

A group of people are in a traditional Indigenous canoe on a body of water. The canoe is dark with red and white patterns. One person is standing at the stern, wearing a red life vest and a black cap. Several other people are seated in the canoe, some wearing hats. The water is calm, and the background shows a shoreline with trees under a clear sky.

# EXECUTIVE SUMMARY OF NORTHERN SHELF BIOREGION CLIMATE CHANGE ASSESSMENT:

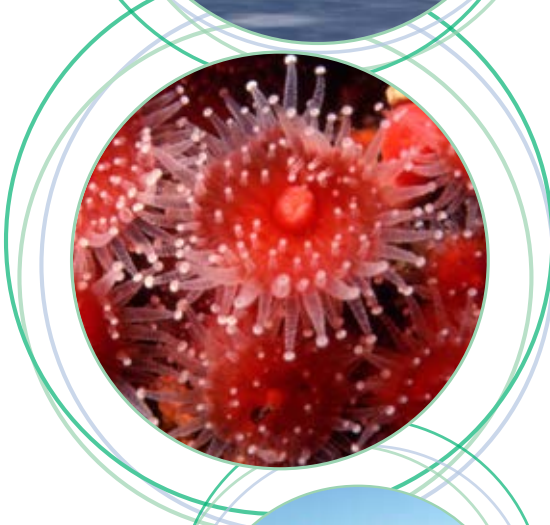
Projected climate changes,  
sectoral impacts, and  
recommendations for  
adaptation strategies across  
the Canadian North Pacific  
Coast (2019)



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**University  
of Victoria**

## **EXECUTIVE SUMMARY OF**

# **NORTHERN SHELF BIOREGION CLIMATE CHANGE ASSESSMENT:**

## **PROJECTED CLIMATE CHANGES, SECTORAL IMPACTS, AND RECOMMENDATIONS FOR ADAPTATION STRATEGIES ACROSS THE CANADIAN NORTH PACIFIC COAST (2019)**

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Photo by Janie Wray

This document summarizes the findings of a larger report, “Northern Shelf Bioregion Climate Change Assessment: Projected climate changes, sectoral impacts, and recommendations for adaptation strategies across the Canadian North Pacific Coast” (2018) prepared for the Marine Plan Partnership for the North Pacific Coast (MaPP) by researchers at the University of Victoria’s Ethnoecology Lab and UBC’s Institute for Resources, Environment and Sustainability.

The full report is available at <https://marxiv.org/rfnk3/> and an interactive web-based version is at <https://northernshelf.docu.li>



Photo by Joanna Smith



## 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 of the full report.

**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.

# CONTENTS

<b>IMPORTANT TEMINOLOGY</b>	<b>iii</b>
<b>INTRODUCTION</b>	<b>1</b>
Limitations	2
Climate Change Threats	2
The Marine Plan Partnership for the North Pacific Coast	4
Social-Ecological Context and Management: BC and the Northern Shelf Bioregion	4
<b>METHODOLOGY</b>	<b>5</b>
<b>GLOBAL AND REGIONAL CLIMATE CHANGE TRENDS</b>	<b>6</b>
<b>REGIONAL CLIMATE CHANGE PROJECTIONS</b>	<b>7</b>
Air temperature	7
Precipitation	7
Sea level rise	8
Sea surface temperature	8
Ocean acidification	8
Ocean deoxygenation	9
Sea surface salinity	9
Extreme weather events	9

