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Abstract

Baseline mapping of coastal characteristics and understanding of the dynamic response of coastal sensitivity to environmental changes provide a strong foundation for climate change adaptation in Canada's coastal regions. CanCoast is a collection of datasets that describe the physical characteristics of Canada's marine coasts. It includes datasets that are not expected to change through time (such as coastal materials and backshore slope), and some that are projected to change as climate changes (such as wave height and mean sea level). CanCoast includes: sea-level change (early and late 21st century); wave-heights including the effects of sea ice (early and late 21st century); ground ice content; coastal materials; tidal range; and backshore slope. These are mapped to a common high-resolution shoreline and used to calculate indices that show the generalised coastal sensitivity of Canada's marine coasts in early and late 21st century climates, and the spatially-variable change in sensitivity between the early and the late 21st century. Because of the scales of the input data, the generalised indices are best used to identify regions that differ in sensitivity to changing climate, rather than local properties or coastal infrastructure with specific characteristics that cannot be resolved in this national-scale approach.

Acknowledgements

Funding for CanCoast has been provided by the Climate Change Geoscience Program of the Lands and Minerals Sector of Natural Resources Canada under the Supporting Adaptation in Coastal Regions project. Additional funding provided by the Climate Change Impacts and Adaptations Division of Natural Resources Canada was critical to starting CanCoast, and continued support has since contributed immensely and is gratefully acknowledged. The CanCoast team has included many people who provided valued advice and assistance throughout. We acknowledge the early work and subsequent support of coastal researchers at the Geological Survey of Canada - Atlantic (GSC-A): John Shaw, Donald Forbes, Robert Taylor, Steven Solomon, David Frobel and Andy Sherin. Their expert knowledge contributed greatly. Phil Spence had the foresight to maintain capacity to convert older data to useable formats. Without Phil's help, early data would have been lost. Paul Fraser, Kimberley Jenner, Barbe Szlavko, Sheila Hynes and Tracy Lynds, all GSC-A, helped to coordinate the changing groups of young researchers including: Chelsea Smith, Scott Hatcher, Nicholas Hosek, Eric Patton, and Elliot Wand. This manuscript benefited greatly from reviews by Patrick Potter, Scott Hatcher and Don Lemmen. We happily welcome Scott Hatcher back to the Canadian coastal research community.

Cover Image: Canadian RADARSAT mosaic provided by the Canada Centre for Mapping and Earth Observation. Photos clockwise (roughly) from lowest left: Vancouver International Airport, BC (Don Lemmen, NRCan); Howe Sound, BC (Gavin Manson, NRCan); Rose Spit, Haida Gwaii, BC (Gavin Manson, NRCan); Stokes Point, YT (Gavin Manson, NRCan); Mackenzie Delta, NT (Gavin Manson, NRCan); Coppermine Delta, Kugluktuk, NU (Gavin Manson, NRCan); Cambridge Bay, NU (Gavin Manson, NRCan); Ellesmere Island, NU (Nicole Couture, NRCan); Whale Cove, NU (Gavin Manson, NRCan); Hall Beach, NU (Gavin Manson, NRCan); Umiujaq, QC (Antoine Boisson, Université Laval), Cape Christian, Baffin Island, NU (Gavin Manson, NRCan); Iqaluit, Frobisher Bay, NU (Gavin Manson, NRCan); Makkovik, NL (Scott Hatcher, NRCan); Fogo Town, NL (Gavin Manson, NRCan); Quidi Vidi, NL (Scott Hatcher, NRCan); Brackley Beach, PEI (Gavin Manson, NRCan); Sable Island, NS (with permission, Parks Canada); Cape Split, NS (Gavin Manson, NRCan).

Introduction

In the context of climate change affecting a marine coast, sensitivity can be defined as the degree to which the coast is physically affected, either adversely or beneficially, by climate variability or climate change (Lemmen et al., 2016). At the coast, climate change effects are often indirect. For example, flooding during storm surges may increase due to sea-level rise, while erosion may increase as wave heights increase due to greater storminess or a reduction in sea ice. The sensitivity of a coast depends not only on these forcing effects, but also on physical characteristics such as coastal materials, which affect erosion, and backshore slope, which affects flooding. A Coastal Sensitivity Index (CSI) and its spatial variability may be calculated arising from a specific forcing, such as sea-level change (e.g. Shaw et al., 1998).

In this report, we consider a CSI to be a relative measure of the response of a coastal area featuring specified geomorphic conditions (e.g., coastal materials, slope, presence of ground ice) and potentially undergoing multiple forcings (e.g., sea-level change, wave height change including the effects of changing sea ice) that may change over time. We calculate generalised indices spanning the early and late 21st century time periods, and map both spatial and temporal variability. We consider them generalised because of the various geographic scales in the input data, and a certain degree of interpretation in the mapping. The CanCoast data are described, together with a general explanation of the development of the input datasets and sensitivity indices. Some considerations on how the data are best used and interpreted are discussed.

CanCoast is a collection of datasets that are used to characterise the sensitivity of Canada's marine coasts in a changing climate through the calculation of indices. CanCoast 2.0 builds upon work conducted by Shaw et al. (1998) on the sensitivity of Canada’s coasts to sea-level rise, and CanCoast 1.0 which took the data of Shaw et al. (1998) and mapped it to a revised shoreline (Smith et al., 2013). CanCoast 2.0 is based on freely available open source data. It can be updated as new data sources become available. As well, it is scalable, so that as higher resolution data become available, the new data can be nested in the CanCoast framework. Version numbers are used to reflect changes in either underlying data or how the data have been treated.

CanCoast includes two versions of a marine shoreline that differ only by line segmentation. CanCoast Marine Shoreline Version 2.0 consists of a single polyline for display purposes whereas CanCoast Marine Shoreline Version 3.0 consists of approximately 15.3×10^6 individual line segments in the polyline that were required for quantitative analyses. Attributes of the following input datasets were assigned to each line segment of CanCoast Marine Shoreline Version 3.0:

- CanCoast Change In Sea Level 2006-2020 Version 1.0
- CanCoast Change In Sea Level 2006-2099 Version 1.0
- CanCoast Significant Wave Height Including Sea Ice Effects 1996-2005 Version 1.0
- CanCoast Significant Wave Height Including Sea Ice Effects 2090-2099 Version 1.0
- CanCoast Ground Ice Version 1.0
- CanCoast Coastal Materials Version 2.0
- CanCoast Backshore Slope Version 5.0
- CanCoast Tidal Range Version 6.0

Guided by expert knowledge, each record in these input datasets was assigned a score of 1 to 5 based on the attribute value or characteristic representing the sensitivity of the particular variable to changing climate (Table 1). The variable scores were used in the calculation of two CSIs, representing sensitivity in the early and in the late 21st century. These were differenced to show the change in coastal sensitivity due to changing climate. These two indices, and the change between them, are given in the dataset CanCoast Coastal Sensitivity Index Version 2.5.6. The CSI naming follows a specific convention: first is the CanCoast version number; second is the formula used in the calculation; and third is the collection of data used in the calculation. We present CanCoast 2.0 which uses a class of non-parametric statistical techniques known as μ-statistics originally applied in medical research (e.g. Hoeffding, 1948; Wittkowski et al., 2004; Morales et al., 2008), and the collection of CanCoast datasets listed above and in Table 1, to calculate a dataset containing the two derived CSIs and their difference. Data are provided in shapefile format with North American Protocol metadata. They are briefly described below, illustrated with low resolution maps.

Table 1: Variable descriptions and scoring used in developing generalised coastal sensitivity indices. Colours are the same as in Figures 3 to 9 in which they represent scores of low to moderate to high sensitivity.

Variables / Scores	1	2	3	4	5
Sea-level change 2006 to 2020 and 2006 to 2100	<= -0.33 m	-0.32 m to -0.20 m	-0.19 m to 0.20 m	0.21 m to 0.70 m	> 0.70 m
Decadal mean wave height 2000s and 2090s	<= 0.25 m	0.26 m- 0.75 m	0.76 m to 1.50 m	1.51 m to 2.25 m	> 2.25 m
Ground Ice	Permafrost does not exist or ground ice is Nil	Nil to Low and Low	Low to Moderate and Moderate	Moderate to High	High
Material	– Intrusive rocks – Metamorphic rocks – Volcanic rocks	– Sedimentary and volcanic rocks – Sedimentary rocks – Unknown bedrock	– Blocks, and rubble with sand and silt – Rubble and silt – Sand and gravel – Sand and gravel and locally diamicton – Sand, gravel and pockets of finer sediment – Sand, silt and gravel	– Thick and continuous till – Sand and locally gravel – Sand and minor silt – Stratified silt, sand, clay and gravel	– Silt, and clay, locally containing stones – Silt, clay and fine sand – Peat, muck and minor inorganic sediments – Fluid silty clay and clayey silt – Ice and minor morainal debris
Slope	> 24°	12.1° to 24°	5.1° to 12.0°	11.1° to 5.0°	<= 1.0°
Tidal range	2.1 m to 4.0 m	4.1 m to 6.0 m	1.1 m to 2.0 m	> 6.0 m	<= 1.0 m

