

Windspeed values were then joined to the coastline using the Intersect Lines With Raster tool and the coastline dissolved down to the NTS sheets.

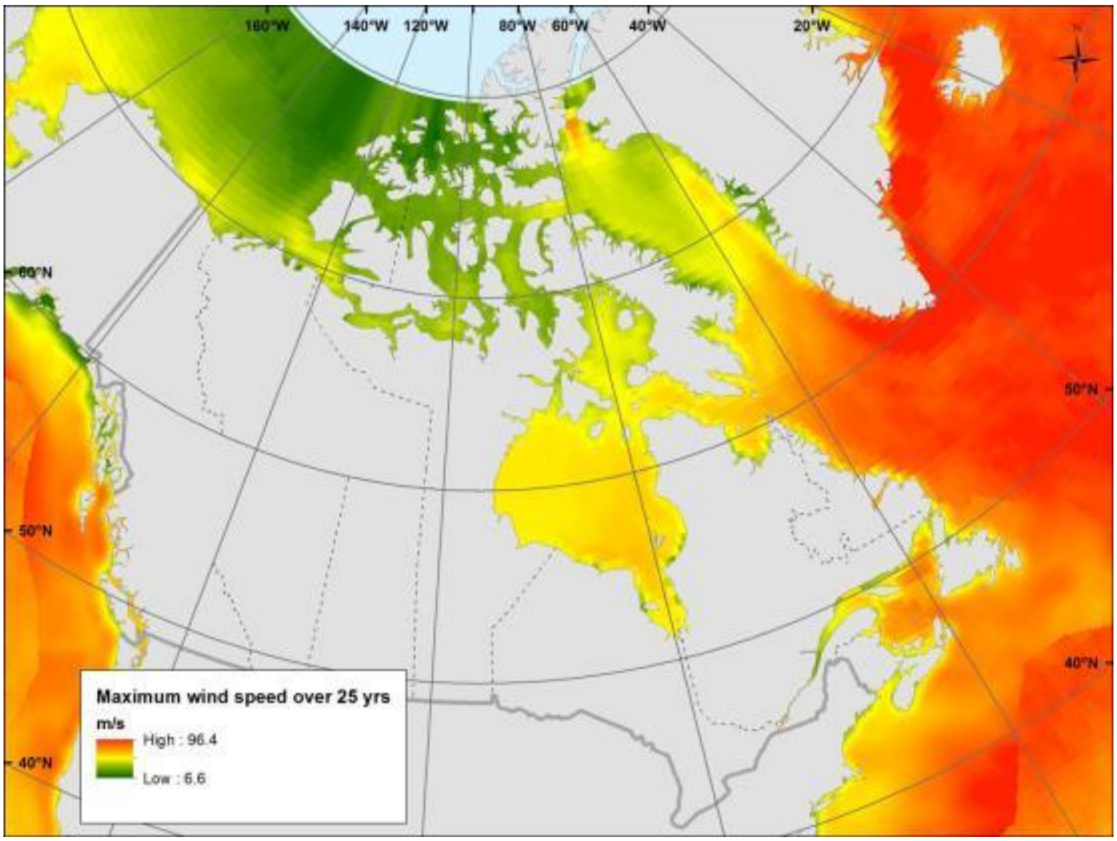


Figure 2 - Maximum windspeed (1990 – 2014)

3.1.3 Wave climate

Modelled hindcasts of yearly maximum significant wave height (1990 – 2014) were used. The dataset was generated from IFREMER wave hindcasts using the WAVEWATCH III model with wind data from NCEP Climate Forecast System Reanalysis (CFSR) (Saha et al. 2010). Two high resolution (10 minute) grids of Atlantic and Pacific maximum significant wave height were used for southern Canadian coastal areas while a coarser (30 minute) worldwide grid was used for the Arctic areas. From these datasets mean maximum significant wave height over 25 years was calculated

As with the SLC grid, areas of the grid that did not intersect with the coast were extended into the gaps with the Focal Statistics (MAXIMUM) function. Missing data areas in western Hudson Bay and southern James Bay were assigned the wave height values of the closest shoreline segment

Wave height values were then joined to the coastline using the Intersect Lines With Raster tool and the coastline dissolved down to the NTS sheets.

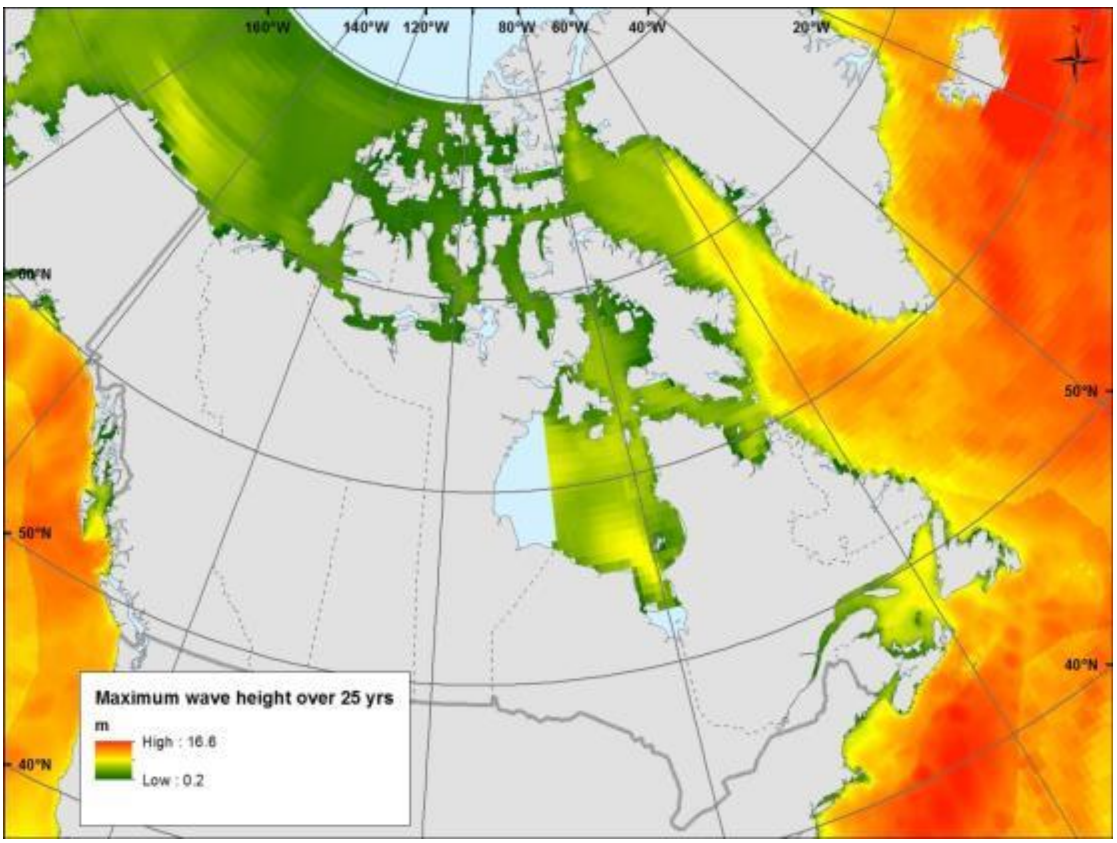


Figure 3 - Maximum significant wave height (1990 – 2014)

3.1.4 <u>Sea ice</u>

Sea ice data from the Canadian Ice Service were acquired for each of the four regions (i.e., Atlantic, Eastern Arctic, Western Arctic and Hudson Bay), representing percent ice coverage for each week over four decades (1970s, 1980s, 1990, 2000s). For each region and decade, a single dataset was calculated to represent the sum of all weeks with ice coverage in excess of 50%, with a maximum possible score of 52 weeks for each decade. To measure change in ice duration, the summary mapsheet from the 2000s was subtracted from the 1970s summary mapsheet. The final dataset represents the change between the 1970s and 2000s in the number of weeks with ice concentrations greater than 50%. A positive number indicates a reduction in weeks of ice coverage, a negative number an increase in ice coverage. While the time frame represented is relatively short it was felt that changes in sea ice coverage was an important variable to include in the exposure sub-index calculation

A spatial join was used to transfer the raster values from the points to the coastline segments, using the average of the grid cells closest to each line segment. Coastal line segments were then dissolved on the NTS sheet ID and the mean, minimum, and maximum change in ice coverage calculated for each coastal segment.

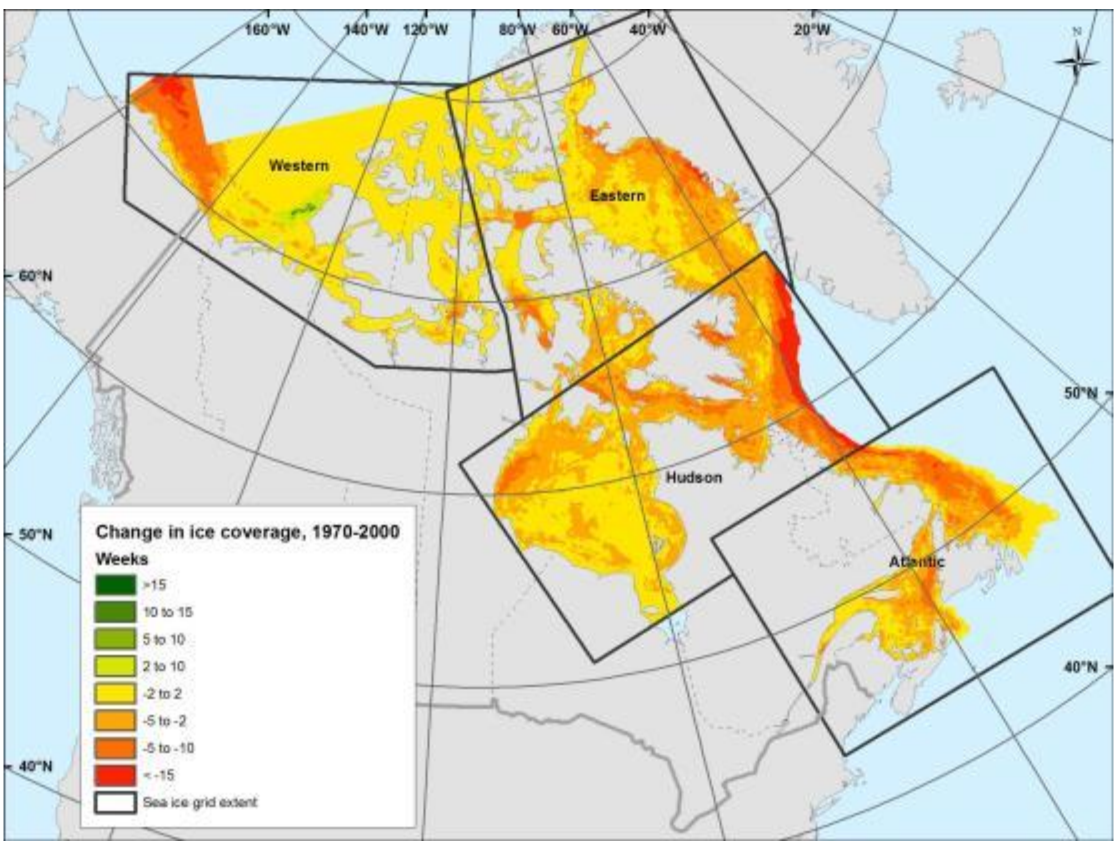


Figure 4 - Change in mean annual number of weeks with sea ice concentrations greater than 50% (2000-2009 minus 1970-1979)

3.1.5 Coastal materials

The base layers from which the coastal materials layer were derived were the Fulton surficial geology (Fulton, 1995) and the Wheeler bedrock geology (Wheeler et al., 1996), both at scales of 1:25 million. Where the surficial geology was greater in thickness than veneer, a score of 3-5 was assigned, with 5 being most erodible (muds, marine clay, materials that will flow) and three being less erodible (sands, gravels). Where there were surficial materials with a thickness of veneer or less, the bedrock geology was used as the basis for the score. Scores based on bedrock geology were assigned 2 if the geology was sedimentary, and 1 if igneous or metamorphic (Dr. Gavin Manson, Natural Resources Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, personal communication, 2015)..

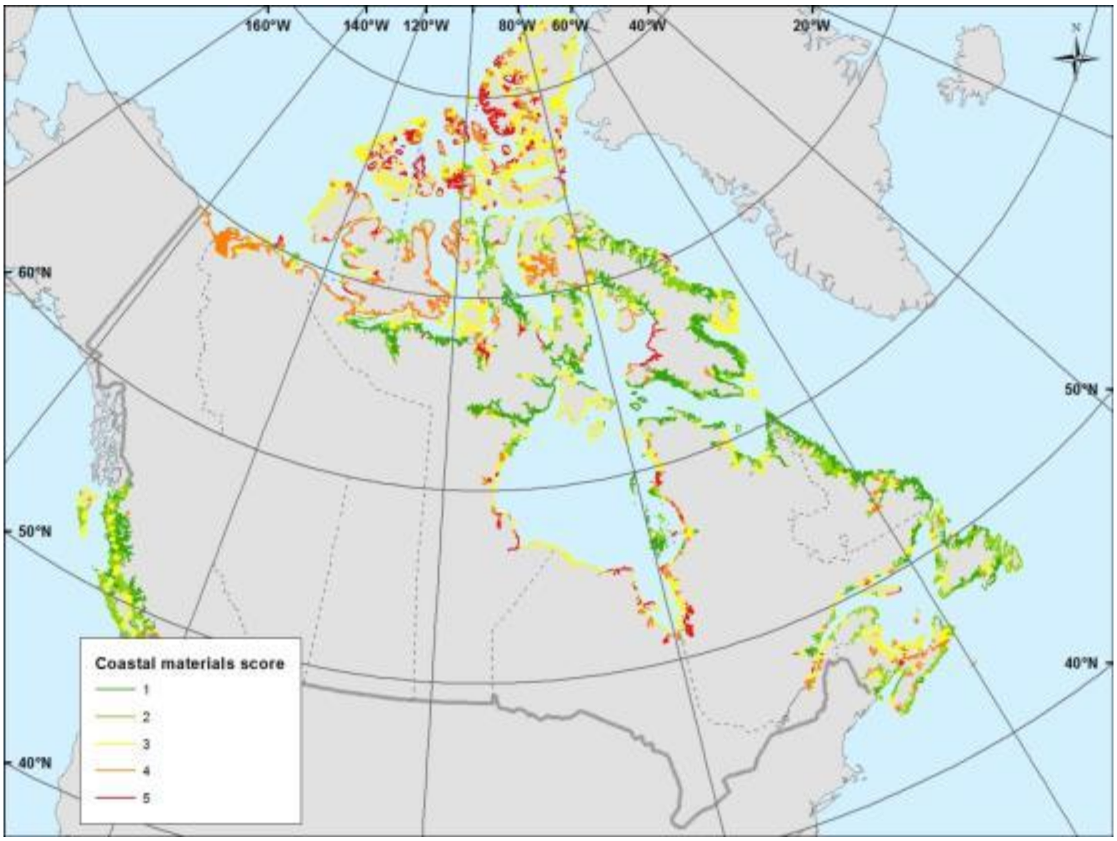


Figure 5 - Coastal materials score

3.2 INFRASTRUCTURE SUB-INDEX (ISI)

A harbour's vulnerability to the potential impacts of climate change depends in large part on their ability to physically withstand the forces associated with these impacts. An infrastructure vulnerability sub-index was developed to provide an indication of a harbour's assets and their ability to withstand the potential exposure impacts related to climate change. Three variables were selected as to not overlap with those used in the exposure sub-index:

3.2.1 <u>Harbour Condition</u>

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 forces which would leave it vulnerable to premature deterioration or in the most severe circumstances, asset structural failure.

This variable is based on the SCH harbour condition index that has been calculated as part of the SCH Long Term Strategy (LTS) study that is currently ongoing. The LTS is assembling data on a wide array of aspects related to the future of the SCH program. One of these aspects is the physical condition of SCH infrastructure. To develop the harbour condition index, each separate facility (ie. breakwater, wharf, etc) at the harbour was evaluated to the component level and assigned a numerical score between 0 and 5. The Harbour Infrastructure Condition index is a weighted average. For each harbour the average of all the individual facility conditions are weighted against the harbour's replacement cost (see Total Facility Replacement Cost Section). This variable was calculated for 707 of the 735 Atlantic harbours and 103 of the 107 Pacific harbours. The remaining harbours had N/A values for individual facilities or harbour replacement costs within the calculation.

Of note, the LTS scoring system is reversed from the standard vulnerability index measurement standard (i.e. 1 is bad in LTS, but is good in CIVI), therefore all harbour condition index ratings were converted into the CIVI standard (e.g. a 4 was converted to a 2).

3.2.2 <u>Degree of Facility Protection</u>

The degree to which a harbour is naturally protected or has manufactured protection from storm surge, wind, and other natural forces was proposed as a variable for the Infrastructure Sub-index of CIVI. To measure the Degree of Facility Protection variable a five-point qualitative scale was developed with 1 being a completely exposed harbour and 5 being a fully enclosed harbour. As this scale is being proposed for the CIVI project only elements of a harbour relevant to the project 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.

This variable score was assigned to each of the pilot harbours by the SCH Regional Engineer in each Region. The variable 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 Appendix 1.

Since degree of protection scores are reversed from the other vulnerability scores (as with Harbour Condition, these scores were converted to the CIVI standard (e.g. a score of 1 is high degree of protection (low vulnerability) and a score of 5 indicates a low degree of protection (high vulnerability).

3.2.3 Total Replacement Cost

The sheer value of infrastructure owned by the department at a harbour can itself be an indication of a harbour'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.

3.3 SOCIO-ECONOMIC SUB-INDEX (SESI)

A socio-economic sub-index was developed to assess the harbours' economic vulnerability due to climate change, as well as the harbours' role within their respective local and regional economies. This section provides the rationale for the selection of specific socio-economic indicators in the development of the socio-economic sub-index for the Atlantic harbour sites, as well as a description of primary data sources and data limitations. The following data were considered for inclusion in the socio-economic sub-index:

Landing Data by Harbour (Fisheries and Oceans Canada)

- Average landed quantity by harbour, 2009 to 2013 (kg)
- Average landed value by harbour, 2009 to 2013 (CAD)
- Change of total landed quantity, 2004 and 2013 (%)

Active vessels by Harbour (Fisheries and Oceans Canada)

- Number of vessels by port of landing, 2013 (most recent year at the time of provision)
- Number of vessels by port of landing, 2009 to 2013

Income by Harbour Census Subdivision (Revenue Canada Agency)

- Average fishing income, 2009 to 2012
- Average Income with total tax filers, 2009 to 2012
- Fishing income compared to total income, 2009 to 2012 (%)

Population by Harbour Census Subdivision (Statistics Canada)

- Total population for harbour census subdivision, 2011

Preliminary socio-economic data have been collected for 677 harbours across Atlantic Canada, with 238 in Nova Scotia, 87 in New Brunswick, 26 in Prince Edward Island, 59 in Quebec and 267 in Newfoundland and Labrador. The socio-economic sub-index has only been computed for Atlantic Canada, as comparable socio-economic data were not available for the Pacific and Central and Arctic Regions.

3.3.1 Landings

Landings data can be used to estimate the economic value of SCH infrastructure for Canada's fishing industry in the Atlantic Provinces as commercial catches in this area are landed through SCH sites. It takes into account the reported quantities and estimated values of harvests from the fisheries landed at each SCH location. However, it does not account for the added value of fish and seafood processing and other indirect or induced economic impact generated for the local regional community.

The landings data was retrieved from DFOs Integrated Catch and Effort System (ICERS, Department of Fisheries and Oceans, 2015). Landing refers to the catch of species landed on shore when the harvester returns to port, regardless of the number of sets or tows of individual catch events while at sea. The landing reported here is the aggregated record of landings of all species returned to a particular Small Craft Harbour over the indicated time frame. All values are in Canadian dollars (CAD). Five-year averages have been used to smooth out annual fluctuations in landing data. The landed values have not been adjusted for inflation.

Landing data provided by ICERS is limited to the four Atlantic regions (Newfoundland and Labrador, Maritimes, Gulf, and Quebec). For the Pacific and Central and Arctic, no landing data are reported for SCH sites. Landing data for 2014 has recently become available, and could be used in future updates of the index.

3.3.1.1 Average Landed Value (ALV) (2009-2013)

The landed value is the average value, in CAD, of the recorded landed quantity in a given port of landing over a 5-year period. It is determined either by multiplying the landed quantity times the price per unit of measure or by using the value reported by the buyer. It is a proxy value for the socio-economic utility of small craft harbour infrastructure for Canada's fishing industry. The value of this variable is nominal and has not been adjusted for inflation.

3.3.1.2 Average Landed Quantity (ALQ) (2009-2013)

The average landed quantity is the estimated weight of harvest landed in a port of landing over a 5-year period. It is the result of multiplying the landed amount by a conversion factor based on species-specific information to derive the live weight equivalent. The quantities provided are aggregated from different species for this project. Similar to average landed value, it is a proxy for the socio-economic value of SCH infrastructure for Canada's fishing industry. There are no economic inflation concerns with landed quantity in contrast to landed value, and due to the high degree of positive correlation between the two, it is recommended that the average landed quantity is used for index calculations.

3.3.1.3 Change in Total Landed Quantity (CTLQ) (2004 and 2013)

This value was calculated as the percentage difference in total landed quantity between 2004 and 2013 for each port of landing. It was provided for consideration as a quick proxy to estimate the differences in small craft harbour infrastructure usage between 2004 and 2013. It was not recommended for use in the final index calculations as it does not account for fluctuations in intermittent years, and does not compensate for potential outliers in the two reference years.

3.3.2 Vessels per Harbour

The number of vessels served by each harbour as port of landing is an estimate of vessel activity by harbour for the purposes of landing harvest from the fisheries. This variable is different from the number of vessels using a specific harbour as home port. Vessel activity of a Small Craft Harbour as the port of landing was used in lieu of harbour as home port as it more reliably captures the presence of economic activity at each harbour location. The number of active vessels that landed harvest in each SCH location was obtained from ICERS. This number of fishing vessels utilizing a specific harbour can also be combined with landing data to calculate average value and quantity per vessel. This variable is another way of assessing the scope of the socio-economic activity reliant on SCH infrastructure.

3.3.2.1 Number of Active Vessels Port of Landing (NAVPL) (2013)

The number of vessels which landed harvest by port of landing in 2013 was provided. This variable provides a measure for the reliance of vessels on each SCH location as port of landing, and is another proxy value to help measure the socio-economic utility of the harbour infrastructure.

3.3.2.2 Average Number of Vessels Port of Landing (Average NAVPL) (2009-2013)

The average number of vessels which landed harvest by each port of landing for 2009 to 2013 was provided. The 5-year average was provided to smooth out fluctuations in the number of vessels in specific ports of landing. Similar to the lone 2013 variable, this variable is a proxy to help measure the socio-economic impact of the harbour infrastructure to the community.

3.3.3 Fishing Income

The income related to fishing at the census sub-division (CSD) level provides an indication of the economic relevance of Small Craft Harbours to specific local and regional economies. Based on the assumption that fishing-related income is dependent on SCH infrastructure, this variable is used to provide an estimate of the economic impact of the SCH infrastructure to the broader community.

