Let’s Talk about Climate Change: Pacific Region

Office of the Chief Ecosystem Scientist

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Parks Canada Parcs Canada

Canada

Let’s Talk about Climate Change: Pacific Region

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This report is one in a series that provides a regional summary of observed and projected climate change trends and impacts facing all of Canada’s national parks, national marine conservation areas and certain national historic sites. This is an internal document to Parks Canada and is intended to encourage and inform broader conversations and support place–based actions on climate change.

The “Let’s Talk about Climate Change” series regions are defined by biogeoclimatic and operational similarities, and include: 1) Atlantic Region; 2) Quebec Region; 3) Great Lakes Region; 4) Prairie and Boreal Plains Region; 5) Mountain Region; 6) Pacific Region; 7) Northwest Region; and, 8) Arctic and Hudson Plains Region.

This report and others in the series are available at the Parks Canada Climate Change SharePoint Website: http://collaboration/sites/PD010/SitePages/Home.aspx

Contents

1. Introduction

The fifth and most recent report from the Intergovernmental Panel on Climate Change (IPCC, 2014) establishes with certainty that the Earth's climate system is warming, "and since the 1950's, many of the observed changes are unprecedented over decades to millennia". Human activity has increased atmospheric concentrations of greenhouse gas (GHG) to levels not observed in at least the last 800,000 years. Worldwide, a rapidly changing climate is having profound impact on our social-ecological systems, amplifying existing risks and creating new ones.

Canada's rate of warming is about double the global rate (even greater in the north) and the last three decades have been the warmest 30-year period in at least 1,400 years. Some of the observed changes include shifts in species distribution and abundance, glacier loss, thawing permafrost, decreasing sea ice, earlier ice break-ups, increasing wildfires, sea level rise along some coasts, changes to phenology, and an increase in extreme weather events such as heat waves, droughts, heavy rainfall and more (e.g., Lemmen *et al.*, 2016; Warren and Lemmen, 2014). The risks and impacts are felt across Parks Canada, from the ecosystems and cultural resources we protect, to the facilities and infrastructure we build and maintain, to the visitor experiences we offer - and most concerning, these impacts are projected to increase for decades to come. It is an uncertain and complex context, one which will test the adaptive capacity and effectiveness of policy, planning, and management frameworks.

To advance place-based climate response efforts, this document is one in a series of regional reports that provides accessible summary information about climate change in Canada's national parks, national marine conservation areas (NMCAs) and certain national historic sites. For some sites this will support preliminary conversations on climate change and for others the content will be eclipsed by a need for more detailed vulnerability assessments, adaptation strategies and decision support tools. Regardless, the intent is to encourage and equip individuals and sites to talk about climate change, both internally and externally, and consider the challenges in their own context.

1.1. "Natural Solution" Concept

As a lead conservation and protected area agency, and the largest federal land owner and third largest federal asset manager in the country, Parks Canada's response to climate change is a matter of importance. Part of the response will involve recognizing and positioning protected areas as a "natural solution" to climate change in regional, national and international plans and programs (e.g., Dudley *et al.*, 2010; Lopoukhine *et al.*, 2012; NAWPA, 2012).

As a "natural solution", well-designed and effectively managed protected areas:

- Mitigate climate change through the sequestration and storage of carbon in forests, coastal wetlands ("blue carbon") and other natural ecosystems.
- Protect biodiversity by providing a safe haven for species.
- Enhance connectivity and species movements within and across protected area networks.

- Provide essential ecosystem goods and services, such as clean water, erosion control, flood/storm water protection, genetic diversity, cultural opportunities, etc…
- Serve as a benchmark for climate change related research and monitoring.
- Provide a context for social learning, good governance, and adaptive management.
- Help people and communities cope by supporting sustainable and resilient economies in and around protected areas and promoting social well-being (healthy parks – healthy people).
- Demonstrate environmental stewardship through "green" design and conservation practices.
- Create and facilitate meaningful experiences that help to inspire, inform, and guide actions in response to climate change.

