NORTHERN SHELF BIOREGION CLIMATE CHANGE ASSESSMENT:

Projected climate changes, sectoral
impacts, and recommendations for
adaptation strategies across the
Canadian North Pacific Coast | **2018**

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PROJECTED CLIMATE CHANGES, SECTORAL IMPACTS, AND RECOMMENDATIONS FOR
ADAPTATION STRATEGIES ACROSS THE CANADIAN NORTH PACIFIC COAST | 2018

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Recommended citation: C. Whitney, T. Conger. Northern Shelf Bioregion Climate Change Assessment: Projected climate changes, sectoral impacts, and recommendations for adaptation strategies across the Canadian North Pacific Coast. University of Victoria, 2018.

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EXECUTIVE SUMMARY

Records indicate that air temperatures in British Columbia have increased ~1.3°C since 1900. Climate projections from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (2014) point to much greater warming for the remainder of the century. These models project increases in annual air temperatures in British Columbia (BC) of, on average, 1.8°C by the 2050s, and 2.7°C by the 2080s (PCIC). Projected changes in annual precipitation for BC are less significant, but overall more precipitation is likely, with warmer wetter winters and drier summers. Sea surface temperatures in BC are projected to increase by 0.5-2°C by 2065-2078, and ocean pH is predicted to continue to decline. Sea levels are projected to increase by 80cm to 120cm by 2100, with variability expected across the region. Dissolved oxygen levels and sea surface salinity in BC will likely decline overall. Increases in extreme weather events and spring runoff, and declining winter snowpack, are likely in BC, with projections consistent across different climate models.

These projected changes are relevant at the scale of the MaPP region. Where data exist, we comment on the nuances of these changes at the MaPP regional and sub-regional scales. With these projected changes, some sectoral impacts to consider for the MaPP region and the wider BC coast include:

ECOSYSTEMS

- Warming waters and increasing rates of ocean acidification are affecting and will likely continue to affect marine ecosystems and species.
- Rising sea levels and increasingly intense waves, winds, and storms will affect coastline habitats and species composition.

FISHERIES AND AQUACULTURE

- The geographical ranges and species composition of marine ecosystems are changing. This is linked to warming ocean temperatures and changing marine habitats.
- Rising stream temperatures will likely negatively affect freshwater fish including the freshwater life history of salmon species. Changing timing of snowmelt, further exacerbated by decreased summer precipitation, may make this impact worse.

HUMAN COMMUNITIES

- Coastal erosion and sea inundation from storm surge, especially in northern areas, will likely increase. These impacts are linked to sea level rise, increased storminess and wave events, and increased precipitation combined with the effects of warming trends on timing of snowmelt, given the contribution of spring snowmelt to floods within the province of BC.
- Increasing air temperatures and changing seasonality may provide opportunities to the tourism sector and economies of coastal communities by lengthening the summer tourist season, but could also provide potential problems to local populations who are adapted to current seasonal timing.
- Changing fish species composition will affect the fishing sector, coastal communities and economies.

MARINE INFRASTRUCTURE:

- Coastal infrastructure is likely to be affected by increasing extreme weather events, rising sea levels, and increased risk of flooding affecting shore-based infrastructure and buildings.
- Transportation corridors for marine shipping will be affected by increasing winds, waves, and storms. Ports and harbours would do well to plan proactively for increased wave heights and storm surge events.

Proactive planning for adaptation based on these climate projections and associated risks for key species would decrease the likely impacts on the sectors outlined above. However, there are critical gaps in knowledge for many climate change projections and impacts, especially in the marine environment and at fine spatial scales. Improved climate projections and sub-regional vulnerability and risk assessments would improve integrated coastal decision making and planning supporting healthy coastal communities and economies.

Photo by Jessica Hawryshyn

TABLE OF CONTENTS

Executive Summary.....2

Acknowledgements.....8

Acronyms and Terminology.....9

 Acronym Definitions.....9

 Important Terminology.....9

Introduction.....10

 Limitations.....11

 Climate Change Threats.....12

 The Marine Plan Partnership for the North Pacific Coast.....14

 Social-Ecological Context and Management: BC and the Northern Shelf Bioregion.....16

Methodology.....18

 Spatial Data Sources.....19

 Existing Climate Change Assessments.....20

Global and Regional Climate Change Trends.....21

Observed Climate Change Trends in British Columbia.....24

 Air temperature.....24

 Precipitation.....25

 Sea level rise.....25

 Sea surface temperature.....25

 Ocean acidification.....26

 Ocean deoxygenation.....26

 Sea surface salinity.....26

Observed Climate Associated Impacts.....27

 Ecosystems:.....27

 Fisheries:.....28

 Human Communities.....28

 Marine infrastructure.....28

Regional Climate Change Projections.....29

Air temperature.....29

Precipitation.....29

Sea level rise.....30

Sea surface temperature.....30

Ocean acidification.....30

Ocean deoxygenation.....30

Sea surface salinity.....30

Extreme weather events.....30

Estimated Regional Impacts associated with Climate Change Projections.....31

Ecosystems.....32

Air temperature and precipitation.....32

Sea level rise.....32

Sea surface temperature.....32

Ocean acidification.....33

Ocean deoxygenation.....33

Sea surface salinity.....33

Other impacts.....33

Fisheries and aquaculture.....34

Sea level rise.....34

Sea surface temperature.....34

Ocean acidification.....35

Ocean deoxygenation.....35

Human communities.....36

Air temperature and precipitation.....36

Sea level rise.....36

Sea surface temperature.....37

Ocean acidification.....37

Winds, waves, and extreme weather.....37

Marine Infrastructure.....38

Sea level rise.....38

Winds, waves, and extreme weather.....38

Sub-regional Projections and Impacts.....39

North Vancouver Island.....39

Central Coast.....41

North Coast.....42

Haida Gwaii.....43

Knowledge gaps and some ongoing research.....46

Uncertainty in climate change impacts, vulnerabilities, and risk.....46

Lack of regionally downscaled projections and vulnerability assessments.....47

Ocean acidification and ocean chemistry.....47

Ongoing and/or recommended research.....47

Extreme weather, storm surge, and sea level rise.....48

Other uncertainties: Invasive species, disease pathways.....48

Moving forward: Adaptation.....49

Current adaptation policies and recommendations for adaptation.....50

Sector level adaptation: Ecosystems, Fisheries and Aquaculture.....50

Sector level adaptation: Human communities.....53

Sector level adaptation: Marine infrastructure.....54

Recommendations.....55

Conclusions.....57

Tables: Predicted climate change impacts across region and sub-regions.....58

References.....70

Appendix 1: Glossary.....80

Appendix 2: Some Climate Change Projections and Impacts
on Fisheries and Aquaculture within coastal BC.....82

Appendix 3: General adaptation actions for climate impacts and sectors.....84

Mapping: MaPP Regional and Sub-Regional Projections and Sectoral Impacts.....85

Triangle Island, South Bay, British Columbia, Canada | Photo by Joanna Smith

ACKNOWLEDGEMENTS

We thank all the researchers who generously shared their time with us to offer insights on the status of climate change research and future recommendations in this area, in particular: Hussein Alidina, Stephen Ban, William Cheung, Katie Gale, Karen Hunter, Rebecca Martone, Trevor Murdock, Cathryn Clarke Murray, Tom Okey, Malin Pinsky, Gillian Vines, and Colette Wabnitz. We thank Natalie Ban for valuable advice and feedback throughout. The maps in this report were produced by Emily Goodman and Glenda Wyatt. Graphic design report layout by Gary Leung.

This project was developed in collaboration with the Marine Plan Partnership for the North Pacific Coast (MaPP). We thank all MaPP Partners for helping to scope this work and for providing valuable feedback throughout the process.

Tides Canada – MaPP Implementation Support Project (grant #GI00128) generously provided the financial support that made this report possible.

ACRONYMS AND TERMINOLOGY

The following acronyms and terminology are used in the context of the Marine Plan Partnership and oceans management in the Northern Shelf Bioregion:

ACRONYM DEFINITIONS

BC	British Columbia
DFO	Fisheries and Oceans Canada
EBM	Ecosystem Based Management
IPCC	Intergovernmental Panel on Climate Change
RAF	Regional Action Framework
RCP	Representative Concentration Pathway
SLR	Sea Level Rise
MaPP	Marine Plan Partnership for the North Pacific Coast
MPA	Marine Protected Area
NSB	Northern Shelf Bioregion
PNCIMA	Pacific North Coast Integrated Management Area

IMPORTANT TERMINOLOGY

Established definitions have been used in this report to frame the theory and methods used in climate change assessments, which are provided here for clarity from the sources. A complete glossary is included in the Appendix.

- Adaptation to climate change** means the adjustment(s) in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.
- Adaptive capacity** describes a system’s ability to cope with the disturbance and self-organize to continue its functioning.
- Climate Change Projections** describe the future and the pathway leading to it. Specific to climate change, projections estimate the change in a climate change indicator or variable derived from models of future climate.
- Exposure** refers to a system’s properties that are subject to potential future harm from a disturbance.
- Sensitivity** refers to a system’s tendency of loss when exposed to a disturbance.
- Impact** is the effect or influence that occurs based on a projected change (in climate).
- Risk** is the probability that a disturbance will happen.
- Vulnerability** is how susceptible a social or environmental system or sector is to the effects of a climate change impacts and it is a function of the systems’ sensitivity, exposure and adaptive capacity.

INTRODUCTION

The world's climate is changing at an increasingly rapid rate due to greenhouse gas emissions from human industrial activity and population growth. While these changes are global, the ramifications occur at all scales, and decisions for adaptation must be made. Governments, regions, and communities need to understand what is happening, what knowledge gaps exist, and how they may be able to respond. Coastal regions are unique and especially vulnerable to climate change, and the impacts are diverse and often cumulative. Identifying how these changes are already starting to occur, and could occur in the future, is important for planning appropriate management responses.

This project was developed in collaboration with the Marine Plan Partnership for the North Pacific Coast (MaPP), whose planning region is similar to the geographic area known as the Northern Shelf Bioregion (NSB). This report is intended to be a tool to help guide future research and climate change adaptations in the region, specific to the interests of MaPP. It outlines the current available knowledge on climate change projections with associated impacts, exposure, and risks to the coastal social-ecological system of the 'MaPP region', also referred to as the Northern Shelf Bioregion.

This report focuses on climate-associated impacts, exposure, and risks to four key sectors of the coastal social-ecological system in the NSB:

1. ecosystems;
2. fisheries and aquaculture;
3. human communities;
4. marine infrastructure.

Key climate change projections for the MaPP region are included based on the literature and expert interviews, with information provided specific to the four MaPP sub-regions where possible given the scale of the data. In particular, we focus on highlighting the differences and similarities among and between the four MaPP sub-regions, if and where feasible given the data available.

Through this work, we also aimed to identify gaps in knowledge and ongoing adaptation actions that have been implemented in the region, as well as recommend further adaptation actions based on the literature. As well, we include recommendations for future research on climate change impacts, vulnerability (including exposure, sensitivity, and adaptive capacity), and risk, in this region, as well as mention any ongoing and planned climate change research pertaining to the key areas of interest to MaPP to help guide future adaptation work.

LIMITATIONS

This report is based on an extensive literature review and a series of discussions with experts involved in relevant research within the coastal region of British Columbia. Information was collected within the constraints of the scope, budget, and time for the component of the project. Research and discussions focused on issues of relevance to climate change impacts and adaptation planning in British Columbia, Canada, and specifically the Northern Shelf Bioregion when possible.

This report is not a comprehensive assessment of climate change impacts in British Columbia's coastal marine environment, nor does it offer new analyses or model outputs projecting climate impacts within the Northern Shelf Bioregion. Rather, this report focuses on a baseline assessment, or scoping

exercise, of known climate impacts and risks to the Northern Shelf Bioregion, in order to determine the strategic next steps that could be taken to address the needs of coastal communities within the Marine Plan Partnership region in terms of climate change adaptation and adaptive capacities.

The literature in this field is wide ranging and growing rapidly, and much of the work is ongoing or in progress and therefore not published or readily available. Researchers do not tend to share ongoing research or early results prior to publication. Thus, while this report and information is integrally based on available peer reviewed literature and government agency reports (federal and provincial), and informed by the insights offered by several key experts, the baseline information expressed in this report is entirely the responsibility of the authors.

Photo by Warren Nelson

Red sea urchins | Photo by Gerd and Linda Mueller

CLIMATE CHANGE THREATS

Global climate change is now widely recognized as the singular greatest threat to the world's ecosystems, cultures, and economies. Increasing anthropogenic emissions over the past century have changed oceanic conditions, impacted marine ecosystems, and negatively affected the ecosystem services and resources that they provide to human society. The effects of climate change are already being felt within Canada's economy and communities, with impacts ranging from decreasing air quality, increasing extreme weather events such as flooding, degrading infrastructure from increased weathering, increasing water stress, declining fisheries and agricultural productivity, and a host of associated health effects. The impacts of extreme weather events and increasing temperatures are growing, especially in recent years and for coastal regions. Severe storms, coastal flooding, rising ocean temperatures, and ocean acidification are among the changes that have already been observed, with numerous resulting impacts to coastal social-ecological systems.

So far, international efforts to mitigate climate change by meeting emissions reductions targets have not been successful, and it seems certain that global temperatures will continue to rise. The next few decades will bring increasing impacts and challenges, as global air temperatures are anticipated to increase by 2-5° C by 2100 [1].

All economic sectors and communities in Canada will be affected by the impacts of climate change. Coastal regions and remote communities are particularly vulnerable to changes because of their dependence upon marine resources, a high level of exposure to many climate effects, and sometimes low adaptive capacity. However, regional, First Nations, and community governments can be adaptive and are place-based, and therefore are especially well situated to make proactive decisions to manage the risks and associated impacts from climate change.

This scoping report is aimed at guiding the next steps for research and implementation of climate change adaptation strategies for the MaPP region (Figure 1) of coastal British Columbia, Canada.

A subsequent report also authored in 2018 by Conger and Whitney reviews existing frameworks and tools for carrying out vulnerability and risk assessments. It includes strengths, weaknesses, opportunities, and threats related to applying existing vulnerability and risk assessment frameworks and tools to the MaPP region.

Humpback whale | Photo by Janie Wray

Steller sea lion | Photo by Scott Harris

THE MARINE PLAN PARTNERSHIP FOR THE NORTH PACIFIC COAST

Through the Marine Planning Partnership, now Marine Plan Partnership (MaPP), provincial and First Nations governments in BC are working towards sustainable development, improving economic opportunity, and supporting ecological integrity for the North Pacific Coast. This collaborative government to government partnership is an agreement between the Province of British Columbia (BC) and 17 member First Nations represented by the Coastal First Nations Great Bear Initiative, Central Coast Indigenous Resource Alliance, the Council of Haida Nation, the Nanwakolas Council, and the North Coast-Skeena First Nations Stewardship Society.

Marine planning through MaPP started in 2011, and four sub-regional marine plans for the North Coast, the Central Coast, North Vancouver Island, and Haida Gwaii were completed in the spring of 2015 (www.mappocean.org). Together, these sub-regions make up the MaPP region, which aligns with the Northern Shelf Bioregion (NSB; Figure 1). Subsequent to the development of the sub-regional marine plans, MaPP produced the Regional Action Framework (RAF) in 2016 to establish regional MaPP actions that are best implemented at a regional scale and also support sub-regional strategies. As part of its planning work, MaPP Partners also completed a series of current conditions and trends reports for the four sub-regions.

Ecosystem Based Management (EBM) is the ‘foundation’ of the MaPP sub-regional plans and the RAF. EBM is a framework that aims to define management strategies for entire systems, rather than managing for individual components, and, importantly, recognizes humans as an explicit component of that system. The MaPP EBM framework was developed by federal, provincial, and First Nations governments in collaboration with stakeholders through the Pacific North Coast Integrated Management Area (PNCIMA) initiative [2]. In the context of MaPP, the marine EBM framework seeks an adaptive approach to management that ensures the co-existence of functioning ecosystems and human communities.

For the MaPP EBM recommendations to be successfully implemented across the region, it is important to consider both the short and long-term effects of climate change. Currently, the MaPP RAF has outlined actions that support monitoring, risk assessment, blue carbon sequestration, education, and public awareness of climate change. Each sub-region has also identified particular objectives and strategies for adaptation to climate change.

Figure 1: The MaPP region (i.e. the Northern Shelf Bioregion), showing the boundaries of the four sub-regions and main communities. The sub-regional boundaries follow the Northern Shelf Bioregion boundary, except for a small area near the western tip of North Vancouver Island

Photo by Ryan Miller

SOCIAL-ECOLOGICAL CONTEXT AND MANAGEMENT: BC AND THE NORTHERN SHELF BIOREGION

In BC, the productive coastal marine food web supports rich First Nations and non-First Nations communities, cultures, and economies. Human communities have lived in this region for thousands of years, supported by abundant terrestrial and marine ecosystems and resources. These also shaped human socio-cultural values, as exhibited by the close co-existence that First Nations cultures have with the landscape and the place-based stewardship that still exists today, despite the modern history of colonization.

The BC coast is managed at a range of scales including bioregions, eco-sections, and habitats [3]. The four bioregions include: 1) Offshore Pacific; 2) Northern Shelf; 3) Southern Shelf; and 4) Strait of Georgia [3]. This report focuses on the MaPP planning region, which is largely the same region as the NSB, with some exceptions (Figure 1). The NSB is one of Canada's five Large Ocean Management Areas (LOMAs) that are used to implement Canada's Oceans Act and is the focus of ongoing initiatives for marine resource and marine conservation planning in BC.

The NSB assumes the same footprint as the Pacific North Coast Integrated Management Area (PNCIMA) [2]. Existing and ongoing research in the NSB has fewer research initiatives than the other southern bioregions in BC [4], but the combination of ongoing management and planning in the NSB suggest that this could change.

Ecologically speaking, Canada's Pacific coast is a highly dynamic and complex transition zone where three large ocean currents converge: the upwelling (southward flowing) California Current, the down welling (northward flowing) Alaska Coastal Current, and the eastward flowing North Pacific Current (Figure 2). In addition, the California Undercurrent transports warm ocean waters from the tropical latitudes to intersect with southern Vancouver Island, and a wind driven coastal countercurrent - the Davidson Current - flows seasonally northwards into BC waters from Mexico [5]. These currents are important drivers of marine nutrient richness and ecological diversity in BC's waters.