Fishing income is aggregated from the reported income of the following four fishing-related sectors: self-employed fish harvesters, wage earning-fish harvesters, fish processing employees, and aquaculture employees. Only individuals who reported a positive amount of income in any of these fishing sectors were included in the analysis. All other employment income is considered non-fishing income.

The Canada Revenue Agency (CRA) compiles fishing income information from individual tax filer data (T1 tax returns). The CRA data used here is based on an approximation of the 2006 CSD boundaries. Subsequent changes to CSD boundaries are adjusted to these boundaries accordingly. Five-year averages have been provided to smooth out annual income fluctuations. The values have not been adjusted for inflation.

The use of income tax data is advantageous as most individuals with earnings from fishing-related activities are required to file a T1 tax return, and thus, the data should provide a high degree of coverage of those working in the fishing industry. However, there are several limitations to income tax data that are likely to contribute to an underestimation of fishing income.

In accordance to CRA's data confidentiality procedures, the value of incomes is suppressed when fewer than 10 individuals report fishing incomes within a specific CSD. When incomes are suppressed, the value of income is set to zero. As such, the suppressed data is not a true zero value. Due to the threshold of the suppressed income data (applied when <10 individual reported income in a census subdivision), it is assumed that the socio-economic impact of the suppressed data would be modest.

Furthermore, not all individuals with positive employment earnings file a T1 return if the income is below the filing threshold and the individual is not eligible (or unaware of) refund credits available to filers. There are also other issues with the reliability of income reporting in cases of accidental or deliberate misreporting of income tax information. While violation of legal filing requirements is a possibility, estimates from CRA suggest that T1 filing compliance is high with 92.8% of all Canadian adults submitting a timely T1 return in 2008-09.

Finally, since the fishing income data is currently only provided at the level of the CSD, it is not possible to accurately attribute fishing income to individual harbours in CSDs with multiple small craft harbour sites.

3.3.3.1 Average Fishing Income (AFI) (2009-2012)

The average fishing income from 2009 to 2012 was provided for the project by CSDs associated with each pilot harbour. The average fishing income is generated from the total reported positive income of the four abovementioned fishing-related sectors. The socio-economic variable provides an indicator of the income contribution of fishing-related activities by each SCH location, which is a proxy for the value commercial fisheries contribute to the local/regional economy.

3.3.3.2 Average Total Income (ATI) (2009-2012)

The average total income is from all industries from 2009 to 2012 was provided for the project by CSDs associated with each pilot harbour. All employment income other than income from the abovementioned sectors is considered non-fishing income. The socio-economic variable provides an indicator of the overall income by each SCH location. This variable is needed to provide the baseline of comparison to measure the relative size of a community's income from fishing related activities.

3.3.3.3 Average Fishing Income to Average Employment Income (AFIAEI) (2009-2012)

The average fishing income by the CSDs of each Small Craft Harbour (2009-2012) was calculated as a percentage of total average employment income. The socio-economic variable provides an indicator of the weight of fishing-related incomes in the CSD of the SCH location. It is a proxy for measuring the socio-economic impact of SCH infrastructure in a given CSD. It is recognized as a possibility that not all fishing related income can be attributed to the Small Craft Harbours of the CSD. However, it is assumed that fishing related income provides a reasonable estimate of utility of Small Craft Harbours to the local and regional community reliant on fishing income.

3.3.4 Total Population (2011)

The population of CSDs that contain Small Craft Harbours provide an indication of the relative importance of the SCH infrastructure to the community. This supplementary variable becomes relevant only when there is existing evidence of socio-economic activity associated with the harbours (i.e. landing by harbour, vessel activity by port of landing or fishing-related income by CSDs).

Population data by CSDs was obtained from Statistics Canada based on the 2011 Census . The data is used as a proxy for the relative socio-economic impact of the harbour infrastructure based on the size of the population it serves. Updated population data by CSDs from the 2016 census is expected to be released February 8, 2017. The population data is not weighted according to usage. As well, the same population data is provided in cases where multiple harbour sites exist within the same CSD.

4 INDEX CALCULATION

Using the coastal exposure, SCH infrastructure, selected fisheries, and population level socio-economic datasets as described in the Sub-index Development section, three vulnerability sub-indices (Exposure, Infrastructure and Socio-Economic) were calculated for each pilot harbour using the geometric mean of the contributing variables. The Geometric mean (gm):

$$\mathbf{GM} = \sqrt[n]{\boldsymbol{a_1 * a_2 * \ldots a_n}}$$

is the n^{th} root of the product of the variables (Clark-Carter, 2005). This method was selected because it minimizes the influence of outliers and retains a similar range and distributional shape of the input variables. Variables with highly skewed distributions were transformed where necessary to achieve roughly normal distributions prior to reclassifying the dataset from 1 to 5, with 5 being most vulnerable and 1 being the least vulnerable.

Further sub-index and variable specific details are provided in the sub-sections below.

The final vulnerability index (CIVI) is the geometric mean of the representative sub-indices:

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

or more generally:

$$\mathbf{CIVI} = \sqrt[n]{\boldsymbol{SI1 * SI2 * SI3 * \ldots SIn}}$$

where SI represents the various sub-indices.

All of these calculations are done programmatically by using R Statistical Computing Software (R Core Team, 2016). Doing the calculations in this manner provides flexibility in the data analysis process and allows for rapid results from readjustments in methodology. While the basic code has been written to fulfill the requirements of this project, it is expected that this code will be further developed to its final state if the tool gains utility beyond this pilot project.

The distribution of sub-indices calculated in this becomes constrained/compressed as more variables are added. Ultimately, the absolute values of the resulting SCH index/sub-index calculations are less important than their relation to all other values calculated the same way and within a similar extent. For this reason, the output maps of index results in this report are often color coded using red (high relative vulnerability), yellow (moderate relative vulnerability) and green (low relative vulnerability). All of the GIS analysis and derived maps were produced in ArcGIS 10.1 (ESRI, 2011).

4.1 ATLANTIC AND PACIFIC REGIONS

The calculation of the main CIVI index and each sub-index was done on a regional scale (Atlantic and Pacific). Conditions in the two regions are sufficiently different in the various sub-index categories that if was felt the calculations should be separate so that the final value would reflect regional conditions and not be influenced by national scale values which may bias the result.

A total of 17 SCH locations were chosen for the pilot study across the 4 Atlantic regions (Quebec, Maritimes, Gulf of St. Lawrence, and Newfoundland and Labrador) using the methodology described in the Pilot Harbours section (Table 1). Figure 6 shows the Atlantic pilot sites.

A total of 4 SCH locations were chosen for the pilot study along the Pacific coast using the methodology described in Pilot Harbours section (Table 1). Figure 8 shows the spatial distribution of the Pacific pilot sites.

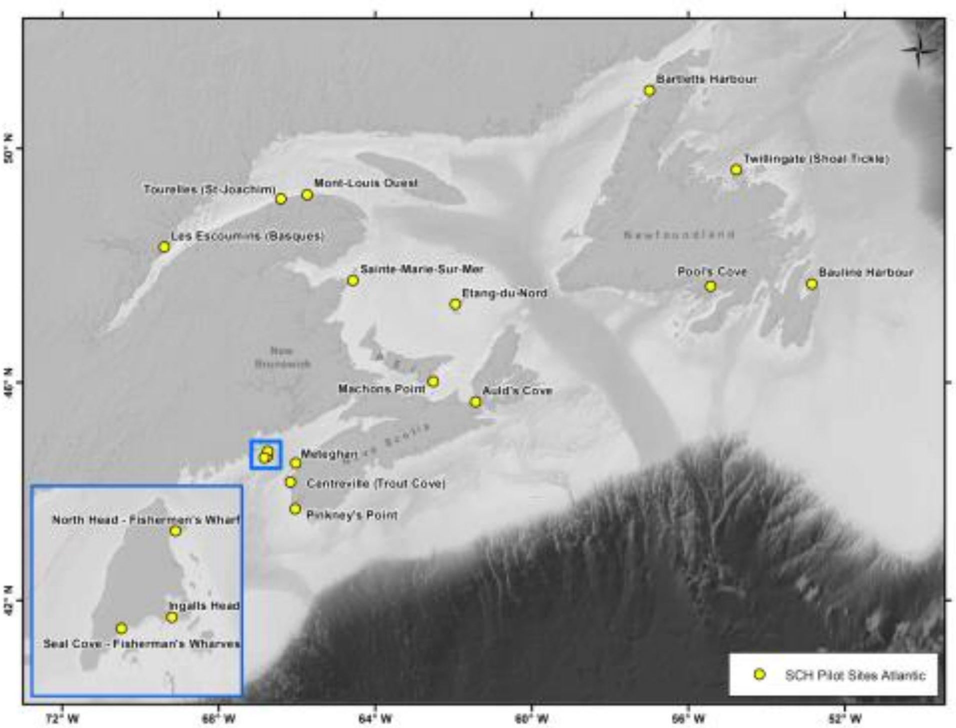


Figure 6 - The 17 Atlantic SCH locations chosen for the pilot study

Note the 3 locations chosen on Grand Manan Island represented in the blue inset map.

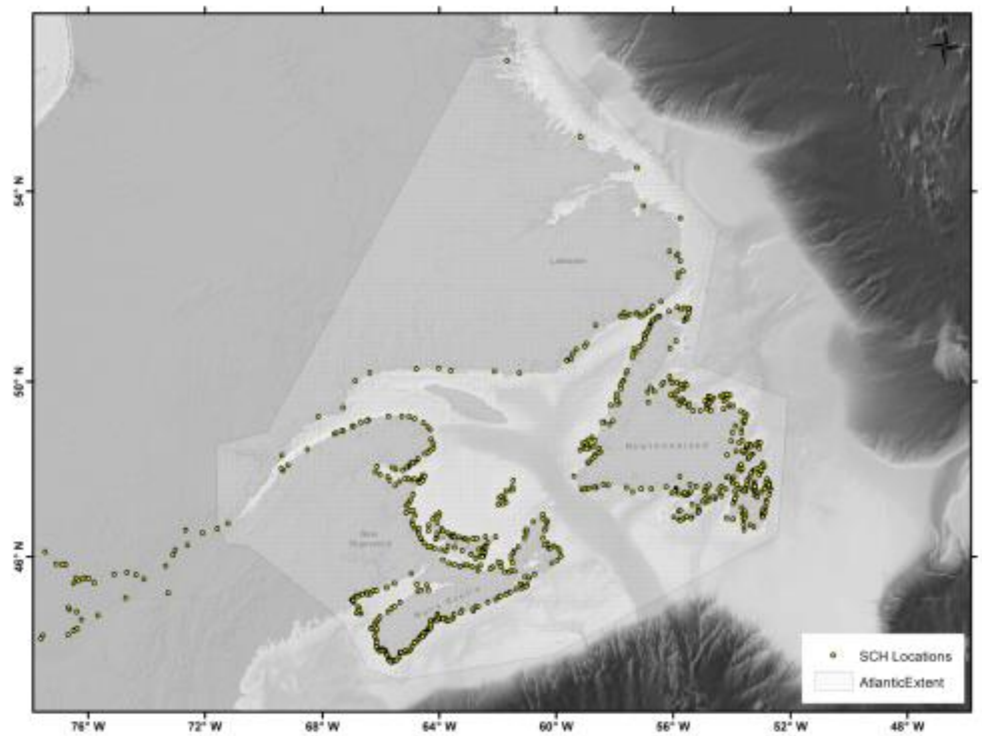


Figure 7 - The Atlantic extent of the pilot study in relation to all Atlantic SCH locations

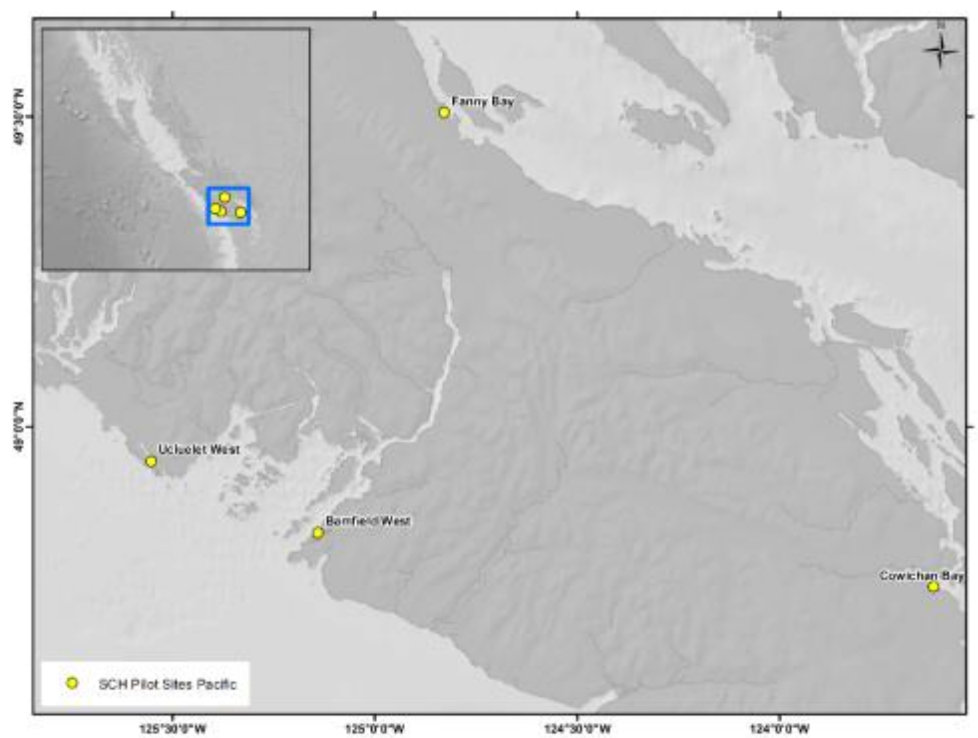


Figure 8 - The 4 Pacific SCH locations chosen for the pilot study

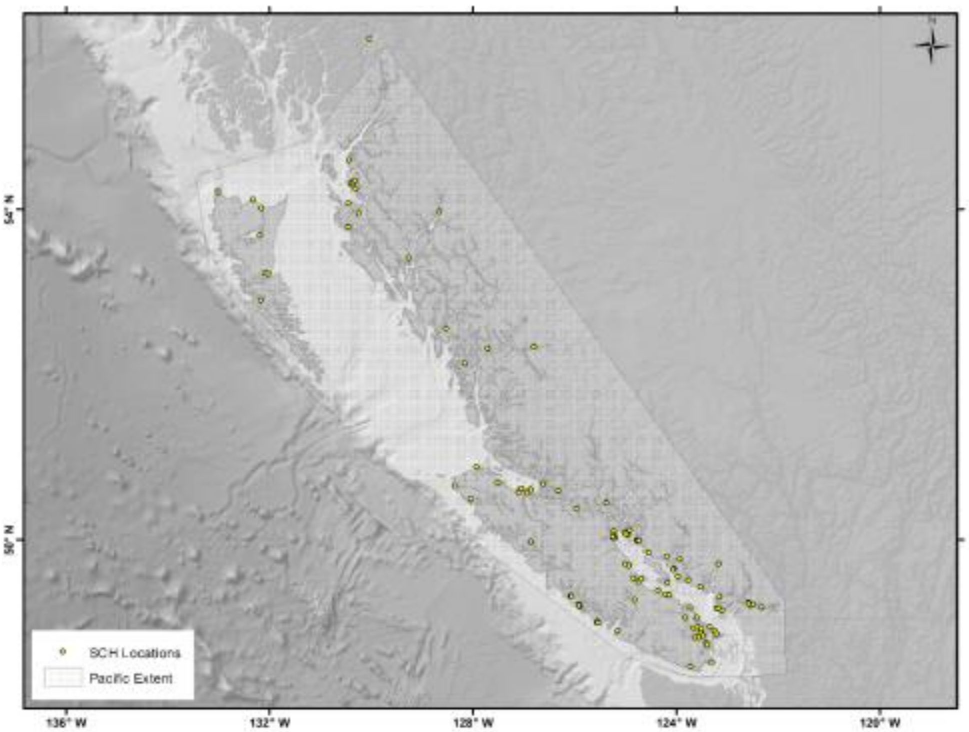


Figure 9 - The Pacific extent of the pilot study in relation to all Pacific SCH locations

The assigning of sub-index values to harbour sites was necessarily different for the exposure values in comparison to the socio-economic or infrastructure values. For the latter two sub-indices, values were assigned directly to the harbour site based upon onsite data. For the exposure sub-index variables, the applicable coastline (e.g. sea level change, wind climate, etc.) was clipped to the sub-region boundary (Atlantic and Pacific, Figures 7 and 9) and from all the coastal values in that sub-region, an index score varying from 1-5 was generated after appropriate distribution analysis and transformation. The harbour sites in that sub-region were then assigned the score of the associated coastline segment (or NTS sheet).

A description of the data preparation and analysis methodology is provided below for each exposure layer. This is followed by a description of the Exposure Sub-Index results for both study extents.

4.2 ESI CALCULATION

4.2.1 <u>Variable Transformation and Scoring</u>

4.2.1.1 Sea level Change (SLC)

A histogram of the distribution from the recently revised, year 2100 mean sea level shoreline segments (refer to Sea level change sub-section under the Exposure Sub-index section) within the Atlantic extent revealed a slightly left skewed data distribution (Figure 10). Prior to recoding, the absolute value of the data was transformed to create a roughly normal distribution (Figure 10). Within the project working group, it was generally agreed that a larger change in sea level, whether positive or negative, could be detrimental to coastal infrastructure. Based upon this recommendation, the absolute value was used to create the starting distribution of shoreline segments of the sea level change layer within both regional extents. The absolute and recoded cut values for sea level change are provided in Table 2. Figure 11 shows the recoded sea level change coastline. Note, that the lowest value (dark green) represents the least amount of sea level change in this layer. It is important to remember that positive and negative sea level change values are recoded with the same value.

Within the Atlantic extent, the areas projected to have the greatest change by year 2100 are southeast Nova Scotia and the Avalon Peninsula of Newfoundland, where the relative mean sea level is expected to increase by just less than 1 m. The areas where sea level is expected to change the least, and in some cases actually decrease due to isostatic adjustment, are the coastline just north of the St. Lawrence Seaway as well as southern Labrador and Northern Newfoundland.

The shoreline segments within the Pacific extent revealed a slightly right skewed distribution prior to being lightly transformed (Figure 10). Unlike the Atlantic sea level change projections for 2100, all Pacific shoreline segments are expected to experience an increase in sea level rise by 2100, so the absolute value did not need to be calculated. The transformed and untransformed recoded cut values for Pacific extent sea level change are provided in Table 2. It should be noted that the range of sea level change within the Pacific extent ranges from only 0.24 to 0.63 m (range = 39 cm), while the Atlantic 2100 sea level change ranges from -0.33 to 0.92 (range = 125 cm). This is a clear demonstration of the practicalities of a zonal approach to infrastructure vulnerability analysis when working over large spatial scales.

Within the Pacific extent, the areas projected to have the greatest change by year 2100 are Haida Gwaii (Queen Charlotte Islands) and the southwestern portion of Vancouver Island. Figure 11 shows the recoded sea level change coastline within the Pacific extent.

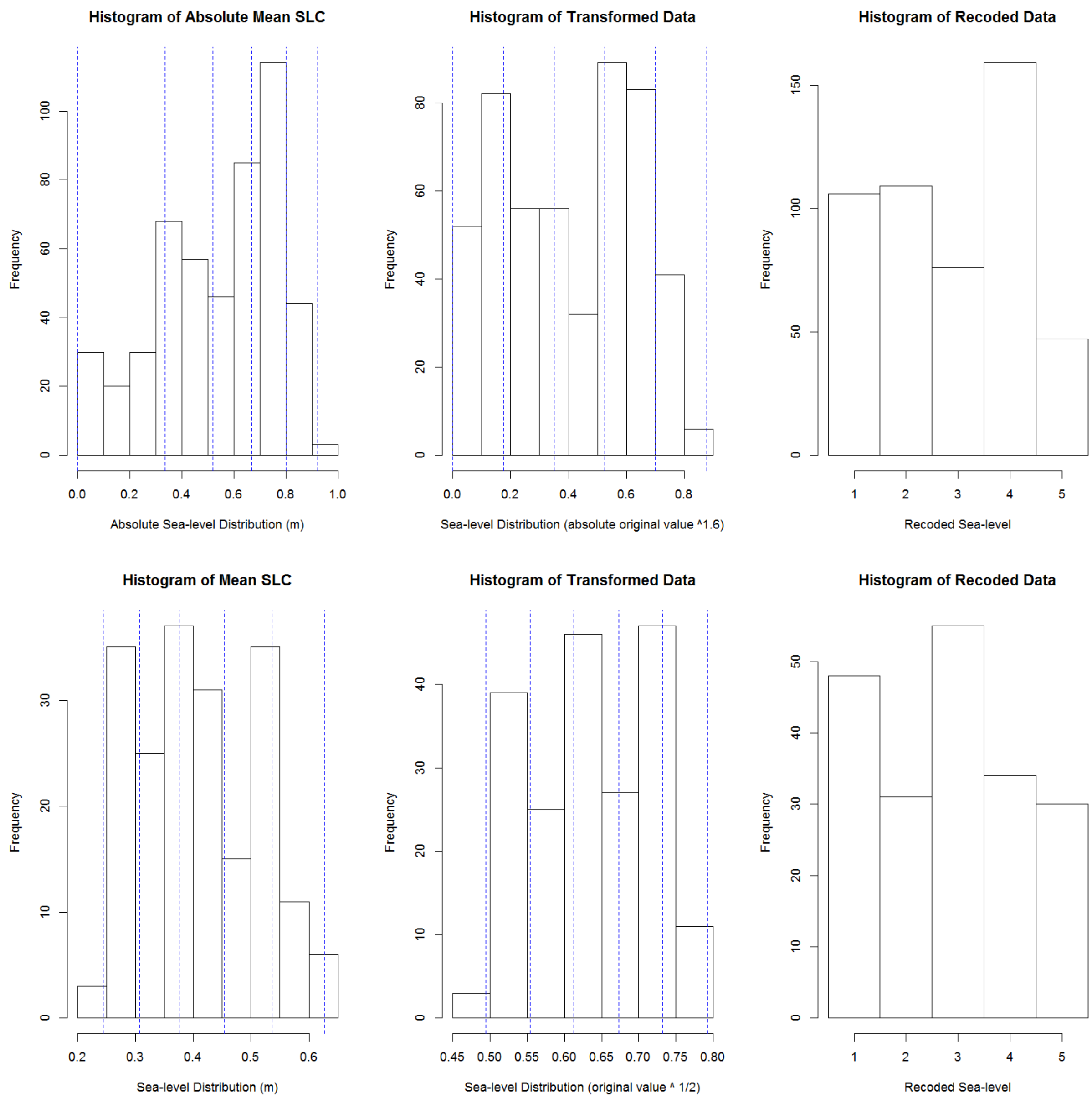


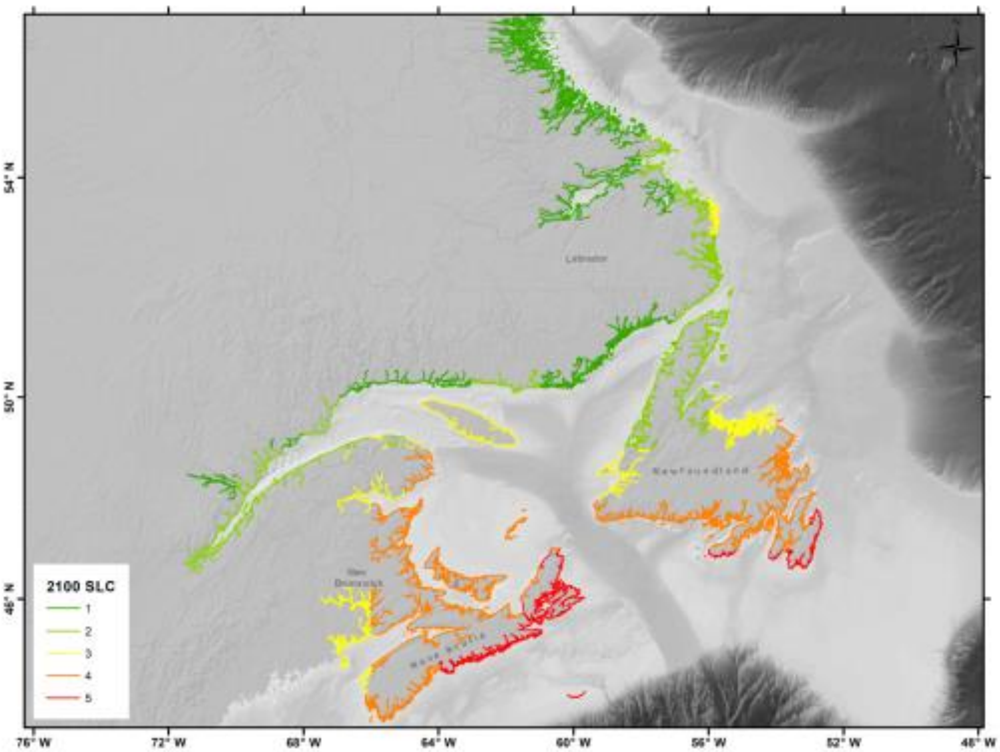
Figure 10 - Frequency distributions of sea level change values

Top – The distribution and cut points for the absolute value of 2100 sea level change shoreline segments of CanCoast within the Atlantic extent (left), the distribution and cut points for the transformed absolute values (middle), and the recoded distribution (right).
Bottom – The distribution and cut points for the original 2100 seal-level change shoreline segments of CanCoast within the Pacific extent (left), the distribution and cut points for the transformed sea level data (middle), and the recoded distribution.