Datasets

CanCoast Marine Shoreline Version 2.0

The CanCoast Marine Shoreline Version 2.0 dataset serves as a basemap for characterising the marine coasts of Canada. This dataset was developed from CanVec 9.0, an existing public digital data source derived from 1:50,000 scale topographic maps (NRCan, 2011a). It consists of a single polyline that can be used to quickly display the CanCoast Marine Shoreline used to develop the datasets contributing to a generalised sensitivity index. In a small number of cases, where sections of the shoreline were not available in CanVec 9.0 (i.e. parts of the Arctic islands), the shoreline was extracted from digital 1:250,000 scale National Topographic Database maps (NRCan, 2011b). The dataset includes the Pacific, Arctic and Atlantic marine coasts, including islands and estuaries. In the

St. Lawrence Estuary, Québec City demarcates the upstream extent of marine (tidal) influence. In smaller estuaries, non-tidal rivers are included in this version to avoid erroneously excluding the upper reaches of tidal estuaries and because a national digital elevation model (DEM) does not yet exist at the resolution required to accurately exclude non-tidal water bodies. An improved DEM is currently being developed by the Canada Centre for Mapping and Earth Observation (CCMEO). CCMEO also continues to improve the CanVec shoreline. Notable anomalies include some small islands that are truncated where they cross map sheets, and at least one area in the Arctic Islands where the shoreline appears to follow an elevation contour greater than zero. With an improved marine shoreline, and tidal amplitude and storm surge height estimates, the CanCoast shoreline is expected to be updated to exclude non-tidal water bodies not susceptible to storm surges.

CanCoast Marine Shoreline Version 3.0

The CanCoast Marine Shoreline Version 3.0 dataset serves as the marine shoreline of Canada for quantifying coastal characteristics. This dataset was developed from CanVec 9.0, an existing public digital data source derived from 1:50,000 scale topographic maps (NRCan, 2011a). It consists of approximately 15.3×10^6 line segments each representing a section of shoreline defined by the digitising resolution in CanVec 9.0. In a small number of cases, where sections of the shoreline were not available in CanVec 9.0 (i.e. parts of the Arctic islands), the shoreline was extracted from digital 1:250,000 scale National Topographic Database maps (NRCan, 2011b). The dataset includes the Pacific, Arctic and Atlantic marine coasts, including islands and estuaries. As with CanCoast Marine Shoreline Version 2.0, Québec City demarcates the western extent of marine (tidal) influence in the St. Lawrence Estuary, the same non-tidal rivers and other anomalies present in CanCoast Marine Shoreline Version 2.0 are present in CanCoast Marine Shoreline Version 3.0. Subsequent versions of this dataset will attempt to incorporate an improved shoreline.

At a nominal scale of 1:50,000, the distribution of the segment lengths is given in Figure 1. The median segment length (d_{50}) is 23 m, meaning that 50 percent of segments are shorter than 23 m. The 90th percentile of segment length (d_{90}) is 69 m.

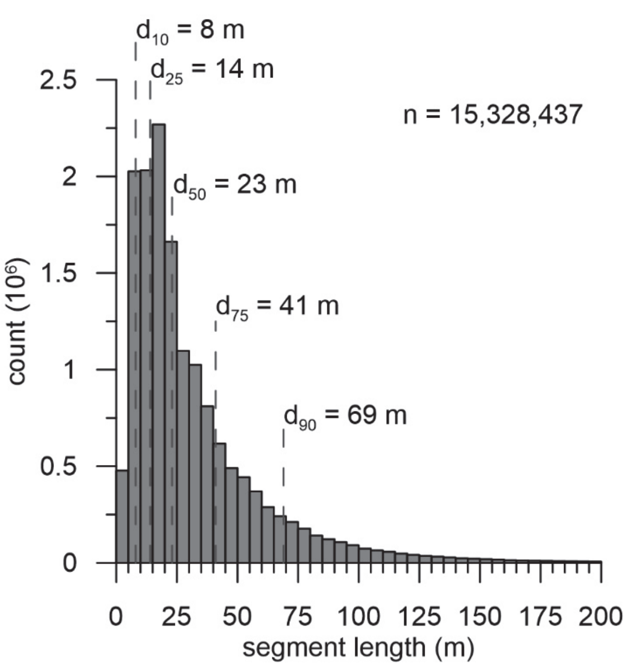

Figure 1. Histogram of shoreline segment lengths showing that 50% of line segments are less than 23 m in length (d_{50}) and 90% of line segments are less than 69 m in length (d_{90}).

CanCoast Change in Sea Level 2006-2020 Version 1.0

This dataset quantifies the amount of relative sea-level (RSL) change along the marine coasts of Canada between 2006 and 2020 and represents relative sea level-change through the early 21st century (Fig. 2) (James et al., in prep., 2019). RSL is a combination of changes in the volume of water in the oceans (global sea-level change) and vertical motion of the land. James et al. (in prep., 2019) combined an ensemble model of global sea-level change projections published for a high-emission scenario Representative Concentration Pathway (RCP) RCP8.5 (Church et al., 2013) with a refined model of vertical land motion developed by the Canadian Geodetic Survey (Robin et al., 2019). The dataset contains a field of sea-level change in which positive values indicate relative sea-level rise and negative values indicate relative sea-level fall, and a field of scores in which sea-level rise is scored high and sea-level fall is scored low (Table 1).

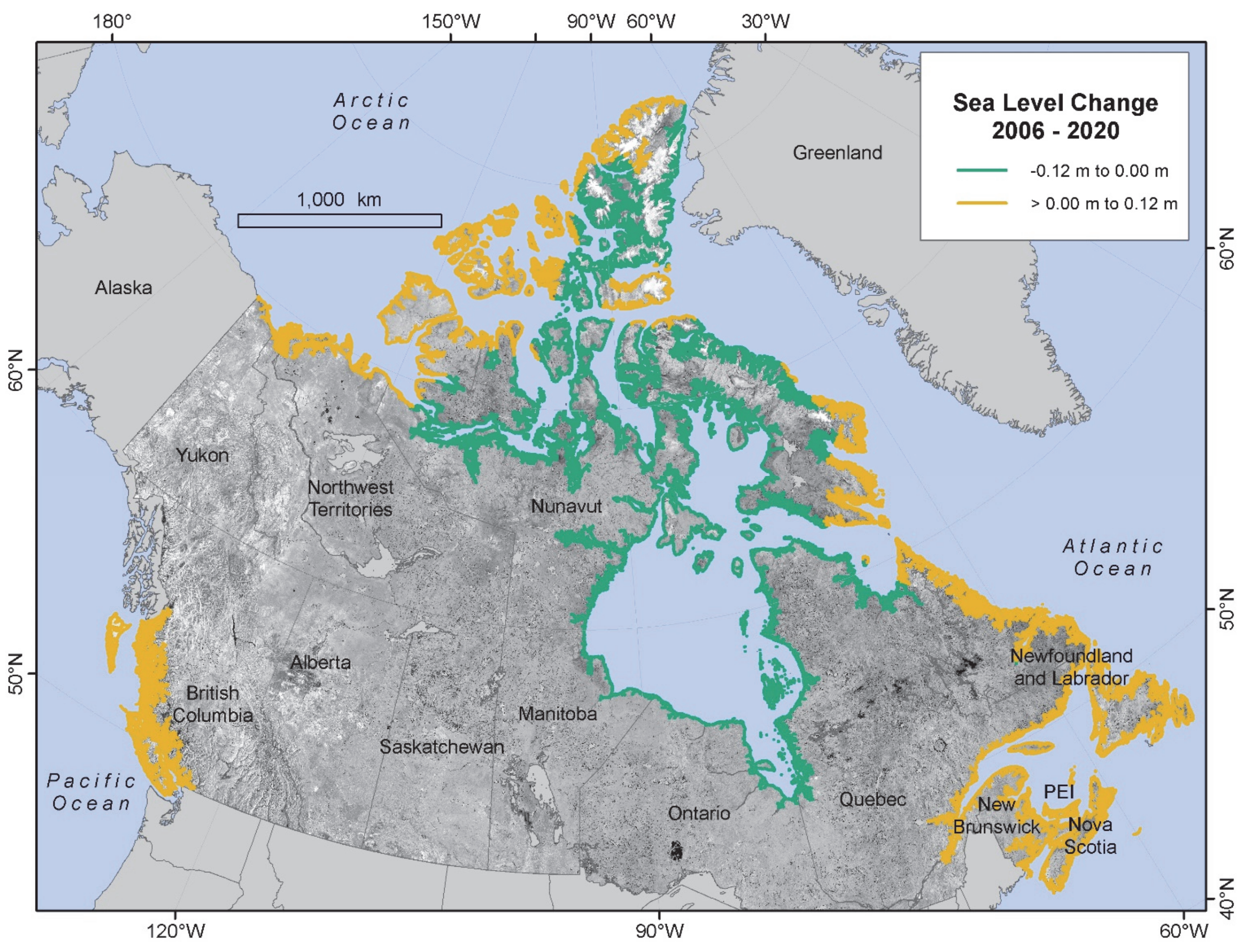

Figure 2. The difference in sea level between the years 2006 and 2020, representing sea-level change through the early 21st century. Note colour classification differs from Table 1 and subsequent figures.