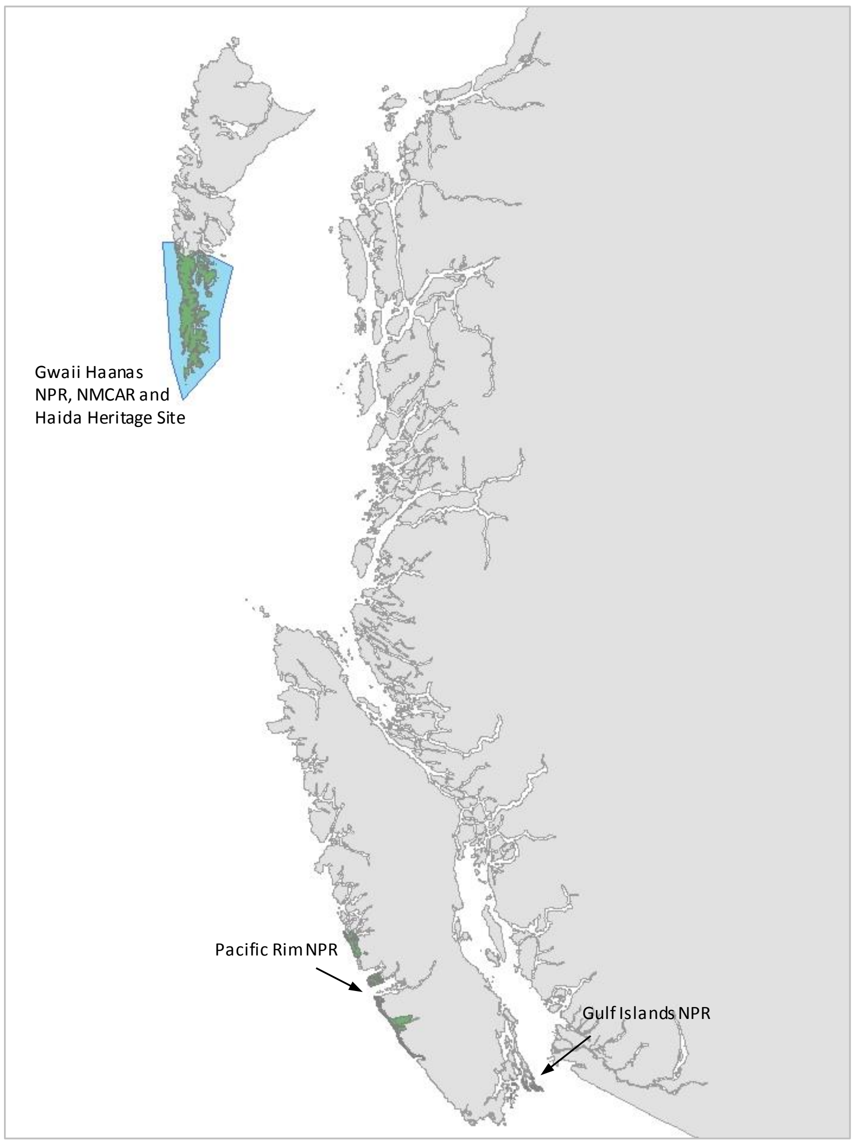


Figure 1. National Park Reserves (NPR) and the National Marine Conservation Area Reserve (NMCAR) included in this regional assessment.

2. Observed and Projected Climate Trends

This section provides site specific summaries of historic observed temperature and precipitation trends as well as future climate projections. These are only a subset of the climate variables available for analysis and presentation (see Appendix 1).

2.1 Methods

Historic observed mean monthly temperature and total precipitation data was accessed from the Adjusted and Homogenized Canadian Climate Data website (http://www.ec.gc.ca/dccha-ahccd) for the climatological stations within or closest to each protected area. Temperature and precipitation stations were not always in the same location and preference was given to selecting stations with the longest and most current data for a protected area. All available years were plotted and the trend was determined using a generalized linear model (R Core Team, 2014) including 95% confidence intervals. For the analysis, winter = December, January and February; spring = March, April and May; summer = June, July and August; and, autumn = September, October and November.

A table with future climate change projections was determined for the centre of each protected area. Season by season descriptions were provided to complement the earlier park-based assessments by Scott and Suffling (2000) and to help inform seasonal operations and activities. The climate projections were determined following Price *et al.* (2011) and used the average of four General Circulation Models (GCMs) and the lowest and highest Representative Concentration Pathway (RCP) GHG scenarios (Vuuren *et al.*, 2011). The RCP 2.6 (lowest) scenario assumes that we take action and GHG emissions peak in 2010-2020 and decline thereafter. The RCP 8.5 (highest) scenario assumes we take no action and emissions continue to rise throughout the 21st century. Figures 2 and 3 also include a projection based on the RCP 4.5 scenario, where emissions peak around 2040 and then decline.

Vertical allowances for each site were acquired from the Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT, http://www.bio.gc.ca/science/data-donnees/index-en.php). The vertical allowances are "recommended changes in the elevation of coastal infrastructure required to maintain the current level of flooding risk in a future scenario of sea level rise". These estimates are based on a future projection of regional sea level rise using the RCP 4.5 and RCP 8.5 scenarios and the historical water level records, including both tides and storm surge. The historical records do not incorporate predicted changes in storm tides.

2.2 Regional Climate Change Summaries

2.2.1 Physical Effects

- In the last century, average annual air temperatures for the region have increased by 1.3°C (Lemmen *et al.*, 2016; PCIC, 2013a; 2013b). All seasons are warming, however summer temperatures have increased the fastest (0.22-0.26°C/decade) (PCIC, 2013a; 2013b). This warming trend is projected to continue and model results indicate a further increase of 1.2-5.0°C by 2100, depending on the location and RCP scenario used (see figure 2; FLNR, 2016) .

- Precipitation patterns naturally exhibit high variability and climate change trends are difficult to discern (PCIC, 2013a; 2013b). It is anticipated that warmer winter and spring temperatures will reduce the percentage of precipitation falling as snowfall. Furthermore, there is concern that extreme-rainfall events will become more frequent, already 20-25% of the regions precipitation falls in heavy rain events (Lemmen et al., 2016; PCIC, 2013a). This may increase risk of flooding, landslides and sediment load in drinking water sources. Summer water supplies is a concern for some coastal communities.
- Adding to the complexity, positive phases of the Pacific Decadal Oscillation (40-60 year cycle) and El Niño-Southern Oscillation (3-5 year cycle) increase the likelihood of a warm and dry winter and spring in the region (St Jacques *et al.*, 2014). Summer and autumn correlations are weaker. A cool and wet winter and spring tends to be associated with the opposite phases (Fleming and Whitfield, 2010). See examination of climate modes effects on streamflow in Georgia-Puget Sound Region (Gulf Island NP)(Fleming *et al.*, 2007).
- There are local differences in the magnitude of sea level change due to factors such as vertical land motion (e.g., tectonic activity and glacial isostatic rebound) and ocean currents. For example, sea levels at Tofino (Pacific Rim NPR) have fallen by 8.4 cm and at Victoria (Gulf Islands NPR) have risen by 3.1 cm in last 50 years (data available, http://www.psmsl.org/data; Christian and Foreman, 2013; Lemmen *et al.*, 2016). Projections for the region indicate a 30-70 cm sea level rise by 2100 (James *et al.*, 2014).
- Saltwater intrusion of groundwater may become more of a concern with higher sea levels (Chang *et al.*, 2011; Rasmussen *et al.*, 2013).
- Walker and Barrie (2006) describe geomorphological impacts of rising sea levels and storm surges on Haida Gwaii. With sea level rise, rates of coastal erosion will vary with landform. While cliffs or bluffs will only recede, marshes, sand dunes and beaches are more dynamic and have the capacity to re-establish and undergo morphological change (e.g., landward migration, overwash and erosion)(e.g., Nye, 2010).