Table 2 - Original and transformed sea level change ranges with score

	Absolute Sea Level Change (2100)		
Extent	**AO* (m)**	**T***	**R***
Atlantic	0 – 0.34	0 – 0.18	1
	0.34 – 0.52	0.18 – 0.35	2
	0.52 – 0.67	0.35 – 0.53	3
	0.67 – 0.80	0.53 – 0.70	4
	0.80 – 0.92	0.70 – 0.88	5
	O (m)	**T**	**R**
Pacific	0.24 – 0.31	0.49 – 0.55	1
	0.31 – 0.38	0.55 – 0.61	2
	0.38 – 0.45	0.61 – 0.67	3
	0.45 – 0.54	0.67 – 0.73	4
	0.54 – 0.63	0.73 – 0.79	5

*****AO=Absolute original data; T=Transformed Data, R=Recoded Data



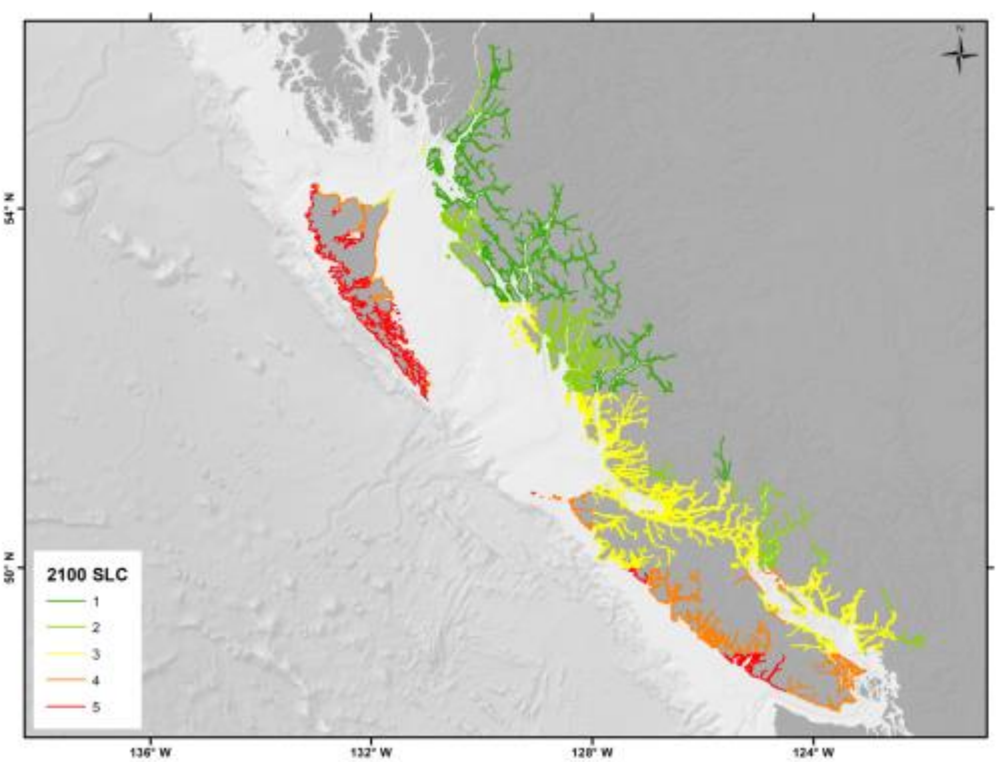


Figure 11 - Sea level change scores

Top - The recoded sea level change CanCoast shoreline layer clipped to the Atlantic extent.
Bottom - The recoded sea level change CanCoast shoreline layer clipped to the Pacific extent.

4.2.1.2 Wind Climate

The creation of the wind speed raster and subsequent CanCoast coastline is described in the Exposure Sub-Index section (Wind climate). Prior to analysis, the wind speed coastline was clipped for both the Atlantic or Pacific extents as described in the Atlantic and Pacific regions subsection. The final Exposure Sub-Index uses the maximum wind speed (m/s). Figure 12 and Table 3 show the distribution of the original cut points used to recode the original data 1 -5 for the Atlantic extent. The Pacific maximum distribution was slightly left skewed and was transformed prior to recoding the data (Figure 12 (bottom) and Table 3). Figure 13 shows the recoded maximum wind speed coastline for both the Atlantic and Pacific extents.

Within the Atlantic extent, the areas with the highest maximum wind speeds are through the Laurentian Channel, northern Avalon Peninsula and along the Labrador coast adjacent to Lake Melville. Within the Pacific extent, the areas with the highest maximum wind speeds are on the eastern side of Haida Gwaii in Hecate Strait.

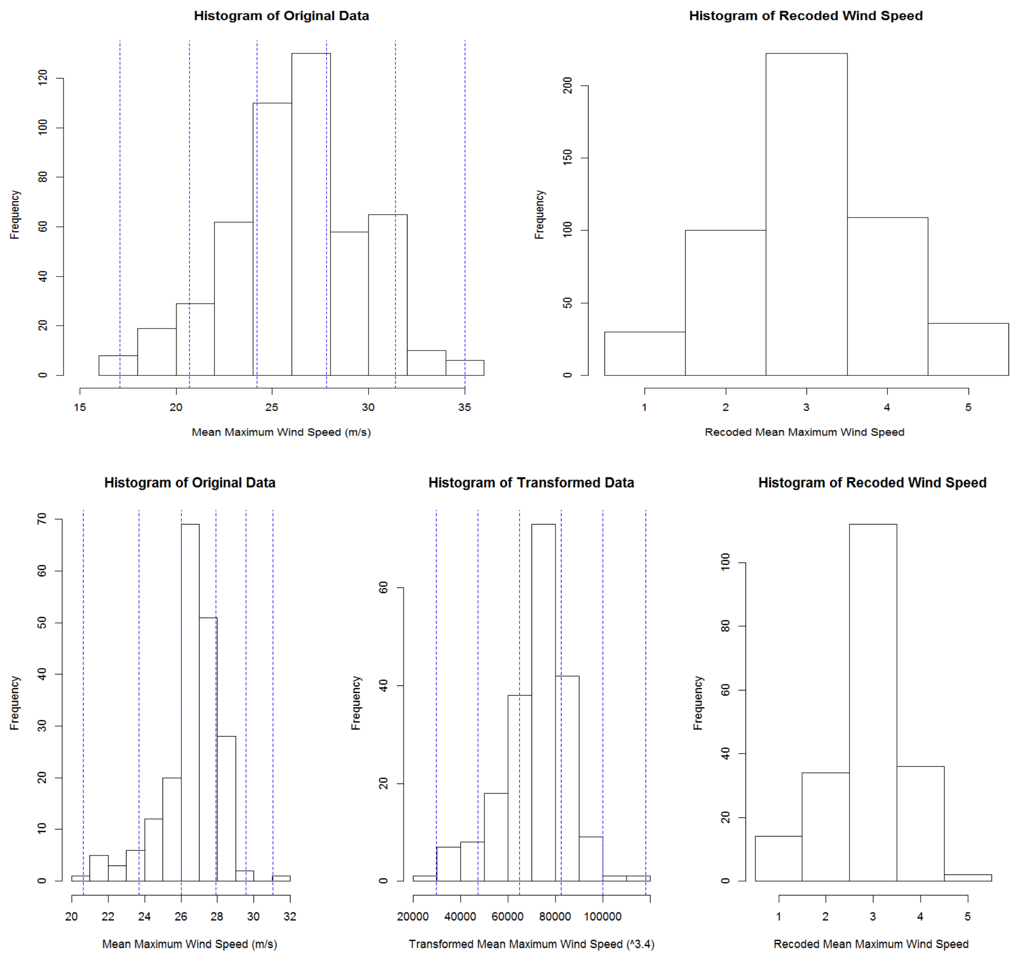


Figure 12 - Frequency distributions of wind speed values

Top - The distribution and cut points for the maximum wind speed (m/s) within the Atlantic extent (left), and the recoded distribution (right).
Bottom - The distribution and cut points for the maximum wind speed (m/s) within the Pacific extent (left), the transformed wind speed (middle), and the recoded distribution (right).

Table 3 - Original and transformed maximum wind speed ranges with score

Mean Maximum Wind Speed			
Extent	**O* (m/s)**		**R***
Atlantic	17.09 – 20.70		1
	20.70 – 24.20		2
	24.20 – 27.80		3
	27.80 – 31.40		4
	31.40 – 35.00		5
	O	**T***	**R**
Pacific	20.7 – 23.7	29,600 - 47,200	1
	23.7 – 26.0	47,200 - 64,900	2
	26.0 – 27.9	64,900 - 83,500	3
	27.9 – 29.6	835,000 - 100,000	4
	29.6 – 31.0	100,000 - 118,000	5

*O=Original data; T=Transformed data; R=Recoded data.

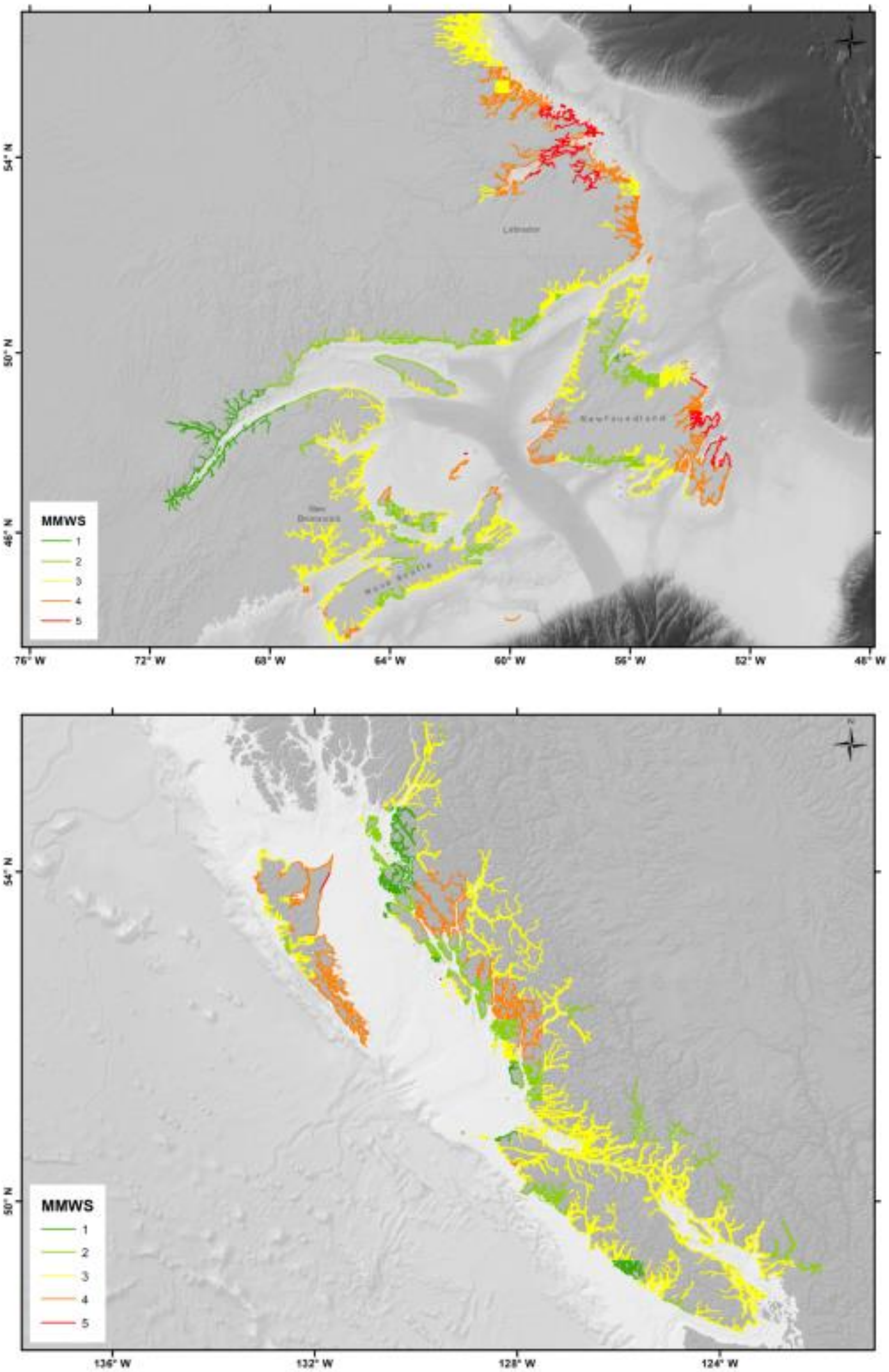


Figure 13 - Wind speed scores

Top - The recoded maximum wind speed CanCoast shoreline layer clipped to the Atlantic extent.
Bottom - The recoded maximum wind speed CanCoast shoreline layer clipped to the Pacific extent.

4.2.1.3 Wave Climate

The creation of the maximum significant wave height raster and subsequent CanCoast coastline layer is described in Exposure Sub-Index section (Wave climate). Prior to analysis, the maximum significant wave height coastline layer was clipped to the either the Atlantic or Pacific extents as described in the Atlantic and Pacific regions subsection. The final Exposure Sub-Index uses the maximum wave height (m). Figure 14 and Table 4 show the distribution the cut points used to recode the original data. Figure 15 shows the recoded maximum significant wave height coastline layer for both the Atlantic and Pacific extents.

Within the Atlantic extent, the areas with the highest wave heights are near Port aux Basques, on the south coast of Newfoundland along the Laurentian Channel. Within the Pacific extent, the areas with the highest maximum significant wave heights are on the western side of the Haida Gwaii.

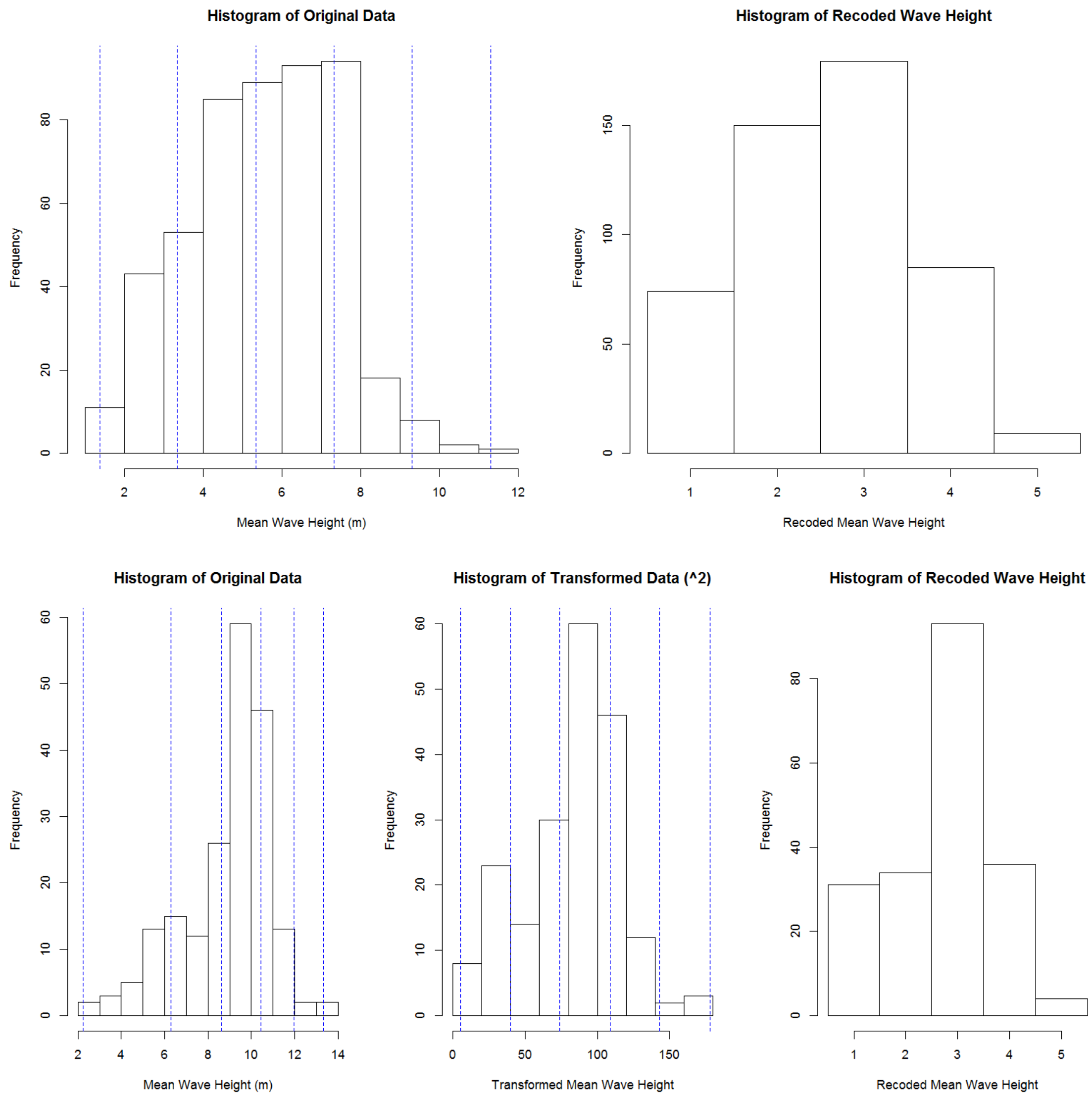


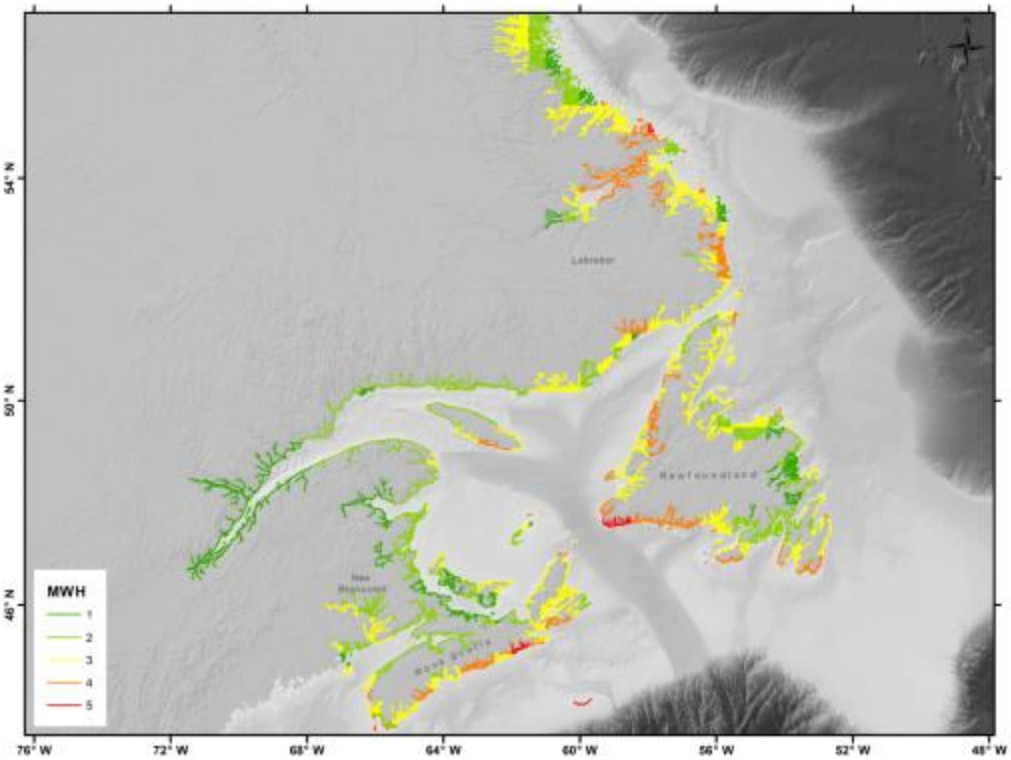
Figure 14 - Frequency distributions of wave height values

Top - The distribution and cut points for the maximum significant wave height (m) within the Atlantic extent (left), and the recoded distribution (right).
Bottom - The distribution and cut points for the maximum significant wave height (m) within the Pacific extent (left), the distribution and cut points for the transformed maximum significant wave height (middle) and, the recoded distribution (right).