CanCoast Change In Sea Level 2006-2099 Version 1.0

This dataset quantifies the amount of relative sea-level (RSL) change along the marine coasts of Canada between 2006 and 2099 and represents relative sea level-change through much of the 21st century (Fig. 3) (James et al., in prep., 2019). RSL is a combination of changes in the volume of water in the oceans (global sea-level change) and vertical motion of the land. James et al. (in prep., 2019) combined an ensemble model of global sea-level change projections published for RCP8.5 (Church et al., 2013) with a refined model of vertical land motion generated by the Canadian Geodetic Survey (Robin et al., in prep., 2019). The dataset contains a field of sea-level change in which positive values indicate relative sea-level rise and negative values indicate relative sea-level fall, and a field of scores in which sea-level rise is scored high and sea-level fall is scored low (Table 1).

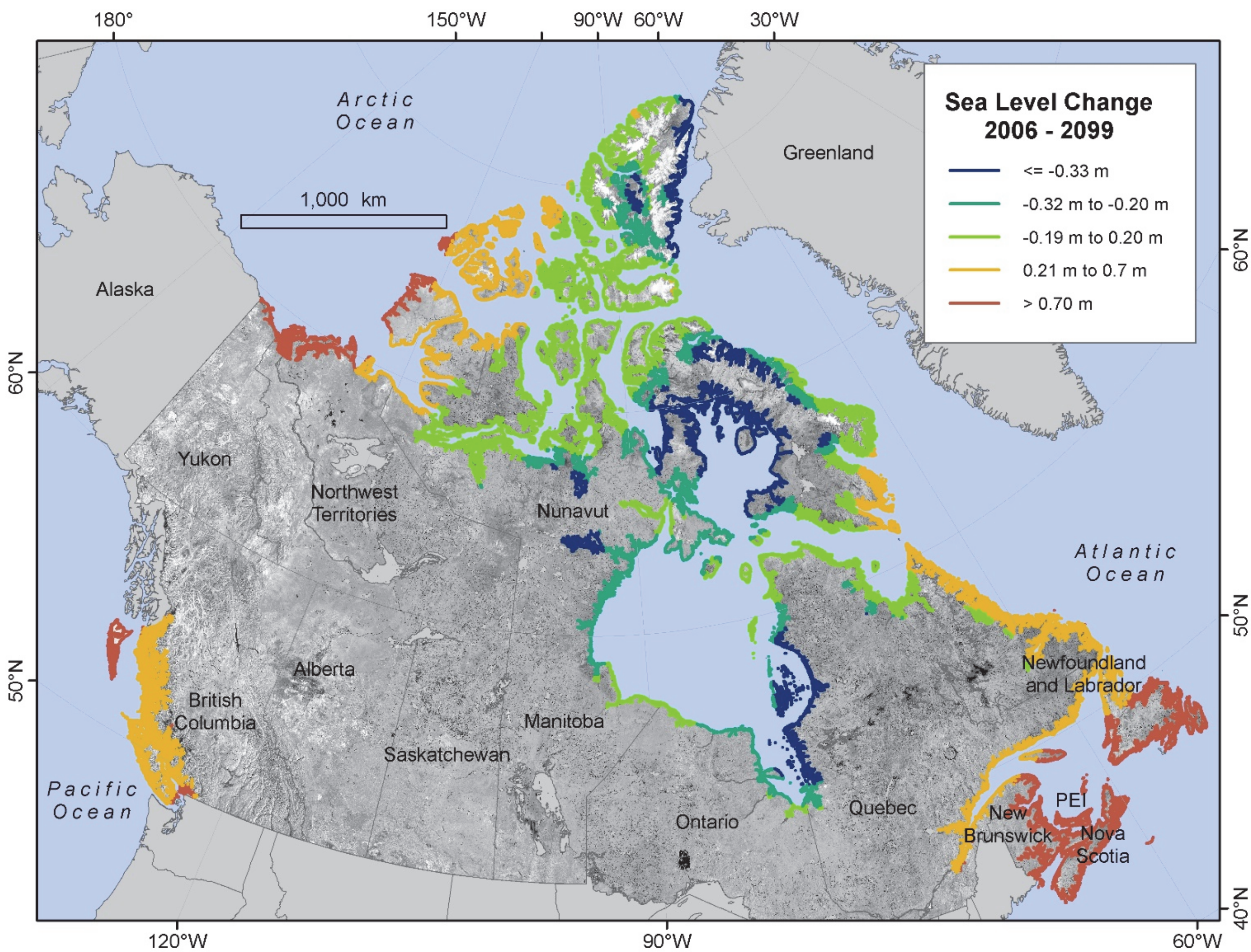

Figure 3. The difference in sea level between the years 2006 and 2099, representing sea-level change through most of the 21st century.

CanCoast Significant Wave Height Including Sea Ice Effects 1996-2005 Version 1.0

This dataset quantifies the spatial variability in decadal mean significant wave heights, including the effects of sea ice, along the marine coasts of Canada from 1996 to 2005 (Fig. 4). The data were developed from the Coupled Model Intercomparison Project Phase 5 (CMIP5) analyses of an ensemble of five projections of climate variables for a high-emission scenario Representative Concentration Pathway (RCP) 8.5 (IPCC, 2013). Output from the BCC-CSM1-1, EC-EARTH, GFDL-ESM2M, INMCM4, and MIROC5 models was resampled and subset at 50 km resolution for coastal Canada by the Climate Research Division, Environment and Climate Change Canada. The dataset includes the average values of these five model outputs for the early and late 21st century (WCRP, 2011) and also scoring for wave heights, where low mean significant wave heights were scored low and high mean significant wave heights were scored high (Table 1).

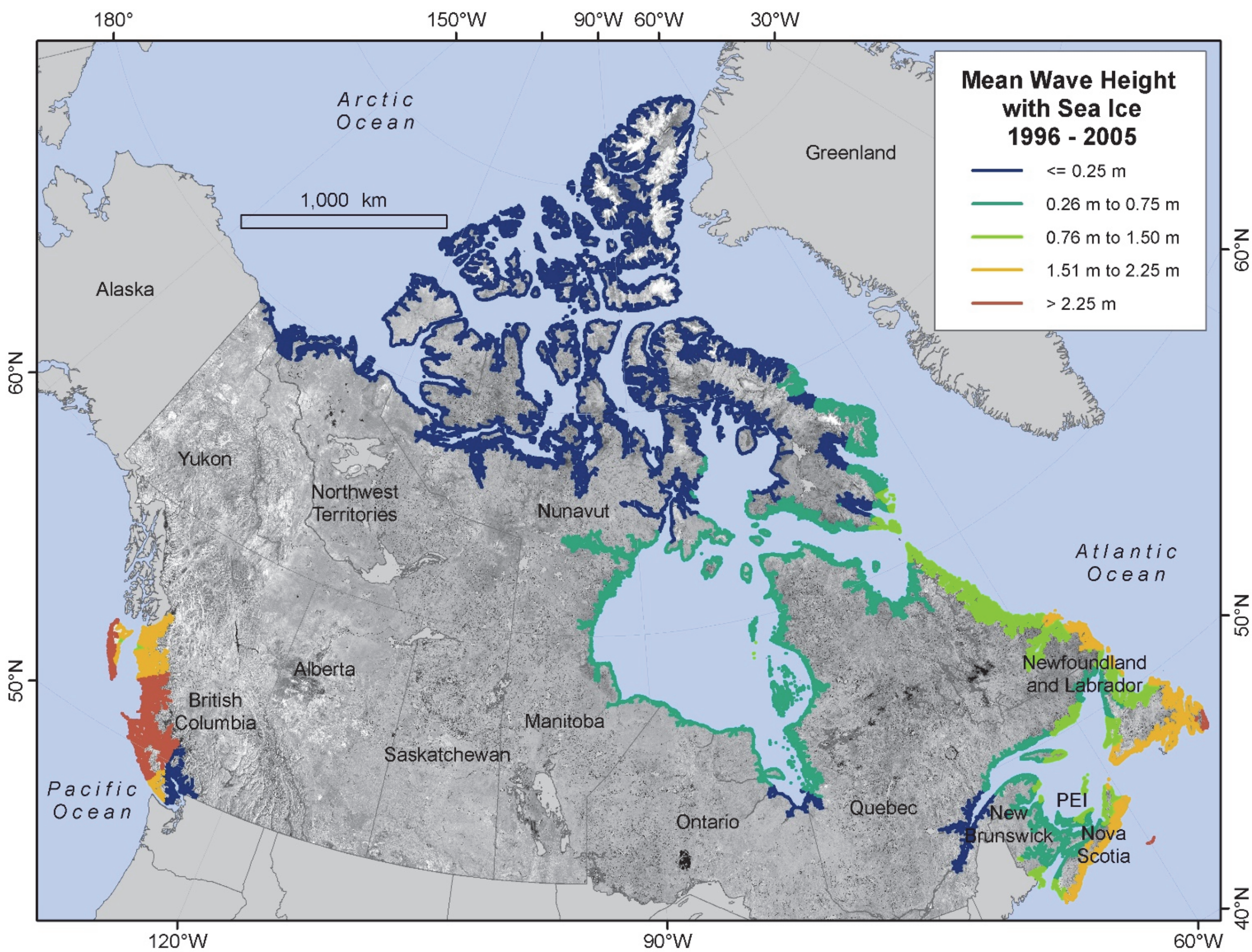

Figure 4. Mean significant wave height, including the effects of sea ice, between the years 1995 and 2005, representing the early 21st century wave climate.