Recent summaries of the ecological status of the marine coastal system of BC emphasize that the ecological complexity and diverse species dynamics within the region are supported by high primary

productivity and highly variable oceanography, hydrology, and geomorphology [5,6]. Ecological productivity in the NSB is driven by upwelling and down-welling patterns that vary seasonally and episodically; variable seasonal patterns of freshwater and tidal mixing also affect oceanographic conditions. Regional bathymetry also affects marine ecological conditions, as deep-water troughs and canyons separate shallow banks in the center of Hecate Strait [5]. Oceanographic conditions are also influenced by the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). The El Niño phase of the ENSO tends to enhance the flows of southern warm currents that tend to correlate with the arrival of southern tropical marine species in these waters [5,7,8]. El Niño also affects the natural variability in air temperature in BC, and year-to-year and decade-to-decade variability in climate and weather across the province may mask observations of long-term climate change during some periods and in some

regions [9,10]. The PDO is a long-term pattern of Pacific climate variability that affects oceanographic conditions across the Northeast Pacific. The variation in the PDO (warm/cool) patterns can affect the region for a decade or longer.

Along the coast of BC, ocean water temperatures are warming, and nearshore waters are becoming less salty, less oxygenated, and more acidic (a chemical process resulting from them becoming enriched in carbon dioxide) [11]. These changes are contributing to biological changes such as shifting species distributions [12,13]. In order to understand and anticipate climate change impacts, a range of modeling approaches have been used to characterize and predict ecological and biological responses along the BC coast and the surrounding marine area. Research focused on and within the NSB has included descriptions of the ecological communities and context, trophodynamic modeling, and the effects of climate change on fisheries and ecosystems [14–20].

Figure 2: Coastal region of British Columbia showing the main current patterns and ocean dynamics. From Okey et al. 2014, "Effects of climate change on Canada's Pacific marine ecosystems: A summary of scientific knowledge".

METHODOLOGY

This project synthesizes the current state of understanding of climate change projections, impacts, and vulnerabilities (exposure, specifically), risk, and adaptation within the MaPP region by reviewing the diversity of relevant information, resources, and spatial data, broadly and specific to the MaPP region and sub-regions wherever possible. Projections and impacts are synthesized so that they are specific to the region and sub-regions, wherever possible. We gathered information from peer-reviewed literature, from provincial and federal government reports (grey literature), and through interviews and emails with key contacts and researchers.

Specifically, in gathering information for this report (Figure 3), we included: previous climate change vulnerability and risk assessment work from MaPP and associated contractors; publications from the Intergovernmental Panel on Climate Change (IPCC) Reports; peer reviewed academic studies on climate change impacts and adaptation strategies; assessment methods for climate change vulnerabilities and risks; external reports on predicted climate changes, impacts, and risks to the region [6]; Fisheries and Oceans Canada reports on climate impacts and risks; and Natural Resources Canada reports. We also included information from other key publications focused on climate change impacts in BC and the MaPP region. Except for some fundamental background information, we only included publications from the year 2000 and newer.

Figure 3: Schematic showing the global and smaller scale data sources informing the report and maps of climate impacts on key sectors within the MaPP region. Spatial data for mapping were derived from these sources as well as from the MaPP database. Particular sectoral impacts from climate projections are shown on the third row.

Photo by Jessica Hawryshyn

We reviewed the literature and extracted relevant information for the region and sub-regions, where possible. We categorized climate projections and associated sectoral impacts and exposure by geographical scale (regional or sub-regional). Wherever possible, as limited by the available data, we also aimed to identify differences between the four MaPP sub-regions. Finally, we also contacted and interviewed key researchers in BC who work in this field to enquire about ongoing projects.

This report focuses on the following climate change variables, both observed and projected:

- Air temperature
- Precipitation
- Sea level rise
- Sea surface temperature
- Ocean acidification
- Ocean deoxygenation
- Sea surface salinity
- Winds, wave patterns, and extreme weather events

To assess reporting of climate change projections and sectoral impacts, vulnerabilities, and risks in the associated regional and sub-regional tables, we used a reliability score used by the IPCC to qualitatively assess document quality and reliability of information. We ranked each reference on a 3-point scale and calculated an overall evidence quality score for each climate variable at both a regional and sub-regional scale. We used the same methodology to assess the evidence quality of the estimated impacts to the sub-regions from the climate variables.

SPATIAL DATA SOURCES

For the maps of climate variables and projections, we sourced both global scale and regional scale data wherever it was available. Spatial data sources included:

- BC Marine Conservation Analysis atlas database:
 - o <http://bcmca.ca/maps-data/data-library-downloadable-sets/>
- MaPP data portal:
 - o <http://mappocean.org/resources/data/>
- 5th assessment report from the IPCC (2014), courtesy of Environment Canada:
 - o <http://climate-modelling.canada.ca/climatemodeldata/data.shtml>
- Foreman et al. 2014 [21,22]
 - o BC Parks Shoreline Sensitivity Analysis 2014 [23]

Kelp research | Photo by Markus Thompson

EXISTING CLIMATE CHANGE ASSESSMENTS

Several reports have provided insight into the overall trends in climate changes and climate change projections, globally and for BC and the BC coastal region. These include global reports from the IPCC. In 1998, Environment Canada released the first national scale assessment of climate change impacts and adaptation, The Canada Country Study [24]. Within that report, a chapter specific to BC highlights key impacts to the coastal region and suggests effective adaptation actions [25]. Also at the national level, the Government of Canada has produced a recent series of climate change assessments that identify observed and predicted impacts to Canada's economy, society, and ecosystems, as well as recommended practices to support adaptation to those impacts. These assessments include:

- Climate Change Impacts and Adaptation: A Canadian Perspective (2004)[26]
- Canada's Marine Coasts in a Changing Climate (2016) [27]
- Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation (2014) [28]

The Pacific Climate Impacts Consortium (PCIC) at the University of Victoria provides regionally adjusted (downscaled) climate change projections at the scale of BC through the publicly available Plan2Adapt tool (<https://www.pacificclimate.org/analysis-tools/plan2adapt>). These projections are

currently available for three future time horizons across the province based on an averaged set of climate models from the IPCC (2020s, 2050s, 2080s). Projections over both terrestrial and ocean areas are included for some key climate change variables. These data were used in this report as well as in the regional and sub-regional tables (see Tables section). Additional projections for ocean biochemistry are available from Environment Canada's Canadian Centre for Climate Modelling and Analysis (<https://www.canada.ca/en/environment-climate-change/services/climate-change/centre-modelling-analysis.html>).

Fisheries and Oceans Canada has released reports on the impacts to climate change in the NSB and for the coast of BC [4,29,30]. The Canadian Parks and Wilderness Society (CPAWS), in collaboration with the World Wildlife Fund (WWF), completed a report in 2014 on climate change impacts and vulnerabilities in Canada's Pacific marine ecosystems [6]. In addition, EcoAdapt completed a report of vulnerabilities specific to the MaPP region [31]. The report included maps on current or projected changes in sea level rise, sea surface temperature, and ocean acidification for the MaPP sub-regions and region. Here we update their report with more recent climate projections, with potential risks and vulnerabilities for particular sectors and sub-regions.

GLOBAL AND REGIONAL CLIMATE CHANGE TRENDS

Rising emissions of carbon dioxide and other greenhouse gases from human populations and industries are causing the global climate to change, profoundly affecting the world's ecosystems [32]. Increasing human populations, increasingly intensifying industries and agricultural production, deforestation and land use practices, and increasing fossil fuel based energy production all contribute to rising greenhouse gas emissions and concentrations [5; Figure 1]. Rising emissions continue to reach record levels each year, despite the year to year attempts of some nations to take up alternative energies and

seek lower carbon solutions to their energy needs (<http://globalcarbonbudget2016.org/>). The increase in emissions is consistent with the increase in global average temperatures (Figure 4). Globally, the year 2016 and 2017 were the warmest two years on record (from NASA [34], and the U.S. National Oceanic and Atmospheric Administration's 137-year time series) [4,13; Figure 5]. As carbon emissions and climate change continues largely unchecked, despite many attempts at reaching international agreements on climate change mitigation [1], these changes and impacts are expected to accelerate [35,36].

Figure 4: Global atmospheric concentration of carbon dioxide (CO₂) at the end of the last ice age (left panel) and in the past half century (right panel). From the World Meteorological Organization Global Atmosphere Watch (GAW) Programme, October 2017.

Bull Kelp, British Columbia, Canada | Photo by Joanna Smith

Anthropogenic climate change poses significant impacts and risks to both natural and human systems. Coastal regions are especially susceptible to these changes as they are affected by both marine and terrestrial impacts. Climate change impacts on coastal regions include increasing ocean temperatures, rising sea levels, changing ocean circulation patterns, precipitation, and water chemistry (ocean acidification and decreasing dissolved oxygen), and increases in the frequency and intensity of storms. Globally, much of the human population (>39%) lives within 100km of the sea, and are therefore dependent upon marine-derived resources for their social, cultural, and economic needs [37]. Coastal communities are closely connected with their adjacent natural systems and are already affected by environmental and social stressors. Climate change impacts can affect coastal social-ecological systems: species, food webs, and associated fisheries and aquaculture; human well-being; cultural and social structures of coastal communities; and the marine infrastructure that communities depend upon for transportation, economic activities, and other services.

Figure 5: Global time series of temperature anomalies, June-August, over the past 100 years relative to the 20th century average. From: *Climate at a Glance, Global Time Series*, NOAA National Centers for Environmental Information, August 2017. <https://www.ncdc.noaa.gov/cag/>.

The IPCC describes the diverse and complex array of threats to coastal systems worldwide, while also highlighting that the overall uncertainties in projections of impacts on coastal systems are generally still quite high [36]. The most recent global projections of climate change impacts and vulnerabilities from the IPCC are based on models of Representative Concentration Pathways (RCPs) [36]. The RCP scenarios specify concentrations of greenhouse gases, and are used to project impacts related to climate change (Table 1).

Table 1: Projections of global mean sea level rise in meters relative to 1986-2005 based on ocean thermal expansion calculated from climate models, shown at the four emissions scenarios used by the 5th report of the IPCC. Source: WGI AR5 Summary for Policymakers. IPCC 2014, Coastal and Low-Lying Systems

Emission scenario	Representative Concentration Pathway (RCP)	CO2 concentration in 2100 (ppm)	Mean sea level rise (m) by year	
			2046-2065	2100
Low	2.6	421	0.24 [0.17-0.32]	0.44 [0.28-0.61]
Medium low	4.5	538	0.26 [0.19-0.33]	0.53 [0.36-0.71]
Medium high	6.0	670	0.25 [0.18-0.32]	0.55 [0.38-0.73]
High ('business as usual')	8.5	936	0.29 [0.22-0.38]	0.74 [0.52-0.98]

In this report, we aim to present the uncertainty in climate change projections by including the projections for climate change variables at the lowest and highest RCP scenario, or the ‘best case’ and ‘worst case’ scenario, whenever possible. Long-term projections or trends within BC are expected to align with global trends in a general sense (i.e. warmer temperatures, more acidic ocean, more marine stratification, rising sea levels), but climate changes may result in regional and sub-regional interactions with localized ocean and atmospheric conditions. The ecological complexity of the BC coast and MaPP region is high, as is the uncertainty in regionally resolved climate change projections. Understanding the ecosystem and the projections of climate effects on the various components of the MaPP social-ecological system is therefore challenging.

In some cases, the spatial data for climate projections within BC are only available for certain scenarios (e.g. sea level rise projections, available for RCP 4.5 and RCP 8.5 only). Many of the available regional and sub-regional climate projections are available through PICS (<https://www.pacificclimate.org/>) who use an average set of climate models from the IPCC to conduct regional analyses for the BC region at a ‘business as usual’ level of emissions (RCP 8.5) [6,7; Figure 6]. Higher resolution projections of climate effects and impacts on important sectors in this region and within BC generally will improve in the future. The current state of uncertainty means that the present report was conducted with relatively simplified, generalizable impact statements, adaptation actions, and recommendations for climate change impact planning in mind.

Figure 6: Modeled global average surface temperature change relative to 1986-2005. The mean projections (lines) and a representation of uncertainty due to the range of models (shading) are shown for the high emissions scenario (RCP 8.5, red) and low emissions scenario (RCP 2.6, blue). The numbers indicate the number of climate models used to calculate the mean values. From the IPCC Climate Change 2014 Synthesis Report.

Kwatna Estuary | Photo by Ian McAllister

OBSERVED CLIMATE CHANGE TRENDS IN BRITISH COLUMBIA

Here, we categorize some observed climate change impacts for BC, and specifically the coastal region. Determining trends in climate conditions has been somewhat problematic in BC due to a lack of long-standing empirical data collection and monitoring efforts, especially for the marine system [40]. Nevertheless, information on key climate variables and associated impacts is available with some detail across the region, depending on the impact and spatial scale of the data.

Air temperature

Air temperatures have increased throughout BC by ~1.3°C over the past century (from 1900-2013; rates of 0.12 - 0.13°C per decade [10,41–43], slightly more than the global average during the same period [36] but less than the rest of Canada [28]. The northern portion of BC has warmed at twice the global average (1.6 to 2.0°C per century versus 0.85°C per century globally), while the south coast has warmed at a rate of 0.8°C per century, roughly the same as the global average [10]. Most of this warming trend has been observed during the winter months (average increase of 2.2°C per century), and in the north (3 to 3.8°C per century) and south-central (2.6 to 2.9°C per century) areas of BC [10,41]. Average daily minimum temperatures have increased the most (increased 2.3°C this century) across the province, while average daily maximum temperatures have increased by 0.7°C per century [10,11].

Both daily average and daily minimum air temperatures in BC reached record high levels in 2016, and monthly temperatures in the winter of 2016 were more than 5°C higher than the baseline period of 1971-2000 [11]. These higher temperatures contribute to other changes in climate, and both negatively as well as positively affect ecosystems and human activities. For instance, increasing air temperatures are associated with decreased heating requirements over the past century in BC, especially in northern BC [10]. Meanwhile, the energy demand for cooling built infrastructure has increased, especially in the southern interior of BC [10]. These changes in energy consumption are directly related to changes in average daily air temperature.

Precipitation

Precipitation is a key indicator of climate change, and changes in precipitation will affect all sectors, ecosystems, and communities. In BC, precipitation has increased over the last 50 years in all seasons by some estimates, or just in the summer months by other reports, with variation across the province [5,25,41]. Province-wide, annual average precipitation has increased by 12% per century [10]. However, these changes have been so far statistically insignificant and can largely be explained by the high natural variation in precipitation patterns across the province [10,42,43]. Winter warming trends led to higher snowpack density (wetter snow) across much of BC from 1950-2014, and as winter temperatures increase, winter snows are likely to continue to be wet and heavy, or even fall as rain [10]. This trend has not yet been significant for the BC coastal region that includes the MaPP region [10].

Changes in the amount, type, and timing of precipitation in BC will certainly affect both terrestrial and marine systems, although the relatively high uncertainty in historical monitoring data means that estimating current precipitation trends and associated impacts is a challenge [10]. In 2016, precipitation levels were higher than average for most regions in BC [11].

Sea level rise

Sea level rise is the direct result of warming temperatures that trigger increased melting of glaciers and ice caps, as well as the thermal expansion of warming oceans [44]. Glacial coverage in BC has declined since 1985, and the volume of glacial ice declined by an average rate of 21.9 km³ from 1985-2000 [10]. In the coastal mountain area of BC, which includes the MaPP region, glacier area decreased by approximately 6.4% from 1985-2000 [10]. Sea levels are also affected by ocean and weather patterns such as wind, currents, and salinity, and also by subsidence and uplift of the adjacent land mass due to geological processes. Changes in sea level threatens coastal systems through coastal erosion, seawater inundation, contamination of freshwater systems, and can affect food crops grown in low lying areas.

Global mean sea levels increased 10-20 cm during the 20th century, and have been increasing by 3.2 mm/year since 1993 [32,36]. In BC, the average sea level between 1910-2014 has risen along most of the coast, at a rate of 13.3 cm/century at Prince Rupert, 6.6 cm/century at Victoria, and 3.7cm/century at Vancouver [10]. Sea levels at Prince Rupert and Victoria continue to increase, while off the west coast of Vancouver Island tectonic uplift (isostatic rebound from the weight of ice age glaciers) offsets sea level rise such that water levels appear to be declining (removing this uplift would result in a sea level increase of 13.5 cm per century) [10,11].

Sea surface temperature

Sea surface temperatures are monitored at lighthouse stations along the BC coastline. Average annual sea surface temperatures have warmed between 0.6 to 1.4°C per century across the coast of BC [10]. This rate is similar to the global average of 1.1°C per century [10,32], although there is significant variation along the BC coast in that some areas have warmed by up to 2.2°C per century (e.g. Strait of Georgia, Entrance Island) [10].

In BC waters, recent sea surface temperature trends have been the result of the interaction of three things: climate change warming, El Niño effects (2015-2016), and the ‘warm blob’ phenomenon (2013-2016) where a large area of very warm water (3°C warmer than usual) settled off the BC coast [13,45]. In 2016, average sea surface temperatures were 1-2°C warmer than the historical average within the Northeastern Pacific Ocean [11]. The average daily sea surface temperature anomaly was higher in 2016 according to both lighthouse station data (0.98°C ± 0.33°C) and weather buoy data (0.7°C average) as compared to the 22-year historical average (1989-2010), which reflects the long term warming trend [11].

Ocean acidification

Ocean acidification is caused by the dissolution of atmospheric carbon dioxide into the oceans, which results in a decrease in seawater pH and increased acidity [46]. Since the pre-industrial era, the oceans have absorbed approximately one-third of human produced carbon dioxide emissions, resulting in an increase in acidity of more than 26%, the lowest levels in 20 million years [46–49]. The impacts of acidification on marine ecosystems are complex and serious, especially for calcareous and planktonic organisms as it impacts the ability of those organisms to produce and maintain their calcium carbonate shell structures [46,50] as well as potentially increases metabolic stress.

In the Northeastern Pacific Ocean, ocean acidification is one of the most urgent threats to both marine ecosystems and human communities. These waters are already among the most acidic of the world's ocean regions, due to ocean currents and upwelling of deep ocean waters [5,51,52]. Upwelling waters already have relatively low pH, and organic matter production driven by upwelling currents further lowers the pH of those waters by remineralization.

Ocean deoxygenation

Globally, dissolved oxygen levels in the ocean have been declining for more than two decades [53]. Declining ocean oxygen levels (hypoxia) is linked with both ocean warming and changing ocean currents, as well as excessive nutrients leading to eutrophication and organic matter decomposition. Oxygen is also less soluble in warmer water, which combined with thermal stratification is predicted to lead to ocean de-oxygenation globally [54]. In the Pacific Ocean, dissolved oxygen levels have been declining over at least the past several decades, at a range of depths from 100-1000m deep down to the sea floor, and oxygen levels between 100-400m depth have decreased by 22% over the past 50 years [5].

Sea surface salinity

Empirical data from lighthouse station monitoring stations in 2016 reflect a long-term trend towards decreasing sea surface salinity (SSS) across the BC coast, except within the Strait of Georgia (Chandler 2017). Longer term data from lighthouse station monitoring shows the same freshening trend; however, this is not associated with longer term climate trends, but with local freshwater sources [55].