Table 4 - Original and transformed wave height ranges with score

	Mean Maximum Wave Height		
Extent	**O* (m/s)**		**R***
Atlantic	1.37 – 3.35		1
	3.35 – 5.33		2
	5.33 – 7.31		3
	7.31 – 9.29		4
	9.29 – 11.30		5
	O (m/s)	**T***	**R**
Pacific	2.2 – 6.3	5.0 – 39.6	1
	6.3 – 8.6	39.6 - 74.1	2
	8.6 – 10.4	74.1 – 109.0	3
	10.4 - 11.9	109.0 – 143.0	4
	11.9 – 13.3	143.0 – 178.0	5

*O=Original data; T=Transformed data; R=Recoded data



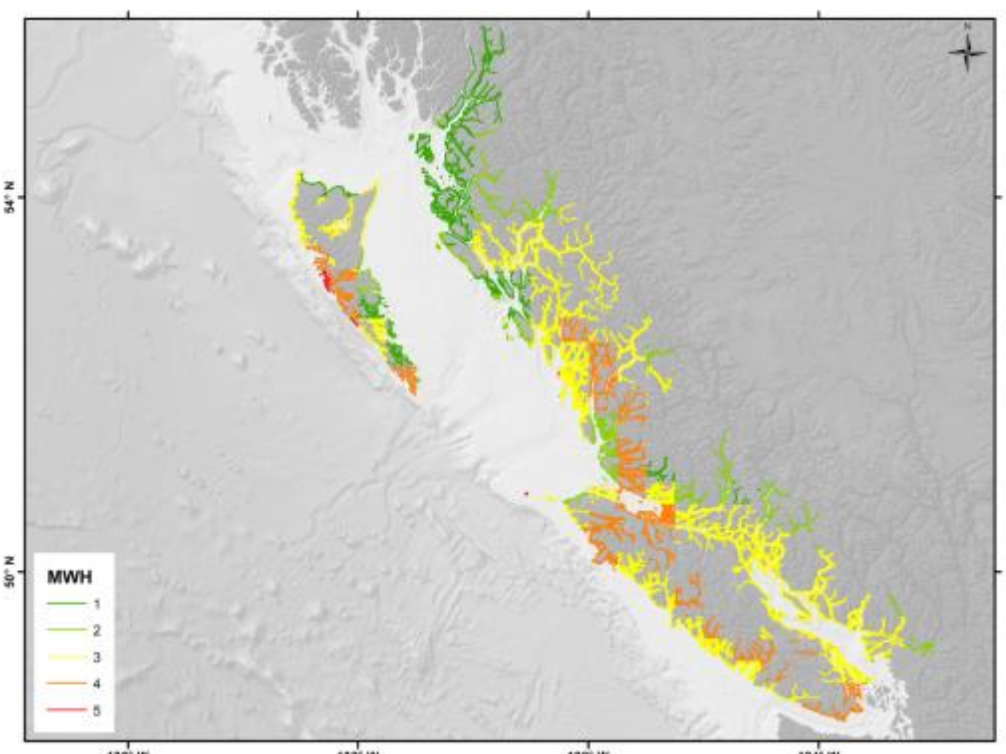


Figure 15 - Wave height scores

Top - The recoded wave height CanCoast shoreline layer clipped to the Atlantic extent.
Bottom - The recoded wave height CanCoast shoreline layer clipped to the Pacific extent.

4.2.1.4 Sea ice

The creation of the sea ice CanCoast coastline layer is described in the Sub-index Development Section 3.1.4. Prior to analysis, the sea ice coastline layer was clipped to only the Atlantic extent as described in the Atlantic and Pacific regions subsection. As with the sea level data within the Exposure Sub-Index, prior to recoding, the absolute value of the sea ice data was transformed to create a roughly normal distribution (Figure 16.). Within the project working group, it was generally agreed that both a shorter and longer period of ice concentrations greater than 50% could adversely impact coastal infrastructure. Based upon this recommendation, the absolute value was used to create the starting distribution of shoreline segments of the sea ice layer within the Atlantic extent. The absolute, transformed and recoded cut values for sea ice are provided in Table 5. Figure 17 shows the recoded change in sea ice coastline. Note, that the lowest value (dark green) represents areas with the least amount of sea ice change between the 1970s and the 2000s, while the dark red represents areas with the largest change. There are large swaths of the Bay of Fundy, south coast of Nova Scotia and the south coast of Newfoundland that rarely or never have sea ice concentrations in excess of 50%. These areas are ranked zero and are equivalent to areas that have experienced no change in the number of weeks of 50% ice coverage between 1970 and 2010. Finally, the large number of zeros affect the distribution of the sea ice data and the transformation applied before recoding is meant to redistribute the non-zero data to represent a roughly normal distribution.

Within the Atlantic extent, the areas that have experienced the greatest change in the number of weeks of >50% sea ice concentration are the Bras D'Or Lakes, P.E.I. and the west coast of New Brunswick, the Strait of Belle Isle, northern Newfoundland and some parts of the Labrador Coast.

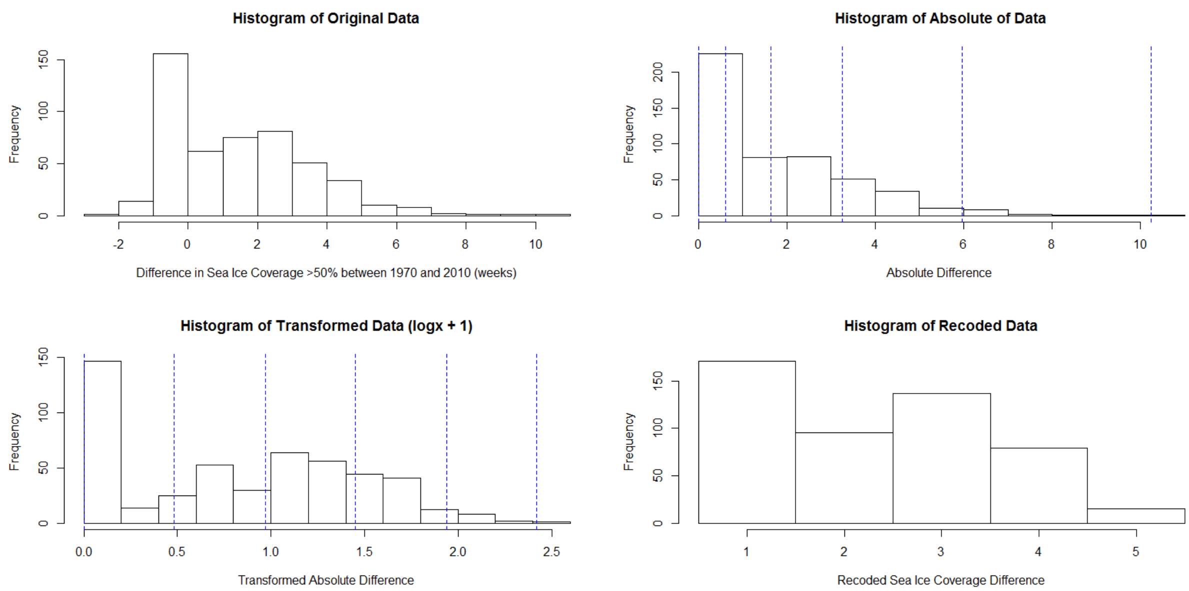


Figure 16 - Frequency distributions of changes in sea ice coverage values

Top Left – The histogram of the original shoreline segments within the Atlantic extent representing the difference (weeks) in >50% ice coverage between 1970 and 2010, where negative values mean more ice in 2010 and positive means less. **Top right –** The absolute value (weeks) of the original data prior to transformation. **Bottom left –** The distribution of the logx + 1 transformed data. **Bottom right –** The recoded distribution derived from the absolute/transformed sea ice coverage data.

Table 5 - Original and transformed change in sea-ice coverage ranges with score

Data cut points for the absolute sea ice >50% coverage difference (weeks) between 1970 and 2010 and log transformed data distributional cut points

Absolute Sea Ice Coverage Change (weeks) between 1970 and 2010		
AO* (weeks)	**T***	**R***
0 – 0.62	0 – 0.48	1
0.62 – 1.64	0.48 – 0.97	2
1.64 – 3.26	0.97 – 1.45	3
3.26 – 5.96	1.45 – 1.94	4
5.96 – 10.25	1.94 – 2.42	5

*AO=Absolute original data; T=Transformed data; R=Recoded data.

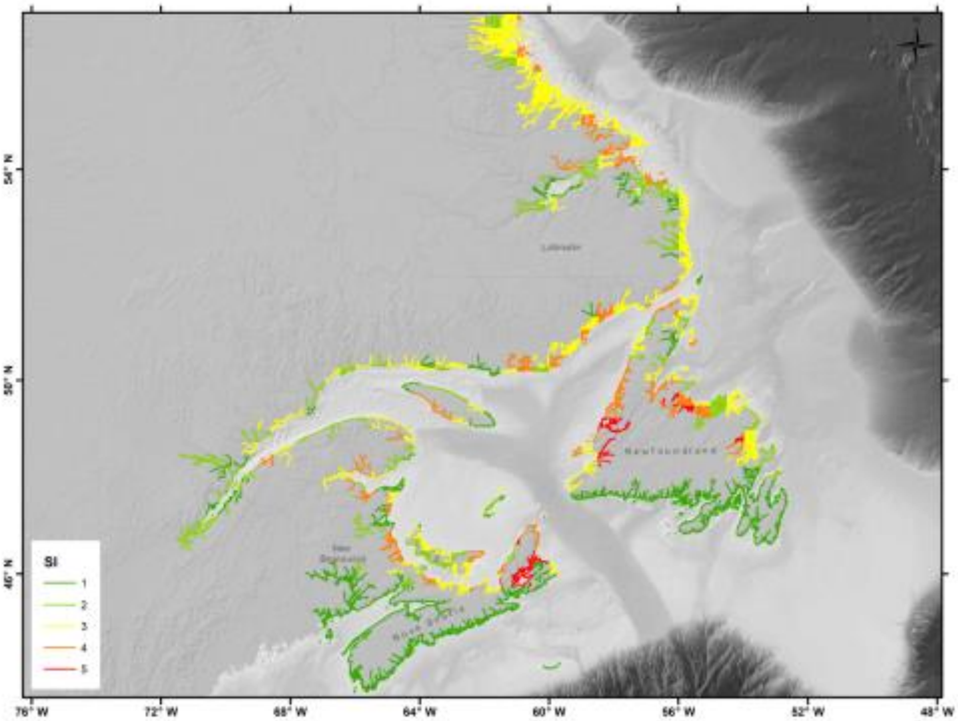


Figure 17 - The recoded mean sea-ice CanCoast shoreline layer clipped to the Atlantic extent

4.2.1.5 Coastal Materials

The creation of the coastal materials CanCoast coastline layer is described in Exposure Sub-Index section (Coastal materials). Prior to analysis, the coastal materials coastline layer was clipped to either the Atlantic or Pacific extents as described in the Atlantic and Pacific regions subsection. Using surficial and bedrock geology layers, coastline segments were ranked from 1-5 based upon expert interpretation. This ranking classification is an assessment of the vulnerability of the coastline to erosional processes with 1 being not vulnerable and 5 being highly vulnerable. The nature of the classification make it impossible to transform these data resulting in a normal distribution (Figure 18), so the original shoreline segment distribution is used for the Exposure Sub-Index calculation. Figure 19 shows the coastal materials CanCoast layer clipped to both the Atlantic and Pacific extents.

Note the areas within the Atlantic extent most susceptible to erosional processes (highest coastal materials value) include the north shore of Nova Scotia, the innermost portion of the Bay of Fundy, the east coast of New Brunswick and Prince Edward Island. In contrast, the Pacific extent has very few areas with areas rated 4 or higher, and coastline segments rated less than 3 represent ~70% of the total segments within the extent.

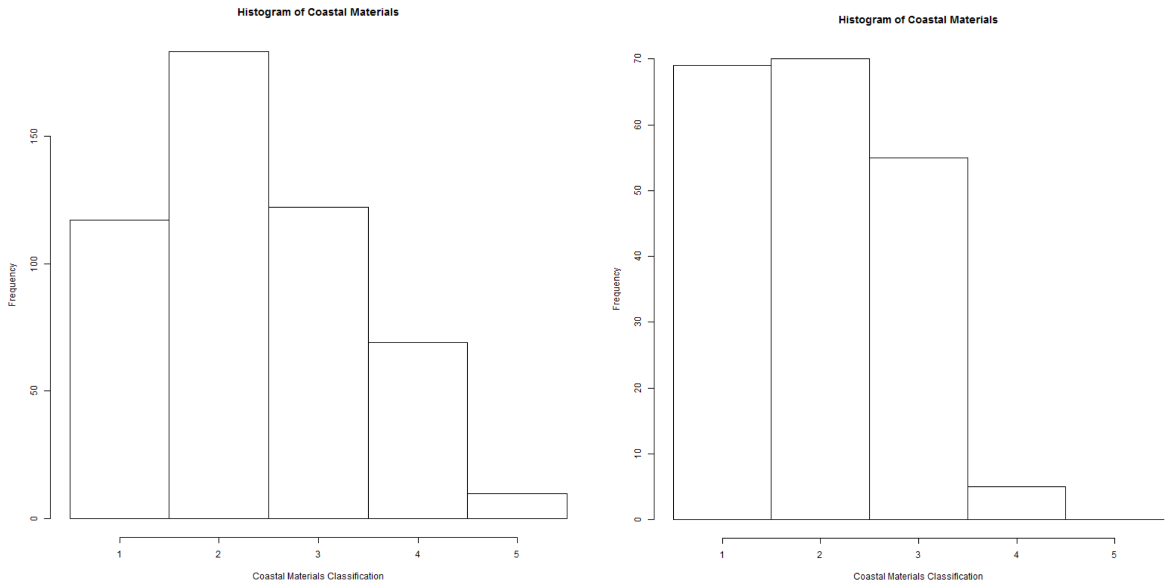


Figure 18 - Frequency distributions of changes in coastal materials values

Left - The distribution of the coastal materials CanCoast Layer within the Atlantic extent.
Right - The distribution of the coastal materials CanCoast Layer within the Pacific extent.

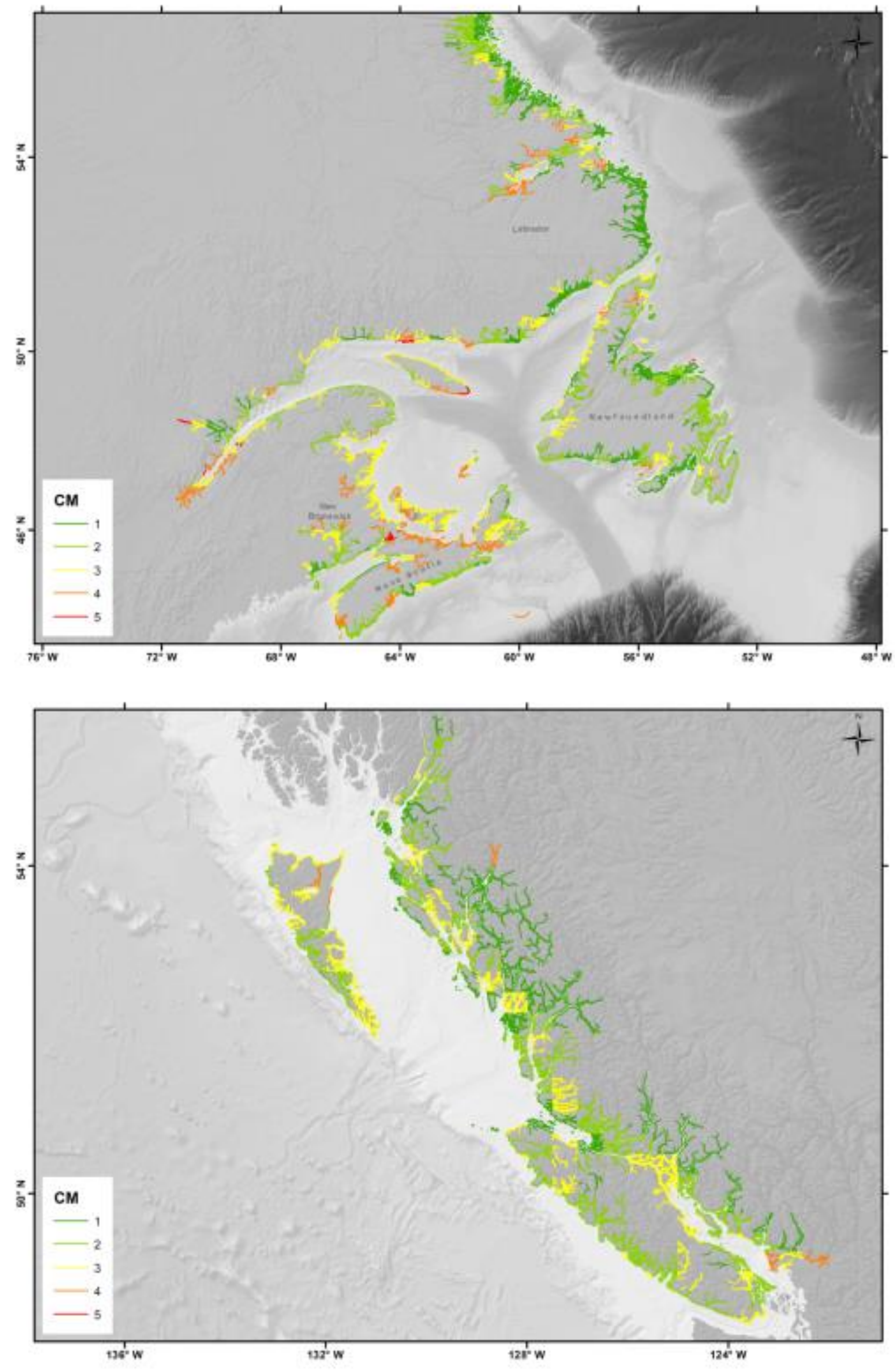


Figure 19 - Coastal materials scores

Top - The coastal materials CanCoast shoreline layer clipped to the Atlantic extent.
Bottom - The coastal materials CanCoast shoreline layer clipped to the Pacific extent.

4.2.2 <u>Exposure Sub-Index Calculation and Results</u>

The SCH pilot sites were linked via a unique ID to the 50 km National Topographic System (NTS) grid, which serves as the cut points for the CanCoast shoreline. Using the ArcGIS 10.1 Join tool, the pilot sites were then assigned the exposure layer data from the NTS grid cell in which they both reside (See Figure 20 for an example). The R statistical package was then utilized to calculate the geometric mean Exposure Sub-Index for each pilot site for both regional extents. The layers described in this section were used to calculate the Exposure Sub-Index within the Atlantic extent. The Sea Ice layer was not used in the calculation of the Exposure Sub-Index for the Pacific extent.

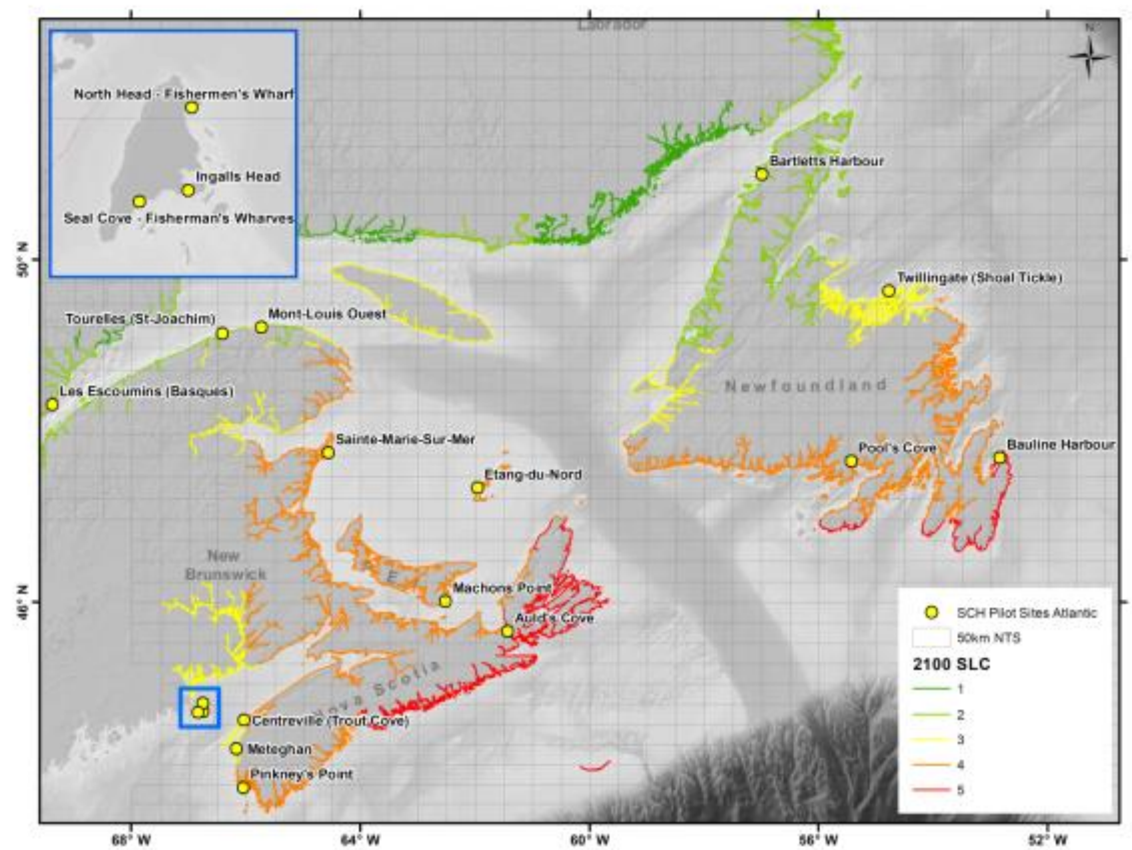


Figure 20 - SCH Pilot sites, NTS mapsheet grid and sea level change CanCoast layer

Table 6 - SCH recoded variables used to calculate the Exposure Sub-Index.

SCH locations listed from greatest to lowest Exposure Sub-Index. The shaded fields below were used to calculate the Exposure Sub-Index.