CanCoast Significant Wave Height Including Sea Ice Effects 2090-2099 Version 1.0

This dataset quantifies the spatial variability in decadal mean significant wave heights, including the effects of sea ice, along the marine coasts of Canada from 2090 to 2099 (Fig.5). The data were developed as from the Coupled Model Intercomparison Project Phase 5 (CMIP5) analyses of an ensemble of five projections of climate variables for a high-emission scenario Representative Concentration Pathway (RCP) 8.5 (IPCC, 2013). Output from the BCC-CSM1-1, EC-EARTH, GFDL-ESM2M, INMCM4, and MIROC5 models was resampled and subset at 50 km resolution for coastal Canada by the Climate Research Division, Environment and Climate Change Canada. The dataset includes the average values of these five model outputs for the early and late 21st century (WCRP, 2011) and also scoring for wave heights, where low mean significant wave heights were scored low and high mean significant wave heights were scored high (Table 1).

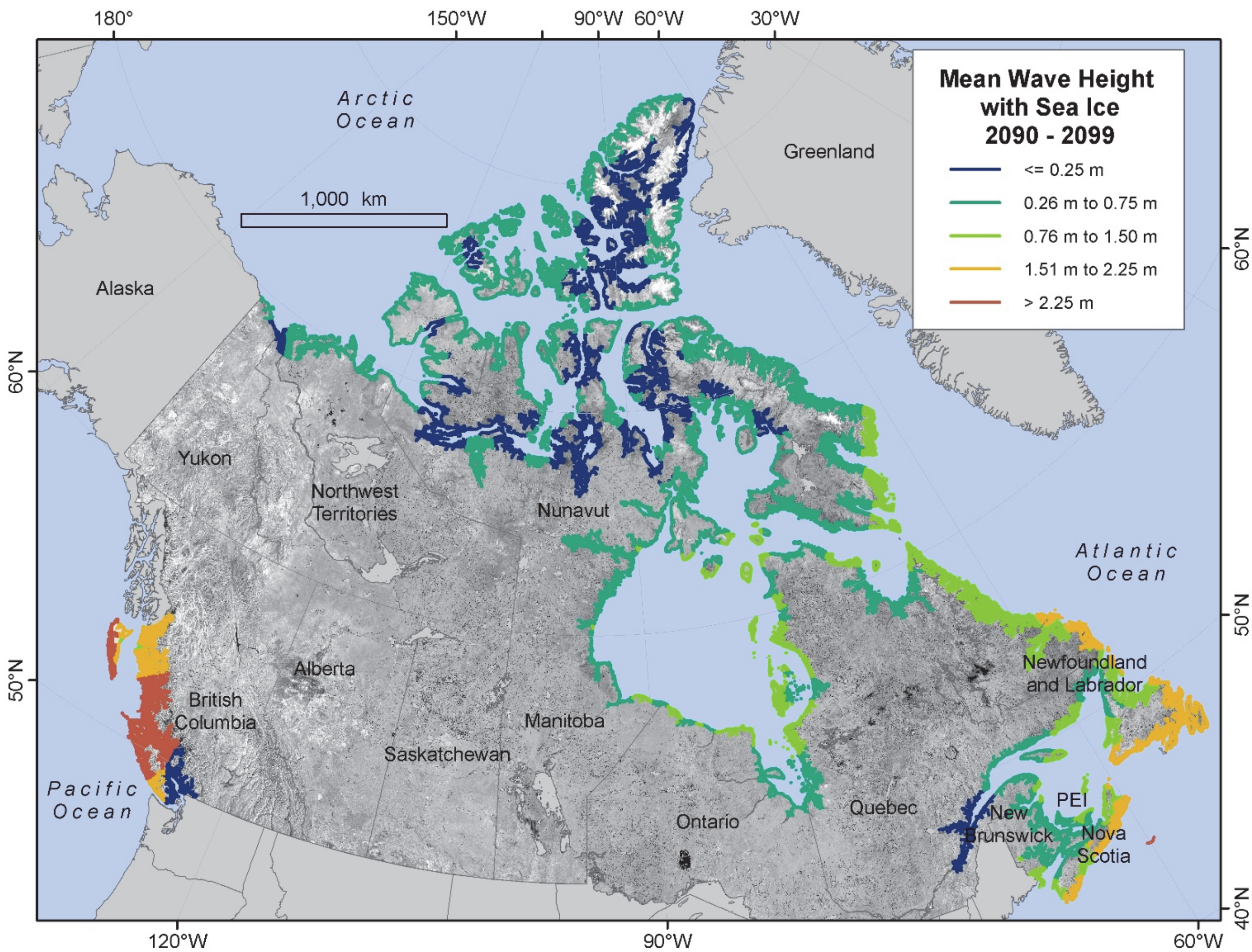

Figure 5. Mean significant wave height, including the effects of sea ice, between the years 2090 and 2099, representing the late 21st century wave climate.

CanCoast Ground Ice Version 1.0

This dataset quantifies and maps the spatial variability of ground ice in permafrost along Canada's marine coasts (Fig. 6). Permafrost is defined as ground that has temperature below 0ºC for more than two consecutive years (Heginbottom et al., 1995). Ground ice forms in unconsolidated sediments with permafrost in the form of pores, veins, lenses and massive bodies. This dataset categorises the amount of present day ground ice along Canada's marine coasts at a scale 1:7,500,000 in a dataset with fields of amount of ground ice and ground ice score. High scores were assigned to areas categorized as being rich in ground ice and low scores were assigned to areas categorized as having little or no ground ice (Table 1). The permafrost map was provided by the Geological Survey of Canada, Natural Resources Canada (Heginbottom et al., 1995).