<b>ESTIMATED REGIONAL IMPACTS ASSOCIATED WITH CLIMATE CHANGE PROJECTIONS</b>	<b>10</b>
<b>ECOSYSTEMS</b>	<b>10</b>
Air temperature and precipitation	11
Sea level rise	11
Sea surface temperature	12
Ocean acidification	12
Ocean deoxygenation	12
Sea surface salinity	13
Other impacts	13
<b>FISHERIES AND AQUACULTURE</b>	<b>14</b>
Sea level rise	14
Sea surface temperature	15
Ocean acidification	15
Ocean deoxygenation	15
<b>HUMAN COMMUNITIES</b>	<b>16</b>
Air temperature and precipitation	17
Sea level rise	17
Sea surface temperature	17
Ocean acidification	18
Winds, waves, and extreme weather	18
<b>MARINE INFRASTRUCTURE</b>	<b>18</b>
Sea level rise	18
Winds, waves, and extreme weather	19
<b>TABLE: PREDICTED CLIMATE CHANGE IMPACTS ACROSS REGION</b>	<b>20</b>
<b>MOVING FORWARD: ADAPTATION</b>	<b>24</b>
<b>CONCLUSION</b>	<b>25</b>









Photo by Gerd and Linda Mueller

## 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 Executive Summary, the full report, and an interactive web-based version of the report were developed in collaboration with the Marine Plan Partnership for the North Pacific Coast (MaPP), whose planning region (the 'MaPP region') is similar to the geographic area known as the Northern Shelf Bioregion (NSB). These educational tools were developed to help guide future research and climate change adaptations in the region, specific to the interests of MaPP. Outlined in the tools are the current available knowledge on climate change projections with associated impacts, exposure, and risks to the coastal social-ecological system of the MaPP region.

Climate-associated impacts, exposure, and risks are presented for four key sectors of the coastal social-ecological system in the NSB:

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

Key climate change projections for the MaPP region are included in this Executive Summary based on the literature and expert interviews. In the full report, information is provided specific to the four MaPP sub-regions where possible given the scale of the data. Also in the full report, differences and similarities among and between the four MaPP sub-regions are highlighted, if and where feasible given the data. Here, gaps in knowledge and ongoing adaptation actions in the region are identified, and further adaptation actions are recommended based on the literature. As well, recommendations for future research on climate change impacts, vulnerability (including exposure, sensitivity, and adaptive capacity), and risk, in this region, are included. Ongoing and planned climate change research pertaining to the key areas of interest to MaPP is presented to help guide future adaptation work.

## LIMITATIONS

The full report on which this Executive Summary is based is not a comprehensive assessment of climate change impacts in BC's coastal marine environment, nor does it offer new analyses or model outputs projecting climate impacts within the NSB. Rather, it focuses on a baseline assessment of known climate impacts and risks to the NSB, to determine the strategic next steps that could be taken to address the needs of coastal communities within the MaPP region. The full report was written from an extensive literature review and discussions with experts involved in relevant research within the coastal region of BC. Information was collected within the constraints of the scope, budget, and time for the project. Research and discussions focused on issues of relevance to climate change impacts and adaptation planning in BC, Canada, and specifically the NSB when possible.

There is still a great deal of uncertainty in global climate change projections for coastal regions, and the associated vulnerabilities and risks. Part of this uncertainty is due to lack of or limited access to reliable and continuous data sources. 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. While the full report on which this Executive Summary is based was based on available peer reviewed literature and federal and provincial government agency reports, and informed by the insights of several key experts, the synthesis of baseline information is entirely the responsibility of the authors.

## 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, and 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 global temperatures are predicted to continue to rise. The next few decades will bring increasing impacts and challenges, as global air temperatures are likely to increase by 2-5° C by 2100.

All economic sectors and communities in Canada will be affected by the impacts of climate change. Coastal regions and communities may be particularly vulnerable because of their dependence upon marine resources, a high level of exposure to many climate effects, and sometimes low ability to adapt to global change. However, coastal communities may also be well situated to make proactive decisions to manage the direct risks and associated impacts from climate change. This Executive Summary, and the full report on which it is based, are aimed at guiding the next steps for research and implementation of climate change adaptation strategies for the MaPP region (Figure 1).