Extent	Harbour Name	Prov.	SLC* (m)	SLC RC*	MMWH* (m)	MMWH RC	MMWS* (m/s)	MMWS RC	SIC* (weeks)	SIC RC	CM*	ESI*
Atlantic	ETANG-DU-NORD (L'ETANG-DU-NORD)	QC	0.76	4	4.44	2	28.96	4	1.38	2	4	3.03
	PINKNEYS POINT	NS	0.73	4	7.34	4	27.06	3	0	1	4	2.86
	BAULINE	NL	0.83	5	6.53	3	31.4	5	0	1	2	2.72
	AULDS COVE	NS	0.76	4	3.45	2	24.11	2	2	3	3	2.7
	METEGHAN	NS	0.65	3	7.66	4	28.95	4	0	1	3	2.7
	CENTREVILLE (TROUT COVE)	NS	0.82	5	7.65	4	26.35	3	0	1	2	2.61
	TWILLINGATE (SHOAL TICKLE)	NL	0.62	3	6.43	3	25.04	3	0.89	2	2	2.55
	MACHONS POINT	PEI	0.78	4	2.79	1	23.13	2	2.42	3	3	2.35
	MONT-LOUIS OUEST	QC	0.53	3	4.21	2	24.77	3	1.23	2	2	2.35
	SAINTE-MARIE-SUR-MER	NB	0.75	4	4.04	2	26.26	3	0.11	1	3	2.35
	INGALLS HEAD	NB	0.65	3	6.17	3	29.48	4	0	1	2	2.35
	POOL'S COVE	NL	0.7	4	4.62	2	25.37	3	0	1	3	2.35
	SEAL COVE-FISHERMEN'S WHARVES	NB	0.65	3	6.17	3	29.48	4	0	1	2	2.35
	BARTLETTS HARBOUR	NL	0.4	2	4.78	2	24.5	3	0.7	2	2	2.17
	TOURELLES (ST-JOACHIM)	QC	0.46	2	4.12	2	20.8	2	1.09	2	2	2
	NORTH HEAD -FISHERMEN'S WHARF	NB	0.65	3	2.43	1	26.37	3	0	1	2	1.78
	LES ESCOUMINS (BASQCS)	QC	0.35	2	2.7	1	19.32	1	0.23	1	3	1.43
Pacific	UCLUELET WEST	BC	0.56	5	9.12	3	26.91	3			3	3.41
	COWICHAN BAY	BC	0.51	4	10.47	4	26.55	3			2	3.13
	BAMFIELD WEST	BC	0.56	5	9.72	3	26.82	3			2	3.08
	FANNY BAY	BC	0.45	3	10.16	3	26.76	3			3	3

*SLC=Sea level Change 2100; RC=Recoded; MMWH=Mean Maximum Wave Height; MMWS=Mean Maximum Wind Speed; SIC=Sea Ice Change; CM=Coastal Materials; ESI=Exposure Sub-Index

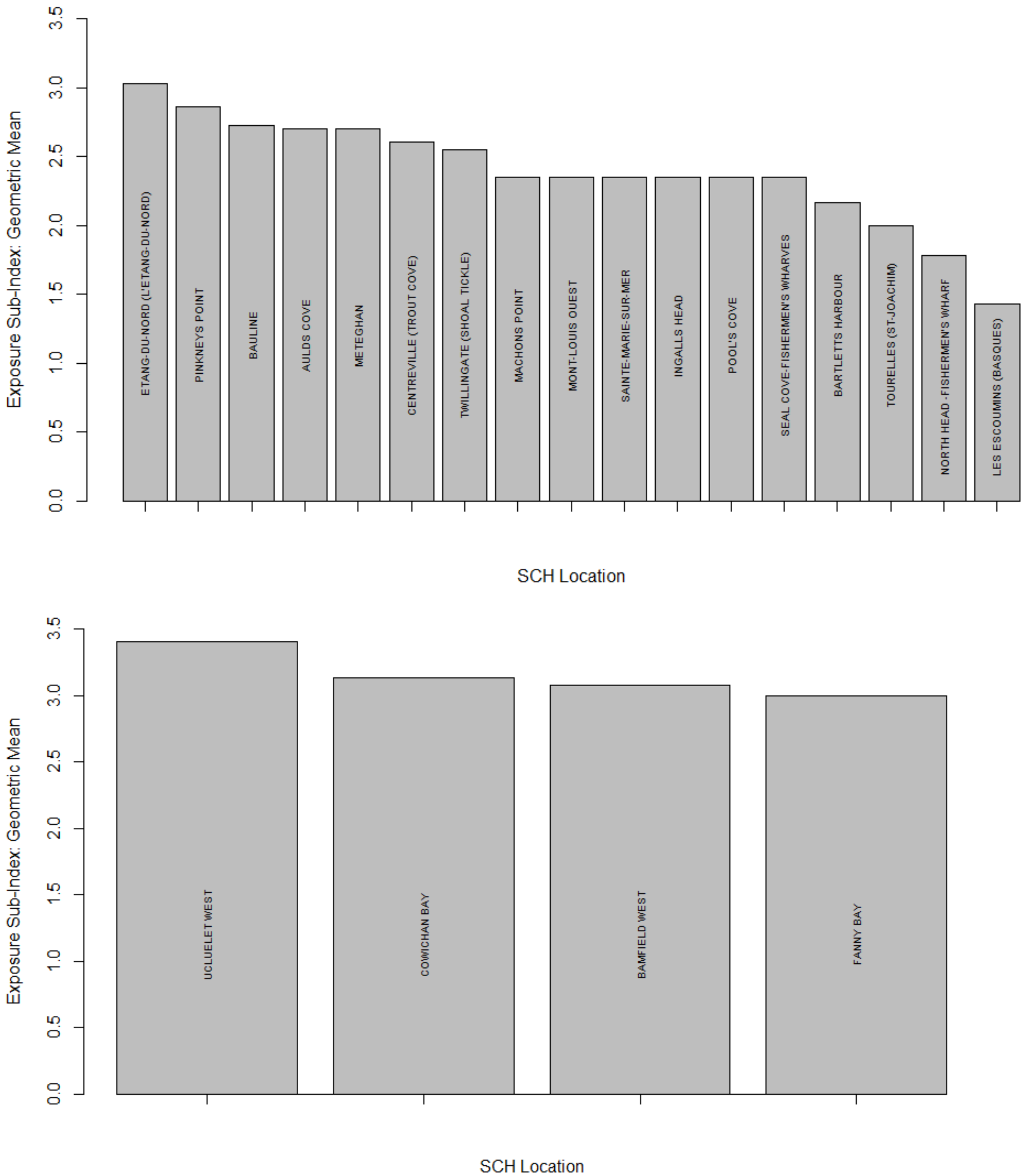


Figure 21 - Ranked Exposure Sub-Index values for SCH pilot sites (most vulnerable to least vulnerable)

Top – SCH pilot locations within the Atlantic extent (most vulnerable to least vulnerable).
Bottom – SCH pilot locations within the Pacific extent.

Figure 22 provides maps of the Atlantic and Pacific extents with their SCH pilot locations color coded, with red representing relatively high and blue relatively low Exposure Sub-Index.

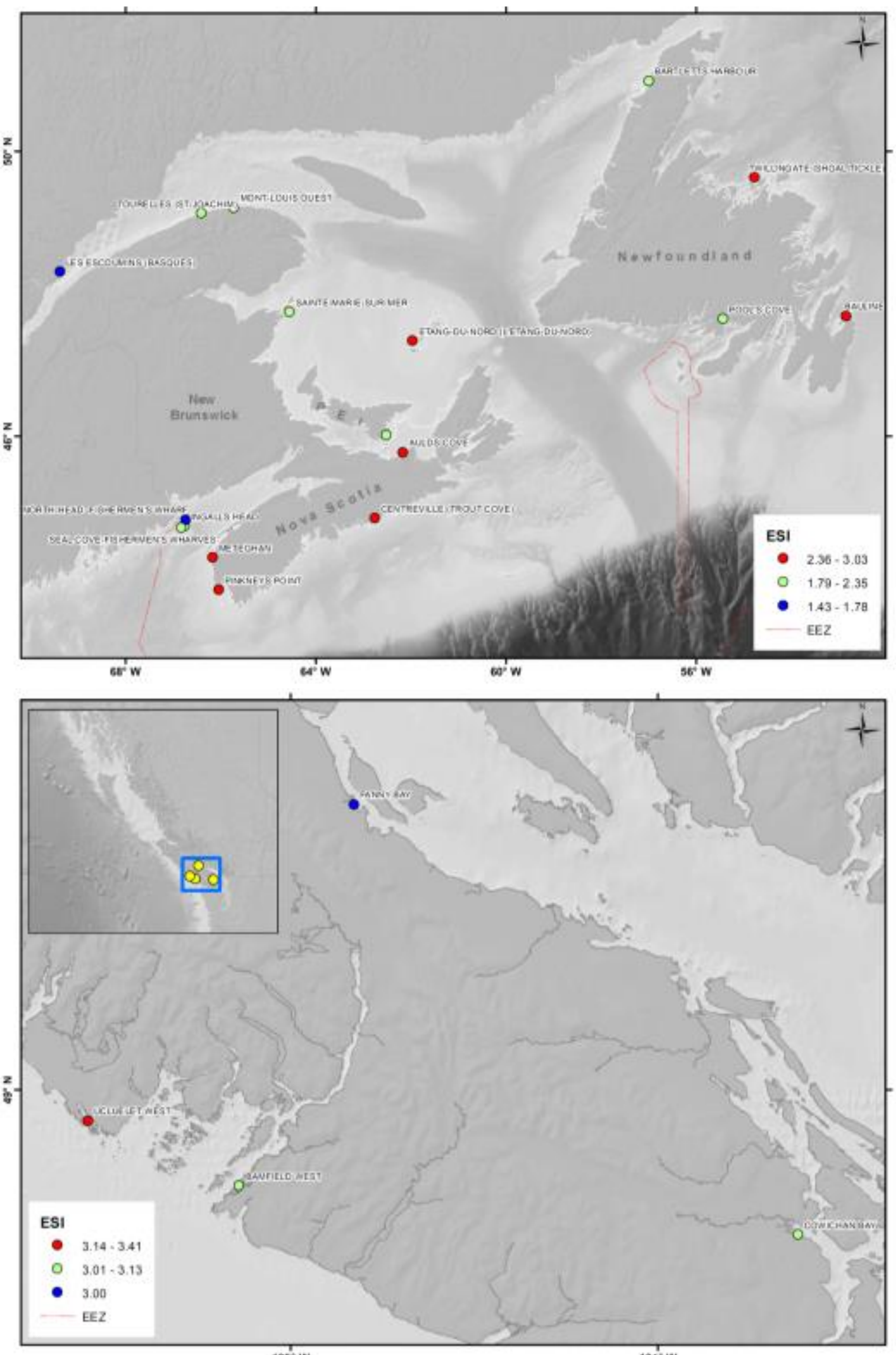


Figure 22 - Colour-coded exposure sub-index scores for SCH pilot sites

Top - Atlantic SCH
Bottom - Pacific SCH

4.3 ISI CALCULATION

4.3.1 Variable Transformation and Scoring

For this analysis SCH provided the locations, total replacement costs, harbour condition index and degree of protection for 1032 SCH facilities throughout Canada. As shown in Figures 7 and 9 only the points within regional polygons were used for their respective sub-index calculations. In total, 735 facilities were represented within the Atlantic extent and 107 within the Pacific extent. The degree of protection value was provided for only the pilot sites within each extent. For the degree of protection variable a normal distribution of the data was assumed but this could change as data becomes available for more SCH locations. As such, a sub-section describing degree of facility protection is not provided in this section, but the inverted original value is included in the final Infrastructure Sub-Index calculation.

4.3.1.1 Harbour Condition

Details of the SCH Harbour Condition criteria are provided in Sub-index Development section (Infrastructure Vulnerability sub-section). The original Harbour Condition data provided for this analysis is a value from 0 – 5, with 5 being the best condition and 0 being the worst. The Harbour Condition was calculated for 707 of the 735 SCH locations within the Atlantic extent and for 103 of the 107 SCH locations within the Pacific extent. Of the 707 Atlantic SCH locations with a calculated Harbour Condition code, 41 had the poorest condition value of 0 (zero). The original distribution was slightly left skewed, so the data were lightly transformed (^1.6) before being reclassified 1 – 5. The reclassified data were then flipped to match the vulnerability index convention of this report, where 5 is most vulnerable (lowest Harbour Condition) and 1 is least vulnerable (highest Harbour Condition) (Figure 23 and Table 7). This methodology was repeated for the SCH locations within the Pacific region (Figure 24 and Table 7).

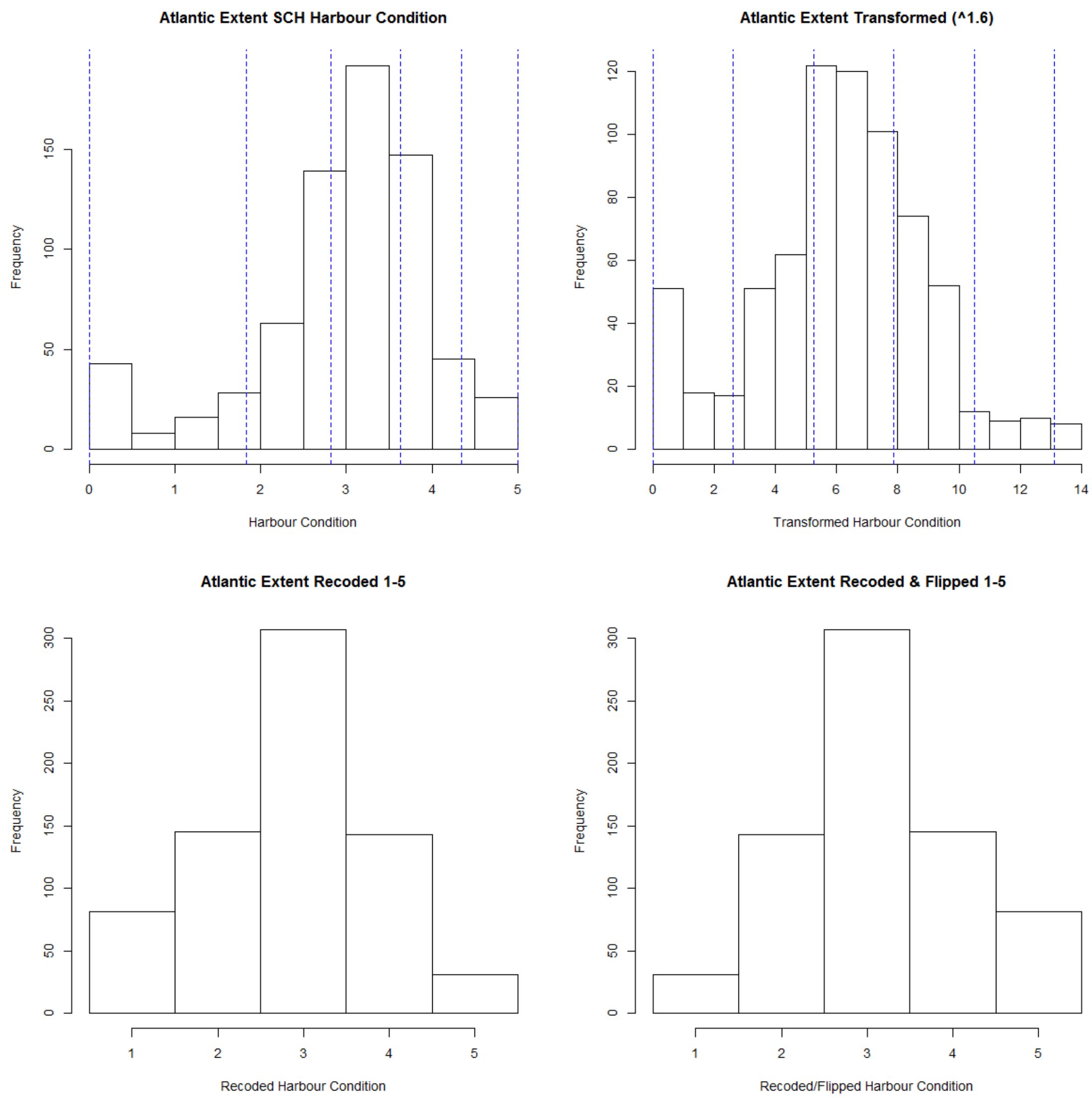


Figure 23 - Frequency distributions of Atlantic SCH pilot sites

Top - The distribution of the original Atlantic extent Harbour Condition data provided by SCH (left); the lightly transformed dataset (right); **Bottom -** the reclassified SCH Harbour Condition (left); the reclassified SCH Harbour Condition flipped to conform with the convention utilized for this report (right) (High Condition (5) = Least Vulnerable (1), Low Condition (0) = Most Vulnerable (5)).

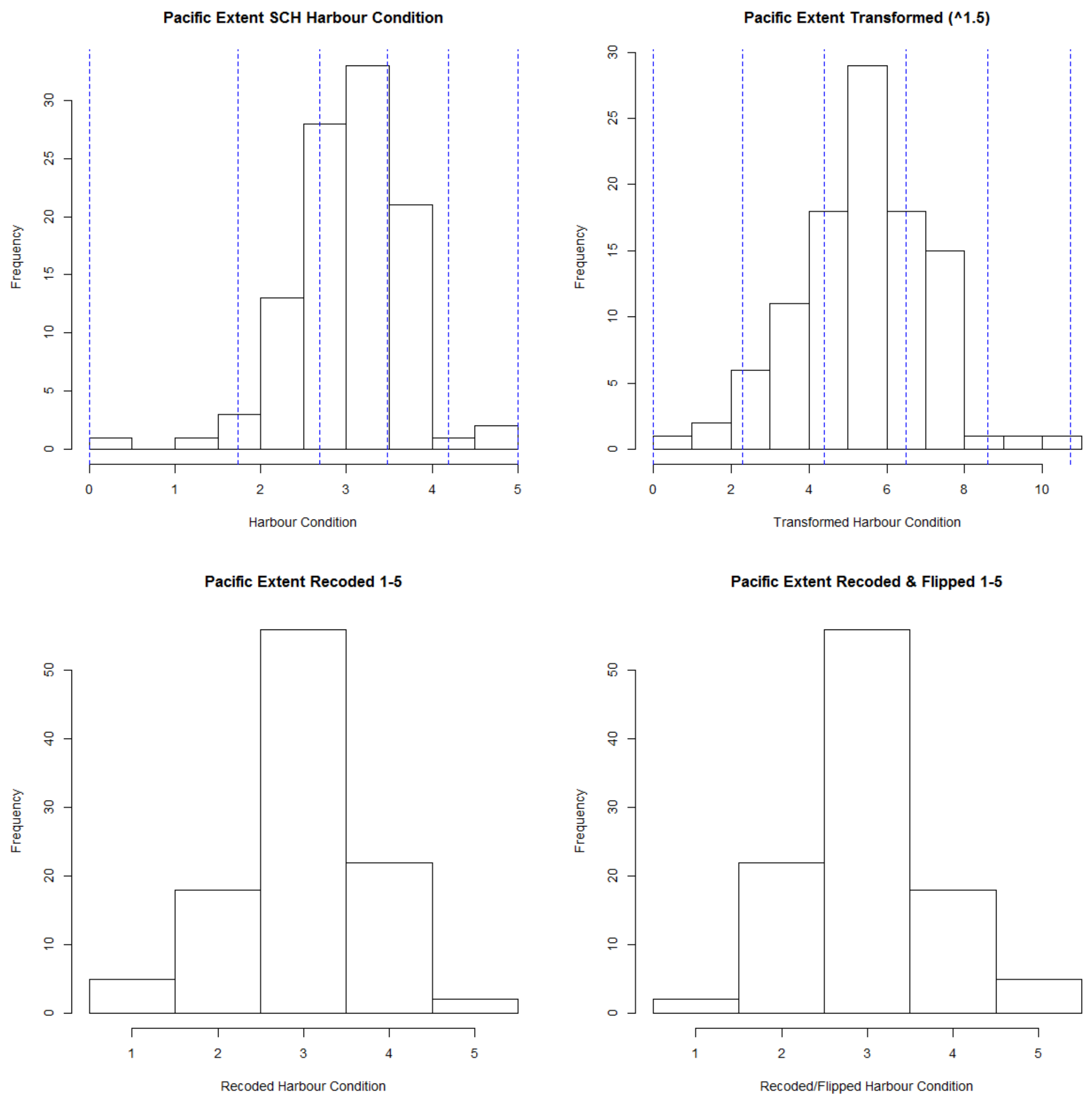


Figure 24 - Frequency distributions of Pacific SCH pilot sites harbour condition

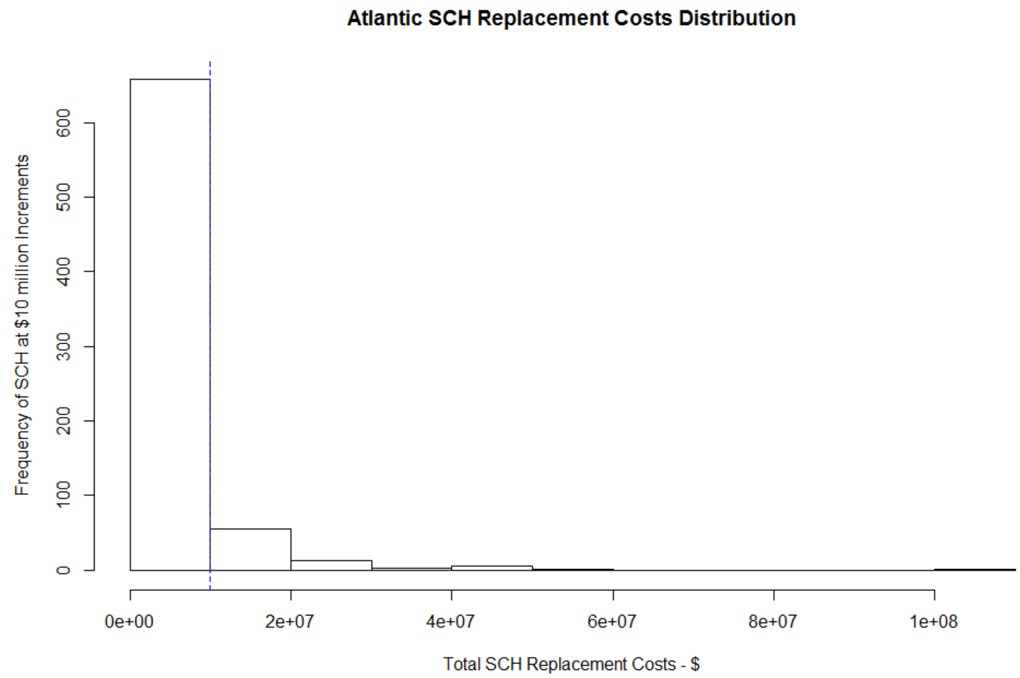
Top - The distribution of the original Pacific extent Harbour Condition data provided by SCH (left), the lightly transformed dataset (right). **Bottom -** the reclassified SCH Harbour Condition (left), the reclassified SCH Harbour Condition flipped to conform with the convention utilized for this report (right) (High Condition (5) = Least Vulnerable (1), Low Condition (0) = Most Vulnerable (5)).

Atlantic and Pacific pre-transformed, transformed and recoded Infrastructure Sub-Index parameters. Note that the regional distribution of the “Degree of Harbour Protection” was assumed to be normal because these data only existed for the pilot study SCH locations and not all SCH sites; the range of values for this parameter were therefore not transformed.

4.3.1.2 <u>Total Replacement Costs</u>

Small Craft Harbours within the Atlantic extent with property values less than $10 million dollars represented ~88% of the properties but only ~52% of the total Atlantic extent SCH replacement costs. Slightly more than 48% of the total replacement costs were represented by 78 (~12%) of the 735 properties within the Atlantic extent (Figure 23). Of the 657 properties less than $10 million, 58 of those had zero replacement costs and represented locations with limited or no infrastructure.

As within the Atlantic extent, 80% of SCH locations within the Pacific extent had total replacement costs less than $10 million dollars (89 of 107). These 89 locations accounted for ~67% of the total replacement costs, while the remaining 18 locations accounted for 33% of the total replacement costs (Figure 25). Four sites had total replacement costs of zero (mooring buoy locations) and as in the Atlantic extent, represented locations with limited or no infrastructure.