OBSERVED CLIMATE ASSOCIATED IMPACTS

Climate change trends have in turn affected coastal ecosystems in BC. As of 2017, some observed impacts that may be associated with climate change trends include both general and specific examples:

Ecosystems

Changing ocean temperatures affect marine species, ecosystems, and the human communities and economic sectors that depend on marine resources. Warming ocean temperatures have been observed with associated impacts on the marine ecosystem and fish, for the past several decades [56]. Increasing sea surface temperatures and declining oxygen levels have affected the northern Pacific Ocean, which has likely led to reduced habitat availability and decreased survival for many fishes and invertebrates [57].

Harmful algae blooms during the 2015 'warm blob' event could also be associated with climate warming [58]. During that event, warm water zooplankton were much more abundant than cold water species in 2016. Changing zooplankton species has potential implications for fish, as warm water zooplankton species have lower nutrient quality [58]. Other unusual biological events during that anomalously warm water period included low chlorophyll levels (2014), potentially due to increased stratification and reduced nutrients [59]. This mass of abnormally warm water has since dissipated (in 2016) [11].

Abnormal warm water species sightings that could indicate dramatic species range shifts include sightings of ocean sunfish and warm water sharks off Washington State and Alaska, high catches of albacore tuna off the Washington and Oregon coasts, juvenile pompano sightings near the Columbia River, and widespread stranding of *Velella velella* off the coast of BC throughout the summer of 2014 [13].

The physical oceanographic impact of increased ocean temperature has had substantial impacts on the marine ecosystem, suggesting that long-term climate warming may have analogous ecosystem responses [13].

- The 'Warm Blob' (2014-2016), a mass of water characterized by water temperatures from 1-3°C above the 30-year average, developed off the west coast of BC, affecting phytoplankton community composition, ocean stratification, and associated with abnormal and dramatic species range shifts [13].
- An abnormal algae bloom was observed in the Strait of Georgia in 2016, possibly in response to long term climate warming [11].
- Warm ocean temperatures have affected the waters off the west coast of Vancouver Island, and the zooplankton community has shifted to more gelatinous species (overall lower nutrient food) and less crustaceans, leading to poor forage conditions for juvenile fish and seabirds [60].

Village Island / Photo by Scott Harris

Haida Gwaii, British Columbia, Canada / Photo by Matthew Justice

Fisheries

Fisheries catches and landed values have declined since the 1990s in BC [56]. A warming trend in sea surface temperatures was detectable even several decades ago [56]. In southern BC, the impacts of warming freshwater and marine water temperatures have been observed, leading to declining fish productivity and diminished returns of Fraser River sockeye salmon [25]. Ocean acidification has been observed in BC, especially along the south coast [61–63]. Increasing rates of acidification are likely to negatively affect calcifying organisms, many of which are important for aquaculture and traditional food resources, including molluscs, bivalves, sea urchins, and sea cucumbers. While observations and field evidence are still limited, the interacting effects of ocean temperature and acidification is of critical concern for many taxa (e.g. molluscs, corals, calcareous algae).

- Warm sea surface temperatures have been observed, along with warm water associated species shifting north into BC waters [13].
- Ocean acidification has affected calcifying organisms, especially larval survival (e.g. Strait of Georgia [61–63]).
- Warm ocean temperatures, combined with summer drought, have created unfavorable conditions for salmonids. Low returns of Fraser River sockeye salmon have been observed (e.g. returns in 2016 were the lowest on record) [64]. Fraser River sockeye were recently recommended for listing with the Species at Risk Act [65].
- Melting glaciers across BC may be releasing historical pollutants into freshwater ecosystems, thus affecting freshwater fish and downstream marine areas [66].

Human Communities

- Energy demands for heating have declined for buildings across BC, especially in northern BC, as average air temperatures have increased [10].
- Increasing storm surge events have been observed along the BC coast, along with an increasing frequency of ‘king tide’ events.
- First Nations cultural sites may be impacted by rising sea levels, storm surge, and king tide events. For example, cultural sites near Prince Rupert and Metlakatla are experiencing erosion and loss of cultural artifacts (A. Paul, pers. comm., November 24, 2017).
- First Nations communities have observed changes to seasonality of local food gathering practices [67].

Clam shucking / Photo by Scott Harris

Marine infrastructure

- Increasing sea levels may be affecting coastal built infrastructure [68,69].
- Increasing frequency and intensity of storm events may affect marine infrastructure (at sea and near-shore) [25].

REGIONAL CLIMATE CHANGE PROJECTIONS

This section describes the current state of knowledge of climate change projections which are likely to affect the MaPP region and four key sectors of interest: ecosystems, human communities and First Nations, fisheries and aquaculture, and marine infrastructure. However, ecosystems are not subject to management boundaries or lines on a map. Anticipated climate changes and associated impacts are more clearly understood at large scales than within the context of a relatively small area such as the MaPP region. The current understanding of climate change projections and associated impacts at the scale of the BC coast and the MaPP region are somewhat uncertain.

In subsequent sections, and where possible, sub-regional differences are identified within the greater MaPP region. Projected climate changes and impacts are also linked with points of vulnerability for those sectors, opportunities for further research based on knowledge gaps, and recommendations for adaptation actions that may alleviate the severity of these impacts. Information on projected impacts and sectoral vulnerabilities, where known, are included (see Maps, Tables).

Air temperature

British Columbia is expected to experience more warming than the global average [70,71]. Even though air temperature is moderated by the ocean, air temperatures are projected to increase by 1.8°C by the 2050s and 2.7°C by the 2080s, and could reach of 3-5°C by the end of the 21st century if emissions continue at current rates [70–72]. On average, air temperatures are likely to increase by 0.1-0.6°C per decade [73].

The summer growing season is projected to lengthen and frost-free days to increase by 20-30 days by 2050-2080 [73] (see MaPP region Summary Table). Winter minimum temperatures across BC may increase by 4-9°C by 2080, and summer maximum temperatures may increase by 3-4°C [70,73].

Precipitation

Projected changes in precipitation in BC are expected to be relatively minor, especially when compared to the historical variability in the province. The Pacific Climate Impacts Consortium (PCIC) projections show that annual precipitation may increase by about 9% by the end of the 21st century, relative to the 1961-1990 baseline (see MaPP region Summary Table), while summer precipitation is projected to decrease by 10% [27,28].

Wetter winters are projected to lead to increased runoff in rivers and streams in the winter. Less precipitation will fall as snow in the winter, which is likely to result in a reduction of the spring snowpack by 55% by 2050 [41]. Glacial runoff in the spring has already declined in southern BC, and this is projected to occur for northern BC glaciers through 2050 and beyond [10,42]. Due to this reduction in snowpack, the spring freshet will likely occur earlier in the spring in many rivers. By the end of the century, spring streamflow will likely have increased significantly, while summer river levels will have decreased [44].

Extreme precipitation events will likely increase during some seasons and in some areas of the province [5,41,70,72]. Heavy precipitation events in BC include phenomena known as ‘atmospheric rivers’ where highly concentrated water vapour streams move moisture from tropical regions towards the poles. These occur frequently in the fall and winter in BC, and impact coastal areas with periods of intense precipitation and flood events [41,70,74]. More frequent atmospheric river events after 2040 (approximately double the current number per year) will affect ecosystems along the coast [74].

Sea level rise

Global climate models project that the average global sea level will rise by up to 100-120cm by 2100 [10]. The rate of sea level rise will vary, depending on variations in ocean temperature increase and ocean current patterns. Relative sea level across the coast of BC is projected to rise by an average of 20-30 cm by 2100 (90% confidence interval of 10-50 cm) (MaPP regional table).

However, there are many uncertainties in the projections for sea level rise. Localized ocean currents, tidal patterns, and river discharge rates will also influence the observed rate of sea level rise to particular areas. For instance, some models project higher observed sea surface height (SSH) values along the northern coast of BC during the next century in winter and spring related to wind patterns and increasing river discharge [21].

Sea surface temperature

Warming ocean temperatures will affect ecosystems and species across the world and within this region. In BC, sea surface temperatures are likely to increase by between 0.5°C to 2.0°C by the end of the century (2065-2078, relative to a 1995-2008 baseline) ([21]; see MaPP Regional Table; Maps). The rate of ocean temperature increase may accelerate, as consistent with the accelerating rise in global sea surface temperatures [14,75].

Ocean acidification

Ocean acidification is occurring faster as higher latitude areas, due to the effects of temperature on carbon dioxide absorption [76–78]). Globally, ocean acidification is projected to increase by 100% or more by 2100, but there is large uncertainty and variation among regions and climate scenarios [32,52,79]. Within the MaPP region, acidification is projected to continue to increase as carbon dioxide emissions continue to rise. Average pH levels could decline to between 7.69-7.96 (RCP8.5 and RCP2.6, respectively) by 2091-2100 [32,80].

Ocean deoxygenation

Ocean oxygen concentrations have been declining in both pelagic (open ocean) and coastal waters for at least the past half-century [81]. Oxygen minimum zones in the open ocean have increased in area, and some coastal areas have low enough oxygen concentrations that marine species distributions and abundances have been affected [81]. Oxygen levels are likely to continue to decline in the northeast Pacific ocean, and coastal shelf and slope marine ecosystems are likely to lose well oxygenated habitats [57]. Seafloor habitats in the North Pacific could experience a reduction of 0.7-3.7% in oxygen levels by 2100 [54].

Sea surface salinity

Ocean salinity is declining globally, along the BC coast, and within the MaPP region [82]. Freshwater discharge from glaciers is a significant contributor to the nearshore waters of BC. Coastal runoff contributes to maintaining the salinity levels along the coast, driven by glaciers, as well as watersheds driven by fall and winter seasonal precipitation. Large river systems (Fraser River, Naas River, Skeena River) also drain large watersheds and experience pronounced spring freshets. Coastal salinity levels are controlled mainly by these processes at the local scale rather than large-scale climate changes [55]. Salinity effects also influence total sea level rise through ocean expansion through global ocean warming [32,83,84].

Extreme weather events

Changes in wind and wave patterns may interact with other climate change projections such as sea level rise, but the projections of future winds and storm events are highly uncertain [36]. Storm intensities in the North Pacific increased during 1940-1998, and storm surge related winds and storms may become more frequent and intense as air and ocean temperatures increase [44,85].

Photo by Birgitte Bartlett

ESTIMATED REGIONAL IMPACTS ASSOCIATED WITH CLIMATE CHANGE PROJECTIONS

Given the increasing rate of carbon emissions and the marginal success of global mitigation efforts, even higher rates of climate changes are expected in the future. Indeed, many of the impacts of climate change, including sea level rise, ocean temperature, and ocean acidification are likely to be worse than current projections [72]. Information on climate change projections, sectoral impacts, associated vulnerabilities and risks, and potential adaptation actions aim to inform policies that will ensure resilient communities and regions. A critical part of this process, therefore, is to include information on the social and economic status of the regions and communities. For example, information on climate change effects on the fisheries sector would be more meaningful if human dependencies on the fisheries sector is also known and included in vulnerability and risk analyses and recommendations of adaptation actions.

In the MaPP region, there is limited information on vulnerability and risk of predicted climate changes for human communities and sectors. While there is some information on exposure to climate impacts, data on adaptive capacity and sensitivity are largely not available across the region at this time. As such, based on the available literature and ongoing research, we comment on predicted climate change impacts from the climate change projections described in the previous section, and on probable exposure and risk to four key sectors: ecosystems, First Nations and non-First Nations communities, fisheries and aquaculture, and marine infrastructure. This information is provided at the MaPP regional scale and, where possible, further details are provided at the sub-regional scale. The MaPP regional level information is always relevant for the sub-regions, just at a coarse scale due to the quality of available data.

ECOSYSTEMS

Climate change will affect ecosystems throughout the region. The vulnerability of marine species to the cumulative effects of climate change depends on intrinsic adaptive capacities and sensitivities (based on biological or ecological traits), and extrinsic threats (impacts), such as increasing sea surface temperature or ocean acidification [86]. The cumulative effects of climate change on the food webs of the northeast Pacific may lead to a 30% reduction in total ecosystem biomass [17].

Air temperature and precipitation

Air temperatures are projected to increase at 0.3°C per decade in BC [72], still less than is expected across the country as a whole [43]. Melting glaciers will result in higher spring time water discharge into streams and rivers in the short term, while over time glacial retreat will likely lead to reduced water levels in glacier-fed streams, particularly during summer [10].

Due to the reduction in snowpack associated with decreased winter precipitation and warmer air temperatures, the spring runoff (freshet) will likely occur earlier in the spring in many rivers. This will have downstream effects on freshwater habitats, and linked marine systems [10,21], which will already be warmer and less oxygenated. These changes are likely to negatively impact the reproductive capacity and survival of fish and other aquatic species [6,87]. The sheer increase in freshwater volume entering coastal marine waters will also affect salinity and stratification of ocean surface waters.

Increased precipitation may lead to more runoff of contaminants and terrestrially derived nutrients - which, when combined with higher water temperatures, could increase the likelihood of toxic algae blooms in freshwater and marine ecosystems [29]. The increase in freshwater volume entering coastal marine waters may also decrease sea surface salinity and of ocean surface stratification. These stressors are likely to affect marine fishes and mammals that depend on nearshore habitats and are adapted to current oceanographic conditions [29].

Sea level rise

Sea level rise may affect coastal ecosystems through changes to habitat, especially for nearshore areas if important intertidal habitat becomes permanently sub-tidal, affecting nearshore plants, algae, and shellfish. Sea level rise is likely to cause an increase in the inland penetration of salt water in tidal systems. The abundance and species composition of coastal plants and algae, along with associated invertebrate habitats, could be altered if important intertidal habitat becomes permanently sub-tidal as sea levels rise [29].

Generally, coastal sensitivity to sea level rise depends on the physical geology of the coastline, and as such low-lying sandy regions will be most impacted. Most of the shoreline of BC has low sensitivity to sea level rise due to the rocky, fjordal coastline, but some areas (near Prince Rupert, Bella Bella, and most of Vancouver Island) are moderately sensitive (based on a recent provincial shoreline sensitivity analysis; [23]). Highly sensitive areas within the MaPP region include the northeast corner of Haida Gwaii [9,44]. For both the MaPP region and sub-regions, some moderate and high sensitive areas correspond with culturally important (First Nations) archaeological sites (see Map Section: Archaeological Sites Sensitive to Sea Level Rise Map, MaPP Region).

Sea surface temperature

Increasing sea surface temperatures are likely to affect zooplankton biomass, contributing to overall biomass declines of lower trophic level species [29]. Increasing ocean temperature and the northerly shift in the California Current may lead to higher abundance of low nutrient zooplankton, which would in turn affect juvenile fish species such as herring and salmonids [60,88]. Phytoplankton species composition is also likely to change, which could also affect higher trophic levels who depend on high quality zooplankton [17,58,60,89]. Kelps (giant kelp and bull kelp) and eelgrass (*Zostera marina*) are also likely to be negatively affected by warming sea surface temperatures; the cumulative impact of temperature along with decreasing salinity and increasing sedimentation from runoff will influence the productivity and distribution of these important habitat forming species [6].

OCEAN ACIDIFICATION

Ocean acidification will certainly continue to affect coastal BC [52], although there are significant knowledge gaps in terms of the effects of ocean acidification on marine organisms (Appendix 2 Table 2). Where data exist, it is more reliable for commercially viable shellfish species (e.g. oysters and other shellfish) and issues that may affect human health (e.g. harmful algae blooms) [52]. Already, the ocean below 300m depth is corrosive to aragonite shells, and it is likely that the saturation depth will continue to decrease, threatening shelled organisms and the fishes that feed on them, including Pacific salmon [4,52]. There is a strong likelihood that the negative impacts associated with ocean acidification could increase rapidly, and that the effects on marine species could potentially cause large shifts in species distribution and community assemblages across both latitude and depth [54].

Ocean acidification may affect habitat availability and the abundance of those species dependent upon calcifying organisms for structural habitats, and those whose larval stage is affected by a decrease in pH. For example, by 2100, cold water corals are projected to degrade due to ocean acidification, which will affect habitat availability for fish populations, therefore affecting fisheries productivity [54]. The effects of ocean acidification on trophic dynamics (food web interactions) and the synergistic effects of ocean acidification with other climate change projections, such as increasing ocean temperature and declining oxygen levels, are uncertain and requires further research [52,63].

Ocean deoxygenation

The expansion of low oxygen zones will affect ecosystem structure and function, especially in the deep sea [54], and in the deep coastal fjords of the northern coast of BC due to their geomorphological and chemical conditions [5]. The effects of warming temperatures are likely to combine with those of deoxygenation, resulting in further habitat contraction for fish and other marine species. Deoxygenation at deeper depths may drive mobile marine species to seek refuge in shallow water; yet those habitats will be more likely to be too warm. The interaction of these impacts may result in physiological stress or challenging species interactions such as predation. The combination of warming temperatures in shallow depths and deoxygenation at deeper depths may lead to habitat compression, unless species can adapt by migrating along continental slopes into more oxygenated environments, where they exist [54].

Sea surface salinity

Changes in salinity can affect both sexual reproduction and vegetative propagation of seagrasses [29,90]. Declining salinity levels may affect the habitat, survival, and growth of marine fish and shellfish; in the Arctic, declining salinity has been shown to reduce phytoplankton size, which in turn affects productivity of higher trophic levels [54].

Other impacts

Changes in the timing of spring currents is also likely to affect biological interactions such as plankton availability, in turn affecting larval fish and invertebrates [29]. These changes could negatively affect marine fish and invertebrate recruitment, but the specifics of this impact are currently unknown [29].

Zostera sea grass / Photo by Joanna Smith

Photo by Allan Bolton

FISHERIES AND AQUACULTURE

Fisheries and aquaculture are an especially important sector for coastal communities and First Nations. For many, fishing is a way of life which cannot be measured by the contribution to the economy alone, as the social and cultural values play a large role. Existing stresses and impacts on BC's coastal fisheries are expected to be exacerbated by climate change, and in some cases (such as salmon), these impacts are already evident. The fishing industry has already declined significantly across the province: since the 1980s, the fishing fleet has shrunk by 60% and there are 70% fewer fishers employed in the industry [91]. The effects of climate change on fisheries in this region are reflected in projected species range shifts, in that the abundance of current target species is projected to decrease, and that the species currently available across the region are likely to change [12,17,92,93]. The impacts of these projected changes in fisheries catches could lead to or amplify other socio-economic impacts of climate change on fisheries and communities through reduced food security and economic loss [92].

Sea level rise

The associated impacts of sea level rise on land erosion and increased runoff is likely to directly affect nearshore species, especially filter feeders (shellfish) if water quality declines. Existing shellfish beds are likely to be affected, which will have implications for many species which depend upon the intertidal ecosystem for habitat and food, especially as juveniles (salmon, crab, eelgrass, algae, clams, humans) [94]. Spawning habitat for forage fish, and rearing habitats for invertebrates, could decrease or be lost due to erosion, subsidence, and submersion due to sea level rise [29]. This may be particularly problematic for Pacific herring,

as that species prefers coastal marine algal species for spawning substrate, habitats that may potentially be lost as sea levels rise [29].