Photo by  
Warren  
Nelson



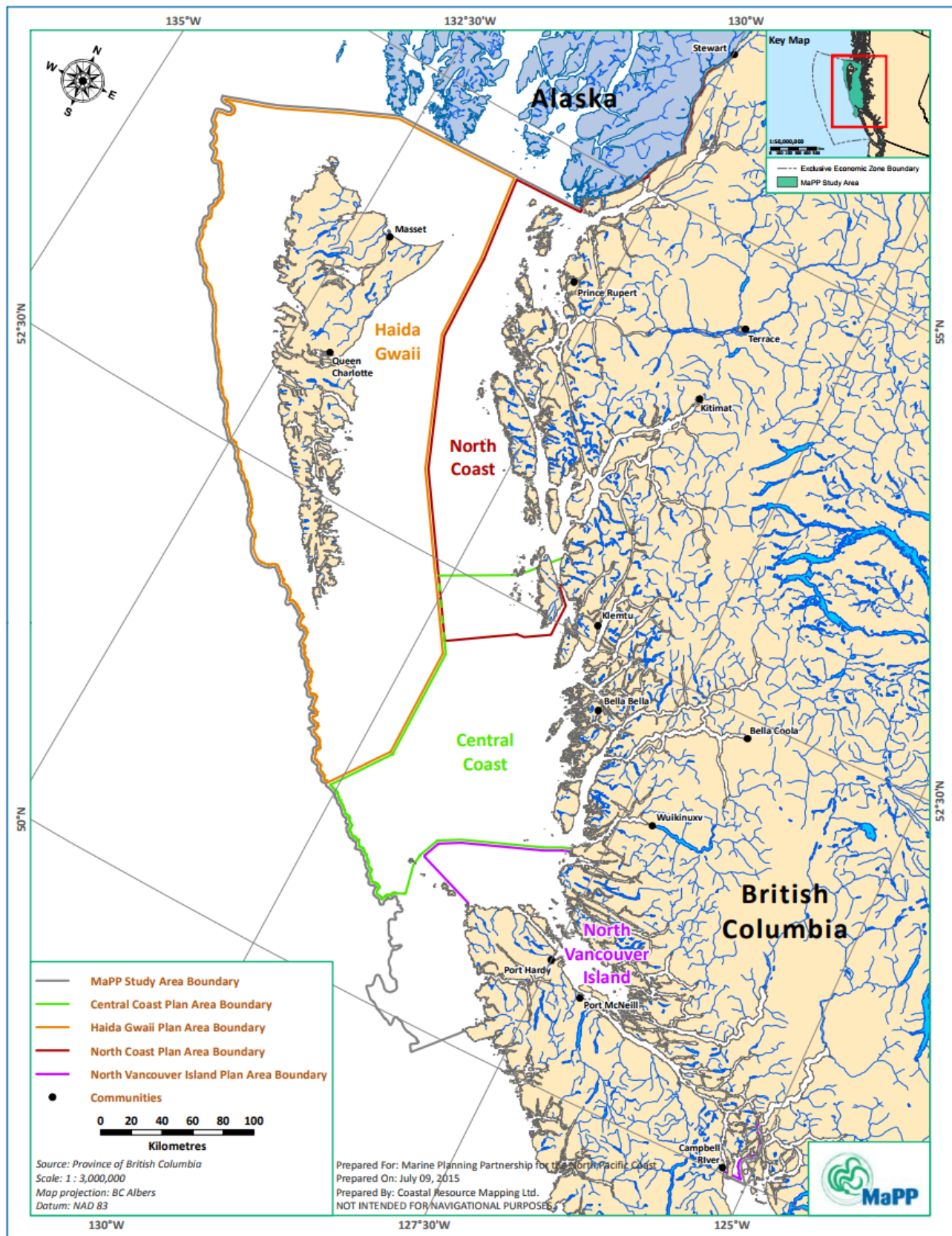


Figure 1: The MaPP region (i.e. the Northern Shelf Bioregion), showing the boundaries of the four sub-regions and main communities. The sub-regional boundaries follow the Northern Shelf Bioregion boundary, except for a small area near the western tip of North Vancouver Island





Photo by Jessica Hawryshyn

## THE MARINE PLAN PARTNERSHIP FOR THE NORTH PACIFIC COAST

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Through MaPP, the provincial government and First Nations in BC are working collaboratively towards sustainable development, improving economic opportunity, and supporting ecological integrity for the North Pacific Coast. 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. 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.