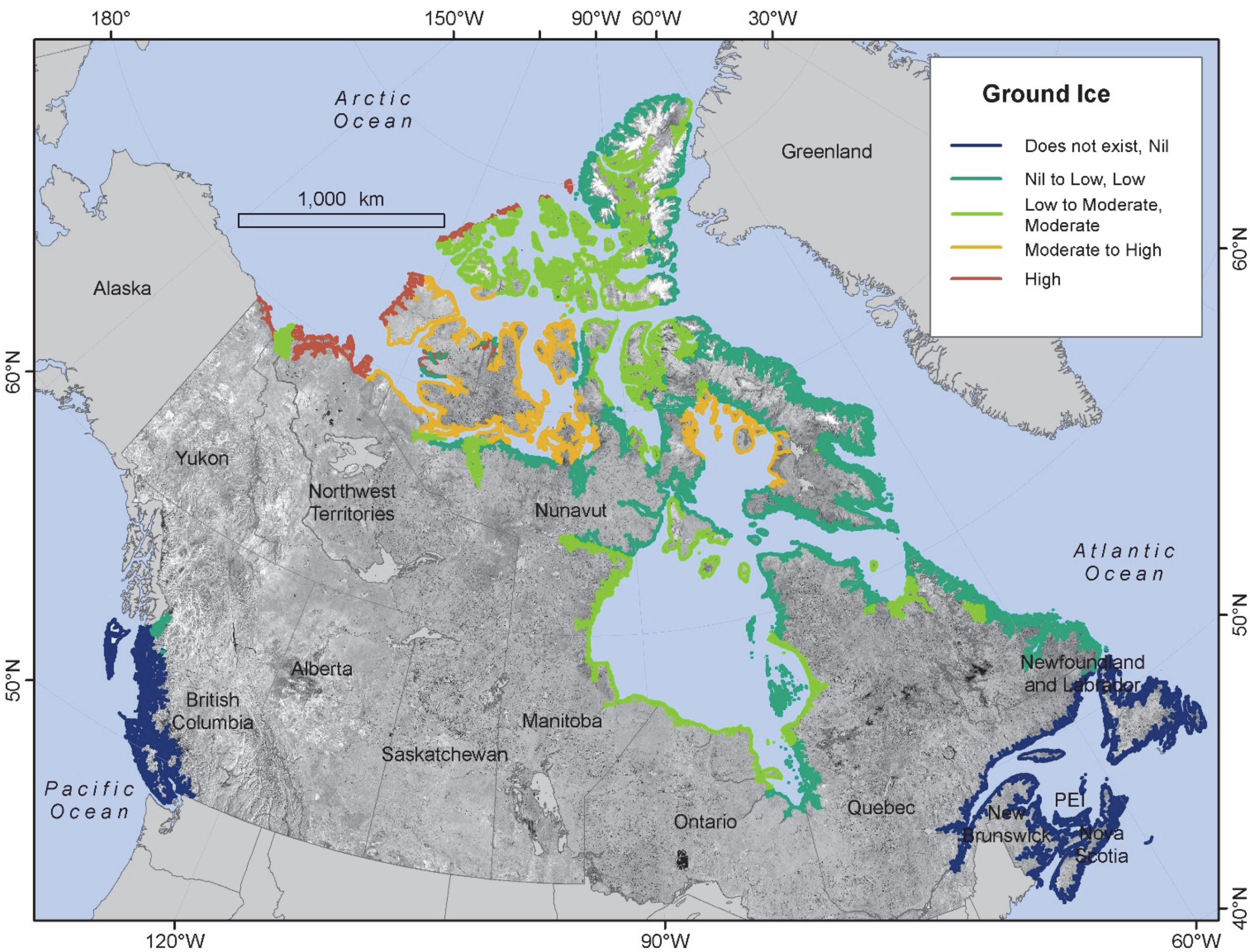

Figure 6. Ground ice in permafrost representing sensitivity to thaw and erosion as temperature increases.

CanCoast Coastal Materials Version 2.0

In this dataset, the spatial variability of bedrock and surficial materials is mapped and its erodibility is categorised into scores (Fig. 7). The dataset is derived from Canada-wide maps of surficial geology (Fulton, 1995) and bedrock geology (Wheeler et al., 1996), both at 1:5,000,000 scale. The bedrock geology map was used to map bedrock types and determine where surficial sediments are present. Where surficial materials were determined to be present, the surficial geology map was then used to map the surficial sediment types and the two maps were combined to provide a single dataset with fields of coastal material and material score. High scores were assigned to areas with erodible materials and low scores were assigned to areas with resistant materials (Table 1). Both maps were provided by the Geological Survey of Canada, Natural Resources Canada.

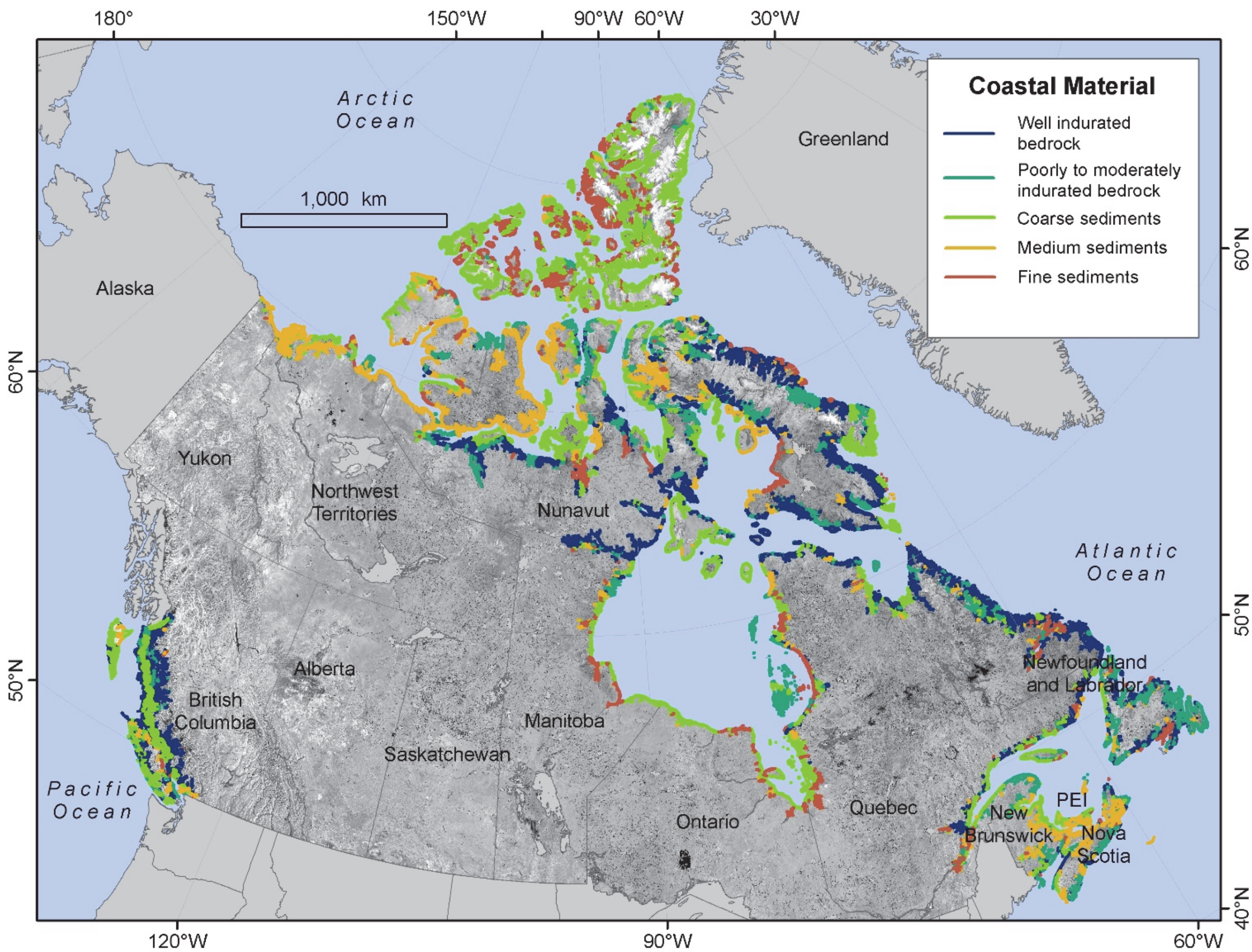

Figure 7. The materials that comprise the bedrock and surficial geology of Canada's coastlines. The nature of the coastal materials strongly influences the erodibility of the coastline.

CanCoast Backshore Slope Version 5.0

This dataset maps the spatial variability of backshore slope along the marine coasts of Canada (Fig. 8). It is derived from slopes in the CDEM (Canadian Digital Elevation Model) dataset produced by Natural Resources Canada (NRCan, 2017) and resampled from approximately 30 m resolution to 100 m resolution using a nearest neighbor search. In this feature class, backshore slope is defined as the slope in degrees from the shoreline landward to the nearest elevation point within 200 m of the shoreline. CDEM data were provided by the Canada Centre for Mapping and Earth Observation, Natural Resources Canada, and subsequent processing was conducted by the Geological Survey of Canada, Natural Resources Canada.