Mean Annual Temperature

Change from 1980-2010 Baseline

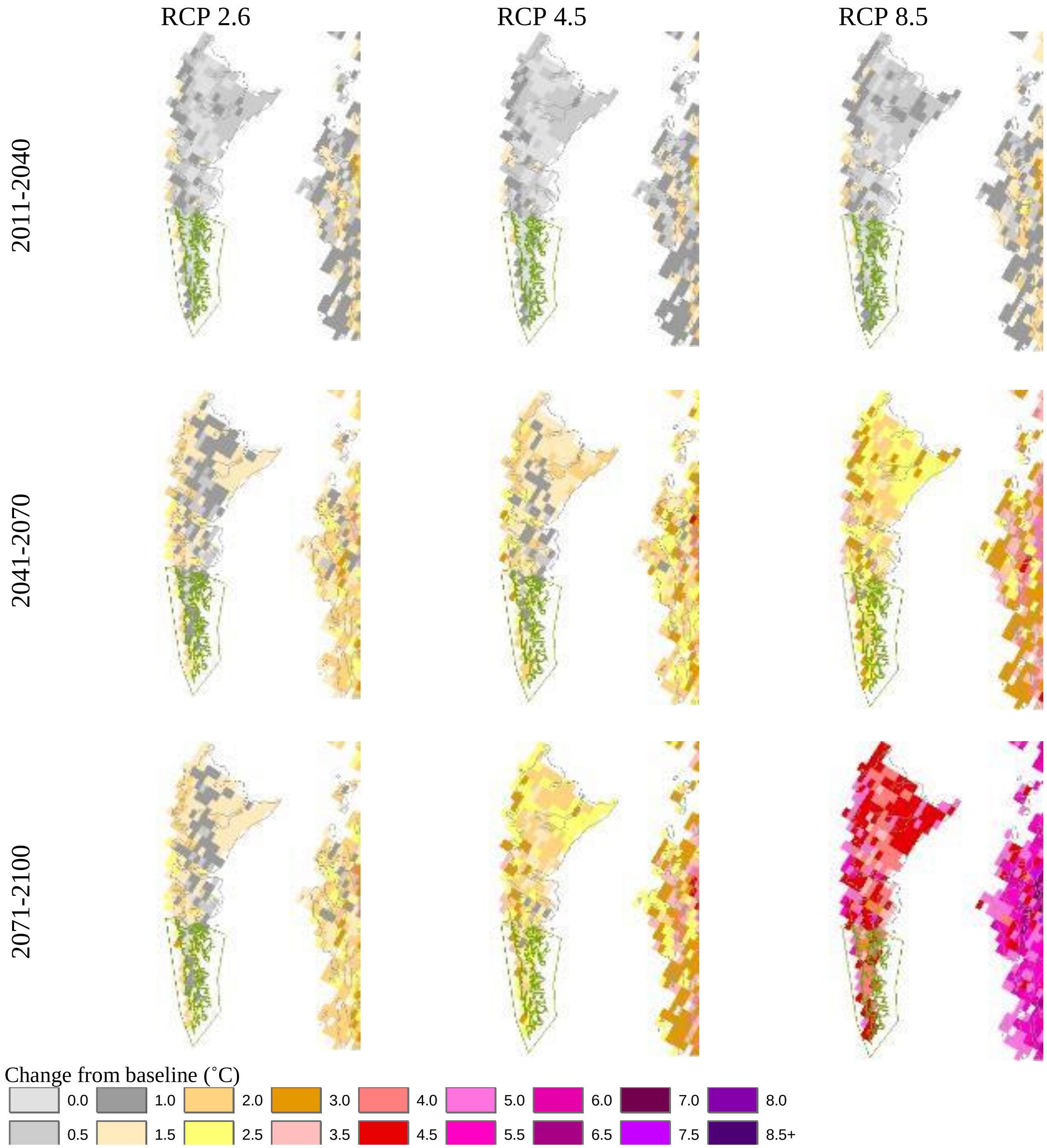


Figure 2a. Gwaii Haanas. Temperature projections represent a composite (average) of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM, using three greenhouse gas scenarios (RCPs) for three future time periods. Climate data provided by Natural Resources Canada, Canadian Forest Service, Sault Ste. Marie (http://cfs.nrcan.gc.ca/projects/3).