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

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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.

Ecologically speaking, Canada's Pacific coast is a highly dynamic and complex region. 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.

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). These changes are contributing to biological changes such as shifting species distributions, which in turn affect human communities. 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.



Photo by Ryan Miller

## METHODOLOGY

The current state of understanding of climate change projections, impacts, and vulnerabilities (exposure, specifically), risk, and adaptation within the MaPP region was synthesized by reviewing relevant resources and spatial data. Projections and impacts were synthesized so that they were specific to the MaPP region and sub-regions, where

possible. Information came from peer-reviewed literature, provincial and federal government reports (grey literature), and from interviews and emails with key contacts and researchers. Except for some fundamental background information, only publications from the year 2000 and newer were included.





Photo by Jessica Hawryshyn

## GLOBAL AND REGIONAL CLIMATE CHANGE TRENDS

The Intergovernmental Panel on Climate Change (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. The most recent global projections of climate change impacts and vulnerabilities from the IPCC are based on models of Representative Concentration Pathways (RCPs). The RCP scenarios specify concentrations of greenhouse gases, and are used to project impacts related to climate change.

Uncertainty in climate change projections is presented 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, 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 were 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 available through the Pacific Institute for Climate Solutions (<https://www.pacificclimate.org>) 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).





Photo by Ian McAllister

## Air temperature

BC is expected to warm more than the global average. 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. On average, air temperatures are likely to increase by 0.1-0.6°C per decade. The summer growing season is projected to lengthen and frost-free days to increase by 20-30 days by 2050-2080 (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.

## Precipitation

Projected changes in precipitation in BC are expected to be relatively minor, especially when compared to the historical variability in the province. 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%. Wetter winters are projected to lead to increased runoff in

ivers 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. 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. 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.

Extreme precipitation events will likely increase during some seasons and in some areas of the province. 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. More frequent atmospheric river events after 2040 (approximately double the current number per year) will affect ecosystems along the coast.





Photo by Doug Neasloss

## Sea level rise

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. Global climate models project that the average global sea level will rise by up to 100-120cm by 2100. 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 20-30cm by 2100 (90% confidence interval of 10-50cm) (see MaPP region Summary Table).

## Sea surface temperature

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) (see MaPP region Summary Table). The rate of ocean temperature increase may accelerate, as consistent with the accelerating rise in global sea surface temperatures.

## Ocean acidification

Ocean acidification is occurring faster as higher latitude areas, due to the effects of temperature on carbon dioxide absorption. 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. 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 (RCP 8.5 and RCP 2.6, respectively) by 2091-2100.

## **Ocean deoxygenation**

Ocean oxygen concentrations have been declining in both pelagic (open ocean) and coastal waters for at least the past half-century. Oxygen minimum zones in the open ocean have increased in area, and some coastal areas have low enough oxygen concentrations to have affected marine species distributions and abundances. 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. Seafloor habitats in the North Pacific could experience a reduction of 0.7-3.7% in oxygen levels by 2100.

## **Sea surface salinity**

Ocean salinity is declining globally, along the BC coast, and within the MaPP region. 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 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. Salinity effects also influence total sea level rise through ocean expansion through global ocean warming.

## **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. 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.



Photo by Barb Dinning





Photo by Scott Harris

## 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. 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.

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. Here (and in the full report), predicted climate change impacts from the

climate change projections, and probable exposure and risk to four key sectors are presented for the MaPP Region. The sectors are: ecosystems, fisheries and aquaculture, First Nations and non-First Nations communities, and marine infrastructure. In the full report, further details are provided at the sub-regional scale, where possible.

### 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. The cumulative effects of climate change on the food webs of the northeast Pacific may lead to a 30% reduction in total ecosystem biomass.