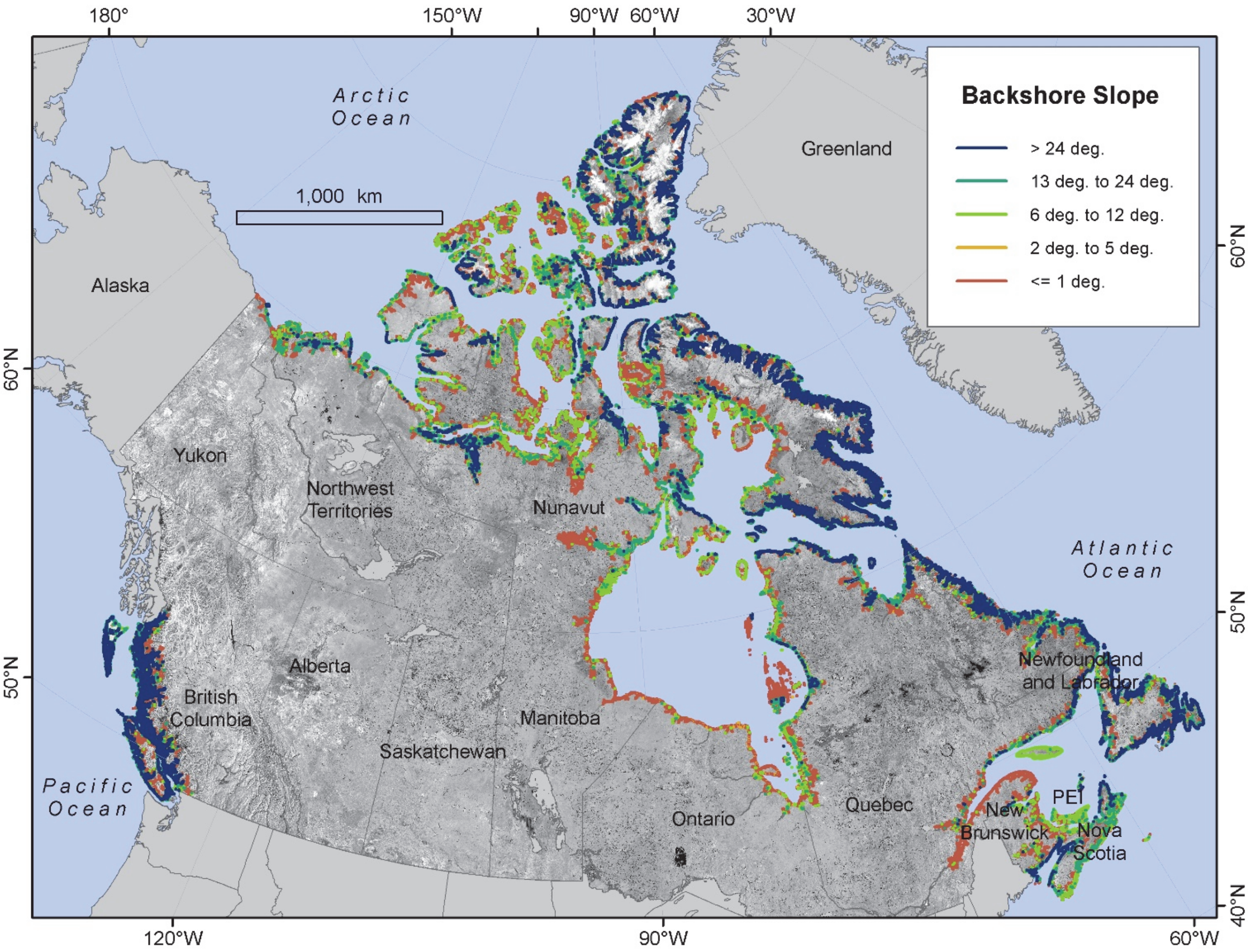

Figure 8. Backshore slope representing the sensitivity of the coast to storm surge flooding and sea-level change.

CanCoast Tidal Range Version 6.0

The purpose of this dataset is to map the spatial variability of tidal range along the marine coasts of Canada (Fig. 9). It is derived from tidal ranges provided by the Fisheries and Oceans Canada WebTide model (Dupont et al., 2002). Tide range is defined as the difference between predicted astronomical lower low water large tides and higher high water large tides, that is, the difference between the lowest and highest expected water levels in the absence of storm surges. This dataset shows the 30 year mean of hourly predicted water levels at 1:50,000 scale. It considers that nearshore currents cause sediment transport and coastal change such that erosion can be expected to be greater in regions with high tide range and less in areas with low tide range. Conversely, flooding during storm surges is less likely to occur in areas with large tide range and more likely to occur in areas with small tide range. Recognising the complex relationships between astronomical tides, storm surge flooding, and coastal erosion, high scores were assigned to both large and small tide ranges while low scores were assigned to moderate tide ranges (Table 1). Data were provided by Fisheries and Oceans Canada.

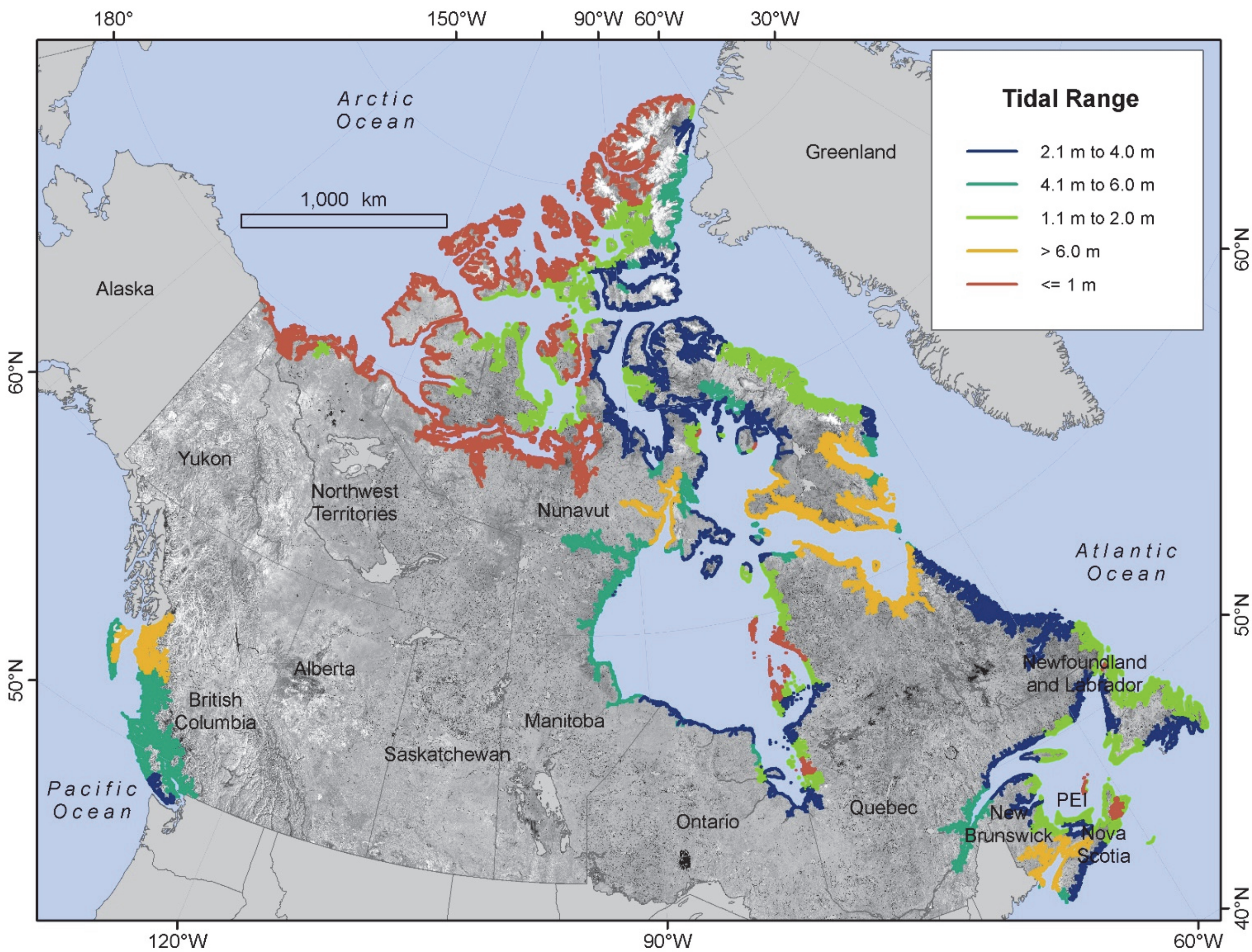

Figure 9. Tidal range representing the sensitivity of the coast to storm surge flooding and erosion by tidal currents. Note non-monotonic scoring (Table 1).

Coastal Sensitivity Indices

This dataset maps the spatial and temporal variability of the physical sensitivity of Canada's marine coasts in a changing climate for two time periods (early and late 21st century), and also provides the change in sensitivity between the two time periods. It employs decadal mean wave height, change in relative sea level, ground ice, coastal materials, backshore slope, and tide range, as described above, to derive a sensitivity index. Sensitivity in the early 21st century is termed CSI_2000s (Fig. 10), sensitivity in the late 21st century is CSI_2090s (Fig. 11), while the difference between the early and late century sensitivity fields is the predicted change in sensitivity over the century (Fig. 12).

Coastal sensitivity indices were calculated using the μ-statistics method, a nonparametric approach of combines indicators into a summary index (Wittkowski 2004). The calculation is based on coastal types, defined as a unique sequence of indicators which are the ranked score from 1-5 for each of the six variables defined above. The basis of the method is a superiority function (equ.1) which determines whether a coastal type is superior to another coastal type. For coastal type $X_{j'}$ to be superior to another coastal type X_j, all of its indicators i (for $i = 1 \ldots I$) must be greater than or equal to the other coastal type's, and at least one indicator must be greater. In order to generate a score for a coastal type, a scoring function (equ. 2) is used in pairwise comparison between that coastal type and all others. This scoring function assigns a value of 1 for every comparison where superiority is found, and 0 for every comparison where it cannot be ordered or it is inferior. The sum of this produces a count of inferior types. To find the sum of superior types, the pairwise comparison is reversed. Finally, to get the CSI value the sum of inferior types is subtracted from the sum of superior types (equ. 3). Summary statistics and nonparametric statistical tests are then possible from a summary score of ordinal indicators (Wittkowski 2004, Morales 2008).

$$X_j < X_{j'} \Leftrightarrow \{i = 1, \ldots, I X_{ji} \leq X_{j'i} \wedge i = 1, \ldots, I X_{ji} < X_{j'i}\}$$ Equation 1

$$I(X_j < X_{j'}) = \begin{cases} 1 & if X_j < X_{j'} \\ 0 & if X_j \text{and} X_{j'} \text{ cannot be ordered} \\ 0 & if X_{j'} < X_j \end{cases}$$ Equation 2

$$u(X_j) = \sum_{j'} I\left(x_j < x_{j'}\right) - \sum_{j'} I\left(x_{j'} < x_j\right)$$ Equation 3

For mapping purposes, the results are classified into five groups indicating areas of very low sensitivity (< -500), low sensitivity (-500 to -150), medium sensitivity (-151 to 150), high sensitivity (151 to 500), and very high sensitivity (> 500).