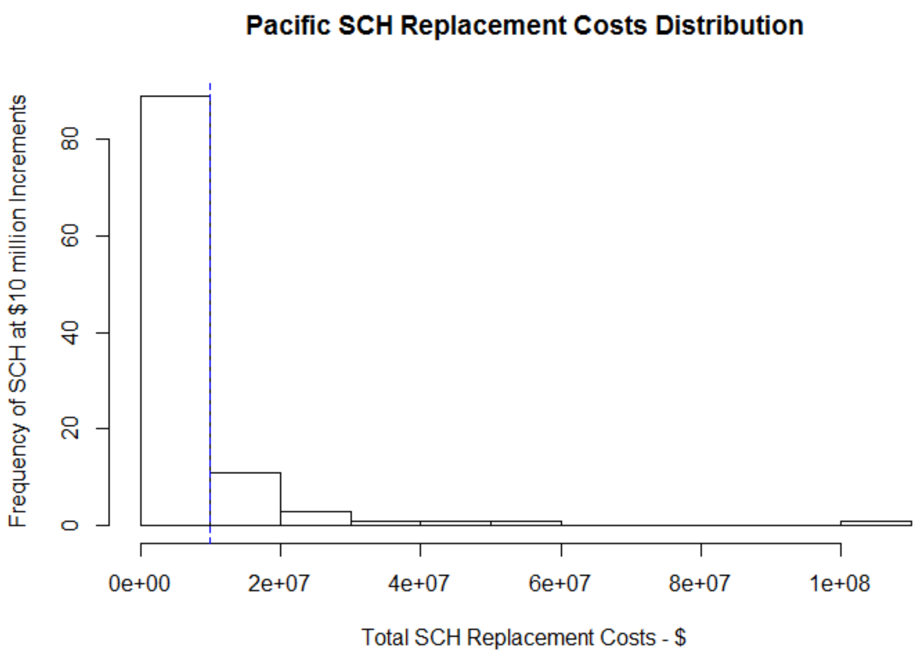


Figure 25 - SCH replacement costs

Top -The distribution of the total replacement costs for each of the 735 SCH within the Atlantic extent. 88% of the SCH have total replacement costs less than $10 million (left of the blue dotted line) and 78 SCH represent 52% of the total SCH replacement costs within the Atlantic extent (right of the blue dotted line). **Bottom** - the distribution of the total replacement costs for each of the 107 SCH within the Pacific extent. 80% of the SCH have total replacement costs less than

$10 million and 18 SCH represent 33% of the total SCH replacement costs within the Pacific extent.

Prior to reclassifying the distribution on a scale of 1 to 5, the datasets for both regions were transformed to approximately normalize the distribution. Figure 26 and Table 7 show the pre-transformed, transformed and recoded cut offs for the total replacement costs.

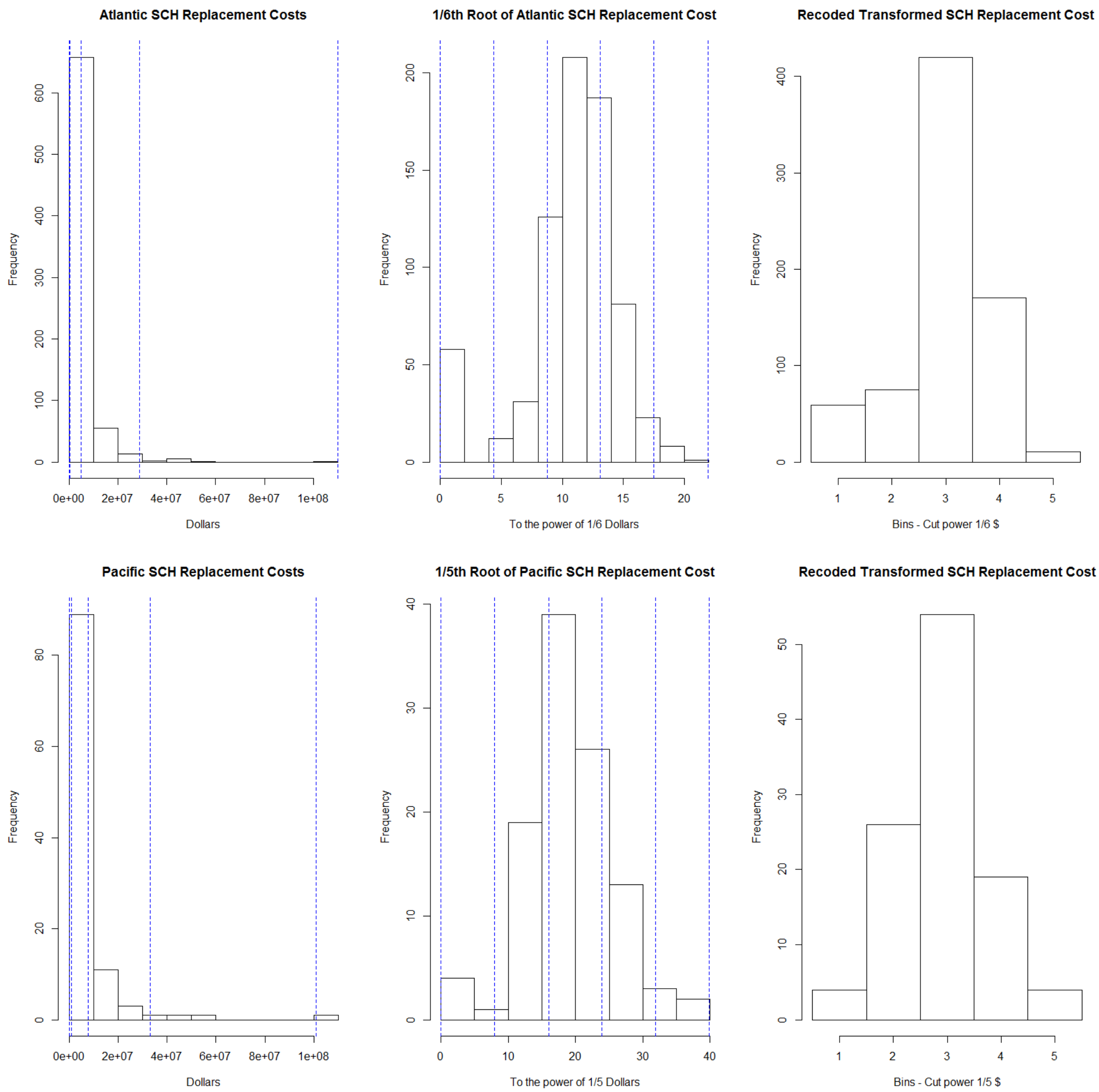


Figure 26 - Frequency distributions of SCH replacement costs

Top - The distribution of the original replacement costs of SCH within the Atlantic extent before transformation (left), after 1/6th root transformation (middle) and after reclassifying the data 1-5 (right). **Bottom -** The distribution of the original replacement costs of SCH within the Pacific extent before transformation (left), after 1/5th root transformation (middle) and after reclassifying the data 1-5 (right). The blue dotted lines for the left and middle panels represent the cut points of the untransformed and transformed distributions that comprise the reclassified distribution on the far right.

Table 7 - Original and transformed infrastructure variable ranges with score

Extent	Infrastructure Sub-Index variable					
	Total Replacement Cost ($)			Harbour Condition Code		
	O*	**T***	**R***	**O**	**T**	**R**
Atlantic	0 - 7,060	0 – 4.4	1	0 – 1.8	0 – 2.6	5
	7,060 - 449,000	4.4 – 8.8	2	1.8 - 2.8	2.6 – 5.7	4
	449,000 - 5,050,000	8.8 – 13.1	3	2.8 - 3.6	5.7 – 7.9	3
	5,050,000 - 28,700,000	13.1 – 17.5	4	3.6 - 4.3	7.9 – 10.5	2
	28,700,000 - 110,000,000	17.5 – 21.9	5	4.3 - 5.0	10.5 – 13.1	1
Pacific	0 - 32,400	0 – 7.9	1	0 – 1.7	0 – 2.3	5
	32,400 - 1,050,000	7.9 – 16.0	2	1.7 – 2.7	2.3 - 4.4	4
	1,050,000 - 7,800,000	16.0 – 23.9	3	2.7 – 3.5	4.4 – 6.5	3
	7,800,000 - 33,000,000	23.9 – 31.9	4	3.5 – 4.2	6.5 – 8.6	2
	33,000,000 - 101,000,000	31.9 – 39.9	5	4.2 – 5.0	8.6 – 10.7	1

*O=Original data; T=Transformed data, R=Recoded data.

4.3.2 Infrastructure Sub-Index Calculation and Results

The infrastructure variables (original and recoded) for the pilot SCH locations within each extent are provided in Table 7. The recoded variables were incorporated into the formula for calculating the Infrastructure Sub-Index discussed in section 3.4 of this report. Table 8 and Figure 27 show the calculated Infrastructure Sub-Index for all SCH pilot locations within each extent.

Table 8 - SCH recoded variables used to calculate the Infrastructure Sub-Index

The recoded variables used to calculate the Infrastructure Sub-Index for the pilot SCH locations within the Atlantic and Pacific study extents. The shaded fields below were used to calculate the Infrastructure Sub-Index.

Extent	Harbour Name	Prov.	HC*	HC RC	TRC* ($)	TRC RC	DFP*	DFP RC	ISI
Atlantic	BARTLETTS HARBOUR	NL	1.23	5	1,288,477	3	1	5	4.22
	ETANG-DU-NORD (L'ETANG-DU-NORD)	QC	2.68	4	38,866,200	5	3	3	3.91
	LES ESCOUMINS (BASQCS)	QC	2.38	4	4,658,000	3	2	4	3.63
	NORTH HEAD - FISHERMEN'S WHARF	NB	3.17	3	17,808,000	4	2	4	3.63
	AULDS COVE	NS	3.09	3	1,555,000	3	1	5	3.56
	MACHONS POINT	PEI	2.78	4	2,525,000	3	3	3	3.30
	MONT-LOUIS OUEST	QC	3.20	3	21,304,450	4	3	3	3.30
	SAINTE-MARIE-SUR-MER	NB	2.90	3	7,690,000	4	3	3	3.30
	CENTREVILLE (TROUT COVE)	NS	2.30	4	7,650,000	4	4	2	3.17
	TOURELLES (ST-JOACHIM)	QC	2.74	4	19,527,250	4	4	2	3.17
	INGALLS HEAD	NB	3.08	3	21,270,000	4	4	2	2.88
	METEGHAN	NS	3.59	3	16,500,000	4	4	2	2.88
	POOL'S COVE	NL	3.87	2	1,583,010	3	3	3	2.62
	SEAL COVE-FISHERMEN'S WHARVES	NB	4.14	2	19,475,000	4	4	2	2.52
	BAULINE	NL	4.14	2	4,985,326	3	4	2	2.29
	PINKNEYS POINT	NS	3.08	3	6,395,000	4	5	1	2.29
	TWILLINGATE (SHOAL TICKLE)	NL	4.73	1	7,235,210	4	4	2	2.00
Pacific	COWICHAN BAY	BC	2.70	3	8,070,004	4	2	4	3.63
	BAMFIELD WEST	BC	3.00	3	1,228,837	3	1	5	3.56
	UCLUELET WEST	BC	3.43	3	6,125,030	3	1	5	3.56
	FANNY BAY	BC	3.86	2	5,662,780	3	2	4	2.88

*HC=Harbour Condition; TRC=Total Replacement Cost; DFP=Degree of Facility Protection; RC=Recoded; ISI=Infrastructure Sub-Index

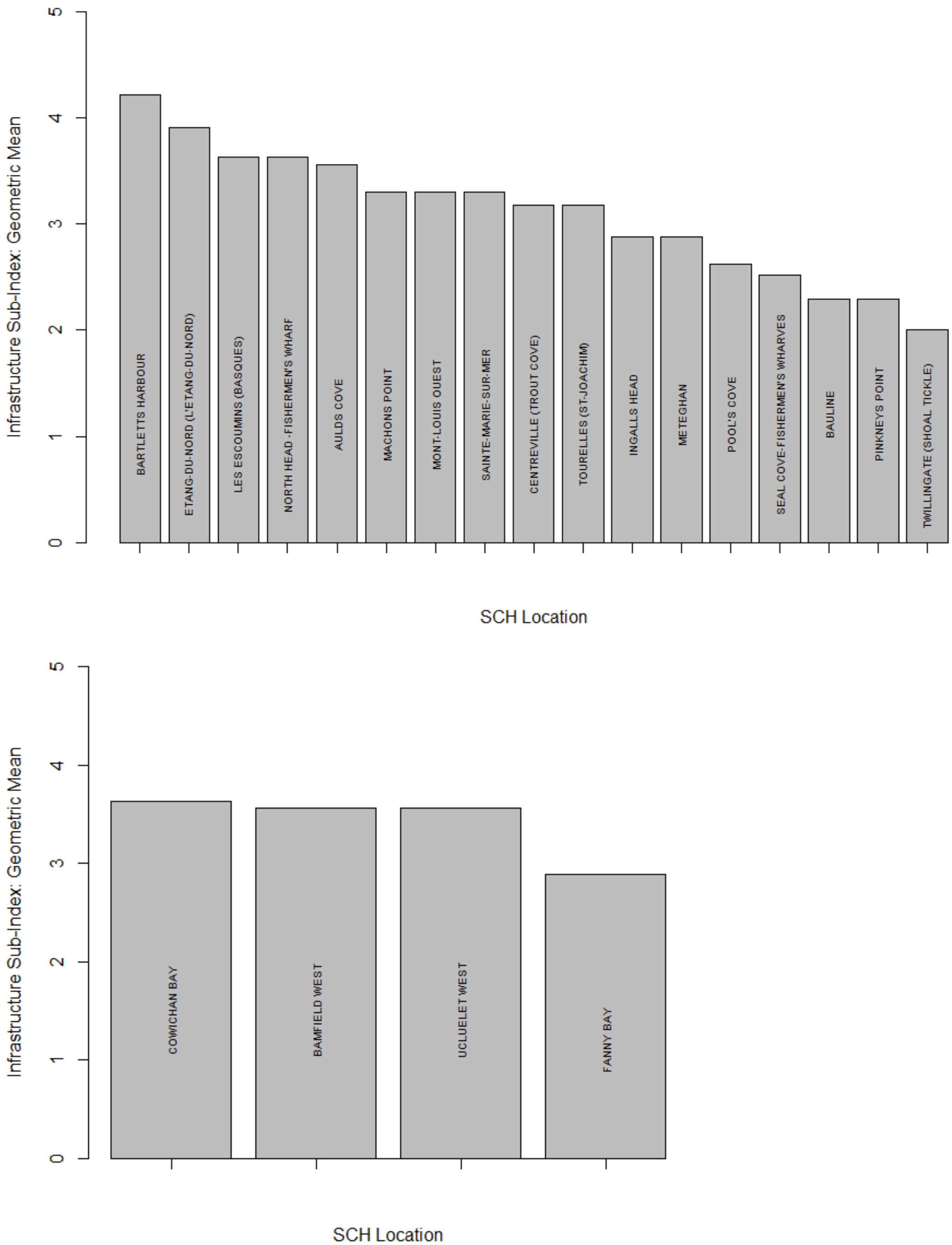


Figure 27 - Ranked Infrastructure sub-Index for SCH pilot sites (most vulnerable to least vulnerable)

Top - Atlantic SCH
Bottom - Pacific SCH

Figure 28 provides maps of the Atlantic and Pacific extents with their SCH pilot sites color coded by Infrastructure Sub-Index with red representing relatively high and blue representing relatively low Infrastructure Sub-Index values.

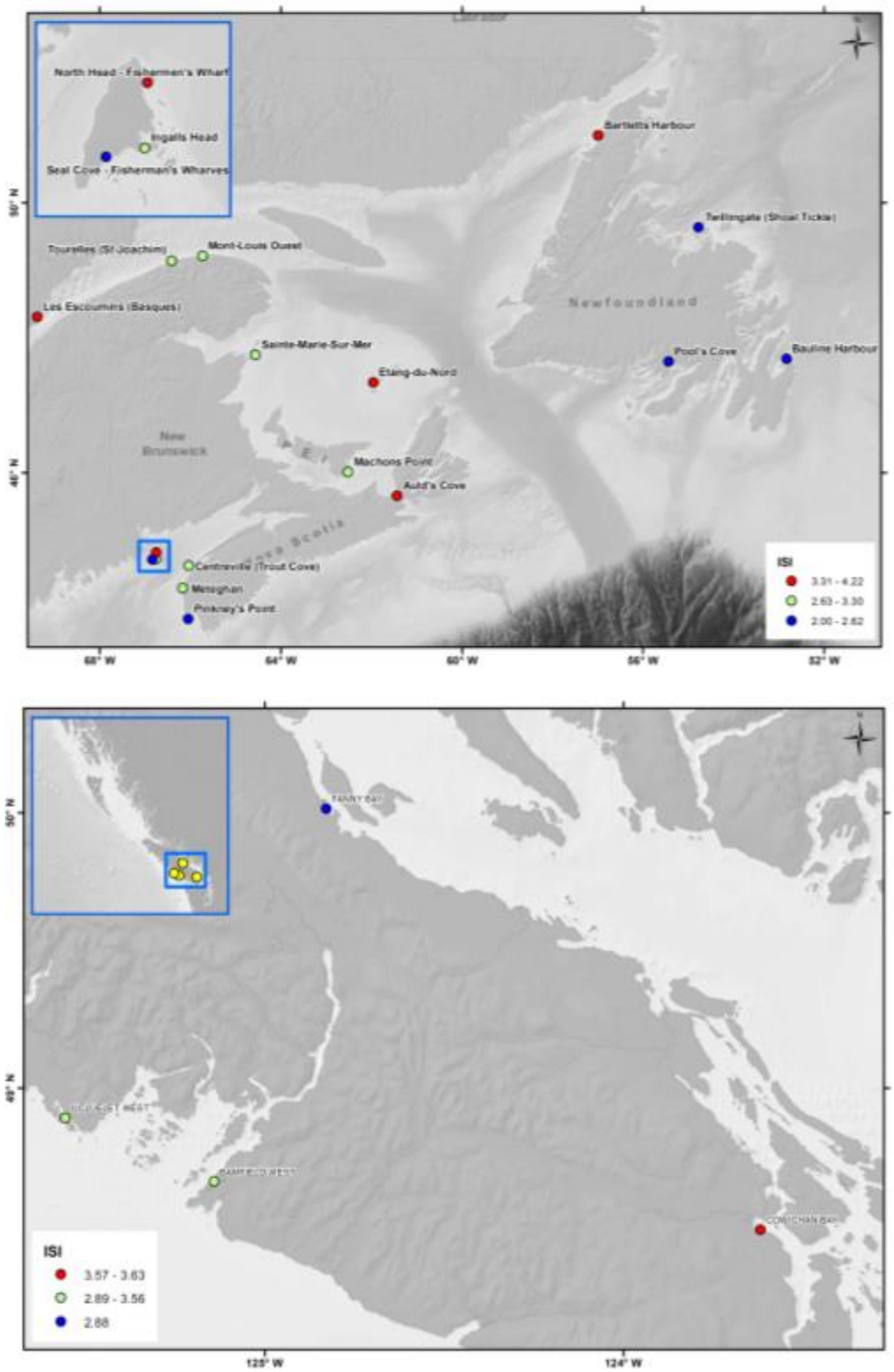


Figure 28 - Colour-coded infrastructure sub-index scores for SCH pilot sites

Top - Atlantic SCH
Bottom - Pacific SCH

4.4 SESI CALCULATION

As described in section 3.3, a selection of socio-economic variables was provided for this pilot study. Section 3.3 also provides justification for why these variables were selected as well as the strengths, weaknesses and caveats for utilizing these data for this type of analysis. This section describes the methodology employed to further refine the variables utilized for the Socio-Economic Sub-Index (SESI) as well as identify some limitations of these data.

First, as stated in section 3.3., while population and fishing-related income data can be obtained across Canada by census subdivisions (CSDs), the landing and vessel activity data directly associated with each SCH site are available only in Atlantic Canada. The association of the former two CSD-based variables to SCH sites are inferred and it is possible that the population size and fisheries-related income are unlinked to SCH usage. For example, some fishing-related income in the Pacific are reported to be generated by non-SCH landing sites. As such, the entirety of the currently selected socio-economic parameters appears to be suitable for just the Atlantic Region. Explorations of other socio-economic variables more directly related to SCH sites would be recommended for the Pacific and Central and Arctic regions. For this reason, this analysis will focus solely on calculating the SESI for SCH facilities within the Atlantic extent. This means, that the Coastal Infrastructure Vulnerability Index (CIVI) for SCH pilot sites within the Atlantic extent will include all 3 sub-indices (Infrastructure, Exposure and Socio-Economic), and the CIVI will not be calculated for pilot SCH sites within the Pacific extent.

The dataset provided by the Economic Analysis and Statistics Directorate was filtered to the 4 Atlantic Regions (Quebec, Gulf of St Lawrence, Maritimes, Newfoundland and Labrador) and contained information for 1150 SCH locations. As with both the infrastructure and exposure variables, this larger dataset was then utilized to establish a distribution and was then recoded to a 1 – 5 scale for each of the 17 SCH pilot sites. Table 9 provides a statistical summary of these variables along with a column showing the number and % of SCH locations that have NA values for each variable.

The challenge with incorporating socio-economic data has been the high percentage of values that have been assumed to be zero. Due to the data collection and reporting methodology in socio-economic data, there remains varying degrees of uncertainty in whether the NA values indicated in this report reflect an absolute zero amount in the socio-economic variables rather than an assumed zero amount when data is suppressed for privacy reasons, unreported, or unavailable for other reasons. For the purpose of this pilot study, it was assumed that all NA entries are zero values for all socio-economic variables. This is a broad-based assumption to ensure the easy of application for the CIVI methodology for the purposes of this pilot.

For future studies, further verification of the income data provided by CRA for data suppression due to privacy purposes is possible. However, uncertainties associated in differentiating the reporting of true zero versus NA values for socio-economic variables related to landing, vessel activity and population are inherent to the data. As such, the development of a protocol in dealing with the prevalence of NA and zero values for socio-economic variables could help to ensure socio-economic considerations remain an integral part of the decision-making process in the absence of certainty in the reporting of such values for socio-economic variables.

Specifically, a flagging protocol could be developed whenever a harbour site has a NA or zero value for variables for either AFIAEI or Average Landed Quantity per Vessel at Port of Landing (ALQVAPL), so that these sites would referred for further assessment by harbour management authorities. For such protocol to work with the current set of variables, harbour sites with zero values for both AFIAEI and ALQVAPL would be automatically flagged for further assessment. For sites with just one NA value between AFIAEI and ALQVAPL, the protocol could work by dropping the variable with the NA socio-economic value from the calculation of the vulnerability and use only the other two socio-economic variables with non-NA values. A risk threshold would be set using the remaining non-zero socio-economic variables, which if triggered, would flag the site into a list for further investigation.

Table 9 - Socio-economic variable statistical summaries for 1150 Atlantic harbour sites.

Variable	Units	Min	Max	Median	Mean	NA	NA%
ALV*	Dollars	2	83,551,822	190,396	1,548,363	97	8.4
ALQ*	KG	1	33,701,892	58,844	667,193	96	8.3
CTLQ*	%	-100	434760	-16.5	974.5	116	10
NAVPL (2013)*	Count	1	157	5	11.7	199	17.3
NAVPL (2009 – 2013)	Count	0	139	5	12	100	8.7
AFI*	Dollars	8	8,301,417	514,888	1,654,860	308	26.8
ATITF*	Dollars	197	1,795,000,000	6,949,000	128,900,000	309	26.9
AFIAEI*	%	0	68.4	8.8	12	309	26.9
TP*	Count	0	390,096	1973	25102.3	132	11.5

*****ALV=Average Landed Value; ALQ=Average Landed Quantity; CTLQ=Change in Total Landed Quantity; NAVPL=Number of Active Vessels Port of Landing; AFI=Average Fishing Income; ATITF=Average Total Income with Tax Filers; AFIAE=Average Fishing Income to Average Employment Income.