Mean Annual Temperature

Change from 1980-2010 Baseline

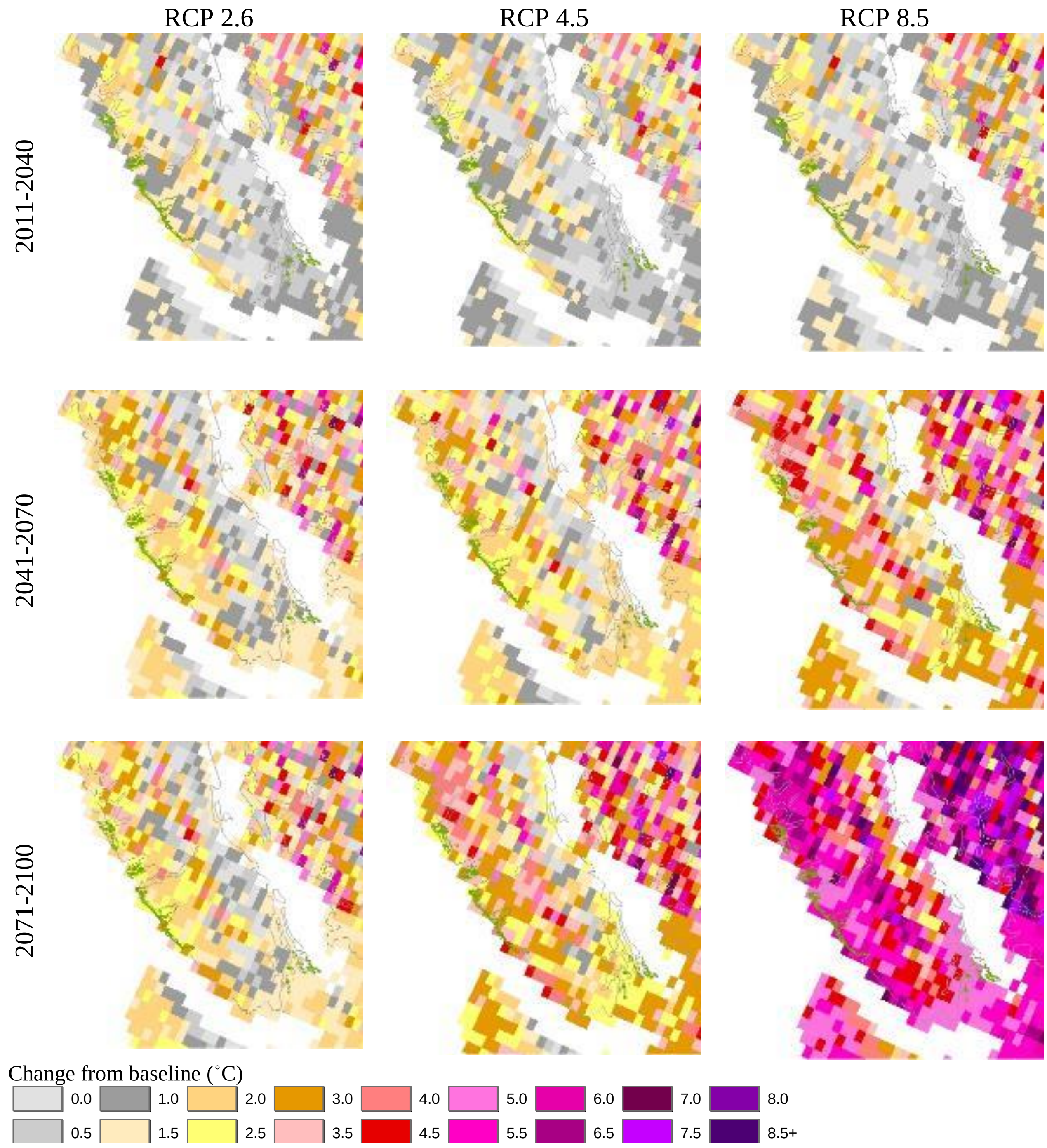


Figure 2b. Pacific Rim and Gulf Islands. Temperature projections represent a composite (average) of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM, using three greenhouse gas scenarios (RCPs) for three future time periods. Climate data provided by Natural Resources Canada, Canadian Forest Service, Sault Ste. Marie (http://cfs.nrcan.gc.ca/projects/3).

Total Annual Precipitation

Change from 1980-2010 Baseline

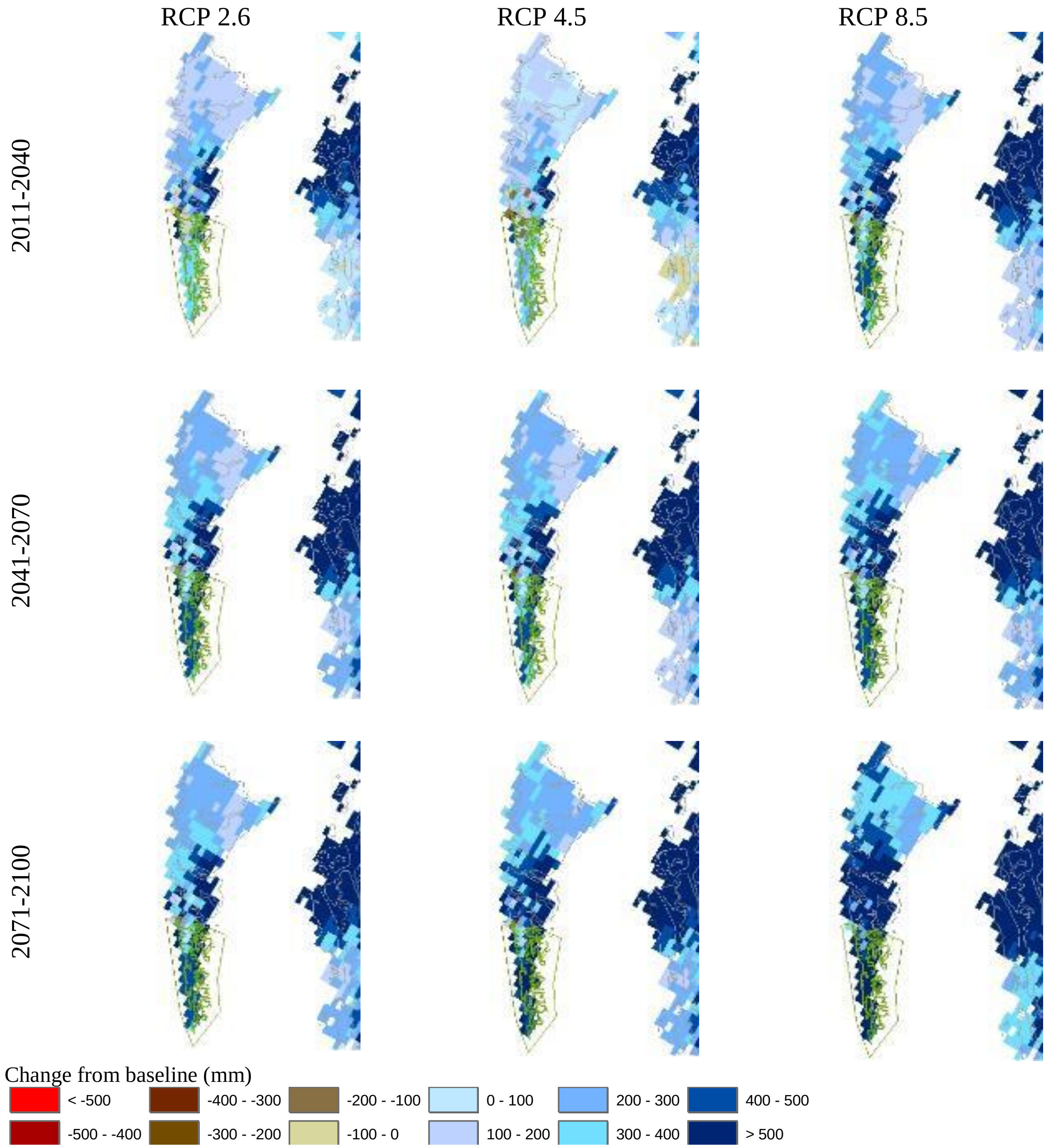


Figure 3a. Gwaii Haanas. Precipitation projections represent a composite (average) of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM, using three greenhouse gas scenarios (RCPs) for three future time periods. Climate data provided by Natural Resources Canada, Canadian Forest Service, Sault Ste. Marie (http://cfs.nrcan.gc.ca/projects/3).