## Air temperature and precipitation

Air temperatures are projected to increase at 0.3°C per decade in BC, still less than is expected across the country as a whole. 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.

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, 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. 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. The increase in freshwater volume entering coastal marine waters may also decrease sea surface salinity and 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.

## 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.

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). Highly sensitive areas within the MaPP region include the northeast corner of Haida Gwaii. For both the MaPP region and sub-regions, some moderate and high sensitive areas correspond with culturally important (First Nations) archaeological sites.

Photo by Barb Dinning







Photo by Joanna Smith

## Sea surface temperature

Increasing sea surface temperatures are likely to affect zooplankton biomass, contributing to overall biomass declines of lower trophic level species. 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. Phytoplankton species composition is also likely to change, which could also affect higher trophic levels who depend on high quality zooplankton. 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.

## Ocean acidification

Ocean acidification will certainly continue to affect coastal BC, although there are significant knowledge gaps in terms of the effects of ocean acidification on marine organisms. 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). 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.

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. 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.

## Ocean deoxygenation

The expansion of low oxygen zones will affect ecosystem structure and function, especially in the deep sea, and in the deep coastal fjords of the



northern coast of BC due to their geomorphological and chemical conditions. 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.

### **Sea surface salinity**

Changes in salinity can affect both sexual reproduction and vegetative propagation of seagrasses. 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.

### **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. These changes could negatively affect marine fish and invertebrate recruitment, but the specifics of this impact are currently unknown.



Photo by Jessica Hawryshyn



Fisheries and aquaculture are very important 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. 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. 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.

### 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). 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. For example, this may be problematic for Pacific herring, which prefers coastal marine algal species for spawning substrate, habitats that may potentially be lost as sea levels rise.



Photo by Birgitte Bartlett



## Sea surface temperature

Fisheries responses to climate change impacts will vary both regionally and by species. Species particularly vulnerable to increasing ocean temperatures include Pacific salmonids. For example, there is a 17-98% chance of 'catastrophic' loss of a Chinook salmon population by 2100, depending on the emissions scenario. 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. 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. 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.

Pelagic fisheries that may be especially affected by increasing sea surface temperature include Pacific herring, Pacific sardine, and Pacific salmon. 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. 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.

## Ocean acidification

The effects of ocean acidification on fisheries are largely unknown, including on the important salmon and Pacific halibut fisheries. In tropical fish, ocean acidification affects behaviour and results in increased mortality, but species responses in temperate regions are unknown. 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.

The effects of ocean acidification on shelled organisms, however, are much more understood. 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). 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, and changes to oceanographic conditions including acidification are likely to affect finfish aquaculture as well. 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.

## 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. Declining oxygen levels, and increasing hypoxia, will also likely affect aquaculture operations for vulnerable species, such as Dungeness crab and spot prawns. Some hypoxia tolerant species (e.g. squid, jellyfish) may increase in abundance and/or distribution, potentially outcompeting less tolerant species (e.g. finfish).



Photo by Birgitte Bartlett

## 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 BC is largely based on the recreational tourism (33%), transport (29%), and seafood (12%) sectors. 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.

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. 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.





Photo by Scott Harris

### **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. 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. 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. 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). Most of the north coast of BC 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 that is amongst Canada's most sensitive coastlines to climate change.

Many remote coastal communities and First Nations heritage sites are vulnerable to enhanced erosion and storm-surge flooding associated with sea level. In addition, groundwater quality could decline due to saltwater intrusion as sea levels rise.

### **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 and also decline in abundance.

## Ocean acidification

Ocean acidification will impact coastal communities that are directly dependent on calcareous organisms such as shellfish for food and income. Acidification will also affect fisheries through negative impacts on food web dynamics and lower trophic level organisms. 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.

## 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 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.

## MARINE INFRASTRUCTURE



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. Sea level rise is expected to inundate some of the critical infrastructure at the coastal areas. A recent analysis found that the costs of sea level related damage to onshore built infrastructure would be higher in coastal BC than any other coastal region in Canada.