Sea surface temperature

Fisheries responses to climate change impacts will vary both regionally and by species [25]. Species particularly vulnerable to increasing ocean temperatures include Pacific salmonids [95–98]. For example, there is a 17-98% chance of 'catastrophic' loss of a Chinook salmon population by 2100, depending on the emissions scenario [95]. Many fish species may expand their range northward (at an average rate of 10-18 km/decade), and in many cases their abundance may decline precipitously [17,25,92]. These impacts are more severe at southern latitudes, so that the relative catch potential is projected to decline more in the North Coast, Haida Gwaii, and Central Coast than southern BC waters [92]. Invasive species are also likely to move north: exotic fish species from sub-tropical and tropical waters have already been observed in BC coastal waters during warm El Niño events and during the 'warm blob' anomaly [13,25].

Pelagic fisheries that may be especially affected by increasing sea surface temperature include Pacific herring, Pacific sardine, and Pacific salmon [29,92]. Warming ocean surface temperatures will also likely decrease the habitable range of sessile species such as shellfish, which are less likely to be able to move northward at the rate of climate change. However, species' responses to climate change will also depend on species-specific adaptive capacity and sensitivity; assessing species specific responses to climate change is highly limited by the lack of data on species traits and potential adaptive responses [86].

Ocean acidification

The effects of ocean acidification on fisheries are largely unknown, including on the important salmon and Pacific halibut fisheries [27,43; Appendix Table 2]. In tropical fish, ocean acidification affects behaviour and results in increased mortality, but species responses in temperate regions are unknown [52]. Adult fish may be more tolerant of ocean acidification than early development stages, but there is limited research on life stage specific responses to pH for BC fishes specifically [52].

The effects of ocean acidification on shelled organisms, however, are much more understood ([52,99–101]. Aquaculture has the potential to improve food security and support remote economies. Across BC, capture fisheries landings are either in decline or somewhat stable, while aquaculture continues to grow (with some exceptions due to recent ocean acidification issues, e.g. Strait of Georgia, [102]). In the MaPP region, aquaculture is of great interest to coastal communities and First Nations. Currently, aquaculture operations in BC focus on salmon and other finfish, as well as shellfish including oysters and geoduck clams. Ocean acidification is likely to negatively affect shellfish aquaculture [99], and changes to oceanographic

conditions including acidification are likely to affect finfish aquaculture as well [52]. The specific effects of ocean acidification on shelled molluscs varies by species, and a recent review suggested that acidification most negatively affects survival and shell growth (calcification), followed by respiration and clearance rates [99].

Ocean deoxygenation

Ocean deoxygenation will affect commercial fish species by reducing high quality fish habitat. Declining oxygen levels across the Pacific Ocean will contribute to the general decline and potential collapse of sessile (immobile) marine species, or sediment-dwelling organisms, as well as any other species who are intolerant of low oxygen levels. Declining oxygen levels are likely to especially affect groundfish species, whose habitat seems to already be decreasing by 2-3m per year, potentially related to declining oxygen levels [4]. Declining oxygen levels, and increasing hypoxia, will also likely affect aquaculture operations for vulnerable species, such as Dungeness crab and spot prawns [29]. Some hypoxia tolerant species (e.g. squid, jellyfish) may increase in abundance and/or distribution, potentially outcompeting less tolerant species (e.g. finfish) [54,77].

Photo by Birgitte Bartlett

Hartley Bay, British Columbia, Canada | Photo by Erin Mutrie

HUMAN COMMUNITIES

Coastal First Nations and non-First Nations communities depend on the ocean and nearshore environments for economic, social, and cultural values. The coastal economy of British Columbia is largely based on the recreational tourism (33%), transport (29%), and seafood (12%) sectors [91,103]. Climate change will affect the coastal communities of the MaPP region through increased air temperature, changing precipitation patterns, accelerated sea level rise and the increased incidence of extreme weather events, such as storm surge related flooding, increased rates of coastal erosion, freshwater contamination from seawater inundation, and a suite of ecological changes associated with other climate changes. These communities are at risk for land loss, damage to coastal infrastructure, and changes to resource availability, all of which will affect economic, social, and cultural historical values [25].

Climate change impacts are likely to continue to unevenly affect communities along the coast due to different exposures to those impacts. An added dynamic is that any climate related impact has a cumulative effect on non-climatic issues already affecting these communities, such as declining resource industries, economic or social restructuring, and ongoing land claims agreements in the case of First Nations communities. In general, rural and remote communities in BC tend to have a lower socio-economic index, which is indicative of economic hardship, education, health, and other risk factors. These trends are indicative of community vulnerability, and low rankings in those social indicators suggests low adaptive capacity to manage large stressors like climate change [91].

Especially for First Nations communities, access and availability of traditional foods has decreased as ecosystems have been exploited or converted to other uses, and the productivity of remaining intact ecosystems has been impacted by factors including pollution, management actions, or invasive species. An example of an observed impact of climate change on community food security is the changing timing of wild plant ripening and harvest [67,94].

Air temperature and precipitation

Increasing air temperatures mean that winter heating requirements are likely to continue to decrease across the province, while summer cooling requirements and costs will increase [10]. In some cases, increasing summer temperatures may negatively impact communities through mortality linked to heat stress. Most homes along the BC coast lack air conditioning, and it is likely that increasing air temperatures, especially during extremely high temperature events, will lead to greater incidence of heat stroke and potential mortality [104]. However, increasing air temperatures may attract more tourism for a longer summer season, which will have positive economic implications for coastal communities.

Sea level rise

Sea level rise will not affect areas along the BC coast equally due to differences in vertical land movement [105]. Observed sea level rise is also affected by local and regional contributions, including melting glaciers and ice sheets, water volume changes due to temperature and salinity effects, and vertical land changes from glacial rebound, tectonic processes, and compaction (land sinking) [44]. Most of the north coast of British Columbia is steep and rocky, and therefore is less likely to be impacted by sea level

rise. Notable exceptions include the northeastern coast of Graham Island, Haida Gwaii, an area which is amongst Canada's most sensitive coastlines to climate change [25].

Many remote coastal communities and First Nations' heritage sites are vulnerable to enhanced erosion and storm-surge flooding associated with sea-level rise (See Regional Map: Archaeological sites sensitive to sea level rise). In addition, groundwater quality could decline due to saltwater intrusion as sea levels rise [25].

Sea surface temperature

Increasing ocean temperatures will impact coastal communities that are reliant on fisheries and other marine species for food security and economic activities. Many species that are currently important to coastal communities (First Nations and non-First Nations) are projected to shift northwards from their current species range (at rates of 10-18 km/decade) and also decline in relative abundance (up to ~40% declines, depending on the species and climate scenario) [92].

Ocean acidification

Ocean acidification will impact coastal communities that are directly dependent on calcareous organisms such as shellfish for food and income [52]. Acidification will also affect fisheries through negative impacts on food web dynamics and lower trophic level organisms [94]. Shellfish are likely to be affected across life stages, and this decline in economically important species (oysters, scallops, abalone, mussels) will affect the economies of coastal communities in the region. Decreased access to these traditional foods also has implications for human health and culture [106].

Winds, waves, and extreme weather

While the impacts from sea level rise combined with extreme events and storm surge are projected to be highly problematic for the region, especially in low-lying areas, little is known about the interactions of extreme weather events and climate impacts along the BC coast [107] and thus within the MaPP region. Regional models of sea level rise and seasonal climatic variability patterns would improve the ability of coastal managers to predict flood hazards and associated risk factors for the region and sub-regions.

Klemtu – Swindle Island, British Columbia, Canada | Photo by Doug Neasloss

MARINE INFRASTRUCTURE

BC has three major international ports, four regional ports, and 40 local harbours [74]. Within the MaPP region, Prince Rupert is the largest port with the capacity for shipping infrastructure and container ships.

Most communities within the MaPP region are highly dependent on marine infrastructure for transportation of goods and services; as support for the fishery and aquaculture industries; and for providing connections with other essential infrastructure and utilities such as roads, sewage systems, power and communications cables. The greatest threats to marine infrastructure in the MaPP region are likely to be sea level rise and increasing extreme weather events.

Sea level rise

Sea level rise already threatens coastal infrastructure, and the added risk of storm surge flooding increases the vulnerability of coastal infrastructure across the province [27,74]. Sea level rise is expected to inundate some of the critical infrastructure at the coastal areas. Some communities in BC have begun to take action to reduce the risk of sea level rise through investments in built infrastructure for shoreline protection as an adaptation measure [27]. Further adaptation examples can be found in urban areas near the Fraser River floodplain, an area that is highly vulnerable to sea level rise due to low lying geology and dense population.

A recent analysis found that the costs of sea level related damage to on-shore built infrastructure would be higher in coastal BC than any other coastal region in Canada [108].

Winds, waves, and extreme weather

Across the MaPP region, increasing intensity and frequency of storms is likely to increase inundation risk (flooding) and erosion risk to marine infrastructure, especially for low lying communities [109]. Properties along the coast also will experience increased risk of wave damage, which is associated with coastal erosion. It is highly likely that climate changes, especially during El Niño events, will lead to high coastal erosion across the entire eastern Pacific region [109].

Extreme weather events are expected to create disruptions to marine transportation lanes, potentially lead to wave and wind damage to infrastructure and utilities, and reduce access to critical services [110]. Extreme precipitation events in particular may damage fixed coastal infrastructure such as airports (e.g. Sandspit Airport on Haida Gwaii), and ports (e.g. Port of Prince Rupert), and well as affect marine transportation lanes [74,110]. Overall, climate-related impacts to marine infrastructure are likely to be higher than anticipated, as many communities in coastal BC already have infrastructure deficits that will require increased investment [91,103]. Future winter and spring sea surface height (SSH) levels are also projected to be consistently higher, which will further exacerbate the flooding impacts of sea level rise [21]. Large peak flows and storms can interrupt delivery of goods such as fuel and food to remote places. On the other hand, climate change may also offer some opportunities for the marine transportation sector: longer construction seasons and reduced winter maintenance could reduce costs and increase annual operating budgets. In the longer term, increased sea levels may mean that vessels with deeper draughts will be able to enter existing ports, perhaps an opportunity for marine shipping [110].

SUB-REGIONAL PROJECTIONS AND IMPACTS

The previous section included climate change projections and impacts at the scale of the BC coast and MaPP region. Here, we include additional projections and impacts that are specific to MaPP sub-regions, while emphasizing that all regional level projections and impacts are still relevant at the sub-regional level. Please reference the sub-regional tables for further details on sub-regional projections and sectoral impacts. Note that for many climate change variables, sub-regional resolution (finer scale) information is lacking or inconsistent (see section on knowledge gaps and recommendations).

NORTH VANCOUVER ISLAND

Air temperatures on the north portion of Vancouver Island are expected to increase by 2050 to the same range as currently experienced in Vancouver [10,42], which reflects approximately 1.4°C warming relative to a 1960s-1990 baseline. Increasing air temperatures threaten fisheries and aquaculture through associated ocean warming which is likely to affect seasonality of traditional food resources as the summer season extends and frost-free days increase. There are potential benefits to tourism, an important sector in this sub-region, as the summer season lengthens and becomes warmer and more appealing.

Winter precipitation is predicted to increase in this sub-region, leading to increasing spring freshwater discharge that will also contribute to stronger flows in Queen Charlotte Sound [21,42,73]. Increased precipitation and stream discharge will increase flood risk to communities, while decreased summer precipitation will increase drought potential in summer months. Tourism may benefit as summer precipitation levels decrease, potentially attracting foreign visitors to outdoor recreation opportunities. However, winter snowfall is likely to decrease by as much as 33%, which could affect winter tourism and recreation.

Sea level rise projections are quite uncertain at the scale of MaPP sub-regions. Sea level rise will potentially not impact this sub-region as much as other sub-regions. By 2100, sea levels are projected to increase by approximately 14cm (range of 4.5 - 32.4cm), but may rise as much as 0.6m to 0.9m [21,44]. Rising sea levels are likely to impact the extensive aquaculture infrastructure in this region (finfish and shellfish), and producers will likely have to adjust the locations of some of their nearshore facilities. Commercial forestry, fisheries, and marine shipping sectors should take sea level rise projections (see North Vancouver Island Sea Level Rise maps) into consideration when planning future processing sites and harbor infrastructure. Commercial tourism facilities such as fishing lodges and marinas will also have to adjust their docks and other near-shore infrastructure to account for rising sea levels and increased storm surge events.

Sea surface temperatures will likely increase, and salinity will likely continue to decrease across the coastline and within this sub-region [55,82]. Average sea surface temperature is projected to increase on average by 1.8°C by the end of the century compared to 1961-1990 baseline [21,22]. Sea surface salinity will decline by ~1% to ~3% with by the end of the century 1961-1990 baseline as the ocean freshens with increased precipitation, terrestrial runoff, and melting glaciers [21,36]. Increasing sea surface temperatures will threaten fisheries productivity, especially for finfish which are sensitive to temperature, and lead to shifts in marine species distribution [92]. Rising temperatures and changing species distributions and abundance is likely to affect marine based food security for local communities. The commercial fishing industry is likely to continue to experience declining catch, particularly for temperature sensitive species such as salmon ([92,96,111]; Appendix 2 Table 1), and the extensive finfish aquaculture in this sub-region may also be affected .

Photo by Ryan Miller

Changes in ocean properties are also expected for the North Vancouver Island region. Ocean acidification is projected to continue, and average projections suggest that that ocean pH will fall to ~7.95 pH -7.68 pH under the IPCC high emissions scenario (RCP 8.5) by 2100 [32].

Some specific impacts at the scale of the North Vancouver Island sub-region are related to sea level rise and extreme weather events. There are numerous cultural and historic sites that may be particularly sensitive to rising sea levels based on recent shoreline sensitivity analyses (see North Vancouver Island Regional Shoreline Sensitivity Map). In particular, lower elevation foreshore or nearshore areas throughout the area are more likely to experience flooding and erosion.

Klemtu | Photo by Charles Short

Cape Caution, British Columbia, Canada / Photo by Scott Harris

CENTRAL COAST

Annual air temperatures in the Central Coast sub-region are expected to increase by approximately 1.6°C by 2050, which is similar to the current temperatures experienced in Vancouver [10,36,42] (see Central Coast Sub-regional Table). Summer precipitation is also predicted to increase in this sub-region, leading to increasing freshwater discharge will also contribute to stronger flows in Hecate Strait [21,42,73].

Changing precipitation patterns means that streamflow patterns are likely to change, such that summer stream flow is lower, with associated impacts to salmon and other anadromous or freshwater fish. It is possible that low flow conditions within the watershed could occur over the entire year, though generally they are likely to occur during the late fall and early winter. Within the context of future climate changes and related vulnerabilities of freshwater habitats, changes in the frequency, timing, and magnitude of such low flow conditions may have greater effects on salmon migration, spawning, and incubation than at present.

Sea levels are projected to increase within the Central Coast sub-region, but not as much as other sub-regions. Some specific impacts at the scale of the Central Coast sub-region are due to sea level rise and extreme weather events. Sea levels near Bella Bella are projected to rise by approximately 9 cm by 2100 (range -5.4 to 22 cm) (Thomson et al. 2008). However, localized land uplifting (+2.3mm per year) means that overall, the Central Coast sub-region is not likely to experience net negative impacts from sea level rise in the foreseeable future [44].

There are some cultural and historic sites that may be particularly likely to be affected by rising sea levels based on recent shoreline sensitivity analyses and locations of historic First Nations sites (see Central Coast Archaeological Sites Shoreline Sensitivity Map).

Sea surface temperatures are expected to increase by ~1.9°C by the latter portion of the century, with impacts to fisheries and communities through loss of fisheries landings and adjustments in fishery target species. Ocean acidification will increase, affecting calcifying organisms and the aquaculture industry. These changes will likely affect coastal communities, especially First Nations communities who rely on bivalves and other shellfish for food security and income.

NORTH COAST

Air temperatures in the North Coast region are projected to increase by up to 2.6°C by 2080, and the sub-region will experience more growing degree days, more frost free days, and higher winter minimum temperatures [73] (see North Coast Sub-regional Table). Rising temperatures will potentially decrease energy requirements for heating in the winter months, and potentially increase energy requirements for cooling in the summer months. Precipitation is projected to increase in the North Coast region by up to 20% in summer months, and by 10-25% in winter [73]. The increase in freshwater volume entering marine waters in this sub-region is likely to be greater than in other sub-regions due to large rivers, including the Skeena River, feeding into the marine area. This increase in freshwater volume will affect marine temperature, salinity, and stratification of nearshore surface layers[29,55]. Increasing freshwater discharge will also contribute to stronger flows in Dixon Entrance [21].

Relative sea level rise is projected to rise the most in the North Coast sub-region, specifically off Prince Rupert Harbour. Mean sea level rise projections for the port of Prince Rupert by 2100 suggest that sea levels will increase by approximately 25cm (range 13.2 - 37cm) with extremely high projections reaching 0.95-1.16m [6,44,68]. Sea level rise impacts are likely to be much higher for the North Coast when compared to southern BC, due partially to increasing precipitation in this sub-region [41,44,73].

Increasing sea levels and high water events are linked to beach erosion in this region; this impact has already been observed over the past two decades [107]. Models based on highest sea level events over the past century project that the frequency of storm-related high water events are likely to increase at twice the rate of the relative mean sea level trend for Prince Rupert, and the frequency of storm winds are also likely to significantly increase [107]. These projections will likely affect coastal communities through changes to food security,

Given the relationships among the PDO, ENSO, and low river flows, it is likely that climate-induced changes to hydrology will also occur in North Coast watersheds. Low flow conditions within the watershed can occur over the entire year, though generally are more prevalent during the late fall and early winter after summer drought. Within the context of future climate changes and related vulnerabilities of freshwater habitats, changes in the frequency, timing, and magnitude of such low flow conditions may have greater effects on salmon migration, spawning, and incubation than at present [41,112].

There are some cultural and historic sites that may be particularly likely to be affected by rising sea levels based on a recent shoreline sensitivity analysis overlaid with locations of historic First Nations sites (see North Coast Archaeological Sites Shoreline Sensitivity Map).

Photo by Renny Talbot

Photo by Warren Warttig

HAIDA GWAII

The average air temperatures in Haida Gwaii may increase by 1.4°C by the 2050s and by 2.2°C by the 2080s. The number of growing degree days will increase and frost free days will increase, as winter minimum temperatures may increase by up to 4-9°C by 2080 [10,42,70,71,73]. The average annual precipitation is likely to increase by 7% on average by the 2050s, and by closer to 9% by the 2080s ([73]; see Sub-regional Table, Haida Gwaii). Rising air temperatures and changing precipitation patterns are likely to threaten fisheries related tourism, yet may also provide potential benefits to the tourist season as the summer becomes warmer and longer. Increasing precipitation poses flooding risks to local communities in Haida Gwaii, which may affect access to traditional food gathering places. Increased spring runoff could damage coastal infrastructure, especially in the case of earlier freshet floods.