Total Annual Precipitation

Change from 1980-2010 Baseline

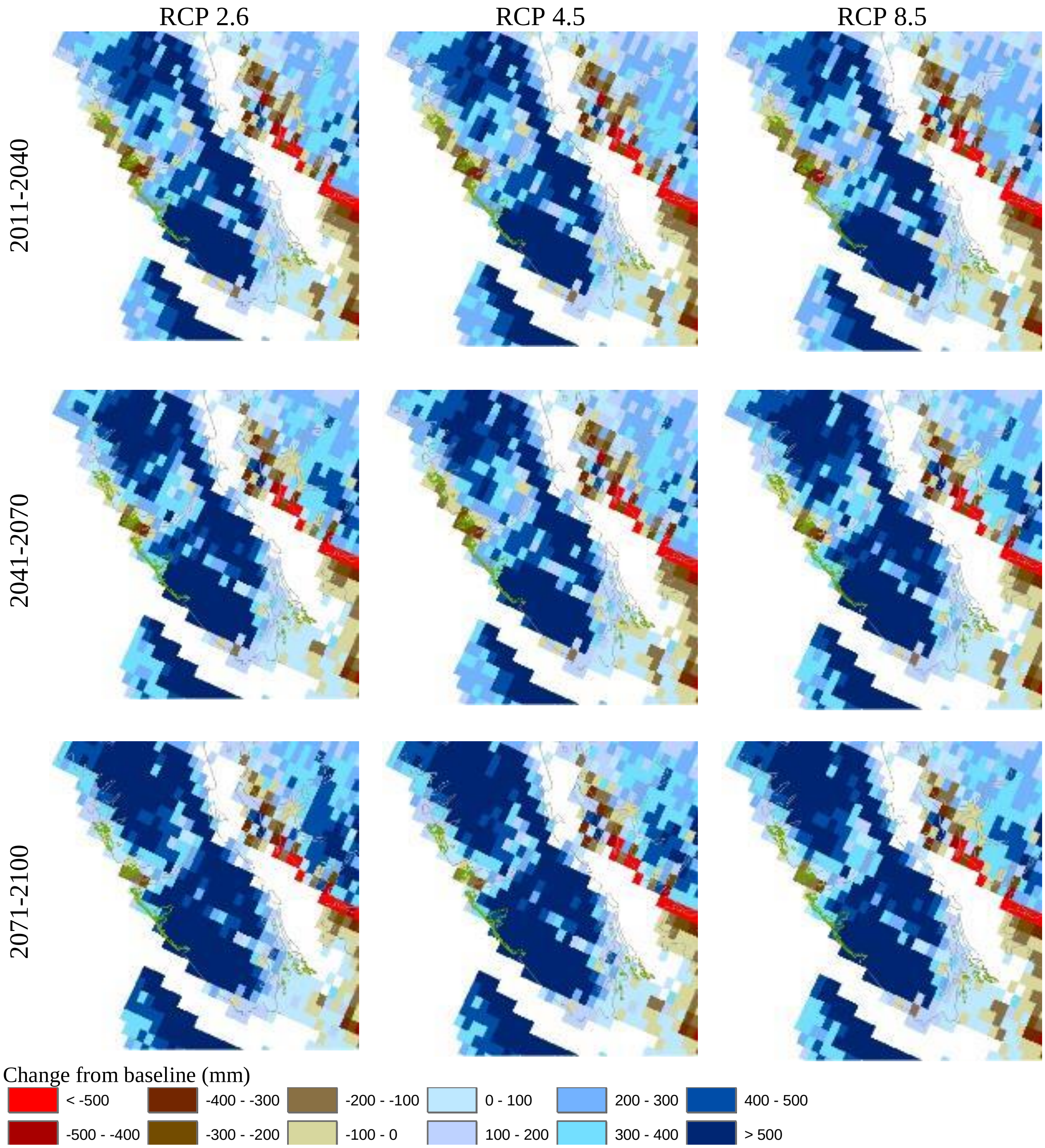
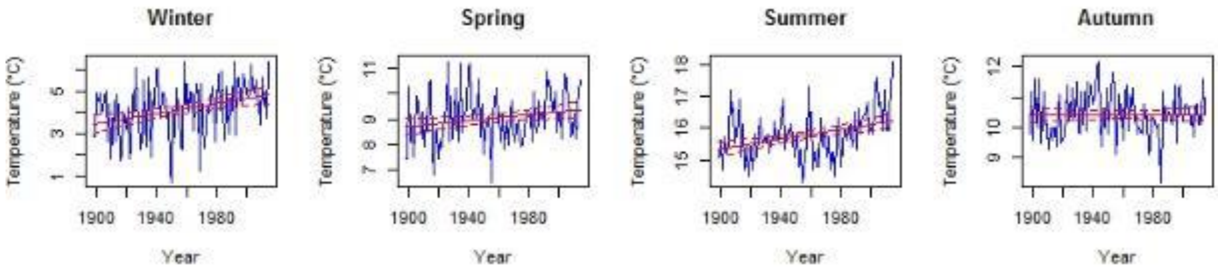


Figure 3b. Pacific Rim and Gulf Islands. Precipitation projections represent a composite (average) of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM, using three greenhouse gas scenarios (RCPs) for three future time periods. Climate data provided by Natural Resources Canada, Canadian Forest Service, Sault Ste. Marie (http://cfs.nrcan.gc.ca/projects/3).