Some communities in BC have begun to take action to reduce the risk of sea level rise through



Photo by Erin Mutrie



investments in built infrastructure for shoreline protection as an adaptation measure. 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.

### **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. Properties along the coast also will experience increased risk of wave damage, 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. 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. 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.

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. 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. 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.


















Photo by Gilian Dusting







# TABLE: PREDICTED CLIMATE CHANGE IMPACTS ACROSS REGION

Ecosystems		Fisheries and Aquaculture	
Communities		Marine Infrastructure	

MaPP Region - Summary table for climate impacts, projected changes and sectoral impacts					
Climate Impact	Projected Changes	Evidence Quality <sup>†</sup>	Sectoral Impacts	Impacts Summary <sup>α</sup>	Evidence Quality <sup>†</sup>
<b>Air Temperature</b>	<p>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<sup>1,2,3</sup>; 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<sup>4*</sup>;</p> <p>Growing degree days: +283 (+179 to +429) 2050 and +468 (+262 to +769) by 2080<sup>1</sup>;</p> <p>Frost free days: +20(+12 to +29) by 2050 and +30 (+16 to +48) by 2080<sup>1</sup>;</p> <p>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<sup>5</sup>.</p>	High	<p><b>Threats to</b></p> <ul style="list-style-type: none"> <li>fisheries<sup>2</sup>,</li> <li>ecosystem, hydrology, and habitats<sup>3,5</sup>,</li> <li>nearshore marine mammals<sup>5,6</sup>,</li> <li>fisheries related tourism<sup>2</sup>,</li> <li>water supply<sup>2</sup>,</li> <li>human health and well-being<sup>7</sup>;</li> </ul> <p><b>Potential increases in</b></p> <ul style="list-style-type: none"> <li>frequency and intensity of toxic algal blooms<sup>6</sup>,</li> <li>Potential benefits to tourism due to longer warm seasons<sup>2</sup>.</li> </ul>	  	High
<b>Precipitation</b>	<p>Increasing average annual precipitation by 6% (2% to 12%) by 2050 and 9% (4% to 17%) by 2080, 10% decrease in summer<sup>1,2*</sup>; up to ~18% more precipitation (low emissions, RCP2.6) and ~25% (high emissions, RCP8.5) by 2091-2100 compared to 1961-1990 baseline<sup>4</sup>;</p> <p>Declining winter snowfall by -10% (-17% to +2%) by 2050 and -12% (-26% to -1%) by 2080<sup>1</sup>;</p> <p>Winter precipitation increase by 10-25%, summer precipitation increase by 20% by 2050<sup>8</sup>; overall precipitation increase in fall, winter and spring seasons<sup>2,3,9,10,11</sup>.</p>	High	<p><b>Threats to</b></p> <ul style="list-style-type: none"> <li>marine infrastructure, operations and transportation lanes<sup>10</sup>;</li> </ul> <p><b>Increased</b></p> <ul style="list-style-type: none"> <li>freshwater discharges and associated turbidity, flow of contaminants, pathogens and nutrients<sup>5,11,12</sup>,</li> <li>summer drought and water scarcity for communities due to earlier freshet in the spring<sup>9</sup>;</li> </ul> <p><b>Changing salinity levels and stronger Vancouver Island Coastal Current<sup>12</sup>;</b></p> <p><b>Potential damaging impacts on ecosystems, ecosystem dynamics, and habitats<sup>2</sup>;</b></p> <p><b>Changes in access and seasonality of traditional foods and food availability<sup>2</sup>.</b></p>	   	High
<b>Sea Level Rise</b>	<p>Rising sea levels from 80cm to 120cm<sup>13</sup> or from 20cm to 130cm<sup>3</sup> by 2100;</p> <p>Increases by ~25.1cm in Prince Rupert; ~9.3cm in Queen Charlotte; ~8.4cm in Bella Bella; ~13.9cm in Winter Harbour by 2100<sup>8</sup>;</p> <p>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<sup>14</sup>.</p>	High	<p><b>Threats to</b></p> <ul style="list-style-type: none"> <li>fish, invertebrates<sup>6</sup>,</li> <li>coastal plants, algae and inter-tidal habitat<sup>6</sup>,</li> <li>First Nations' heritage sites<sup>10,12,15,16,17</sup>,</li> <li>groundwater quality due to salt water intrusion<sup>15</sup>;</li> </ul> <p><b>Increased coastal flooding and erosion risks on communities<sup>10,12,15,16,17</sup>;</b></p> <p><b>Economic impacts on</b></p> <ul style="list-style-type: none"> <li>built environment and communities<sup>10</sup>,</li> <li>marine infrastructure, operations and transportation lanes<sup>16,17,18</sup>.</li> </ul>	   	Medium