Sea level rise is projected to impact Haida Gwaii, especially low-lying areas along the east coast of Graham Island [21,25,85]. The coast of Haida Gwaii, especially the east coast of Graham Island, is highly dynamic; with sea level rise, the area is likely to erode as beaches and sand dunes migrate onshore. This sediment transfer is likely to cause shoreline retreat along coastal beaches (Walker and Barrie 2006). Previous projections by the Geological Survey of Canada have identified that area as among the top 3% most sensitive coastlines in Canada, due to the combination of low lying shoreline and easily eroded shorelines with large tidal ranges [69,107]. The ecosystems of Haida Gwaii are highly exposed to rising sea levels and increasing sea surface temperatures. Rising sea levels increase the risk of permanent inundation of important coastal habitats and can lead to loss of wetlands which are critical for bird and fish species. In addition, increasing sea surface temperatures are likely to diminish ecosystem health and alter coastal habitat composition [6]. There are also many cultural and historic sites that may be affected by rising sea levels based on a recent shoreline sensitivity analysis (see Haida Gwaii Archaeological Sites Shoreline Sensitivity Map).

Extreme storms and associated storm surge events are expected to intensify in this region due to the cumulative impacts of El Niño, the PDO, and sea level rise [69]. Previous El Niño events led to sea level rise and erosion along the same shoreline, and high water levels have since increased significantly [25]. Increasing winter winds are projected to increase seasonal currents and eddies near Rose Spit, Middle Bank, and Goose Island Bank [21]

Climate change impacts on fisheries in the area of the Queen Charlotte basin are somewhat uncertain [25]. While projections suggest declining species abundance and changing species compositions [92], the effects of warmer waters, altered production regimes, and exotic species have not yet produced obvious declines of herring and salmon in this area [25].

Climate change will impact the social, economic and environmental exposure of Haida Gwaii’s coastal communities. Particularly, sea level rise, and wind, wave and storms will have the highest direct impacts. Indirectly, changes in the ecosystems and fisheries and aquaculture will result in negative social and economic impacts on Haida Gwaii communities due to the high dependence to resource based life. Coastal communities and cultural and historical sites along the low-lying coastal areas of Haida Gwaii are the most exposed to rising sea levels, and winds, waves and storms. This is due to the increased likelihood of coastal flooding and erosion, and increased frequency,

strength, and duration of storms and wind/wave action [31,42,107]. Increasing maintenance and insurance costs associated with the sea level rise and storm damages will also affect all Haida Gwaii communities [25].

Due to its geographic positioning, Haida Gwaii highly depends on its marine infrastructure for delivery of and access to goods and services, fishing and harvesting practices, and provisioning of utilities. Marine infrastructure in Haida Gwaii is increasingly exposed to climate change impacts, particularly to rising sea levels, and to increasing wave and wind actions from storms. The risk of marine transportation interruption is increasing due to increase in intensity, frequency and duration of storms, which will directly impact the delivery of goods and services, and access to the mainland [25].

Besides the marine transportation links and lanes, the infrastructure that supports the marine and land transportation is also likely to be affected by rising sea levels and heavy wind and wave actions. For example, the likelihood of damage to fixed coastal infrastructures, such as the Sandspit Airport, is likely to increase over time [74]. In addition, roads, utilities, power, communication, and flood protection infrastructures will experience inundation and/or structural damages with the increased risk of flooding, erosion and damage caused by rising sea levels, and wind and wave actions [25,42,113].

Wooden fish weir, Knight Inlet / Photo by Barb Dinning

Photo by Charles Short

Ecstall River | Photo by Jessica Hawryshyn

KNOWLEDGE GAPS AND SOME ONGOING RESEARCH

Adapting to climate change requires a comprehensive understanding of climate change projections and sectoral impacts in order to identify priorities, find solutions, and implement adaptation actions. Based on our literature review and discussions with researchers, we highlight some knowledge gaps and ongoing research relevant to the MaPP region and sub-regions.

This is certainly not a comprehensive review of all ongoing or planned research, and the points below are merely to provide a starting point for understanding and framing next steps for directing research on climate change projections, impacts, vulnerabilities, risk, and adaptations. Ongoing research efforts are not in the public realm, and as such it is difficult to systematically document upcoming results or new projects. Recommendations for future research are from published literature, recent government reports, and/or discussions with specific researchers, and as such there are likely more opportunities for research than are mentioned here.

UNCERTAINTY IN CLIMATE CHANGE IMPACTS, VULNERABILITIES, AND RISK

There is still a great deal of uncertainty in global climate change projections for coastal regions, and the associated vulnerabilities and risks [1,114,115]. Part of this uncertainty is due to lack of or limited access to reliable and continuous data sources. Specifically, large population centers and regions often draw

most of the resources for long-term observations and other scientific monitoring necessary for adequate research. The other part of the uncertainty is the unpredictability of humans and their actions. New technologies are developed every day, but the diffusion and adoption of these technologies is often relatively slow. Understanding vulnerability and risk is more meaningful in smaller scales as characteristics of each community, their socio-economic structure, coastal context, environmental conditions, and institutional capacity contributes to their local vulnerability. Therefore, for uncertainties surrounding vulnerability and risk, the main knowledge gap lies with the lack of existing studies investigating the local and regional exposure and sensitivity to various climate change impacts.

This uncertainty in global climate projections and knowledge of local vulnerabilities and risk is further amplified by regional variations in local climate which interact with climate change, such as the El Niño – Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) [5,7,36]. Investments in monitoring and research will improve our understanding of climate change projections and impacts across the coastal region and at fine scales such as the MaPP sub-regions. Within BC, additional monitoring programs through the Hakai Institute (<https://www.hakai.org/>) and MEOPAR (<http://meopar.ca/>) are in progress to monitor key climate change indicators including ocean acidification.

LACK OF REGIONALLY DOWNSCALED PROJECTIONS AND VULNERABILITY ASSESSMENTS

Statistical downscaling can be used to map coarse-scale global climate model outputs to finer scale (regional or local) detail, using the empirical relationship between observed climatology at the finer resolution, and coarse-scale model fields. Regional climate models can also produce local projections, which may better represent the local responses to climate change [116]. There is a lack of reliable downscaled projections or regional climate modeled data for most climate impacts in the marine environment of BC, and within the MaPP region. Much of the climate impacts work within BC is focused on terrestrial impacts (e.g. [117]; AdaptTree), rather than marine and coastal impacts, and as such is of more limited applicability to the marine and coastal focus of the MaPP region (T. Murdoch, PCIC, pers. comm. July 2017). Regional climate vulnerabilities are also unknown for most sectors within BC. Fisheries and Oceans Canada has an ongoing project to model climate change vulnerabilities in some fisheries (Karen Hunter, pers. comm. July 2017.), with early results expected within the next year. Other work is focused on modeling the impacts of warming river temperatures on juvenile salmon, with results forthcoming (K. Hunter, DFO, pers. comm. July 2017).

OCEAN ACIDIFICATION AND OCEAN CHEMISTRY

The existing state of knowledge for ocean acidification is limited, and other than global datasets, there are currently no projections at the scale of the BC coast [63]. This is partly due to a lack of empirical data as model inputs. Sampling for alkalinity and dissolved organic carbon has occurred as a regular part of DFO surveys since 1992 and 1986 respectively, but the data has been fragmented and inconsistent [63]. Very little is known about the state of the nearshore waters. Ongoing efforts to model changes in ocean chemistry (nitrogen, carbon, and oxygen) will improve the overall understanding of coastal biochemical

processes and nearshore acidification and hypoxia levels (K. Hunter, DFO, pers. comm. July 2017). In addition, further efforts to model changes and extremes in pH (Ianson and Monahan, in progress; [29]) will improve the understanding of projected changes in acidification and the associated impacts.

ONGOING AND/OR RECOMMENDED RESEARCH

- The Hakai Oceanography Program (HOP) has been maintaining year-round measurements of physical, chemical, and biological parameters on the Central Coast at 4 main stations. The aim of this research is to improve the understanding of the implications of climate change for coastal ecosystem productivity (Hunt et al. 2017). Additional research started in 2017 looking at ocean acidification using the Alaska Marine Highway System, whereby a monitoring system will be installed on the motor vessel Columbia which will monitor ocean pH while underway along the length of the BC coast.
- The West Coast Ocean Acidification and Hypoxia Science Panel has proposed an ocean acidification and hypoxia monitoring network to pool regional scientific data and information to evaluate impacts and guide priorities and actions across the region (Newton et al. 2016).
- Increased research and monitoring at vulnerable locations (aquaculture sites) across a range of dissolved carbon dioxide levels is recommended [52,63].
- More research on cumulative impacts of acidification and other impacts is recommended [52].
- Laboratory experiments on biological effects of ocean acidification on regionally important species and taxa is recommended [52].
- Ongoing research at Saint Mary’s University is looking at the risks to coastal communities from ocean acidification, using a fuzzy logic approach (Community-based Ocean Acidification Risk Analysis Tool, CORA) (B. Paterson, Saint Mary’s University & MEOPAR; pers. comm. September 2017).

**EXTREME WEATHER, STORM SURGE,
AND SEA LEVEL RISE**

Models and projections of extreme weather events are lacking for coastal BC [74]. There is little available data on future extreme weather, storm surge, or sea level rise at the scale of the MaPP region. Existing estimates of future sea-level rise vary widely, and projections at a regional scale are either largely unavailable or even more variable.

Investment in this research area would allow decision makers to better plan and implement operational adaptive actions to improve the outcome of high wind events and storm surge impacts. Risk assessments for extreme weather and storm surge, especially as these impacts combine with sea level rise, will continue to be an important area of research in order to develop the appropriate information to maintain and build infrastructure along the coastal region.

Improved projections of sea level rise for Canada’s coastlines are in progress with Fisheries and Oceans Canada through the Regional Mean Sea-Level Rise Scenarios for the Canadian Coasts program, which will produce four regional sea level scenarios (from low to high) for the Atlantic, Pacific, and Arctic coasts [30]. These data will improve the ability of regions, communities, and sectors to manage infrastructure and development in a way that facilitates effective adaptation to the risks associated with sea level changes. Sea level rise projections [36] have been produced at decadal time periods through to 2100 and are included in this report (see Maps section), but are at a coarse scale and not at a fine scale for

in-shore waters. Forthcoming marine connectivity analyses will help to identify communities that are highly dependent on marine infrastructure and would be very vulnerable to disruption [118].

There is ongoing work through Fisheries and Oceans Canada to develop a hind-castwave model for coastal BC waters (expected in 2 years), which will characterize storm surge patterns across the coast and fill data gaps in the northern coast where tide gauges are sparse (T. James, Natural Resources Canada, pers. comm. June 2017). The Canadian Geodetic Survey is also working to develop sea level rise projections for Canada’s coastal areas, but results are not yet available (T. James, Natural Resources Canada, pers. comm. June 2017).

**OTHER UNCERTAINTIES: INVASIVE SPECIES,
DISEASE PATHWAYS**

Projected changes to climate variables are likely to interact to affect the likelihood of species invasions in BC waters, as habitats and oceanographic conditions change to facilitate the establishment of warm water species through species range expansions [12,13]. Marine diseases are also likely to increase in frequency and intensity, as species already stressed due to direct climate changes such as rising ocean temperatures are also more susceptible to infection [5]. The biological interactions and additive effects of disease and invasive species, such as green crab which is already invading BC waters [119], are highly uncertain [5,86,120].

Gitxaala Nation, crab fishing | Photo by Jessica Hawryshyn

MOVING FORWARD: ADAPTATION

Adaptation involves both proactively preparing for expected climate changes, as well as adjusting to climate change or its impacts after they occur. Minimally, adaptation can serve to moderate the harmful impacts of change, or allow for positive outcomes by taking advantage of new arising opportunities. Both human and natural systems can adapt to climate change and/or to the impacts of climate changes. While natural ecosystems can only adjust to climate changes once they occur, human communities can plan by using climate predictions to anticipate the impacts and benefits of climate change. Successful adaptation actions will mean that the impacts of climate change could be reduced or be less severe than if no adaptations had occurred. For communities, successful adaptation may mean that adaptation strategies allow them to function (economically, socially, built environmentally, and institutionally) even after the disturbances occur.

Effective climate change adaptation requires a strategic stepwise approach that includes identifying climate impacts within the context of the MaPP region. This would include initial assessments of vulnerability and risk in order to prioritize adaptation

actions, and an adaptation plan that fits the governance structure and communities at stake. Across Canada, awareness of climate change impacts and the necessity of adaptation planning is increasing [27]. In British Columbia, the provincial Adaptation Strategy [121] aims to prepare the province for the impacts of climate change to the environment and social systems. Under the BC Climate Action Plan, there are a range of actions that are intended to help increase resilience to climate change and reduce vulnerabilities. This adaptation plan is based on three key components: building a strong knowledge base with tools for decision makers to prepare for climate change, incorporating climate adaptation within policy decisions, and improving assessment and implementation of appropriate adaptation actions in especially vulnerable sectors [121]. While these reports and adaptation plans are encouraging and signify a shift in management and governance investment in climate adaptation, there has been until recently far less investment in adaptation research and planning for coastal management and fisheries sectors when compared to terrestrial areas and sectors such as forestry and agriculture [28].

Photo by Charles Short

CURRENT ADAPTATION POLICIES AND RECOMMENDATIONS FOR ADAPTATION

The overall goal of climate change adaptation is to reduce vulnerability and risk associated with climate change and its impacts. Adaptation to climate change can be either proactive or reactive. Reactive management includes responses to changes that have already happened, and proactive management prepares for changes before they occur. While acting earlier (more proactively) will generally increase management flexibility, there are also financial costs to implementing adaptation actions [122]. Finding the balance of adaptive and reactive actions to climate impacts and associated risk may be different for different sectors. Adaptation actions can include policy changes, improvements or changes in technology, behavioral or management responses, or adjustments to regulations that affect local and regional decision making: successful adaptation requires a flexible, adaptive management system. Adaptive capacity can be further enhanced or reduced by the governance and decision-making policies at play [123].

In BC, recent efforts to increase community involvement at both local (municipal) and regional scales has resulted in better incorporation of local interests and values in long term planning [25,85,112,121,124]. Local community-based planning has been a key mechanism for community members and stakeholders to evaluate and incorporate climate change effects in order to improve adaptive capacity. However, there are few examples of decision making processes, policies, or institutions that explicitly incorporate or consider climate change impacts within BC [25,125].

Climate change adaptation is a growing focus for the province of BC. Municipal governments have been particularly focused on issues of sea level rise and associated coastal flooding issues. Much of this work is ongoing in southern BC, outside of the MaPP region. Sea level rise and coastal inundation threatens much of low lying Metro Vancouver, where projects including extensive dike systems and sea level adaptation plans are either in place or in

process [25]. These projects can serve as examples of potential future work for the communities of the MaPP region, especially as results of implementation become more apparent.

Adaptation to climate change can be either to respond to negative impacts or to generate positive benefits, for example:

Negative:

- Adapting to sea level rise by increasing shoreline protection;
- Adapting to more intense coastal storms by developing emergency response plans.

Negative or positive:

- Adapting to shifting fisheries species availability by changing fisheries regulations and management plans;
- Adapting to longer and warmer growing seasons by supporting local agriculture and developing water conservation planning.

SECTOR LEVEL ADAPTATION: ECOSYSTEMS, FISHERIES AND AQUACULTURE

Climate change impacts on ecosystems are diverse and cumulative. Managing for ecological resilience and adaptation to climate change will require integrative approaches that will also benefit ecological productivity and fisheries. Climate change impacts in the fisheries sector primarily demands management responses to protect or enhance existing fisheries and stocks. However, First Nations fisheries may have fewer options for adaptation, especially given the coast-wide dependence on marine resources for food security and cultural uses [25,67,92]. In these cases, traditional ecological knowledge may offer examples of adaptive strategies to enhance food security and thus community resilience in these systems. As an example, recent research on clam garden mariculture has illuminated the historical importance of First Nations aquaculture on this coast [126,127]. First Nations communities on the BC coast have a long and diverse history of traditional food production practices; learning from these techniques may offer adaptive strategies for communities now and in the future.

Proactive management options aim to increase the resilience of a fishery, fishers, or ecosystem, based on predicting the effects of change. In some cases, reactive management approaches may be suitable or successful given that predictive modeling of future environmental conditions and associated fisheries may be uncertain [122,128,129]. Proactive management for supporting fishery-based economies and coastal communities can support the resilience of fishers and the communities that depend upon fishing. As fish distributions and abundances shift with climate change, fisheries will have to adjust by changing target species, fishing areas, fisheries openings, and processing locations [122,130].

Proactive management approaches for supporting fisheries and ecosystem health

1. Scenario planning to identify management options despite uncertainty. These can be simplistic or highly technical.

Examples: Descriptive scenarios to identify options for management to move fisheries or add value to fishery products; simulation modeling.

2. Marine reserves/Marine protected areas: Support functional diversity of an area or ecosystem.

Examples: Protect current and future habitats of protected species, protect core areas of stock distribution through time by modifying reserve boundaries, manage dynamic reserves based on environmental conditions over time, e.g. dynamic ocean management (DOM).

3. Management that promotes adaptive capacity of fish species and populations. Aim to improve or maintain genetic diversity of fish species and populations by reducing stressors, protecting populations with high genetic diversity, or highly tolerant populations (e.g. high temperature tolerance). Avoid targeting populations at the edges of species distribution.

Examples: Area based fishing closures, increase research on genetic diversity and plasticity of populations.

4. Protect fish population age structure, especially old females to increase population resilience to changing conditions.

Examples: Increase marine protected areas, use maximum size limits, modify fishing gear to prevent capturing large fish, increase post-release survival, use area-based or temporal fishing closures to limit catching large individuals.

Examples of protection-related adaptation actions include:

- Reducing fisheries harvest rates;
- Increasing habitat protection and ecosystem restoration; and
- Improving regulations to manage fisheries and freshwater rearing systems, which are especially important for salmon species as marine ecosystems [25].

Other sectoral responses may include increasing hatchery production and aquaculture development, although these changes have other ancillary tradeoffs that may not contribute to overall ecosystem health.

Adaptive management techniques for fishers and the fisheries sector include:

- Diversifying fisheries regulations and harvest licenses before available species change, to allow fisheries and fishers to target new species and exotics as current targeted species decline in abundance or shift northwards [25,122,128]. Examples: Rights-based fisheries management; community based quota systems.
- Insure fishers to provide stability to fishers in low income years and decrease overfishing. Example: Analogous to crop insurance. Premium-based regional or federal insurance system to support fishery-based communities.
- Potentially relocate fisheries infrastructure as major fishing grounds change locations [122].
- Increase flexibility in the processing and supply chain for fisheries to reduce impacts to local fishing economies when fisheries change rapidly.