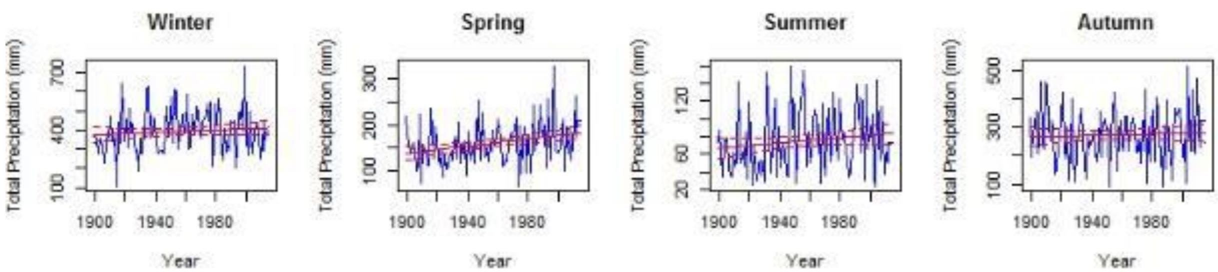
Gulf Islands National Park Reserve

A. Mean Temperature



Seasonal mean temperature at Victoria Climatological Station (1018621) from 1898 to 2015. A significant trend (P<0.05) observed for winter (0.012°C/yr), spring (0.006°C/yr) and summer (0.008°C/yr). No significant trend (P<0.05) observed for autumn.

B. Total Precipitation



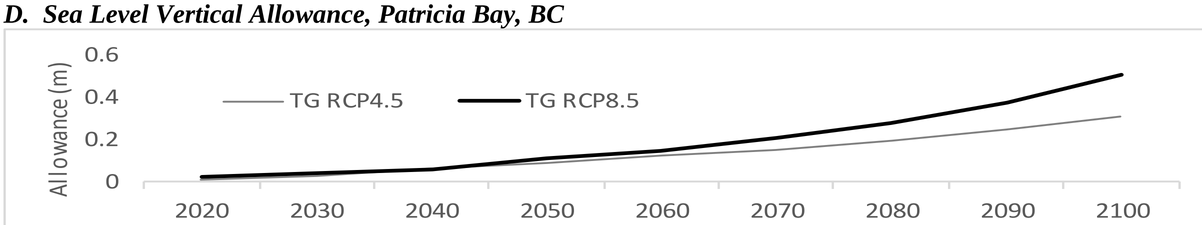
Seasonal total precipitation at Victoria Climatological Station (1018620) from 1899 to 2013. A significant trend (P<0.05) observed for spring (0.39mm/yr). No significant trend (P<0.05) observed for winter, summer or autumn.

C. Climate Change Projection for Centre of Park Relative to 1981-2010 Baseline Mean (Appendix 1)

Geo-centroid: 123° 12' 56.05" W, 48° 45' 48.68" N; elevation 96m

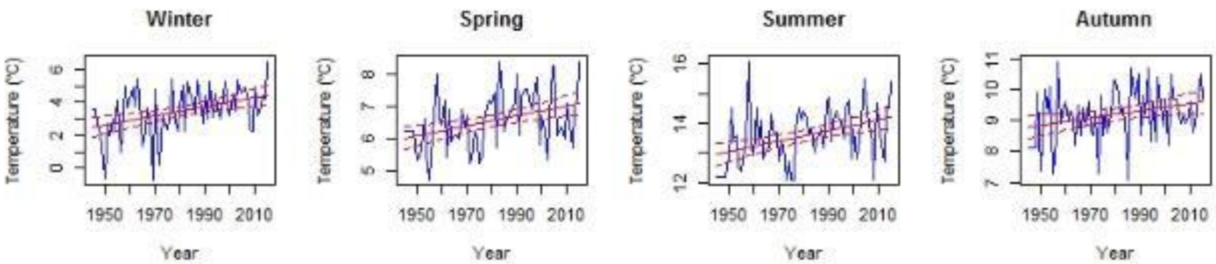
Increase / decrease in:	2011-2040			2041-2070			2071-2100		
Mean Winter Temperature (°C)	0.9	to	1.2	1.8	to	3.2	2.1	to	5.1
Mean Spring Temperature (°C)	0.9	to	0.8	1.6	to	2.7	1.8	to	4.7
Mean Summer Temperature (°C)	0.9	to	0.9	1.7	to	3.1	1.5	to	5.9
Mean Autumn Temperature (°C)	0.9	to	0.9	1.6	to	2.8	1.5	to	5.5
Precipitation in Winter (%)	16%	to	14%	18%	to	20%	20%	to	20%
Precipitation in Spring (%)	-5%	to	-5%	-1%	to	-1%	-4%	to	0%
Precipitation in Summer (%)	-13%	to	-17%	-6%	to	-17%	-4%	to	-27%
Precipitation in Autumn (%)	2%	to	1%	2%	to	4%	9%	to	2%
Growing degree-days during growing season	15%	to	16%	29%	to	54%	31%	to	99%
Climate Moisture Index (sum May-Sept)	-24.6	to	-25.0	-25.5	to	-29.8	-24.2	to	-38.1

D. Sea Level Vertical Allowance, Patricia Bay, BC



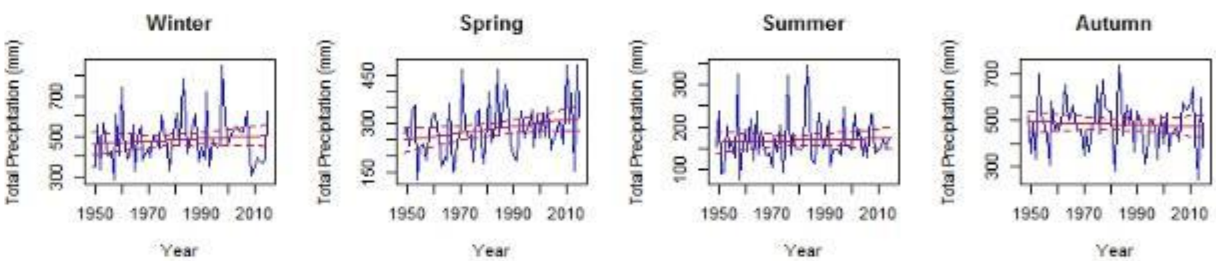
Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site

A. Mean Temperature



Seasonal mean temperature at Sandspit Climatological Station (1057050) from 1945 to 2015. A significant trend (P<0.05) observed for winter (0.028°C/yr), spring (0.016°C/yr), summer (0.018°C/yr) and autumn (0.012°C/yr).