Climate Impact	Projected Changes	Evidence Quality <sup>†</sup>	Sectoral Impacts	Impacts Summary <sup>α</sup>	Evidence Quality <sup>†</sup>
<b>Sea Surface Temperature</b>	Average sea surface temperatures may reach ~11.4°C with RCP 2.6 and ~14°C with RCP 8.5 by 2091-2100 <sup>4</sup> ;  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 <sup>12</sup> .	High	<b>Threats to</b> <ul style="list-style-type: none"> <li>water quality<sup>15,23,24</sup>,</li> <li>nearshore habitats and ecosystems<sup>6,15,19,24</sup>,</li> <li>diversity, abundance, growth, movement, range, interactions, distribution and survival of species<sup>4,6,11,19,23,24,25</sup>,</li> <li>cascading impacts on ecosystems<sup>6</sup>;</li> </ul> <b>Increased incidence of marine diseases, harmful algal blooms and invasive species<sup>15,23,24</sup>;</b>  <b>Economic, social and cultural impacts on communities as fisheries migrate across regional and political boundaries<sup>15,19</sup>.</b>	  	High
<b>Ocean Acidification</b>	Average ~7.96 ph level with RCP 2.6 and ~7.69 ph level with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline <sup>4</sup> ;  Overall decreasing pH levels <sup>19,20,21</sup> .	High	<b>Threats to</b> <ul style="list-style-type: none"> <li>ecosystems and habitats<sup>11,19,20</sup>,</li> <li>production, growth, survival and structure of shelled organisms and fish<sup>6,19,20,21,22</sup>,</li> <li>plankton community structure<sup>6,20</sup>,</li> <li>fished species, particularly to salmon aquaculture and shellfish industry<sup>11,19,20,22</sup>,</li> <li>overall food safety<sup>11,19,20</sup>;</li> </ul> <b>Economic, social and cultural impacts of alterations to habitat and fishery industry<sup>19,20,22</sup>.</b>	  	High
<b>Oxygenation</b>	Declining dissolved oxygen levels for the Northeast Pacific Ocean <sup>6,11,19</sup> .	High	<b>Threats to</b> <ul style="list-style-type: none"> <li>species with low mobility or species adapted to low oxygen<sup>6</sup>,</li> <li>primary productivity, growth and distribution of fish populations<sup>6,11,22</sup>,</li> <li>fished species compared to unfished species<sup>11,19,22</sup>;</li> </ul> <b>Impacts on the ecosystem and habitat of groundfish<sup>15,22,23</sup>;</b>  <b>Economic, social and cultural impacts due to changes in fisheries<sup>11,19,22</sup>.</b>	  	High
<b>Streamflow</b>	Increases in spring flow with slight increases in during summer by 2080 <sup>8,15</sup> ;  Stronger Vancouver Island Coastal Current, stronger flows in Queen Charlotte Sound, Hecate Strait and Dixon entrance <sup>12</sup> ;  Decreased summer flows in glacier and snowmelt dominated watersheds <sup>9,15</sup> .	High	<b>Threats to</b> <ul style="list-style-type: none"> <li>nearshore marine mammals due to alterations to temperature, salinity and stratification in ocean surface layers<sup>6</sup>,</li> <li>ecosystems due to oxygen and nutrient upwelling<sup>6,12</sup>;</li> </ul> <b>Increased and periodic water scarcity during the summer<sup>9</sup>.</b>	  	High
<b>Sea Surface Salinity</b>	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 <sup>4</sup> ;  Decreases in sea surface salinity by ~1% (~0.2 decrease in psu unit) by 2065-2078 compared to 1995-2008 baseline <sup>12</sup> .	High	<b>Threats to</b> <ul style="list-style-type: none"> <li>species range and food web structure<sup>19</sup>,</li> <li>fisheries industry<sup>19</sup>;</li> </ul> <b>Reduction in total ecosystem biomass<sup>19</sup>.</b>  <b>Economic, social and cultural impacts on communities as fisheries migrate across regional and political boundaries<sup>19</sup>.</b>	  	High