Reactive management approaches for fisheries and fishing-based communities include:

1. Flexible and adaptive management systems that reward innovation, coordination, and collaboration between regions and management bodies. Increased monitoring and use of indicators can help to prepare managers and planners as conditions change and management needs shift.
Example: Dynamic ocean management (DOM): Dynamic spatial closures to adjust fisheries activity based on real-time data on environmental conditions and distribution of fish species.
2. Adjusting fisheries reference points often to reflect changes in species or stock abundance.
Depends on high quality monitoring data of fisheries and environmental variability.

3. Adjusting fisheries allocations after species distributions or abundances have changed.
Depends on high quality monitoring and modeling of species distributions and abundances, and clearly defined allocation rules based on indicators of change.
4. Adjusting fishing practices or fishing gear once fish communities change. As fish species distributions and abundances shift in response to climate impacts, fishers could adjust their fishing practices or gear to reduce interactions with non-target stocks or protected species.
Can have negative tradeoffs based on economic costs, and changes to social structure of communities. Depends on involving fishers early in management discussions.

Chief Don Roberts Fishing Eulachon
Photo by Kitsumkalum Nation

SECTOR LEVEL ADAPTATION: HUMAN COMMUNITIES

In order to build adaptive capacity at the scale of the region and sub-regions, it is important to build on existing programs and attributes. Governments and communities need to remain open to communication and collaboration in order to develop tools and resources to enable regional and sub-regional decision making for effective adaptation action. They need to adopt integrated and adaptive management practices that increase access to and distribution of resources such as allocating roles and responsibilities, distribution of relief goods and provision of relief services; developing early warning and evacuation systems; creating education and awareness programs; and making arrangements for secure shelter and food, and access to health care, education, economic and social resources [75,131–134]. In addition, through adaptive management practices, higher sectoral, institutional, and stakeholder representation can be achieved in decision-making processes [132].

The coastal community context is especially relevant within the MaPP region. Adaptive capacity building at the community level should be supported by national, regional, and sub-regional institutions and policies. Regional and sub-regional management should understand how local communities and local institutions function and are managed in order to support local adaptation actions and community resilience to major change. Remote communities may already possess attributes of resilience through their sociocultural context that may improve their adaptive capacity to climate change. A transparent knowledge- and data- based climate change adaptation process can enhance existing adaptive capacities [129,132,135–137]. Particularly, by empowering local organizations (e.g. First Nations offices), socio-economic groups that are already vulnerable can be included in decision-making processes [134,138].

Building adaptive capacity and resilience in remote communities is dependent on a variety of factors, including: 1) existing local and regional institutional capacity; 2) local socio-economic development; 3) infrastructure development and condition; and 4) local experience with extreme weather events and other environmental or socioeconomic stress [132,139]. Other factors that can contribute include social networks and cohesion, income diversification, and self-reliance [25,140]. However, current social and economic stressors are likely to reduce the capacity for remote communities to undertake or even consider climate change adaptation. Many coastal communities within the MaPP region already experience economic hardship and are limited in their capacity to undertake new initiatives or projects, even if the long-term benefits are relevant. Building on initiatives that are already in place to address environmental and economic changes and incorporating considerations of the impacts of climate change should be more effective for those communities [25].

Especially for First Nations communities, past experiences with historical social, cultural or economic changes can offer lessons for adapting to climate change. For example, in southern Vancouver Island the W̱SÁNEĆ people share a historic story involving rising sea levels and community adaptation responses which may offer insight into adaptation actions for communities in response to climate change in the present day [141]. Key attributes of social adaptive capacity such as social capital and community networks are often already evident in place-based communities and community ties. However, for effective adaptation planning, climate change impacts and adaptation needs to be seen as relevant for present-day local community planning and management [25,124].

**SECTOR LEVEL ADAPTATION:
MARINE INFRASTRUCTURE**

In BC, the provincial government has conducted vulnerability assessments for highway systems and continues to monitor and assess sea level rise. The British Columbia Ministry of Transportation and Infrastructure is one of the first jurisdictions to require infrastructure design work for the ministry to include climate change implications. However, infrastructure operators in BC have primarily been responding reactively to failures, rather than anticipating and proactively preparing for projected changes or impacts [74]. This approach typically results in impacts being more costly or severe than if proactive adaptation actions had been taken.

Across the infrastructure sector, proactive approaches such as integrated vulnerability and risk assessments that incorporate climate projections, using effective guidelines for data interpretation by managers and decision-makers, could improve adaptive learning and decisions. Incorporating the results of climate change vulnerability and risk assessments into planning and adaptation efforts for the marine transportation sector would reduce the risks from climate impacts and improve the likelihood of adaptation. Proactive climate change adaptation can foster environmentally and socially responsible planning strategies, that protect communities, built environments, and marine infrastructure. Responsible planning strategies can be limiting to human activities and development in vulnerable areas, preserve and enhance coastal ecosystems that provide flooding and erosion protection [142], or support communities to retreat from hazardous areas.

While attributes of resilience may exist inherently, the impacts of climate change challenge long term adaptive capacities through rapidly rising sea levels and coastal storms, new impacts that threaten coastal communities who are dependent on vulnerable infrastructure and a lack of essential relief services [25]. Limited economic resources and support to cope with increasing impacts, and the lack of land use planning that considers climate change, also affects the adaptive capacity of coastal communities.

To date, most climate change related adaptations have been reactive responses to unpredicted events, such as extreme forest fires or the mountain pine beetle epidemic. Planning for climate change seems to compete with a host of other priorities for the limited capacity of local and regional governance, as only one of the many stressors that affect the ecosystems, industries, and communities of British Columbia. For these reasons, cumulative impacts assessment [143–146] may be highly appropriate for regional (and/or sub-regional) adaptation planning.

Proactive adaptation examples for coastal marine infrastructure include:

- Investments in early warning systems, particularly for storm surge related activities, as well as other disasters such as tsunamis;
- Planning in emergency management, such as planning for alternative routes for evacuations; and
- Identifying infrastructure under risk roads, docks, rail routes, etc., and planning phased programs to either mitigate impacts, or retreating and relocating options.

RECOMMENDATIONS

Meaningful adaptation actions will need to consider the projected climate impacts and sectoral impacts, as well as the risk and vulnerabilities associated with these impacts. The evaluation of the risks and vulnerabilities along with climate and sectoral impacts will allow a more in-depth understanding of how the region and sub-regions are impacted by climate change. A number of risk and vulnerability assessments/frameworks will be evaluated in the second report. Here we present a number of recommendations for improving the understanding of climate change impacts for the region and implementing effective adaptation actions.

Ecosystems

For ecosystem level adaptation to climate change, a bet-hedging strategy for management is to aim to generally promote, protect, and restore biodiversity [5,147,148]. While key species are certainly of particular importance for ecosystems and human values, intact ecological communities with genetically diverse populations and high biodiversity are generally considered to be more resilient to the impacts of climate change [147]. To that end, some general recommendations for managing ecosystems within the MaPP region in an era of accelerating climate change include:

- Incorporate climate change modeling and projections into coastal and marine resource management and planning at appropriate scales.
- Seasonal climate forecasts for incorporating ENSO and PDO effects are currently underutilized and could be more effective for year to year planning and management [25].
- Continue participating in and developing assessments of climate change impacts on marine ecosystems [149,150].

- Develop feasibility analyses to identify and prioritize management strategies for specific sectors.
- Develop integrative and cross-sectoral climate adaptation implementation plans that identify actions to reduce climate vulnerability and risk, monitor climate impacts and adaptations, and approaches for identifying trade-offs among sectors and activities within the region.
- Promote, protect, and restore biodiversity as a way of bet-hedging and coping with climate dynamics and non-linearities. Create protected areas at ecologically-meaningful scales in order to protect marine ecological processes and key sites for vulnerable species [151–153].
- Improve and integrate monitoring for key climate change variables and indicators at fine temporal and spatial scales, and integrate empirical data with modeling of climate projections (e.g. Hunter et al. forthcoming work, K. Hunter, pers. comm., July 2017).

Compton Island, Blackfish Sound | Photo by Scott Harris

Photo by Barb Dinning

Fisheries and aquaculture

- Consider and apply both reactive and proactive fisheries adaptation responses at the regional and sub-regional level [122].
- Support and integrate scenario planning for possible future management options [93,154].

Human Communities

- Improve monitoring frameworks: Invest in climate impacts monitoring both regionally and sub-regionally.
 - o Example: Nanoos in the Salish Sea: <http://nvs.nanoos.org/>.
 - o Example: Local Environmental Observer Network (LEO) platform: <https://www.leonetwork.org/>.
- Investigate the applicability of tools such as “Surging Seas” for visualizing sea level rise and improving local understanding of risk and adaptations: <https://seeing.climatecentral.org>.
- Apply a marine protected areas vulnerability assessment tool in marine protected areas planning processes to incorporate climate change impacts on marine systems.
 - o Example: CEC North American Marine Protected Area Rapid Vulnerability Assessment Tool [153].
- Consider local and regional priorities and investigate applicable and relevant vulnerability and risk assessment frameworks and tools. An evaluation of these tools is upcoming from MaPP contractors (“Project 2”; early 2018). Some examples include but are not limited to:
 - o CEC North American Marine Protected Area Rapid Vulnerability Assessment [153],
 - o HRVA BC Government Hazard Risk Vulnerability Assessment,
 - o CVI Coastal Vulnerability Assessment,
 - o CCVI Climate Change Vulnerability Assessment – Canadian Index,
 - o CVCA Climate Vulnerability and Capacity Analysis,
 - o VI Environmental Vulnerability Index,
 - o GRaBS Assessment Tool; and more.

- Support diversification of economic sectors, reducing single sector dependencies on fisheries in cases where species are likely to decline significantly [111,122].
- Provide support and resources for community groups, to increase public educations and participation in identifying climate change impacts and local level management [155,156].

Marine infrastructure

- Prioritize local level assessments of infrastructure vulnerability and risk to help prioritize actions [157,158].
- Once assessments are carried out, proactively aim to reduce the vulnerability of exposed infrastructure (e.g. coastal roads, low-lying essential services).
- Plan for sea level rise by developing high elevation alternative transportation and infrastructure.
- Reduce the impacts of sea level rise on nearshore habitats and infrastructure with marine reserves that protect coastal wetlands, estuaries, mudflats, kelp forests, and eelgrass beds [151].
- Invest in economic development to diversify remote local economies and increase community resilience (i.e. invest in tourism, resource conservation, arts and culture).
- Consider adaptive and multi-functional solutions that can be altered to address low to high level impacts and can provide multiple benefits.
 - o Example: Soft coastal protection measures such as sand dunes or wetlands can both protect coasts from rising sea levels and low to moderate wave action, and provide ecosystems services (like increasing biodiversity, providing habitat for primary and secondary production, increasing recreation opportunities, etc.) [159].

CONCLUSIONS

This report serves as a scoping exercise to provide a baseline of understanding of the expected climate changes and associated impacts across coastal BC and the NSB over the coming decades. The available data project that rising air temperatures and changing precipitation patterns will lead to warmer summers, milder winters with less snowpack, and drier summer months. Sea surface temperatures will likely continue to increase. Ocean acidification is likely to increase as carbon dioxide is absorbed by the ocean. More extreme weather events can be expected, with more storms, atmospheric river events, and coastal flooding. These impacts will likely have cumulative effects across the region.

The climate changes – both observed and projected – that are outlined in this report are likely to result in multiple impacts to the key sectors in the MaPP region, some of which are understood but many of which have a great deal of uncertainty associated with them. Long-range planning and early, proactive adaptation efforts will be very important to accommodate those predicted and also unanticipated impacts. This report is a starting point for additional research on climate changes, vulnerability and risk assessments, and climate change adaptation in the MaPP region and sub-regions.

When new global projections are available from the IPCC, and new regionally downscaled projections are available within BC and the MaPP region (and possibly sub-regions), a more specific understanding of the multiple impacts of climate change may be possible. However, acting now on climate change adaptation is important to prepare for the predicted changes ahead, to increase resilience, and to ensure that economic, social, and cultural opportunities are still available to the communities of the MaPP region.

Vulnerability and risk assessments may be conducted to set regional and sub-regional priorities for further research and monitoring, to understand the economic costs of climate impacts, and to inform planning and implementation of adaptation actions. To that end, additional work undertaken by Conger and Whitney in 2018 includes a review of vulnerability and risk assessment tools including strengths, weaknesses, opportunities, and tradeoffs of each as relevant to the context of the MaPP region and sub-regions. Looking ahead, we emphasize that given the uncertainty that currently exists in climate change projections and associated impacts, adaptation actions should be chosen that support resilient social-ecological systems and are flexible to allow management and communities to evolve as climate change unfolds.

Photo by Jessica Hawryshyn

TABLES: PREDICTED CLIMATE CHANGE IMPACTS
ACROSS REGION AND SUB-REGIONS

MaPP Region - Summary table for climate impacts, projected changes and sectoral impacts					
Climate Impact	Projected Changes	Evidence Quality	Sectoral Impacts	Impacts Summary ^a	Evidence Quality
Air Temperature	Average air temperatures may increase by 1.8°C (1.3°C to 2.7°C) by 2050 and 2.7°C (1.7°C to 4.5°C) by 2080 ^{1,2,3} ; and average temperatures may reach ~7.8°C with low emission scenario (RCP 2.6) and ~11.6°C with high emission scenario (RCP 8.5) by 2091-2100 ^{4*} ;	High	Threats to <ul style="list-style-type: none">fisheries²,ecosystem, hydrology, and habitats^{3,5},nearshore marine mammals^{5,6},fisheries related tourism²,water supply²,human health and well-being⁷;		High
	Growing degree days: +283 (+179 to +429) 2050 and +468 (+262 to +769) by 2080 ¹ ;		Potential increases in <ul style="list-style-type: none">frequency and intensity of toxic algal blooms⁶,Potential benefits to tourism due to longer warm seasons².		
	Frost free days: +20(+12 to +29) by 2050 and +30 (+16 to +48) by 2080 ¹ ;				
Precipitation	Winter minimum temperatures in northern BC may increase by 4–9°C by 2080 and summer maximum temperatures may increase by 3–4°C. Increases in frost-free periods, growing-degree days, and frequency of extremely warm days ⁵ .	High			High
	Increasing average annual precipitation by 6% (2% to 12%) by 2050 and 9% (4% to 17%) by 2080, 10% decrease in summer ^{1,2*} ; up to ~18% more precipitation (low emissions, RCP2.6) and ~25% (high emissions, RCP8.5) by 2091-2100 compared to 1961-1990 baseline ⁴ ;		Threats to <ul style="list-style-type: none">marine infrastructure, operations and transportation lanes¹⁰;		
	Declining winter snowfall by -10% (-17% to +2%) by 2050 and -12% (-26% to -1%) by 2080 ¹ ;		Increased <ul style="list-style-type: none">freshwater discharges and associated turbidity, flow of contaminants, pathogens and nutrients^{6,11,12},summer drought and water scarcity for communities due to earlier freshet in the spring⁹;		
Sea Level Rise	Winter precipitation increase by 10-25%, summer precipitation increase by 20% by 2050 ⁸ ; overall precipitation increase in fall, winter and spring seasons ^{2,3,9,10,11} .	High	Changing salinity levels and stronger Vancouver Island Coastal Current ¹² ;		Medium
	Declining winter snowfall by -10% (-17% to +2%) by 2050 and -12% (-26% to -1%) by 2080 ¹ ;		Potential damaging impacts on ecosystems, ecosystem dynamics, and habitats ² ;		
	Winter precipitation increase by 10-25%, summer precipitation increase by 20% by 2050 ⁸ ; overall precipitation increase in fall, winter and spring seasons ^{2,3,9,10,11} .		Changes in access and seasonality of traditional foods and food availability ² .		
Sea Level Rise	Rising sea levels from 80cm to 120cm ¹³ or from 20cm to 130cm ³ by 2100;	High	Threats to <ul style="list-style-type: none">fish, invertebrates⁶,coastal plants, algae and inter-tidal habitat⁶,First Nations' heritage sites^{10,12,15,16,17},groundwater quality due to salt water intrusion¹⁵;		Medium
	Increases by ~25.1cm in Prince Rupert; ~9.3cm in Queen Charlotte; ~8.4cm in Bella Bella; ~13.9cm in Winter Harbour by 2100 ⁸ ;		Increased coastal flooding and erosion risks on communities ^{10,12,15,16,17} ;		
	Moderate rate of sea level rise until 2025, and rapid rate from 2025 up to 2100. May be counteracted by vertical land movement (uplift) by 1 and 3 mm/yr, but not enough to moderate SLR rates ¹⁴ .		Economic impacts on <ul style="list-style-type: none">built environment and communities¹⁰,marine infrastructure, operations and transportation lanes^{16,17,18}.		