Interpreting the the μ-statistics results is quite different from the more traditional approach of Gornitz (1991) and Shaw et al. (1998). Rather than individual coastal segments being assigned a score independent of other segments, the μ-statistics approach assigns scores to coastal types depending on the number of coastal types that are more or less sensitive. Scores near zero indicate that equal numbers of coastal types are more and less sensitive than the coastal type under consideration. Negative scores indicate that a large number of coastal types are more sensitive and the type under consideration is relatively insensitive. In contrast, positive values indicate that a large number of coastal types are less sensitive, and the type under consideration has relatively high sensitivity.

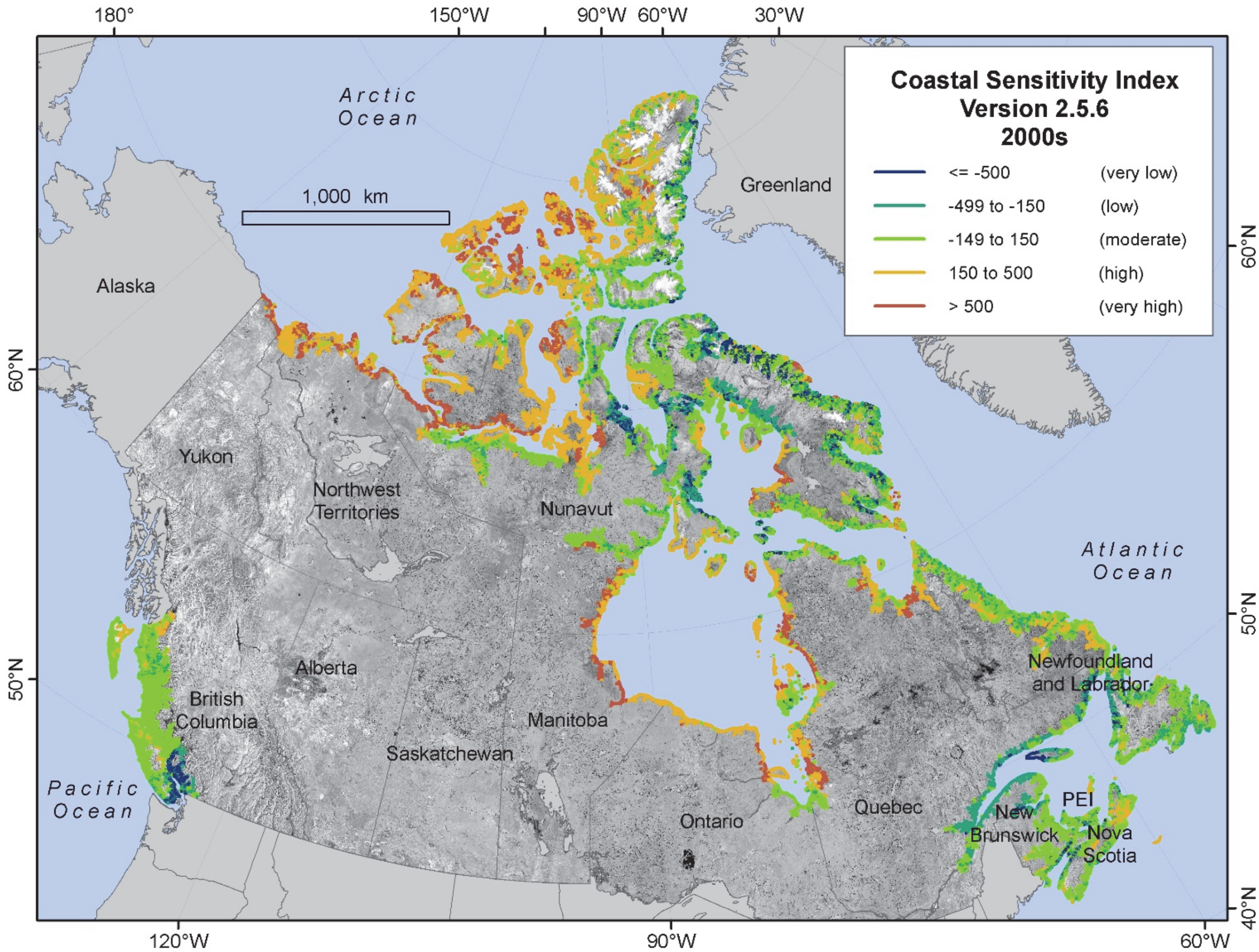

Figure 10. The sensitivity of Canada's marine coasts in the early 21st century (Equations 1, 2, and 3).

The early century sensitivity map (Fig 10) does not show many areas with very high sensitivity, with the exception of small areas in the Beaufort Sea. Figure 10 show areas of low sensitivity in associated with fjiords in BC, Baffin and Ellesmere Islands and Labrador, some of which remain low in the late century sensitivity (Fig. 11). Figure 11 shows very high sensitivity for most of the western Arctic. Limited regions of high and very high sensitivity are present in Hudson Bay, and Atlantic Canada has regions of high sensitivity.

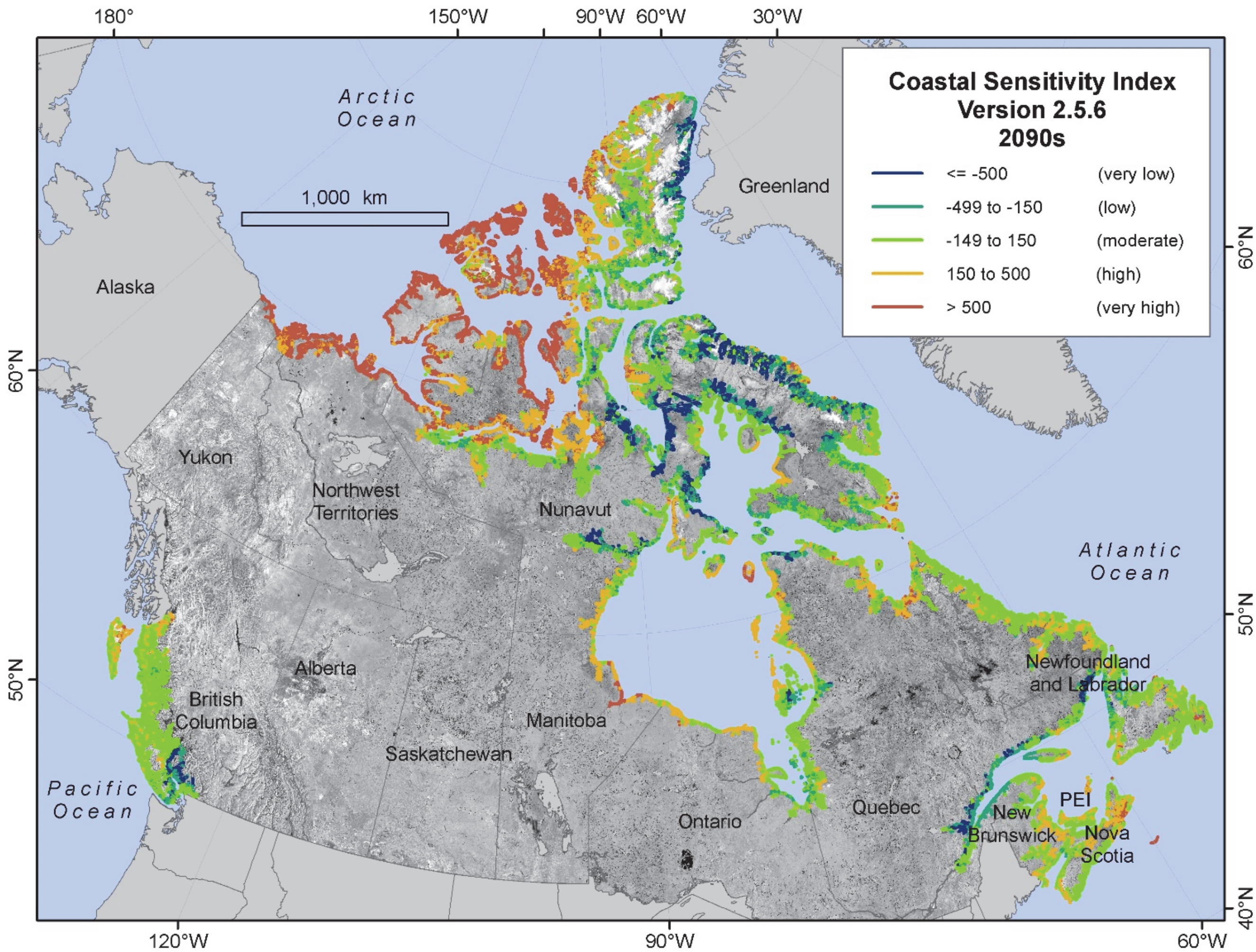

Figure 11. The sensitivity of Canada's marine coasts in the late 21st century (Equations 1, 2, and 3).