B. Total Precipitation

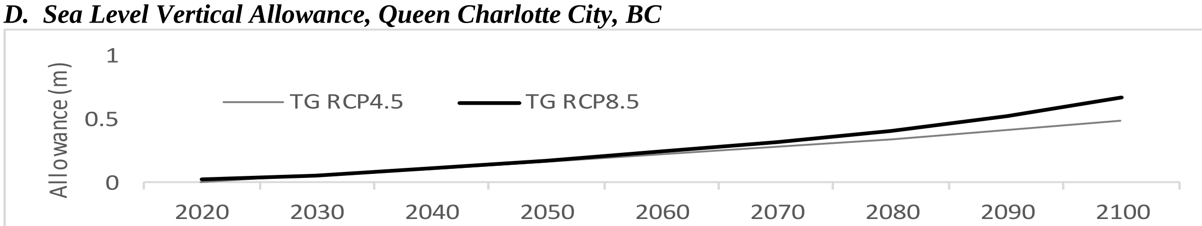


Seasonal total precipitation at Sandspit Climatological Station (1057050) from 1949 to 2015. A significant trend (P<0.05) observed for spring (1mm/yr). No significant trend (P<0.05) observed for winter, summer or autumn.

C. Climate Change Projection for Centre of Park Relative to 1981-2010 Baseline Mean (Appendix 1)
Geo-centroid: 131° 28’ 36.25” W, 52° 25’ 50.36” N; elevation 192m

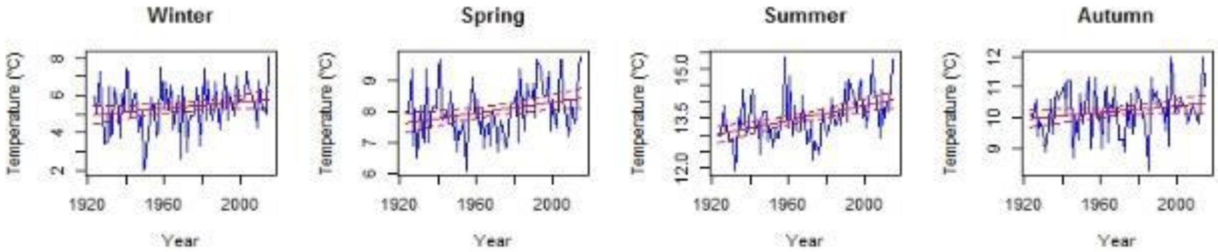
Increase / decrease in:	2011-2040			2041-2070			2071-2100		
Mean Winter Temperature (°C)	0.5	to	0.8	1.3	to	2.6	1.7	to	4.4
Mean Spring Temperature (°C)	0.6	to	0.8	1.4	to	2.4	1.6	to	4.0
Mean Summer Temperature (°C)	1.1	to	1.0	1.8	to	3.0	1.9	to	4.9
Mean Autumn Temperature (°C)	1.1	to	1.1	1.8	to	2.9	1.9	to	5.1
Precipitation in Winter	13%	to	16%	19%	to	25%	19%	to	28%
Precipitation in Spring	9%	to	13%	11%	to	12%	13%	to	16%
Precipitation in Summer	-4%	to	4%	0%	to	-11%	-14%	to	2%
Precipitation in Autumn	20%	to	22%	24%	to	27%	24%	to	36%
Number of days of growing season	50.0	to	80.0	80.0	to	80.0	80.0	to	80.0
Growing degree-days during growing season	22%	to	22%	43%	to	79%	47%	to	139%
Advance in start of growing season (days)	50.0	to	80.0	80.0	to	80.0	80.0	to	80.0
Climate Moisture Index (sum May-Sept)	51.0	to	53.0	43.2	to	49.2	39.3	to	52.1

D. Sea Level Vertical Allowance, Queen Charlotte City, BC



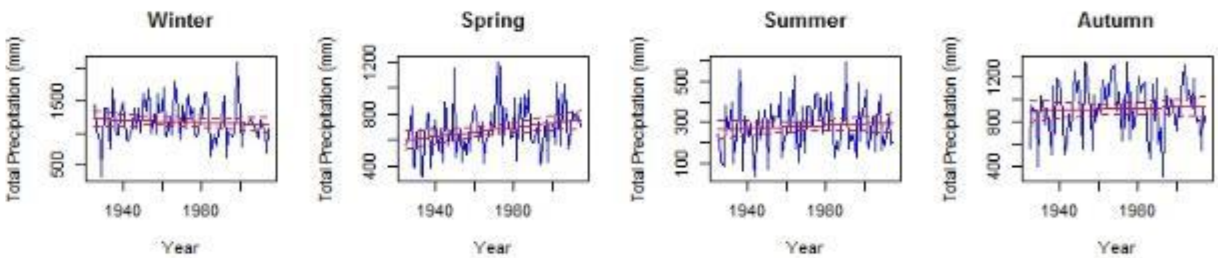
Pacific Rim National Park Reserve

A. Mean Temperature



Seasonal mean temperature at Estevan Point Climatological Station (1032730) from 1923 to 2015. A significant trend (P<0.05) observed for spring (0.009°C/yr) and summer (0.011°C/yr).). No significant trend (P<0.05) observed for winter or autumn.

B. Total Precipitation



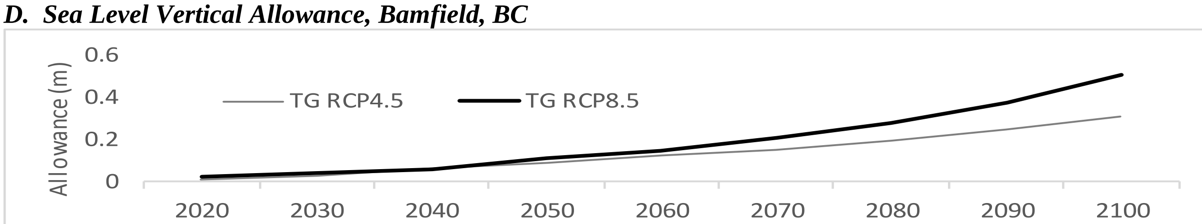
Seasonal total precipitation at Pachena Point Climatological Station (1035940) from 1925 to 2015. A significant trend (P<0.05) observed for spring (1.77mm/yr). No significant trend (P<0.05) observed for winter, summer or autumn.