Sea Surface Temperature	Average sea surface temperatures may reach ~11.4°C with RCP 2.6 and ~14°C with RCP 8.5 by 2091-2100 ⁴ ;	High	Threats to <ul style="list-style-type: none">water quality^{15,23,24},nearshore habitats and ecosystems^{6,15,19,24},diversity, abundance, growth, movement, range, interactions, distribution and survival of species^{4,6,11,19,23,24,25},cascading impacts on ecosystems⁶;		High
Ocean Acidification	Increases between 0.5°C and 2.0°C and average temperatures to be around 10-14°C by 2065-2078 compared to 1995-2008 baseline ¹² .	High	Increased incidence of marine diseases, harmful algal blooms and invasive species ^{15,23,24} ;		High
Oxygenation	Overall decreasing pH levels ^{19,20,21} .	High	Economic, social and cultural impacts on communities as fisheries migrate across regional and political boundaries ^{15,19} .		High
Streamflow	Declining dissolved oxygen levels for the Northeast Pacific Ocean ^{6,11,19} .	High	Threats to <ul style="list-style-type: none">ecosystems and habitats^{11,19,20},production, growth, survival and structure of shelled organisms and fish^{6,19,20,21,22},plankton community structure^{6,20},fished species, particularly to salmon aquaculture and shellfish industry^{11,19,20,22},overall food safety^{11,19,20},		High
Sea Surface Salinity	Increases in spring flow with slight increases in during summer by 2080 ^{8,15} ;	High	Threats to <ul style="list-style-type: none">species with low mobility or species adapted to low oxygen⁶,primary productivity, growth and distribution of fish populations^{6,11,22},fished species compared to unfished species^{11,19,22};		High
Streamflow	Stronger Vancouver Island Coastal Current, stronger flows in Queen Charlotte Sound, Hecate Strait and Dixon entrance ¹² ;	High	Impacts on the ecosystem and habitat of groundfish ^{15,22,23} ;		High
Sea Surface Salinity	Decreased summer flows in glacier and snowmelt dominated watersheds ^{9,15} .	High	Economic, social and cultural impacts due to changes in fisheries ^{11,19,22} .		High
Sea Surface Salinity	Increases in spring flow with slight increases in during summer by 2080 ^{8,15} ;	High	Threats to <ul style="list-style-type: none">nearshore marine mammals due to alterations to temperature, salinity and stratification in ocean surface layers⁶,ecosystems due to oxygen and nutrient upwelling^{6,12};		High
Sea Surface Salinity	Decreases in sea surface salinity by ~1.25% with RCP 2.6 and ~3.2% with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline ⁴ ;	High	Increased and periodic water scarcity during the summer ⁹ .		High
Sea Surface Salinity	Decreases in sea surface salinity by ~1% (~0.2 decrease in psu unit) by 2065-2078 compared to 1995-2008 baseline ¹² .	High	Threats to <ul style="list-style-type: none">species range and food web structure¹⁹,fisheries industry¹⁹;		High
Sea Surface Salinity	Decreases in sea surface salinity by ~1% (~0.2 decrease in psu unit) by 2065-2078 compared to 1995-2008 baseline ¹² .	High	Reduction in total ecosystem biomass ¹⁹ .		High
Sea Surface Salinity	Decreases in sea surface salinity by ~1% (~0.2 decrease in psu unit) by 2065-2078 compared to 1995-2008 baseline ¹² .	High	Economic, social and cultural impacts on communities as fisheries migrate across regional and political boundaries ¹⁹ .		High

Winds, Waves and Storms	More intense and more frequent winter storms, surges and waves ^{2,26} ; Increases in damaging extreme high-water events ¹⁵ ; Increases in coastal wind strength in summer ⁶ .	High	Threats to <ul style="list-style-type: none">ecosystems and habitats²,recruitment for fisheries⁶,traditional way of life and First Nations food supply due to altered timing of seasons²⁷,marine infrastructure, operations and transportation lanes^{10,15}; Increase in <ul style="list-style-type: none">marine infrastructure maintenance and insurance costs^{10,15},coastal erosion and flooding²⁸; Alterations in the timing or strength of the spring weather transition, coastal currents and upwell strength and timing ⁶ .		Medium
General	Increasing occurrence and frequency of climate impacts ^{2,15,23,24,28} .	High	Threats to <ul style="list-style-type: none">access to traditional foods^{25,26},species abundance and distribution²⁵,catch potential for all commercial fisheries²⁵,fish spawning¹³; 21% decline in Sockeye salmon, 10% decline in Chum salmon, 15% decline in Sable fish stocks, and 1.33\$, 0.77\$ and 0.65\$ increase per pound, respectively ²² ; 15.0% to 20.8% decline in commercially and culturally important fisheries species relative abundance by 2050 ²⁵ ; Economic, social and cultural impacts due to changes in fisheries ^{22,25} .		High

* Data specific to MaPP region

α Unless indicated, all sectoral impacts are negative

Ecosystems

Communities

Fisheries and Aquaculture

Marine Infrastructure

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North Vancouver Island - Summary table for climate impacts, projected changes and sectoral impacts					
Climate Impact	Projected Changes	Evidence Quality	Sectoral Impacts	Impacts Summary ^a	Evidence Quality
Air Temperature	Average air temperatures may increase by 1.5°C (0.9°C to 2.3°C) by 2050 and 2.5°C (1.3°C to 3.7°C) by 2080 ^{1,2} and average air temperatures could reach as much as ~8.5°C (low emissions, RCP2.6) to ~12°C (high emissions, RCP8.5) by 2091-2100 ³ ; Likely more growing degree days: 313 (+189 to +478) more growing degree days by 2050 and 521 (+270 to +832) more growing degree days by 2080 ¹ ; Likely more frost-free days: 23 (+13 to +35) more frost free days by 2050 and 35 more (+19 to +52) by 2080 ¹ .	High	Threats to <ul style="list-style-type: none">fisheries²,fish stocks and species distribution^{4,5},fisheries related tourism²,water supply²,traditional food resources as seasonality changes and becomes unpredictable⁶; Potential positive benefits to tourism due to longer summers ^{2,7} .	+ –	Low
Precipitation	Average annual precipitation may increase by 6% (-1% to 10%) by 2050 and 8% (1% to 16%) by 2080 ¹ ; ~10% decrease in summer ² ; up ~15% more (low emissions RCP2.6) and ~21% (high emissions, RCP8.5) by 2091-2100 (relative to 1961-1990 ³ ; Winter snowfall may decrease by -25% (-42% to -8%) by 2050 and -33% (-59% to -13%) by 2080 ¹ ; Stronger Vancouver Island Coastal Current ⁸ .	High	Threats to fish stocks due to lower stream flows and decreased summer precipitation ⁴ ; Potential damaging impacts on ecosystems, ecosystem dynamics, habitats and altered current patterns ^{2,8} .		High
Sea Level Rise	Sea level may rise from 0.6m to 0.9m by 2100 ⁸ .	High	Threats to <ul style="list-style-type: none">cultural and heritage resources^{7,9},traditional food sources^{7,9},docking and processing infrastructure⁷,access to, or loss of natural recreation and tourism assets⁷,marine infrastructure, operations and transportation lanes⁷.		High
Sea Surface Temperature	Average sea surface temperature to be ~11°C with RCP 2.6 and ~14°C with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline ³ ; Increasing sea surface temperature by ~1.8°C and average temperature to be ~11-13°C by 2065-2078 compared to 1995-2008 baseline ⁸ .	High	Threats and changes to <ul style="list-style-type: none">aquaculture productivity⁷,marine species distributions^{5, 12},marine food resources for local communities^{7, 12}; Potential positive effect on tourism due to warm water temperatures ⁷ ; Poleward species range shifts at a rate of 10-18 km/ decade ¹² to 30.1 ± 2.34 (S.E.) km per decade from 2000 to 2050 ⁵ ; Economic impacts on communities due to changes in fish species and abundance ⁷ .		Medium
Ocean Acidification	Average ~7.95 pH with RCP 2.6 and ~7.68 pH unit with RCP 8.5 by 2091-2100 ³ ; Decreasing ocean pH levels (increasing ocean acidification) ⁷ .	Medium	Threats to <ul style="list-style-type: none">habitats and ecosystems^{7,10},calcifying organisms^{7,10},aquaculture industry^{7,10},food web structure^{7,10},species composition^{7,10},reproductive and recruitment success^{7,10},timing of growth and development stages^{7,10},prey availability^{7,10}.		Medium

Oxygenation	Declining dissolved oxygen levels ⁷ .	Low	Threats to <ul style="list-style-type: none">availability of food resources⁷,habitat range of species that tolerate low oxygen habitats; negative impacts to fisheries productivity^{10,11}.		High
Streamflow					
Sea Surface Salinity	Likely declining sea surface salinity by ~1.5% with RCP 2.6 and ~3% with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline ³ ; Declining sea surface salinity by ~1% by 2065-2078 compared to 1995-2008 baseline ⁸ , ~9% decrease in sea surface salinity at the mouth of the Homathko River ⁸ , ~2.5% increase in sea salinity (~0.6 increase in psu unit) at Johnstone Strait by Port Neville ⁸ .	High	Threats to <ul style="list-style-type: none">reproduction of seagrasses⁹,the availability of marine derived food resources^{7, 10}.		Low
Winds, Waves and Storms	Increasing frequency and intensity of storms and storm surge, flooding as mean sea level increases ^{2,4,7} ; estimated 75.3cm storm surge height for a 100-year storm surge event ¹³ .	High	Threats to <ul style="list-style-type: none">ecosystems and habitats²,docking and fisheries processing infrastructure⁷,traditional harvesting practices due to unpredictable seasonality⁶.		Low
General	Increasing intensity of cumulative climate impacts ^{7, 9, 10} .	Medium	Threats to <ul style="list-style-type: none">access to traditional foods^{6, 7, 12},biodiversity¹⁰,species abundance and distribution^{5, 12},catch potential for all commercial fisheries¹²,resource conservation due to ecosystem stress⁷,tourism and wildlife viewing opportunities as species distribution and habitat change⁷; Northward shift in species range and abundance ¹² ; Health and economic implications for coastal communities due to altered access to traditional foods ^{6, 7, 12} .		Low

α Unless indicated, all sectoral impacts are negative

Ecosystems

Communities

Fisheries and Aquaculture

Marine Infrastructure

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North Coast - Summary table for climate impacts, projected changes and sectoral impacts					
Climate Impact	Projected Changes	Evidence Quality	Sectoral Impacts	Impacts Summary ^α	Evidence Quality
Air Temperature	Average air temperature may increase by 1.7°C (1.1°C to 2.5°C) by 2050 and 2.6°C (1.5°C to 4.3°C) by 2080 ^{1, 2} ; and average temperatures may reach ~7.5°C with low emission scenario (RCP 2.6) and ~11.5°C with high emission scenario (RCP 8.5) by 2091-2100 ³ ; Likely more growing degree days: 237 (+150 to +369) growing degree days by 2050 and +362 (+213 to +700) by 2080 ¹ ; Likely more frost free days: +24 (+13 to +36) frost free days by 2050 and +37 (+18 to +58) by 2080 ¹ ; Higher winter minimum temperatures (4–9°C higher) and summer maximum temperatures (3–4°C higher) by 2080 ⁴ .	High	Higher energy requirements for heating and cooling ⁵ ; Lower water availability ² .		Medium
Precipitation	Annual precipitation may increase by 7% (3% to 12%) by 2050 and 12% (7% to 22%) by 2080, in all seasons except summer ^{1, 2} ; up to ~18% more precipitation with low emissions (RCP2.6) and ~25% more with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline ^{3, 6} ; Winter snowfall may decrease by -10% (-18% to +5%) by 2050 and -11% (-32% to -1%) by 2080 ¹ ;	High	Threats to <ul style="list-style-type: none">ecosystems and habitats⁵,species abundance and/or distribution⁵,fisheries industry^{5,6},food security⁵,slope stability²,community safety due to increased risk of landslides²; Increases in <ul style="list-style-type: none">fresh water input into oceans, associated impacts on fisheries⁶,freeze-thaw processes².		High
Sea Level Rise	Rising sea levels are likely: 0.6m to 1.2m. Areas in the northern parts may experience a greater increase ~1.2m ^{6,7} .	Medium	Threats to <ul style="list-style-type: none">ecosystems and habitats⁵,species abundance and/or distribution⁵,fisheries industry^{5,6},cultural and heritage resources^{5,7},food security and traditional food sources^{5,7},marine infrastructure, operations and transportation lanes⁵,access to, or loss of natural recreation and tourism assets⁵; Increase in coastal erosion and associated impacts on communities and marine infrastructure ⁸ .		Medium
Sea Surface Temperature	Increases in sea surface temperatures by ~2°C and average temperatures to be ~10-11.5°C by 2065-2078 ⁶ ; ~2.5°C increase in sea surface temperatures at the east of Dundas Islands ⁶ .	High	Threats to <ul style="list-style-type: none">ecosystems and habitats⁵,species abundance and/or distribution^{5, 10},fisheries industry⁵,food security⁵; Economic impacts on communities due to changes in fisheries and ecosystem health ⁵ .		Medium

Ocean Acidification	Decreasing in pH levels leading to ocean acidification ⁵ .	Low	Threats to <ul style="list-style-type: none">ecosystems and habitats^{5,9},species abundance and/or distribution⁵,fisheries industry⁵,calcifying organisms^{5,9},aquaculture industry^{5,9},commercial harvests⁵,food security⁵; Economic impacts on communities due to changes in fisheries and ecosystem health ^{5,9} .		Medium
Oxygenation	Declining dissolved oxygen levels ⁵ .	Low	Threats to <ul style="list-style-type: none">ecosystems and habitats⁵,species abundance and/or distribution⁵,fisheries industry⁵,habitat range of species that tolerate low oxygen habitats⁹;commercial harvests⁵,food security⁵; Economic impacts on communities due to changes in fisheries and ecosystem health ⁵ .		Medium
Streamflow					
Sea Surface Salinity	Decreasing sea surface salinity by ~1% (~0.2 decrease in psu unit) by 2065-2078 compared to 1995-2008 baseline ⁶ , ~1.4% increase in sea surface salinity (~0.4 increase in psu unit) around at the east of Dundas Islands ⁶ , ~8% decrease in sea surface salinity (~1.2 decrease in psu unit) around Larcom Island ⁶ , ~5% increase in sea surface salinity (~1.2 increase in psu unit) north east of Gil Island ⁶ .	High	Threats to <ul style="list-style-type: none">species abundance and/or distribution^{5, 10},fisheries industry⁵,food security⁵; Economic impacts on communities due to changes in fisheries and ecosystem health ⁵ .		Medium
Winds, Waves and Storms	Increasing frequency and severity of storm events ^{2,5} .	Medium	Threats to <ul style="list-style-type: none">ecosystems and habitats⁵,species abundance and/or distribution^{5, 10},fisheries harvests⁵,food security⁵; Economic impacts on communities due to changes in fisheries and ecosystem health ⁵ ; Increase in coastal erosion and associated impacts on communities and marine infrastructure ⁸ .		High

General	Climate change effects are expected to become even more dramatic in coming years ⁹ .	High	Threats to <ul style="list-style-type: none">species abundance and distribution¹⁰,catch potential for all commercial fisheries¹⁰,salmon catch potential¹⁰,access to traditional foods^{5,10}; Northward shift in species range and abundance ¹⁰ ; Economic, social and cultural impacts on communities due to salmon running later, berries ready earlier, and unpredictable weather observations ^{10,11} .		Medium
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α Unless indicated, all sectoral impacts are negative

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Central Coast - Summary table for climate impacts, projected changes and sectoral impacts					
Climate Impact	Projected Changes	Evidence Quality	Sectoral Impacts	Impacts Summary ^a	Evidence Quality
Air Temperature	Increasing average air temperatures by 1.6°C (0.9°C to 2.4°C) by 2050 and 2.4°C (1.3°C to 3.7°C) by 2080 ^{1, 2} ; Average air temperatures may reach between ~7°C with low emission scenario (RCP 2.6) and ~11°C with high emission scenario (RCP 8.5) by 2091-2100 ³ ; Growing degree days: +287 (+171 to +425) by 2050 and +466 (+255 to +747) by 2080 ¹ ; Frost free days: +27(+13 to +39) by 2050 and +38 (+20 to +60) by 2080 ¹ ; Increasing winter minimum temperatures by 4–9°C and summer maximum temperatures by 3–4°C by 2080 ⁴ .	High	Threats to <ul style="list-style-type: none">fisheries²,fisheries related tourism²,water supply²; Potential benefits to tourism due to longer warm seasons ² ; Potential increases in energy requirements for heating and cooling ⁵ .		Medium
Precipitation	Increasing average annual precipitation by 5% (0% to 11%) by 2050 and 9% (3% to 18%) by 2080, ~10% decrease in summer ^{1,2} ; Decreasing winter snowfall by -23% (-40% to -6%) by 2050 and -30% (-60% to -12%) by 2080 ¹ ; Increasing average precipitation by ~15% with RCP 2.6 and ~29% with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline ³ .	High	Threats on fisheries due to increases in fresh water input and associated changes in salinity levels ⁶ ; Potential damaging impacts on ecosystems and habitats ² ; Changes in access and seasonality of traditional food availability ² .		High
Sea Level Rise	Sea level rise from 0.75m to a little over 1m. Areas in the northern parts to experience a greater increase; ~1m ⁷ .	Low	Threats to <ul style="list-style-type: none">cultural and heritage resources and traditional food sources^{5,7},water quality and availability⁵,fisheries industry⁵,marine infrastructure, operations and transportation lanes⁵; Reduced access to, or loss of natural recreation and tourism assets ⁵ ; Economic impacts on communities due to changes in fisheries ⁵ .		Low
Sea Surface Temperature	Average sea surface temperature to be ~11°C with RCP 2.6 and ~14°C with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline ³ ; Increases in sea surface temperature by ~1.9°C and average temperature to be ~11-12.5°C by 2065-2078 compared to 1995-2008 baseline ⁶ .	High	Threats on fisheries industry ⁵ ; Economic impacts on communities due to changes in fishery species abundance and distribution ^{5, 9} .		Medium
Ocean Acidification	Average ~7.95 ph unit with RCP 2.6 and ~7.68 ph unit with RCP 8.5 by 2091-2100 comoared to 1961-1990 baseline ³ ; Decrease in pH levels will increase ocean acidity ⁵ .	Medium	Threats to <ul style="list-style-type: none">calcifying organisms^{5,8},aquaculture industry^{5,8},larger scale ecosystems^{5,8}; Economic impacts on communities due to changes in fisheries ^{5,8} .		Medium

Oxygenation	Decreases in dissolved oxygen levels ⁵ .	Low	Threats to <ul style="list-style-type: none">fisheries industry⁵,the habitat range of species that tolerate low oxygen habitats⁸; Economic impacts on communities due to changes in fisheries ⁵ .		Medium
Streamflow					
Sea Surface Salinity	Declining sea surface salinity by ~1.5% with RCP 2.6 and ~3% with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline ³ ; Declining sea surface salinity by ~1% (~0.2 decrease in psu unit) by 2065-2078 compared to 1995-2008 baseline ⁶ , ~4% increase in sea surface salinity (~0.8 increase in psu unit) around Penrose Island ⁶ , ~1% increase in sea surface salinity (~0.5 increase in psu unit) around Klemtu to Butedale ⁶ .	High	Impacts on <ul style="list-style-type: none">ecosystems and habitats⁵,fisheries⁶; Economic impacts on communities associated with impacts on fisheries ^{5, 9} .		High
Winds, Waves and Storms	Increasing frequency and severity of storm events ^{2,5} .	Medium	Threats to <ul style="list-style-type: none">ecosystems and habitats²,water quality and availability for communities⁵,marine infrastructure, operations and transportation lanes⁵; Impacts on climate-sensitive sectors such as tourism and fisheries ⁵ .		Medium
General	Increasing intensity of cumulative climate impacts ^{2,8} .	High	Threats to <ul style="list-style-type: none">access to traditional foods^{5,9},biodiversity⁸,species abundance and distribution⁹,catch potential for all commercial fisheries⁹,resource conservation due to ecosystem stress⁵,tourism and wildlife viewing opportunities as species distribution and habitat change⁵; Northward shift in species range and abundance ⁹ .		High