The change in coastal sensitivity was calculated by taking the difference between the early and late century CSIs (2090s – 2000s). In Figure 12, positive values indicate increased sensitivity and negative values indicate decreased sensitivity. The sensitivity of much of Canada's coasts is expected to increase, but other areas are projected to experience negligible change or small decreases. The largest increases in sensitivity are in the western Arctic. This region is subject to some of the highest rates of relative sea-level rise in Canada (Figs. 2 and 3), wave heights are expected to increase with decreasing sea ice (Figs. 4 and 5), and ground ice (Fig. 6) is expected to thaw, particularly where there are unconsolidated sediments (Fig. 7). Decreasing sensitivity is found in areas where there are steep slopes (Fig. 8) composed of well-indurated materials (Fig. 7) and where relative sea level is projected to fall (Fig. 3). Regions with negligible change in sensitivity typically have low rates of relative sea-level change (Fig. 3), zero to nil ground ice (Fig. 6), poorly to moderately indurated bedrock or coarse sediments (Fig. 7), moderate slopes (Fig. 8), moderate tide range (Fig. 9), and where wave height is not expected to change (Figs. 4 and 5). It is important to consider Figures 10, 11 and 12 together. For example, in the Fraser Delta region (Vancouver), sensitivity is very low to moderate in the early and late century, but shows large increases over the 21st century. While sensitivity may be relatively low, adaptation planning in the region should consider a large increase in sensitivity by end of the 21st century.

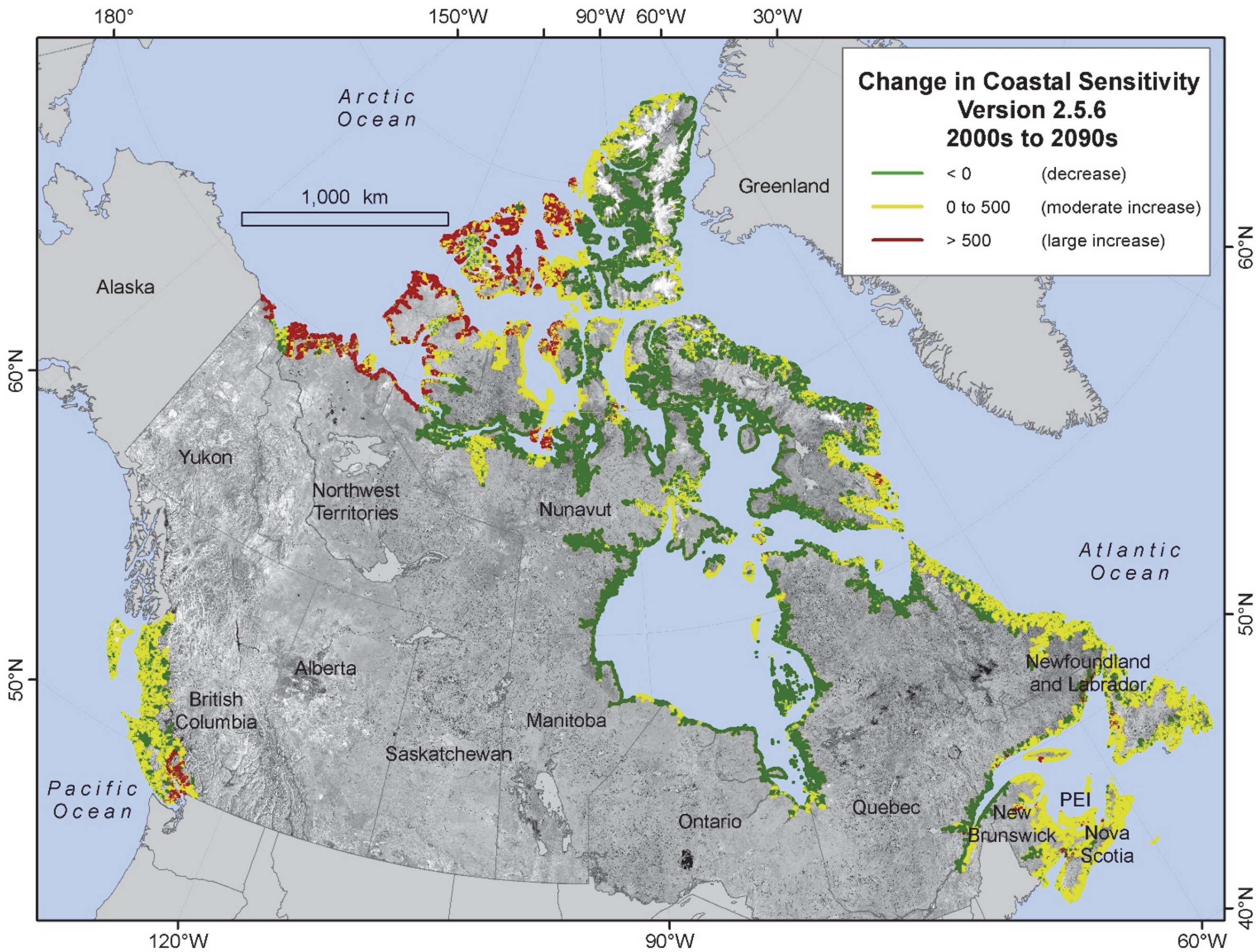

Figure 12. Predicted change in sensitivity through the century of Canada's marine coasts in a changing climate determined from the difference of the late (Fig. 11) and early (Fig. 10) 21st century sensitivities.

Consideration of Scale

The various scales of the input data are given in the dataset descriptions above. The scales of the CSIs (Figs. 10 and 11) are a combination of the scales of the input datasets and their data types. Some input datasets were provided as raster or gridded data so the resolution is defined by pixel size in metres (e.g. 30 m). Other datasets originated as vectors and the scale is defined by the ratio of centimetres on the map to metres on the ground (e.g. 1:750,000). The scale of the shoreline is 1:50,000 to 1:250,000 over which overlapping datasets with various scales were intersected. The distribution of shoreline lengths in the CSIs is presented in Figure 13.

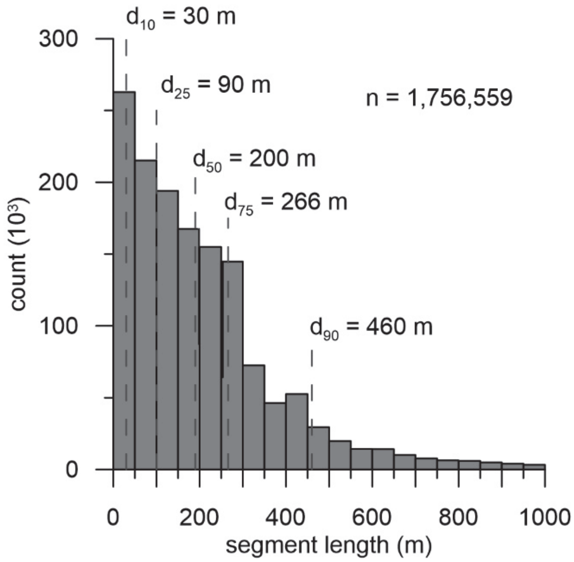

Figure 13. Histogram of segment lengths in the CSIs showing that 50% of line segments are less than 200 m in length (d_{50}) and 90% of line segments are less than 460 m in length (d_{90}).

In a digital map, a user can zoom in and out, and consideration of scale becomes important because zooming does not change the scale of the data, just the viewing resolution. The versions of the input data to the CanCoast CSIs and the change in sensitivity over the 21st century presented here contain coarse data and are not applicable for fine-scale analyses, such as comparing the sensitivities of adjacent properties at a local scale. Comparisons between regions are more meaningful, such as comparing the North Coast of British Columbia to Nova Scotia's Eastern Shore, or the coast of southern James Bay to the coast of Canada's Beaufort Sea. The maps presented are best interpreted at the national-scale, and in the context of comparing the sensitivity of different regions to each other, and whether the sensitivity of a region is expected to change.

Summary and Continuing Research

The datasets presented here contribute to early and late 21st century generalised indices of coastal sensitivity and suggest how coastal sensitivity may change in a changing climate. The difference between the two generalised indices shows where the indices are expected to change. While some coastal areas are expected to decrease in sensitivity or experience negligible change, the sensitivity of much of Canada's coast is expected to increase. Because these results incorporate data at various scales, they should be considered only in comparisons between regions, rather than from neighbourhood to neighbourhood, or local property to local property. The data included in the indices are considered, at time of publishing, the best and most consistent. The derived indices should be considered as contributions to an ongoing study.

Continuing research aims to address the spatial and temporal coastal sensitivity within regions. Additional high resolution data are required, including an improved shoreline and an improved digital elevation model. These are under development by project collaborators and could be incorporated into a future version of CanCoast.

Different calculations of sensitivity indices are also being explored. Future regional investigations, using the approach described here, will generate higher-resolution sensitivity indices for selected regions, and enable the national scale indices to be refined and improved. Anomalies identified in the national scale indices will be used to identify areas where the coastal sensitivity is not well understood, and to direct continuing research.

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