4.4.1 <u>Variable Selection, Transformation and Scoring</u>

The Change in Total Landed Quantity (CTLQ) variable was dropped from the analysis because it assumed a linear trend in landed quantity over a nearly 10 year period based only on the first and last year and does not account for annual variability in catch statistics. The Number of Active Vessels Port of Landing (NAVPL - 2013) was also dropped because it provided data for only 1 year and was highly significantly correlated with the average NAVPL (2009 – 2013) (*rho*=0.91). In addition, the average Number of Active Vessels Port of Landing (2009 - 2013) was reported as an integer. This is problematic, as it is possible to have a value of less than 1 when calculating this variable (e.g., a single vessel in 2013 but no vessels of every other year). For the purposes of this preliminary analysis and until the data can be properly recalculated, it was assumed that anytime that Average Landed Value (ALV), Average Landed Quantity (ALV), CTLQ or NAVPL (2013) was greater than 0 that the average NAVPL (2009 – 2013) was equal to 1.

As discussed in section 3.3, the income statistics Average Total Fishing Income (AFI), Average Total Income with Tax Filers (ATITF), and Average Fishing Income to Average Employment Income (AFIAEI) are provided by 2006 CSD, Total Population (TP) by 2011 CSD, and landings are provided by harbour sites on an annual basis. This can create some confusion as there is often many SCH within a single CSD with only a few harbours reporting landings but all harbours reporting AFI, ATITF and AFIAEI. The opposite can also be true when landings have been reported but AFI, ATITF and AFIAEI are not available (NA). This could be because the data was suppressed due to the low number of fishermen or population within the sub-division, or because the SCH is utilized by fishermen that report their income outside of the census area of the SCH. For the purposes of this report a decision was made to treat landings and income values in the following way and with the associated assumptions:

- All NA values are considered to be zero for both landings and income:
- If NA values are present for landings variables (ALV and ALQ) for a SCH within a CSD, it is possible that the income variables reported for this SCH include income from other SCHs within the same CSD that reported landings.
- It is possible to have one or multiple SCH sites within a CSD that report income but no landings because the fishermen within the CSD might not report their landings at a SCH within the CSD in which incomes are reported.
- Finally, it is possible to have a relatively high NAVPL (2009 – 2013) value with no income values associated with a SCH site. As state indirectly in the abovementioned assumptions, these otherwise busy SCH locations could report vessel activity but no income if the fishermen reported income in different CSD (CSDs).

The socio-economic variables of the SCH require a longer list of caveats than those from both the exposure and infrastructure sub-indices. In addition, many of the variables are significantly correlated (Hierarchically Ranked Spearman Correlation -

Figure 29). This figure shows that all SCH level variables (ALV, ALQ, NAVPL and NAVPL_09_13) are clustered together, and highly significantly correlated with one another (lower left of Figure 29). It is not surprising that ALQ and ALV show strong correlation (*rho*=0.93) as it would be expected that landing quantity and value would be tightly linked. The same could be said for the NAVPL for a single year and the average NAVPL from 2009 to 2013 (*rho*=0.91). For this many small craft harbours, it is likely that a single year is generally representative of the pattern over multiple years. As well, while not always the case as is reflective of a slightly lower correlation coefficient, it also generally makes sense that the number of vessels that a SCH experiences is correlated with landings. For this reason, a decision was made to combine ALQ and the average NAVPL (2009 – 2013) into a new variable called the Average Landed Quantity per Vessel at Port of Landing (2009 – 2013) or ALQVAPL (ALQ/NAVPL (2009-2013) = average kg/vessel (2009-2013)).

A number of strong and significant correlations were also observed between census level variables. In particular, there were strong correlations between the ATITF and AFI, TP (*rho* = 0.9 and 0.84 respectively). There strong significant correlation between AFI and TP, AFIAEI (*rho*=0.75, AFIAEI=0.70). As well, it is not surprising that AFIAEI is significantly correlated to AFI and ATITF because AFIAEI is a % value created from these 2 variables. It would be generally expected that in areas where there is a higher population (TP) that this would result in a correspondingly larger ATITF and larger AFI. Interestingly, the AFIAEI variable was not highly (*rho*=0.29) but was significantly correlated with TP. Based on these correlations, a decision was made to remove both AFI and ATITF from the subsequent socio-economic index calculation, leaving just TP and AFIAEI and the newly created ALQVAPL.

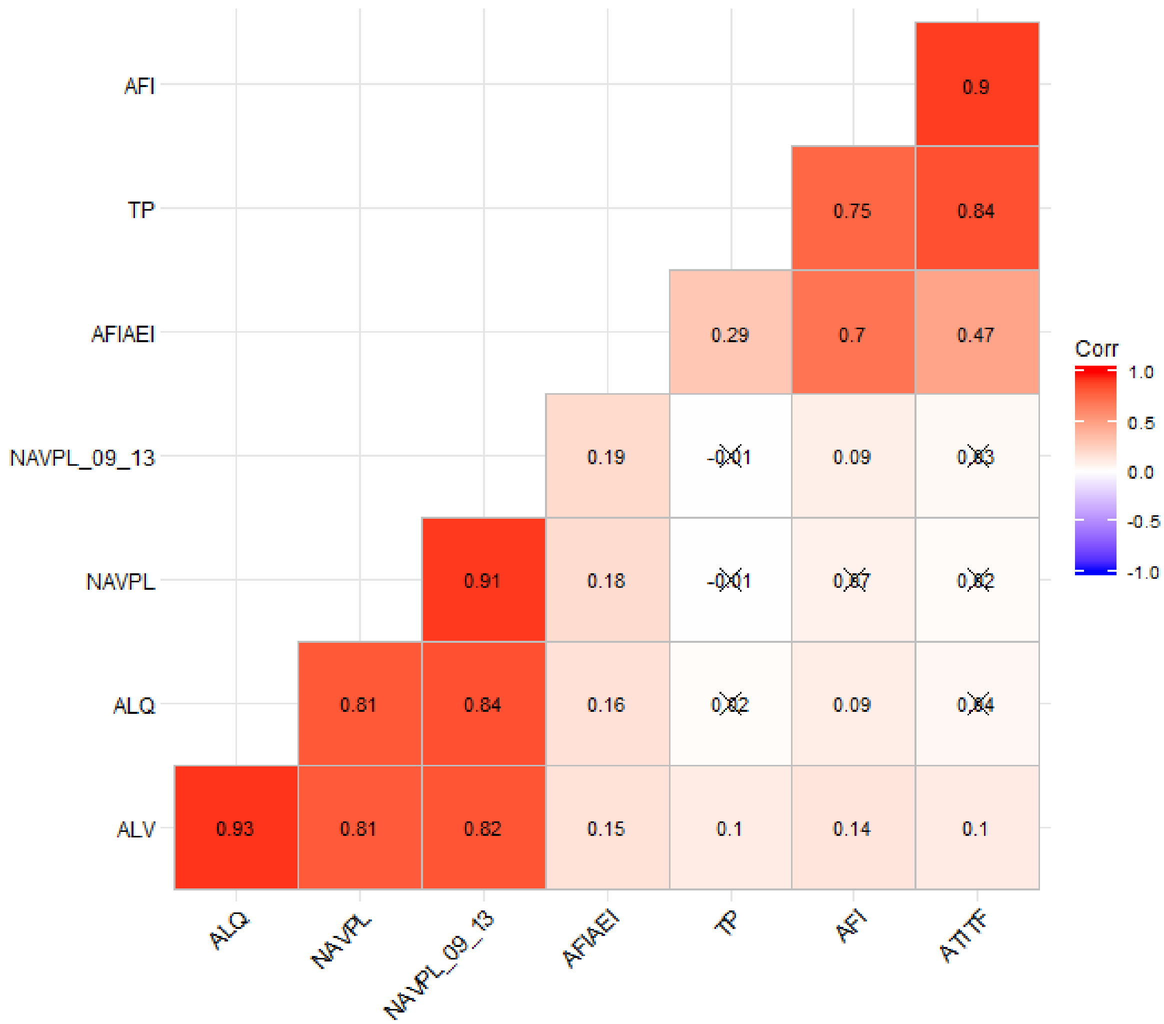


Figure 29 - Hierarchically clustered Spearman Correlation correlogram of socio-economic factors

X'd out *rho* values represent correlations with p-values < 0.01. Note that landings and vessels are clustered, correlated and highly significant. The same is true, but to a lesser extent for census level variables TP/AFI/ATITF and AFIAEI.

4.4.1.1 Total Population

The distribution of the total population for CSD within the Atlantic extent is highly right skewed and is mostly represented by low population sub-divisions. The data set was strongly transformed (^1/8) before being recoded. The recoded data was then flipped, with the largest populations represented in the lowest vulnerability classification (Figure 30). It is assumed that communities with lower population would be more susceptible to climate change impacts to publically-funded SCH sites because they are less likely to have a diversification of economic opportunities to overcome impacts to coastal infrastructure and/or fisheries ecosystems. Sites with no population (zero) were given the same value as sites with high population, as no one within the CSD is likely to be impacted. This logic is a decision built in the assumption of the correlation between population and dependency of economic opportunities on SCH sites. It is also possible that SCH sites representing the largest number of people could be deemed more vulnerable. More important than population size is the connection of the population to SCH infrastructure which is measured by the landing and income data. The distributional cut points for the pre-transformed, transformed and recoded data are shown in Table 10.

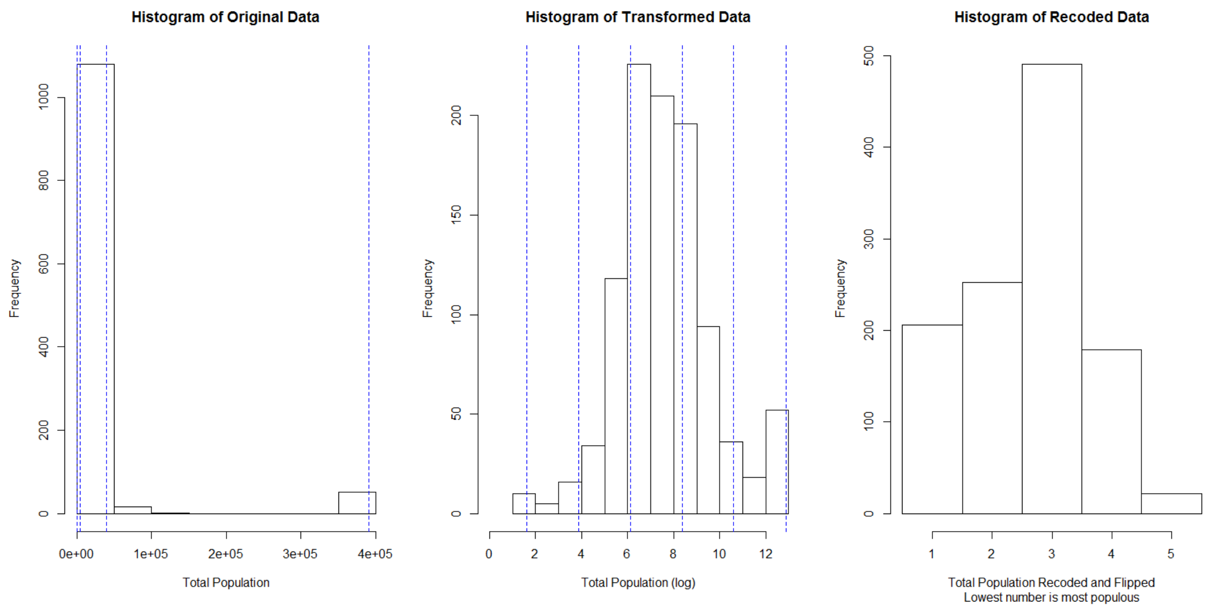


Figure 30 - Frequency distributions of Atlantic SCH Total Population

Left – original data, **Middle** – transformed, **Right** - recoded and flipped distribution.

Table 10 - Original and transformed Atlantic SCH total population ranges with score

	O*	T*	RF*
Atlantic	5 - 475	1.61 – 3.80	5
	48 - 455	3.80 – 6.12	4
	455 - 4,320	6.12 – 8.37	3
	4,320 - 40,100	8.37 – 10.60	2
	40,100 - 390,000 (& 0)	10.60 – 12.87 (& 0)	1

*O=Original data; T=Transformed data; RF=recoded and flipped data

4.4.1.2 Average Fishing Income to Average Employment Income

The distribution of the AFIAEI for sub-census areas within the Atlantic extent is right skewed and is mostly represented by sub-divisions where fishing represent less than 30% or lower of the employment income (~93%). Figure 31 shows the pre-transformed, transformed (^1/3) and recoded distribution of AFIAEI within the Atlantic study extent. Table 11 shows the associated distributional cut points for these data.

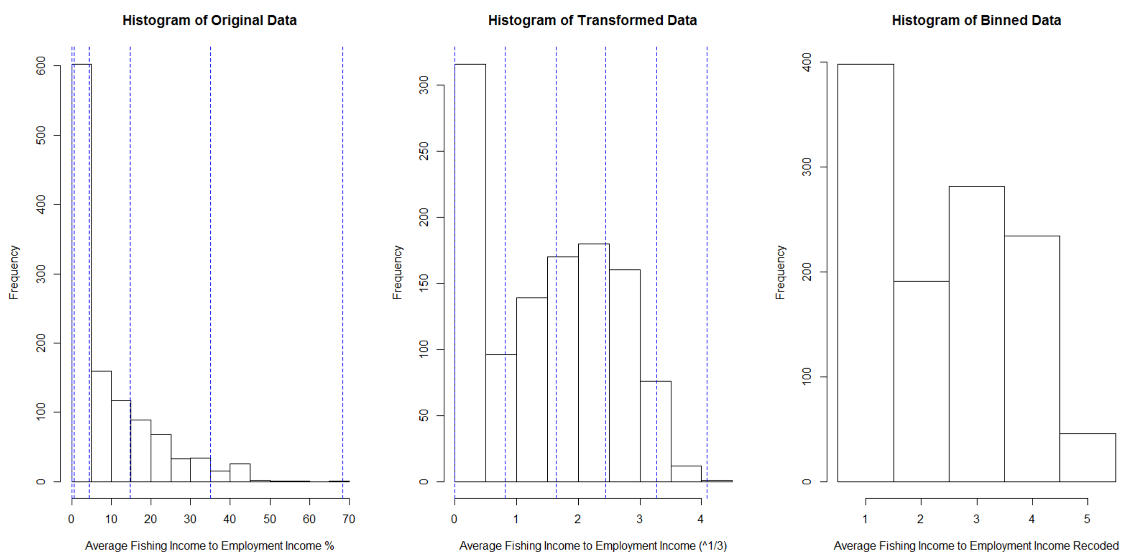


Figure 31 - Average Fishing Income to Employment Income of Atlantic SCH

Left – original data, **Middle** – transformed, **Right** – recoded distribution.

Table 11 - Original and transformed Atlantic SCH AFIAE ranges with scores

	O (%)*	T*	RF*
	0 – 0.55	0 – 0.82	1
	0.55 – 4.41	0.82 – 1.64	2
Atlantic	0.41 – 14.71	1.64 – 2.45	3
	14.71 – 34.97	2.45 – 3.27	4
	34.97 – 68.38	3.27 – 4.09	5

*O=Original data; T=Transformed data; RF=recoded data

4.4.1.3 Average Landed Quantity per Vessel Port of Landing

The distribution of the ALQVAPL within the Atlantic extent is highly right skewed and is mostly represented by low landings per vessel. The data set was strongly transformed (^1/10) before being recoded 1- 5 (Figure 32). Table 12 shows the associated distributional cut points for these data.

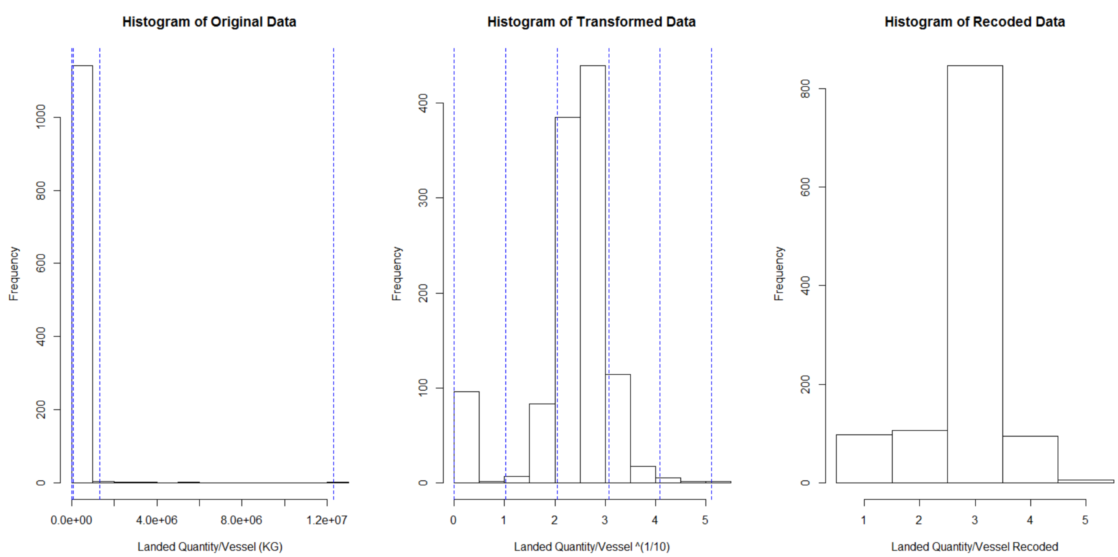


Figure 32 - Frequency distributions of Atlantic SCH ALQVAPL

Left – original data, **Middle** – transformed, **Right** – recoded distribution.

Table 12 - Original and transformed Atlantic calculated ALQVAPL ranges with scores

	O (kg/Vessel)*	T*	R*
Atlantic	0 - 1.2	0 – 1.02	1
	1.2 - 1,310	1.02 – 2.05	2
	1,310 - 74,400	2.05 – 3.07	3
	74,400 - 1,310,000	3.07 – 4.09	4
	1,310,000 - 12,300,000	4.09 – 5.12	5

*O=Original data; T=Transformed data; RF=recoded data

4.4.2 Socio-Economic Sub-Index Calculation

The selected socio-economic variables (original and recoded) for the pilot SCH locations within the Atlantic extent are provided in Table 13. The recoded variables were incorporated into the formula for calculating the Socio-Economic Sub-Index discussed in section 3.4 of this report. Table 13 and Figure 33 show the calculated Socio-Economic Sub-Index for all SCH pilot locations within the Atlantic extent.

Table 13 - Atlantic SCH recoded variables used to calculate the Socio-Economic Sub-Index

The fields shaded gray were used to calculate the Socio-Economic Sub-Index.

Extent	Harbour Name	Prov.	TP[1]	TP RC	AFIAEI[1] ($)	AFIAEI RC	ALQVAPL[1]	ALQVAPL RC	SESI
Atlantic	ETANG-DU-NORD (L'ETANG-DU-NORD)	QC	12,291	2	38.8	5	912,756	4	3.42
	BARTLETTS HARBOUR	NL	2,729	3	17.32	4	1,466	3	3.3
	AULDS COVE	NS	4,189	3	19.84	4	5,119	3	3.3
	METEGHAN	NS	8,319	2	18.53	4	83,137	4	3.17
	MONT-LOUIS OUEST	QC	1,118	3	7.16	3	61,355	3	3
	PINKNEYS POINT	NS	10,105	2	14.49	3	37,671	3	2.62
	LES ESCOUMINS (BASQUES)	QC	2,000	3	0.72	2	55,216	3	2.62
	POOL'S COVE	NL	5	5	0	1	-----[2]	3	2.47
	TWILLINGATE (SHOAL TICKLE)	NL	211	4	0	1	46,564	3	2.29
	INGALLS HEAD	NB	2,377	3	0	1	118,171	4	2.29
	MACHONS POINT	PEI	905	3	0	1	26,310	3	2.08
	NORTH HEAD -FISHERMEN'S WHARF	NB	2,377	3	0	1	41,335	3	2.08
	CENTREVILLE (TROUT COVE)	NS	7,463	2	15.38	4	0	1	2
	SAINTE-MARIE-SUR-MER	NB	5,032	2	22.98	4	0	1	2
	BAULINE	NL	115	4	0	1	0	1	1.59
	TOURELLES (ST-JOACHIM)	QC	6,933	2	1.93	2	0	1	1.59
	SEAL COVE-FISHERMEN'S WHARVES	NB	2,377	3	0	1	0	1	1.44

[1]TP=Total Population; AFIAEI=Average Fishing Income to Average Employment Income (%); ALQVAPL=Average Landed Quantity per Vessel at Port of Landing.
[2] Average landed quantity per vessel for Pool’s Cove not shown due to privacy restrictions

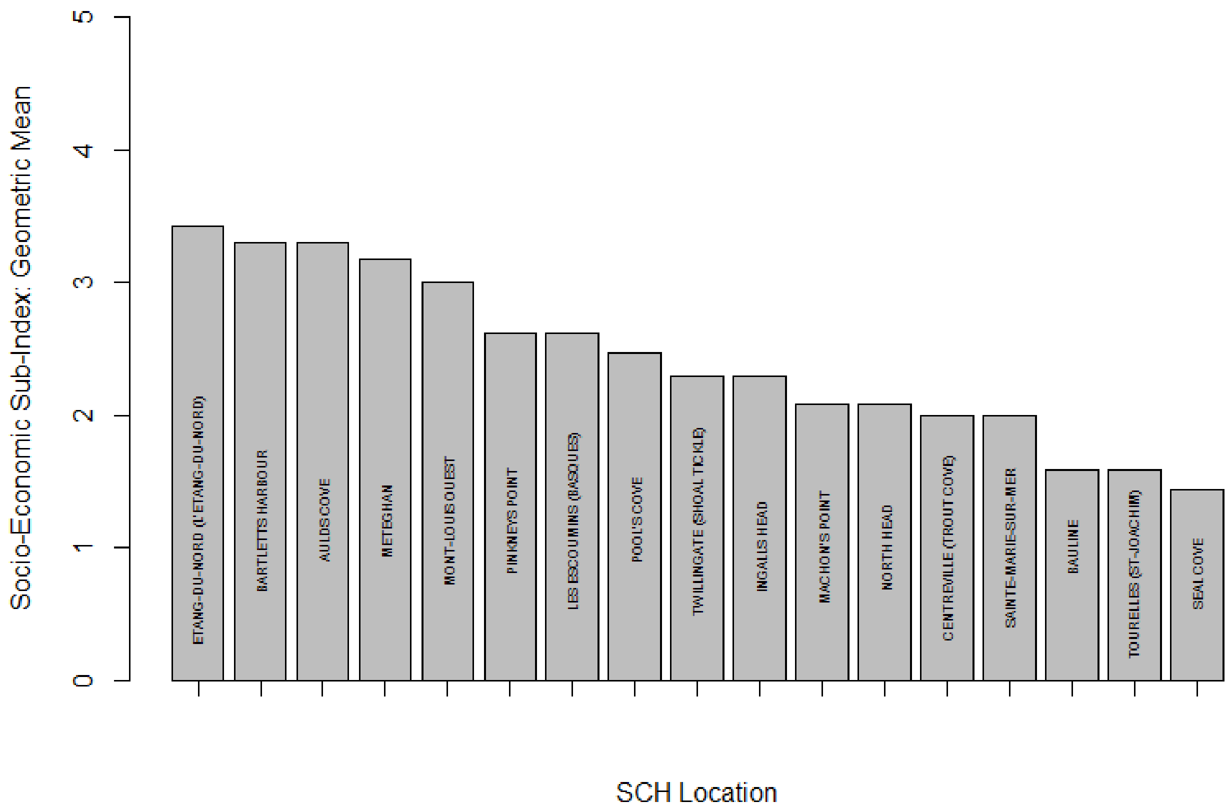


Figure 33 - Ranked Socio-Economic Sub-Index for Atlantic SCH pilot sites

(most vulnerable to least vulnerable).