α Unless indicated, all sectoral impacts are negative

Ecosystems

Communities

Fisheries and Aquaculture

Marine Infrastructure

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Haida Gwaii - Summary table for climate impacts, projected changes and sectoral impacts					
Climate Impact	Projected Changes	Evidence Quality	Sectoral Impacts	Impacts Summary ^a	Evidence Quality
Air Temperature	Average air temperatures may increase by 1.4°C (0.8°C to 2.2°C) by 2050 and 2.2°C (1.1°C to 3.5°C) by 2080 ^{1,2} ;	High	Threats to <ul style="list-style-type: none">fisheries²,fisheries related tourism²,water supply²; Potential positive benefits to tourism due to warmer and longer summer season ² .	+	High
	South Haida Gwaii: Average air temperatures may reach ~7.5°C with low emission scenario (RCP 2.6) and ~11.5°C with high emission scenario (RCP 8.5) by 2091-2100 ³ ;				
	North Haida Gwaii: Average air temperatures may reach ~8.5°C with low emission scenario (RCP 2.6) and ~12°C with high emission scenario (RCP 8.5) by 2091-2100 ³ ;				
	Growing degree days: +317 (+182 to +506) by 2050 and +514 (+264 to +855) by 2080 ¹ ;				
Precipitation	Frost free days: +22 (+13 to +31) by 2050 and +32 (+18 to +46) by 2080 ¹ ;	High	Potential damaging impacts on ecosystems and habitats ² ;		High
	Increases in winter minimum temperatures by 4–9°C by 2080 and summer maximum temperatures by 3–4°C ⁴ .				
	Decreasing winter snowfall by -35% (-54% to -11%) by 2050 and -48% (-72% to -22%) by 2080 ¹ ;				
	South Haida Gwaii: Increasing average precipitation by ~18% (low emissions, RCP 2.6) and ~25% (high emissions, RCP 8.5) by 2091-2100 compared to 1961-1990 baseline ³ ;				
Sea Level Rise	North Haida Gwaii: Increasing average precipitation by ~20% (low emissions, RCP 2.6) and ~22% (high emissions, RCP 8.5) by 2091-2100 compared to 1961-1990 baseline ³ .				
	Extreme low projections of 0.1-0.31m, mean projections of 0.25-0.46m, extreme high projections of 0.95-1.16m ⁵ ;	Medium	Threats to <ul style="list-style-type: none">cultural and historic sites⁶,coastal development and settlements due to flooding and erosion^{7,8},marine infrastructure due to flooding and erosion^{7,8},ecosystem health, resilience and productivity as well as coastal habitats, loss of wetlands and pollution⁸; Ecological, economic, social and technological impacts and adaptation challenges ⁸ .		Medium
	Average sea level may increase by 0.7-1.32m. North and northwest coast may experience ~1.32m, northeast and the southwest coast may experience ~1-1.2m ⁶ .				
Sea Surface Temperature	South Haida Gwaii: Average sea surface temperature to be ~11.75°C with RCP 2.6 and ~14°C with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline ³ ;	High	Potential positive benefits to seagrasses and the kelp species <i>Macrocystisspp</i> ⁵ ;	+	High
	Increasing sea surface temperature by up to 1.5°C in less than 100 years ⁵ ; or by ~2.1°C compared to 1995-2008 baseline ⁹ ; average temperature to be ~10.5-12.5°C by 2065-2078 ⁹ .				
Ocean Acidification	Decreasing ocean pH levels. South Haida Gwaii: Average ~7.96 ph unit with RCP 2.6 and ~7.69 ph unit with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline ³ .	High	Threats to <ul style="list-style-type: none">calcifying organisms^{5,8},aquaculture industry^{5,8},larger scale ecosystem effects^{5,8}; Economic impacts on communities due to impacts on aquaculture and potential impacts on fisheries ^{5,8} .		Medium

Oxygenation	Declining ocean oxygen levels ⁹ .	High	Impacts on <ul style="list-style-type: none">ecosystems and habitats due to decreased salinity levels⁵,fisheries due to increases in fresh water input and associated changes in salinity levels⁹.		High
Streamflow	Changing timing of streamflow - earlier freshet, less snowpack, higher water volume earlier in spring ⁸ .	Low	Threats on salmon migration, spawning, and incubation ⁸ .		Low
Sea Surface Salinity	South Haida Gwaii: Decreasing sea surface salinity by ~1% with RCP 2.6 and ~3.4% with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline ³ ;	High	Impacts on <ul style="list-style-type: none">ecosystems and habitats due to decreased salinity levels⁵,fisheries due to increases in fresh water input and associated changes in salinity levels⁹.		High
	Decreasing sea surface salinity by less than 1% (~0.3 decrease in psu unit) by 2065-2078 compared to 1995-2008 baseline ⁹ , ~5% decrease in sea surface salinity (~1.2 decrease in psu unit) around Masset Inlet ⁹ .
Winds, Waves and Storms	Stronger future storm events ^{2,10} and increases in storm surge frequency ² .	High	Threats to <ul style="list-style-type: none">ecosystems and habitats²,coastal development and settlements due to flooding and erosion^{2,8},marine infrastructure and flood protection infrastructure due to severe weather events and associated wave and erosion damage^{2,7,8},critical infrastructure such as utility lines, power, communications transmissions, and access to grocery and other supplies^{8,11},marine and land transportation lanes due to severe weather events^{8,11}.		High
General	Increasing intensity of cumulative climate change impacts ⁵ .	High	Threats to <ul style="list-style-type: none">species abundance and distribution¹²,catch potential for all commercial fisheries¹²,salmon catch potential¹²,access to traditional foods^{5,12}; Northward shift in species range and abundance ¹² .		High

^a Unless indicated, all sectoral impacts are negative

Ecosystems

Communities

Fisheries and Aquaculture

Marine Infrastructure

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APPENDIX 1: GLOSSARY

Adaptation:	Adjustment in natural human systems to a new or changing environment. Activities that reduce the negative impacts of climate change and/or take advantage of new opportunities that arise from those impacts. Adaptations can be anticipatory (taken before the impacts are observed) or reactive (taken after the impacts have occurred). Adaptation actions can be planned (through deliberate policies and planning) or reactive (through spontaneous, in the moment responses) (Warren and Lemmen 2014; IPCC 2014).
Adaptation benefits:	The avoided costs or the benefits of following the adoption and implementation of adaptation actions (IPCC 2014).
Adaptation costs:	The costs of planning, preparing for, facilitating, and implementing adaptation actions (IPCC 2014).
Adaptive capacity:	A measure of a system’s ability to adjust to change, to take advantage of the opportunities, or cope with the consequences. Used to describe a set of conditions that may allow adaptation to external stressors. Social indicators of high adaptive capacity include social capital, institutional learning, network restructuring, use of experiential knowledge, and flexibility in problem solving. Ecosystems with high adaptive capacity may exhibit high functional redundancy, connectivity among habitats, or contain species with high population diversity or phenotypic plasticity ((Bohensky et al. 2010, Marshall et al. 2010, Biggs et al. 2012, IPCC 2014).
Adverse effects:	One or more of the following impacts: <ul style="list-style-type: none">• Reduction of the quality of a natural ecosystem for any use or value that can be made from it;• Injury or damage to property, species, or community;• Harm or material discomfort to anyone;• Negative effects on human health;• Making a place or ecosystem unfit for human use values;• Loss of enjoyment of a natural place;• Interference with normal life or business.
Climate change:	A change in the mean state of the climate, or in climate variability, that persists for decades or longer. This can be reflected in warming of mean air or water temperatures, and also changes in the frequency and intensity of extreme weather events such as heat waves, heavy rain, storms, and drought. Recent and rapid climate change is attributed to human activities, including the burning of fossil fuels and management actions such as land use changes, that alter the composition of the global atmosphere in addition to natural climate variability (UNFCCC, IPCC 2014).
Climate scenario:	A projection of future climate conditions.

Climate variability:	Fluctuations in climate over a shorter term that differ from long term averages or trends, over seasons or several years, such as the El Niño Southern Oscillation phenomenon (UNFCCC).
Impact:	The consequences or product of climate change, such as changes to air temperature or ocean temperature. Something that logically occurs from a condition related to climate change or climate variability.
IPCC:	Intergovernmental Panel on Climate Change. A group of several thousand qualified experts who review and assess, periodically, all published climate change research.
Hazard:	A source of potential harm, or a situation with the potential for causing harm, in terms of damage to human health, property, the environment, other things of value, or a combination of these.
Ecosystem based management (EBM):	An adaptive approach to managing human and natural systems so that healthy functioning ecosystems may coexist with human communities. The MaPP EBM framework has three key elements: Ecological integrity, Human well-being, and Governance.
Resilience:	The ability of a system to maintain its current identity, structure, and function through change or disturbance (Adger 2000, Walker et al. 2004).
Representative Climate Pathway (RCP):	RCPs describe potential 21st century scenarios of greenhouse gas (GHG) emissions, atmospheric GHG emissions, aerosols, and land use impacts. RCPs are used for making projections as to the impacts of climate change, and are based on the factors that drive human GHG emissions: population size, economic activities, lifestyle choices, energy use, land use patterns, technology adoption, and climate policy. Hence, each of the RCP scenarios directly relate to the choices made by global society (IPCC 2014, PCIC 2013).
Risk:	The change of loss as a product of the frequency of occurrence and the severity of the consequence, such as an adverse effect to the environment or property or other thing of value. The level of risk is also affected by the impact to stakeholders.
Sea surface height (SSH):	A measure of the difference between the actual height of the sea surface and that which it would have been if the ocean were at rest; the thickness of the water column from the seabed to the free surface of the ocean can be affected by tides, stratification, winds, and currents.
Stakeholder:	Any individual, group, or organization able to affect, be affected by, or believe they might be affected by a decision or activity. Decision makers are also stakeholders.
UNFCCC:	The United Nations Framework Convention on Climate Change (1992).
Vulnerability:	A measure of a system’s susceptibility to change or a particular impact, and the inability to cope with that impact. A function of the exposure, sensitivity, and adaptive capacity of a system. Vulnerability to climate change is therefore the function of the character, size, and rate of climate variation to which a system is exposed to, its sensitivity, and its adaptive capacity (IPCC 2014).

APPENDIX 2: SOME CLIMATE CHANGE PROJECTIONS AND IMPACTS ON FISHERIES AND AQUACULTURE WITHIN COASTAL BC

Appendix 2 Table 1: Summary of climate impacts on key fisheries in the north Pacific and British Columbia [92,160].

Fisheries species of interest	Ecological variable affected by climate change	Probable impacts
Sablefish (<i>Anoplopoma fimbria</i>)	Ocean temperature	May negatively affect egg, larval and juvenile survival. Declining ocean productivity may affect recruitment. Overall: Climate change over the next 50 years may not impact adult sablefish or long term population dynamics. Projected change in relative abundance of -9 to -11% by 2050.
Pacific herring (<i>Clupea pallasii</i>)	Ocean temperature	Herring ocean habitats will be affected. Predation from increasing populations of Pacific hake may affect herring populations. Overall: Abundance is projected to decline by 32-49% by 2050.
Pacific hake (<i>Merluccius productus</i>)	Ocean temperature	Hake biomass may increase. More migration into northern range (BC waters) Overall: Abundance may increase.
Pacific halibut (<i>Hippoglossus stenolepis</i>)	Ocean temperature	Overall: May reduce recruitment. Projected change in relative abundance of -12 to -13% by 2050.
Pacific ocean perch (<i>Sebastes alutus</i>)	Ocean temperature	Overall: Recruitment may decline if Aleutian Lows decrease.
Pacific sardine (<i>Sardinops sagax</i>)	Ocean temperature Oceanographic conditions	Unlikely to impact or unknown projected change in relative abundance of 33-44% by 2050.
Pacific cod (<i>Gadus macrocephalus</i>)	Ocean temperature	Likely to severely deplete populations by reducing or eliminating recruitment. Projected change in relative abundance of -13 to -35% by 2050.
Pink salmon (<i>Oncorhynchus gorbuscha</i>)	Ocean temperature River temperatures Oceanographic conditions	Overall: Abundance is likely to decline, particularly for southern populations. Projected change in relative abundance of -40 to -44% by 2050.
Sockeye salmon (<i>Oncorhynchus nerka</i>)	Ocean temperature River temperatures Oceanographic conditions	Mortality is likely to increase during all life stages when exposed to warm water temperatures. Overall: Abundance is very likely to decline, particularly for southern populations. Projected change in relative abundance of -10 to -36% by 2050.
Chum salmon (<i>Oncorhynchus keta</i>)	Ocean temperature River temperatures Oceanographic conditions	Mortality is likely to increase, but uncertainty is high. Overall: Abundance is likely to decline, particularly in the southern portion of the coast. Projected decline in relative abundance of 10-12% by 2050.

Appendix 2 Table 2: Summarized key risks and knowledge gaps related to ocean acidification (OA) [52,63]

Species	Details	Sectoral impact	Uncertainty or opportunity
Shellfish	Shell formation will be negatively affected by OA Increasing toxicity of harmful algae blooms	Fisheries and aquaculture	Wild shellfish may be more able to adapt than farmed. No studies yet on geoduck clams. Likely to be increasing shellfish closures, Potential for decreased reproductive success and mass mortality at higher trophic levels (predators) including fish, seabirds, marine mammals
Salmon (farmed Atlantic salmon, <i>Salmo salar</i>)	Algae blooms are likely to increase (fish killing alga <i>Heterosigma akashiwo</i>)	Fisheries and aquaculture	High uncertainty
Food web dynamics	Changes in species composition of phytoplankton's Decline of pteropods Potential decline of echinoderms Observed behavioural changes at various trophic levels e.g. decreased predator avoidance in larval fish Potential behavioral changes at various trophic levels, e.g. increased movement to refugia, eelgrass meadows	Ecosystems Fisheries and aquaculture	High uncertainty Likelihood of impacts at higher trophic levels (fish) e.g. Pink salmon (<i>Oncorhynchus gorbuscha</i>). Likelihood of impacts to predators e.g. rockfish and flatfish. Significant knowledge gaps.
Algae	Changing algal species e.g. upright macroalgae may shift to algal turf. This will change habitats for juvenile fish Declining coral species (especially octocorals) Seagrasses are likely to benefit from increased carbon, but increased grazing will have negative effects. Net effect will be neutral for seagrasses.	Fisheries and aquaculture Ecosystems	High uncertainty
Finfish	Potential difficulties with olfaction (sense of smell), osmoregulation, and cardiorespiratory control Direct negative impacts (reproduction, growth rates, survival) at high levels of carbon dioxide	Fisheries and aquaculture	High uncertainty Minimal research Significant knowledge gap

Crustaceans	Crabs may be negatively affected Juvenile stages of all crustaceans are more vulnerable	Fisheries and aquaculture	Significant knowledge gap
Marine mammals	Ocean acidification may lead to a 'noisier' ocean which could impact marine mammals	Ecosystems	Uncertainty exists

Unknown/not studied: Cold water corals (Octocorals), glass sponges

APPENDIX 3: GENERAL ADAPTATION ACTIONS FOR CLIMATE IMPACTS AND SECTORS

Appendix 3 Table 1. Recommended adaptation actions for conservation and management.

Climate change projection	Regional or Sub-regional impacts, by sector	Suggested Adaptation Actions
Warming ocean temperatures	Fisheries: Shifting species ranges	Consider adaptive or dynamic ocean management [161,162] Fisheries: Adapt fisheries allocations after species abundance/distributions have changed [122] Adjust fishing practices or gears to new species or changing fishery openings [122]
Ocean acidification	Aquaculture: Declining productivity, larval survival, and reproductive capacity of calciferous organisms	Consider land-based saltwater flow-through aquaculture systems as an alternative to at-sea net pen aquaculture systems
Sea level rise	Ecosystems: Intensifying storms and warming oceans will affect coastal regions through erosion and degradation of shorelines and wetlands	Marine reserves: Nearshore habitat protection can reduce loss and damage, and promote intact habitats that offer natural coastal defense, ultimately supporting human livelihoods and ecological recovery [151]
Wind, waves, and storm events	Higher coastal erosion and flooding	Apply a precautionary approach: Use extreme recurrences for both winds and water levels in setting scenarios for mitigation and adaptation. Research gaps: Impacts of storm surges, especially on low lying regions. More modeling is needed to improve projections of storm events and impacts including changes in frequency, intensity, and direction of future extreme events.

MAPPING: MAPP REGIONAL AND SUB-REGIONAL PROJECTIONS AND SECTORAL IMPACTS

MaPP Region: Marine Infrastructure

Vertical allowances by 2100 (RCP 4.5)
Recommended changes in coastal infrastructure
elevation to maintain current flood risk

MaPP Region: Marine Infrastructure

MaPP Region: Marine Infrastructure

MaPP Region: Fisheries Infrastructure

NE Pacific: Precipitation Flux Projections

NE Pacific: Precipitation Flux Projections

MaPP Region Sea Level Change Projections

MaPP Region Sea Level Change Projections

MaPP North Coast: Sea Level Anomaly 2100

Data Source: IPCC AR5 (Church et al. 2013a, 2013b)

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

MaPP North Coast: Sea Level Anomaly 2100

Data Source: IPCC AR5 (Church et al. 2013a, 2013b)

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

**MaPP Central Coast: Sea Surface Temperature
1995-2008 vs. 2065-2078**

Baseline: 1995-2008
Data Source: Foreman et al.

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

**MaPP North Coast: Sea Surface Temperature
1995-2008 vs. 2065-2078**

Baseline: 1995-2008
Data Source: Foreman et al.

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

NE Pacific: Sea Surface Temperature Flux Projections

NE Pacific: Sea Surface Temperature Flux Projections

NE Pacific: Surface pH Flux Projections

NE Pacific: Surface pH Flux Projections

MaPP North Vancouver Island: Sea Surface Salinity 1995-2008 vs. 2065-2078

Baseline: 1995-2008
Data Source: Foreman et al.

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

MaPP Central Coast: Sea Surface Salinity 1995-2008 vs. 2065-2078

Baseline: 1995-2008
Data Source: Foreman et al.

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

MaPP Central Coast: Sea Surface Salinity 1995-2008 vs. 2065-2078

Baseline: 1995-2008
Data Source: Foreman et al.

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

MaPP North Coast: Sea Surface Salinity 1995-2008 vs. 2065-2078

Baseline: 1995-2008
Data Source: Foreman et al.

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

MaPP North Coast: Sea Surface Salinity 1995-2008 vs. 2065-2078

Baseline: 1995-2008
Data Source: Foreman et al.

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

MaPP Haida Gwaii: Sea Surface Salinity 1995-2008 vs. 2065-2078

Baseline: 1995-2008
Data Source: Foreman et al.

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

MaPP North Vancouver Island: Shoreline Sensitivity to Sea Level Rise

Data Source:
Doug Biffard and Tory Stevens, 2014.
BC Parks Shoreline Sensitivity to Sea Level Rise Model

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

MaPP Central Coast: Shoreline Sensitivity to Sea Level Rise

Data Source:
Doug Biffard and Tory Stevens, 2014.
BC Parks Shoreline Sensitivity to Sea Level Rise Model

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
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Projection: Transverse Mercator
Datum: North American 1983

MaPP Haida Gwaii: Shoreline Sensitivity to Sea Level Rise

Data Source:
Doug Biffard and Tory Stevens, 2014.
BC Parks Shoreline Sensitivity to Sea Level Rise Model

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

MaPP Central Coast: Archaeological Sites Highly Sensitive to Sea Level Rise

Data Source: Overlay of
Archaeology Branch, FLNRO, and Coastal Resource Mapping Ltd.
BC Parks Shoreline Sensitivity to Sea Level Rise

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

MaPP North Coast: Archaeological Sites Highly Sensitive to Sea Level Rise

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