Climate Impact	Projected Changes	Evidence Quality†	Sectoral Impacts	Impacts Summary α	Evidence Quality†
<b>Winds, Waves and Storms</b>	<p>More intense and more frequent winter storms, surges and waves<sup>2,26</sup>;</p> <p>Increases in damaging extreme high-water events<sup>15</sup>;</p> <p>Increases in coastal wind strength in summer<sup>6</sup>.</p>	High	<p><b>Threats to</b></p> <ul style="list-style-type: none"> <li>ecosystems and habitats<sup>2</sup>,</li> <li>recruitment for fisheries<sup>6</sup>,</li> <li>traditional way of life and First Nations food supply due to altered timing of seasons<sup>27</sup>,</li> <li>marine infrastructure, operations and transportation lanes<sup>10,15</sup>;</li> </ul> <p><b>Increase in</b></p> <ul style="list-style-type: none"> <li>marine infrastructure maintenance and insurance costs<sup>10,15</sup>,</li> <li>coastal erosion and flooding<sup>28</sup>;</li> </ul> <p><b>Alterations in the timing or strength of the spring weather transition, coastal currents and upwell strength and timing<sup>6</sup>.</b></p>	   	Medium
<b>General</b>	<p>Increasing occurrence and frequency of climate impacts<sup>2,15,23,24,28</sup>.</p>	High	<p><b>Threats to</b></p> <ul style="list-style-type: none"> <li>access to traditional foods<sup>25,26</sup>,</li> <li>species abundance and distribution<sup>25</sup>,</li> <li>catch potential for all commercial fisheries<sup>25</sup>,</li> <li>fish spawning<sup>13</sup>;</li> </ul> <p><b>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<sup>22</sup>;</b></p> <p><b>15.0% to 20.8% decline in commercially and culturally important fisheries species relative abundance by 2050<sup>25</sup>;</b></p> <p><b>Economic, social and cultural impacts due to changes in fisheries<sup>22,25</sup>.</b></p>	 	High

\* Data specific to MaPP region

α Unless indicated, all sectoral impacts are negative

† For details on how 'Evidence Quality' was determined, refer to the full report



Photo by Jessica Hawryshyn



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# MOVING FORWARD: ADAPTATION

Across Canada, awareness of climate change impacts and the necessity of adaptation planning are increasing. In BC, the provincial Adaptation Strategy 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. While these documents 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.

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 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. 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.



Photo by Kitsumkalum Nation



# CONCLUSION

This Executive Summary and the full report 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, and will likely result in multiple impacts to key sectors in the MaPP region. Some of the impacts are understood but many have a great deal of uncertainty associated with them. Long-range planning and early, proactive adaptation efforts will be important to accommodate predicted and unanticipated impacts.

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. For example, 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. Adaptation actions should be chosen that support resilient social-ecological systems and that are flexible enough to allow management and communities to evolve as climate change unfolds.



Photo by Jessica Hawryshyn

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