Figure 34 provides a map of the Atlantic extent with their SCH pilot sites color coded, with red representing relatively high and blue relatively low Socio-Economic Sub-Index.

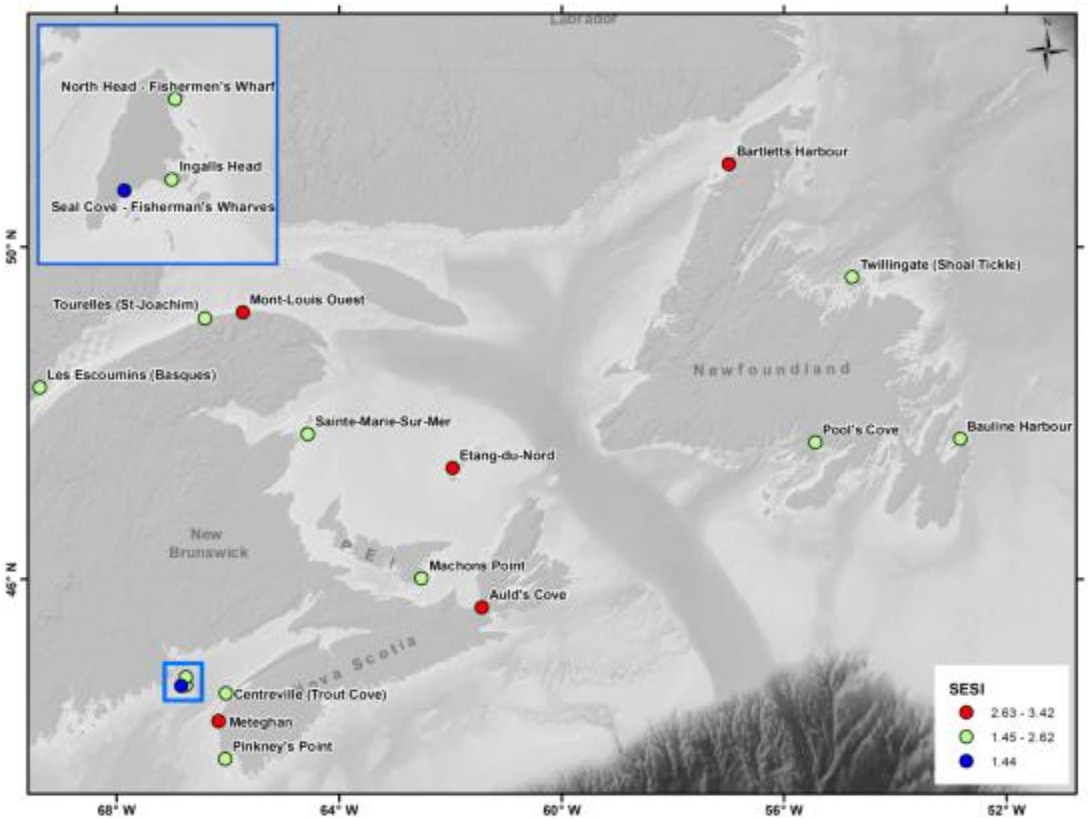


Figure 34 - Colour-coded Socio-Economic sub-index scores for Atlantic SCH pilot sites

4.5 COASTAL INFRASTRUCTURE VULNERABILITY INDEX

The Coastal Infrastructure Vulnerability Index (CIVI) is calculated as the geometric mean of the 3 sub-indices (Exposure, Infrastructure and Socio-Economic) discussed above. The CIVI has been calculated for each Atlantic pilot SCH site. As mentioned at the beginning of Socio-Economic Sub-index section, the socio-economic data utilized for this report was not suitable for Pacific SCH sites, so the CIVI for this extent could not be calculated and will not be described here. Table 14 shows the ranked CIVI values and their corresponding ESI, ISI and SESI values, for the Atlantic pilot SCH locations. Figures 35 and 36 display these values in both graphical form and geospatially.

Table 14 - Atlantic recoded sub-indices variables and calculated CIVI

Extent	Harbour Name	Prov.	ESI*	ISI*	SESI*	CIVI*
Atlantic	ETANG-DU-NORD (L'ETANG-DU-NORD)	QC	3.03	3.91	3.42	3.44
	AULDS COVE	NS	2.70	3.56	3.30	3.17
	BARTLETTS HARBOUR	NL	2.17	4.22	3.30	3.11
	METEGHAN	NS	2.70	2.88	3.17	2.91
	MONT-LOUIS OUEST	QC	2.35	3.30	3.00	2.86
	PINKNEYS POINT	NS	2.86	2.29	2.62	2.58
	CENTREVILLE (TROUT COVE)	NS	2.61	3.17	2.00	2.55
	MACHONS POINT	PEI	2.35	3.30	2.08	2.53
	INGALLS HEAD	NB	2.35	2.88	2.29	2.50
	SAINTE-MARIE-SUR-MER	NB	2.35	3.30	2.00	2.50
	POOL'S COVE	NL	2.35	2.62	2.47	2.48
	LES ESCOUMINS (BASQUES)	QC	1.43	3.63	2.62	2.39
	NORTH HEAD - FISHERMEN'S WHARF	NB	1.78	3.63	2.08	2.38
	TWILLINGATE (SHOAL TICKLE)	NL	2.55	2.00	2.29	2.27
	TOURELLES (ST-JOACHIM)	QC	2.00	3.17	1.59	2.16
	BAULINE	NL	2.72	2.29	1.59	2.15
	SEAL COVE-FISHERMEN'S WHARVES	NB	2.35	2.52	1.44	2.04

*ESI=Exposure Sub-Index; ISI=Infrastructure Sub-Index; SESI=Socio-Economic Sub-Index, CIVI=Coastal Infrastructure Vulnerability Index.

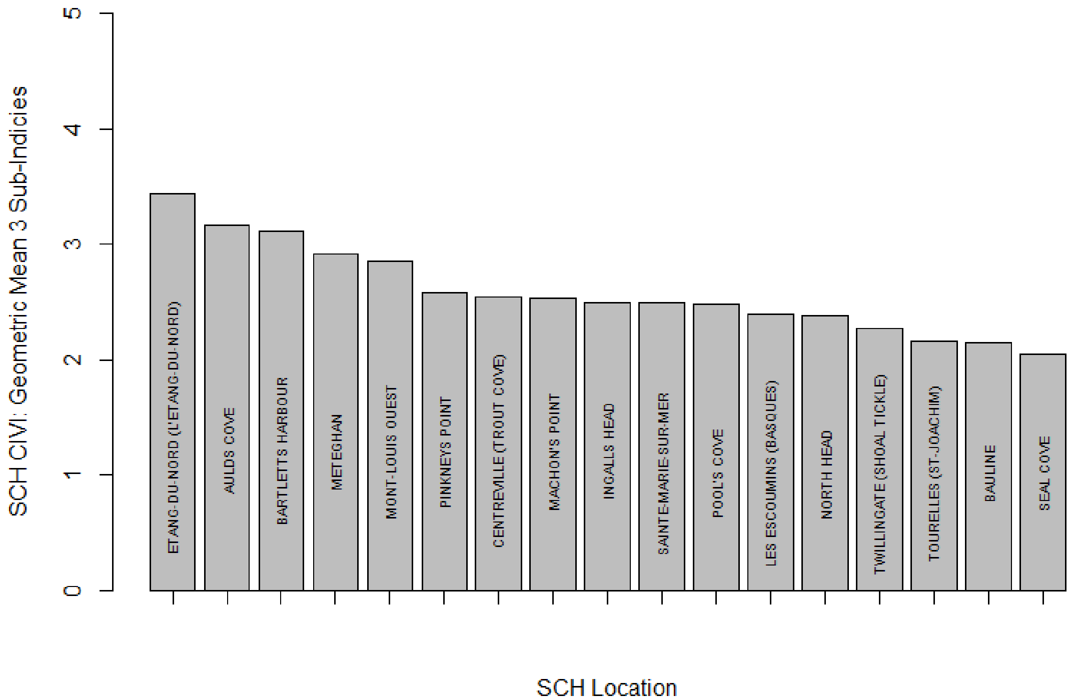


Figure 35 - Ranked Coastal Infrastructure Vulnerability Index for Atlantic SCH pilot sites

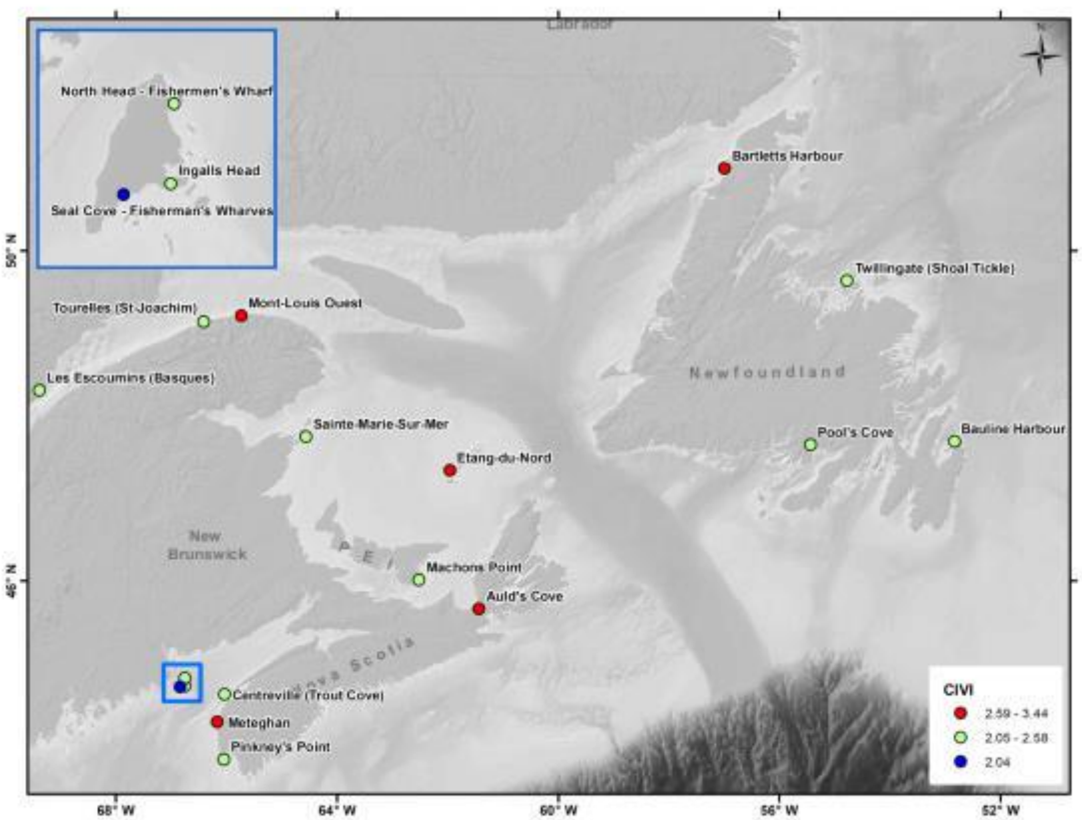


Figure 36 - Colour-coded Coastal Infrastructure Vulnerability Index for Atlantic SCH pilot sites

5 DISCUSSION

The purpose of the project as stated in the Terms of Reference for the National Coastal Infrastructure Vulnerability Index (CIVI) Project Steering Committee was to “develop a simple coastal/harbour climate change vulnerability index to guide SCH decision-makers”. It was to “build on the SCH climate change study completed in 2011” and “leverage recent climate change work completed by Science, including the CAN-EWLAT sea level rise adaptation tool.” The primary objective of the project, to develop a coastal infrastructure vulnerability index, was met for pilot sites within the Atlantic extent. The project resulted in a revised vulnerability index equation (Index Calculation section) that improves upon the earlier approach by Shaw *et al.* (1998). A face to face meeting of the Project Steering Committee on January 13th, 2015 in Ottawa laid the foundation of parameters and sub-indices that would be used to describe SCH vulnerability. Through the winter of 2015, Science began the compilation and refinement of the exposure layers described in the Sub-index Development and Index Calculation section (Exposure sub-sections). In June 2015, another remote meeting of the Steering Committee took place and the final list of revised parameters within each sub-index was provided. It was at this time that Science made it clear that the early vision of applying a standard approach to all SCH locations would not be feasible and that a zonal approach would be more suitable given various limitations to both data spatial extent (e.g., little or no exposure data for the interior regions of Canada) and data availability (e.g., fisheries statistics not reliable for Pacific SCH locations). After this, the analysis focused primarily on the Pacific and Atlantic extents described in this document, with the full suite of sub-indices available for the Atlantic extent and only exposure and infrastructure sub-indices available for the Pacific extent. This approach to assigning vulnerability to SCH locations can be a useful tool for assessing the relative vulnerability of locations within a predefined extent. Caution should be used when further developing this method by avoiding vulnerability index comparisons with SCH locations from other study extents.

In general, the Pacific SCH pilot sites chosen for this study showed only minor differences in both exposure and infrastructure sub-index. The Pacific sites were all clustered on the southern coast of Vancouver Island and did not display the diversity of conditions observed for SCH locations within the Atlantic extent. In retrospect, a more spatially dispersed and larger sub-set of SCH locations within the Pacific extent should have been selected in order to observe a broader sub-index spectrum for proof of concept.

The Atlantic extent contains the majority of SCH assets. The SCH pilot locations chosen were spread throughout the extent and the resulting sub-indices showed a broader range of values than seen in the Pacific extent. This method showed its utility in this region and seemed able to discern broad classifications of most vulnerable and least vulnerable locations. Within this extent, this method was demonstrated as a high level utility that may help managers cluster the most vulnerable locations, mid-range vulnerable locations and the least vulnerable locations for decision making purposes. For example L'Étang-du-Nord ranked 1st for ESI, 1st for ISI and 2nd for SESI. This location is located on the Magdalen Islands in the Gulf of St. Lawrence and is at risk for sea level change, has poorly consolidated coastal materials that are easily erodible, high wind speeds, a poor harbour condition value, a high replacement cost and an economy heavily reliant on fishing. There is little doubt that this harbour is the most vulnerable of the Atlantic extent pilot sites. Where it would rank amongst all SCH within the extent is somewhat less clear, but it is clear that this site is one of concern. On the other hand, Seal Cove – Fisherman's Wharves had the lowest SESI, the 4th lowest ISI and tied for 5th lowest ESI. This SCH has both moderate sea level rise projections and wave heights, with higher than normal winds, but no impact from ice changes and well consolidated coastal materials resistant to erosion. The harbour is in good condition, and while it has a high replacement cost it is well protected. The census sub-division has a moderate population, but in the census sub-divisions there seems to be little local income reported from the fishery and no landings reported at the SCH.

Utilizing base R Statistical Software tools to mine these indices and contributing variables would allow decision makers to visualize the SCH or group of harbours in relation to, and in the context of, other SCH facilities within a study extent. Displaying these data spatially, either in Google Earth or in ArcGIS, would provide a site by site decision making utility for SCH managers and engineers that could be made broadly available through a link on an internal website. During the last face-to-face meeting in Quebec City in February of 2016, data in this report were presented to the group, both in tabular format and as a Google Earth KMZ. The utility in the digital product was apparent and there was interest in furthering its development to accompany the final product. It is expected that a more refined digital product could be made available in the future that would include the exposure layer rasters and CanCoast coastlines described in the sub-index development section.

As it has been noted throughout this document, there are limitations to this approach of assigning a vulnerability index to each SCH location regardless of region. For this study, exposure layer values were assigned to SCH facilities by linking the corresponding CanCoast shoreline segment with the nearby SCH location. CanCoast is limited to the "marine" environment and does not include the interior water bodies of the country. As well, it is important to reiterate the complexity and zonal specificity of these exposure layers. When calculating an exposure index in the future, it is important to spatially contextualize the study extent to avoid including coastline exposure characteristics that would otherwise never be experienced by the SCH facilities for which the study is supposed to represent. These "out of bounds" conditions, if used to establish the normal curve from which the recoded shoreline distribution is derived, could ultimate bias results by miss-classifying the SCH to either a higher or lower vulnerability status. As well, if a similar approach is to be taken for assigning vulnerability to inland SCH locations (i.e., Central and Arctic), then a scoping exercise will be required to identify alternate sources of exposure data that may be suitable for assessing SCH vulnerability. The types of available data will be specific to an extent and multiple approaches may be required to assess SCH vulnerability to exposure parameters within that extent.

Assessments of Harbour Condition have already been carried out for all SCH locations using the parameters described in Sub-index Development section (ISI sub-section) of this report. The Total Replacement Cost has also been estimated for each facility.

However, more effort will be required to assess the Degree of Facility Protection beyond the pilot sites identified for this study. It is estimated, that once engaged this process should not take more than a few months. The Regional Engineers will be instructed to have someone familiar with their harbours complete the task and limit the number of people completing the task. Ideally one person from each region would complete the assignment in order to maintain consistency of the valuations within the Region.

As stated earlier, the Socio-economic data utilized in this report to calculate the SESI for SCH locations were difficult to interpret and were only suitable for the Atlantic extent. There are 2 primary shortcomings of these data: 1) there is little associated meta-data to accompany these data, so the reasoning provided for their absence was often derived through deductive reasoning. For example, it was possible to have landings data between 2009 and 2013, but because the Average Number of Active Vessels Port of Landing over the same time period was an integer, if the value was less than 1 per year, it was categorized as zero. There were a number of these assumptions that were required in order to fully comprehend these data, but unfortunately it wasn't clear whether missing data was just not available or was withheld, and 2) depending on the type of data provided, the spatial extent from which they were derived was different. For example, landings data and vessel traffic data were provided by SCH, but all income and population statistics were provided by CSD. So, it was entirely possible for a SCH to show disproportionate income and landings numbers. This is possible, either when landings are reported at a SCH but the fish harvester reports their earnings in another CSD, or when earnings are reported in the CSD but the local SCH is not utilized as their home port. Additionally, in the Pacific region, landings may be reported at processing plants, offshore vessels and other private facilities, rather than at SCH sites. Without reports of landings at SCH locations, other variables (i.e. fishing-related income and population size by CSDs) cannot be assumed to be meaningful indicators of socio-economic contribution by SCH infrastructure. Other socio-economic proxies are therefore required for assessing the socio-economic value and vulnerability of small craft harbours in the Pacific.

Due to the existence of significant positive correlation between certain variables provided, not all socio-economic variables were used toward the final index calculations. For example, since landed average value and quantity are highly correlated, only the latter was included in the calculation of the index. Similarly, the decision was made to combine highly correlated variables (i.e. average landed quantity by harbour location and the average number of vessels at the port of landing) into one variable.

For the most part, it was through exploring these data that these issues and their impacts on analysis became apparent.

A more thorough description of the socio-economic data caveats and meta-data should be provided before these data are utilized to complete the CIVI calculation for all of the SCH locations within the Atlantic extent.

Finally, this method results in products that are well organized, easily visualized and ultimately provide SCH managers with another high level tool to assess SCH vulnerability. The sub-indices and associated parameters can be adjusted, removed and added in the future to provide a project specific assessment of the SCH vulnerability to whatever likely impact that might be of concern. The project was a success because it engaged multiple departments with the expertise necessary to develop a pragmatic tool that can be immediately implemented for decision making purposes. It is expected that a continuation of this project would result in the CIVI being calculated for all remaining SCH within the Atlantic extent. As well, the Infrastructure and Exposure sub-indices would be completed for the SCH locations within the Pacific extent. Despite the relative success of this project, a scoping exercise would be required to assess the short and longer term feasibility of applying this methodology for assigning a vulnerability index to SCH locations within the Central and Arctic Region.

6 RECOMMENDATIONS

A progress update on the project was provided to the SCH National Management Committee (NMC) on February 18, 2016. NMC supported a continued effort on this work and recommended a roll-out to all SCH locations for which accurate data exist.

Based on the endorsement of NMC, we recommend the following:

1. SCH regional engineers complete the assessment of the degree of protection component of the Infrastructure sub-index for all harbours in the Atlantic and Pacific regions.

   - **Degree of protection and harbor protection scores are assessed on all SC harbours every three years**

2. DFO Science investigate adding CanCoast layers to the Google Earth tool.

   - **This tool was developed but has been superseded by a Government of Canada Intranet site which is updated as new data become available.**

3. The CIVI working group continue investigating the feasibility of extending the tool to freshwater SCH sites and make further recommendations by 31 March 2017.

   - **Data availability for inland SCH sites was not available to the same extent as for marine harbour sites. Extending the vulnerability index to inland harbours is not possible at this time**

4. Continued effort is required on exploring the socio-economic data for potential variables in order to ensure the best possible advice to SCH senior management.

   - **Additional data sources for population have been found and substituted in the final calculation and work is being done on using alternative measures of socio-economic vulnerability.**

5. DFO Science investigate the feasibility of incorporating hydrology into the Exposure sub-index of CIVI to account for expected changes in river flooding at SCH sites such as those along the Fraser River in British Columbia.
    - **Work has not commenced on this.**

7 DISCLAIMER

Please be advised that the data contained in this report was developed and used on a pilot basis only and no guarantee can be made as to the accuracy of such information in representing current conditions.

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APPENDIX 1 - DEGREE OF FACILITY PROTECTION

1 – Completely Exposed	2 – Predominantly Exposed	3 – Moderately Exposed/Enclosed	4 – Predominantly Enclosed	5 – Completely Enclosed
<u>Basin</u> 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. <u>Harbour Entrance</u> No channel <u>Breakwaters</u> No breakwaters	<u>Basin</u> Structures are located in shallow basin and/or partially protected by floating breakwaters or insufficient fixed breakwaters. <u>Harbour Entrance</u> 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) <u>Breakwaters</u> 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.	<u>Basin</u> Structures may be located in shallow basin and partially protected by fixed breakwaters but are still exposed to strong weather forces. <u>Harbour Entrance</u> Entrance not protected from prevailing winds and/or beam waves, Subject to significant sedimentation. (i.e. maintenance dredging every 2-4 years). <u>Breakwaters</u> 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.	<u>Basin</u> Structures are largely located within small natural harbour, enclosed by fixed breakwaters. <u>Harbour Entrance</u> Entrance may not be protected from prevailing winds and/or beam waves, Subject to moderate sediment deposition (i.e. maintenance dredging every 5+ years). <u>Breakwaters</u> 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.	<u>Basin</u> Structures located within natural harbour or completely enclosed by fixed breakwaters. Basin is completely sheltered from severe weather events. <u>Harbour Entrance</u> Entrance away from prevailing winds and/or beam waves, Subject to little or no sediment deposition. <u>Breakwaters</u> 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.

The degree to which a harbour is naturally protected or has man-made protection from storm surge, wind, and other natural forces was proposed as a vulnerability factor for the Infrastructure Sub-index of CIVI. To measure the Degree of Facility Protection variable a five-point qualitative scale is used with 1 being a completely exposed harbour and 5 being a fully protected harbour. Only elements of a harbour relevant to the CIVI project were included in the analysis, this includes the basin, wharves, floats, shore protection, slipways and breakwaters, but not buildings, roads or parking lots. These elements are examined together to determine the final Degree of Facility Protection score