C. Climate Change Projection for Centre of Park Relative to 1981-2010 Baseline Mean (Appendix 1)

Geo-centroid: 125° 08' 49.54" W, 48° 49' 37.40" N; elevation 0 m

Increase / decrease in:	**2011-2040**			**2041-2070**			**2071-2100**		
Mean Winter Temperature (°C)	0.9	to	1.2	1.7	to	3.0	2.1	to	4.8
Mean Spring Temperature (°C)	1.1	to	1.1	1.9	to	2.9	2.0	to	4.6
Mean Summer Temperature (°C)	1.3	to	1.4	2.1	to	3.3	2.0	to	5.6
Mean Autumn Temperature (°C)	1.2	to	1.3	1.9	to	3.1	1.9	to	5.4
Precipitation in Winter	-4%	to	-4%	-1%	to	1%	1%	to	3%
Precipitation in Spring	-5%	to	-6%	-2%	to	-3%	-2%	to	-6%
Precipitation in Summer	-20%	to	-23%	-16%	to	-26%	-15%	to	-31%
Precipitation in Autumn	-1%	to	-3%	-1%	to	1%	2%	to	7%
Number of days of growing season	0.0	to	0.0	0.0	to	0.0	0.0	to	0.0
Growing degree-days during growing season	24%	to	25%	42%	to	67%	44%	to	114%
Advance in start of growing season (days)	0.0	to	0.0	0.0	to	0.0	0.0	to	0.0
Climate Moisture Index (sum May-Sept)	17.4	to	19.1	13.6	to	18	6.5	to	20.7

D. Sea Level Vertical Allowance, Bamfield, BC



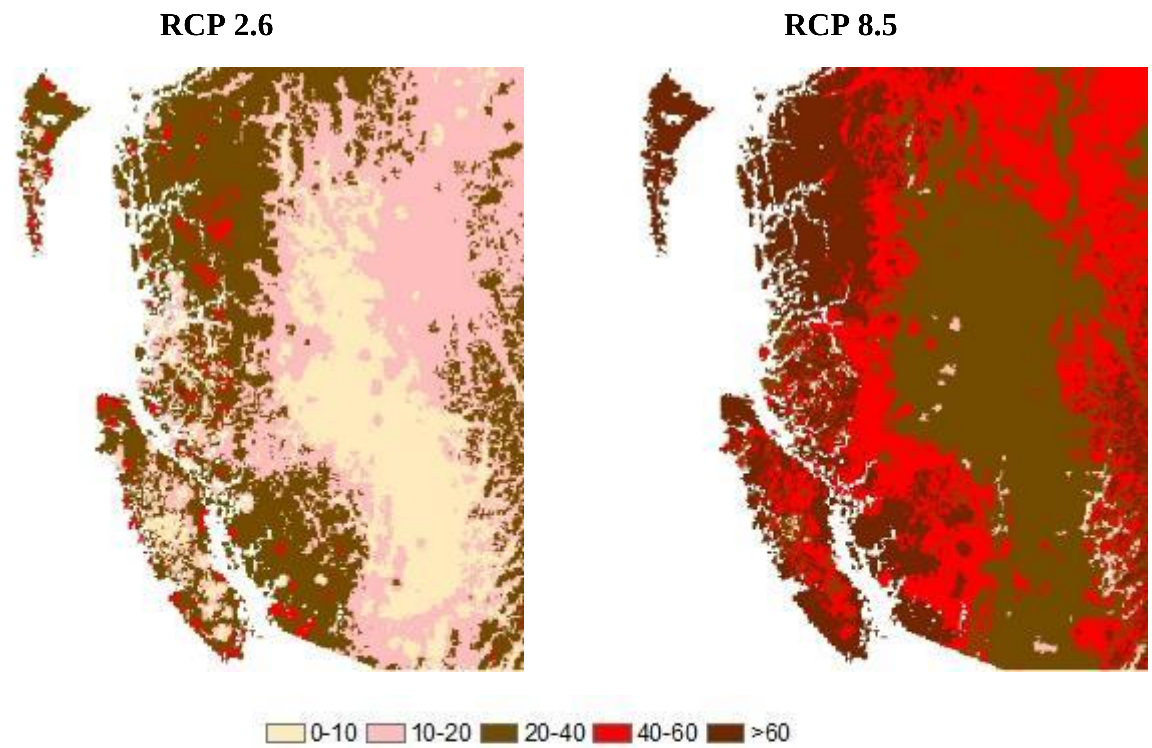


Figure 4. Projected increase in wildfire season length in days from baseline (1981-2010) by 2071-2100 under RCP 2.6 and 8.5 scenarios (data source: http://cfs.nrcan.gc.ca/fc-data-catalogue).

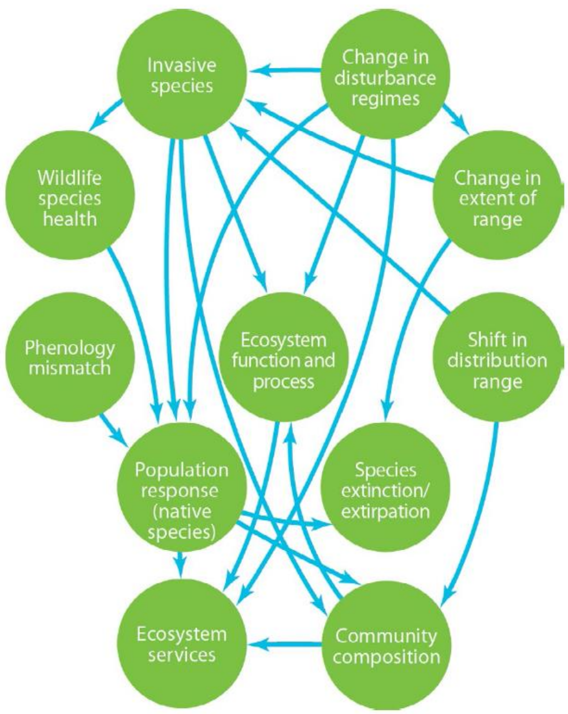
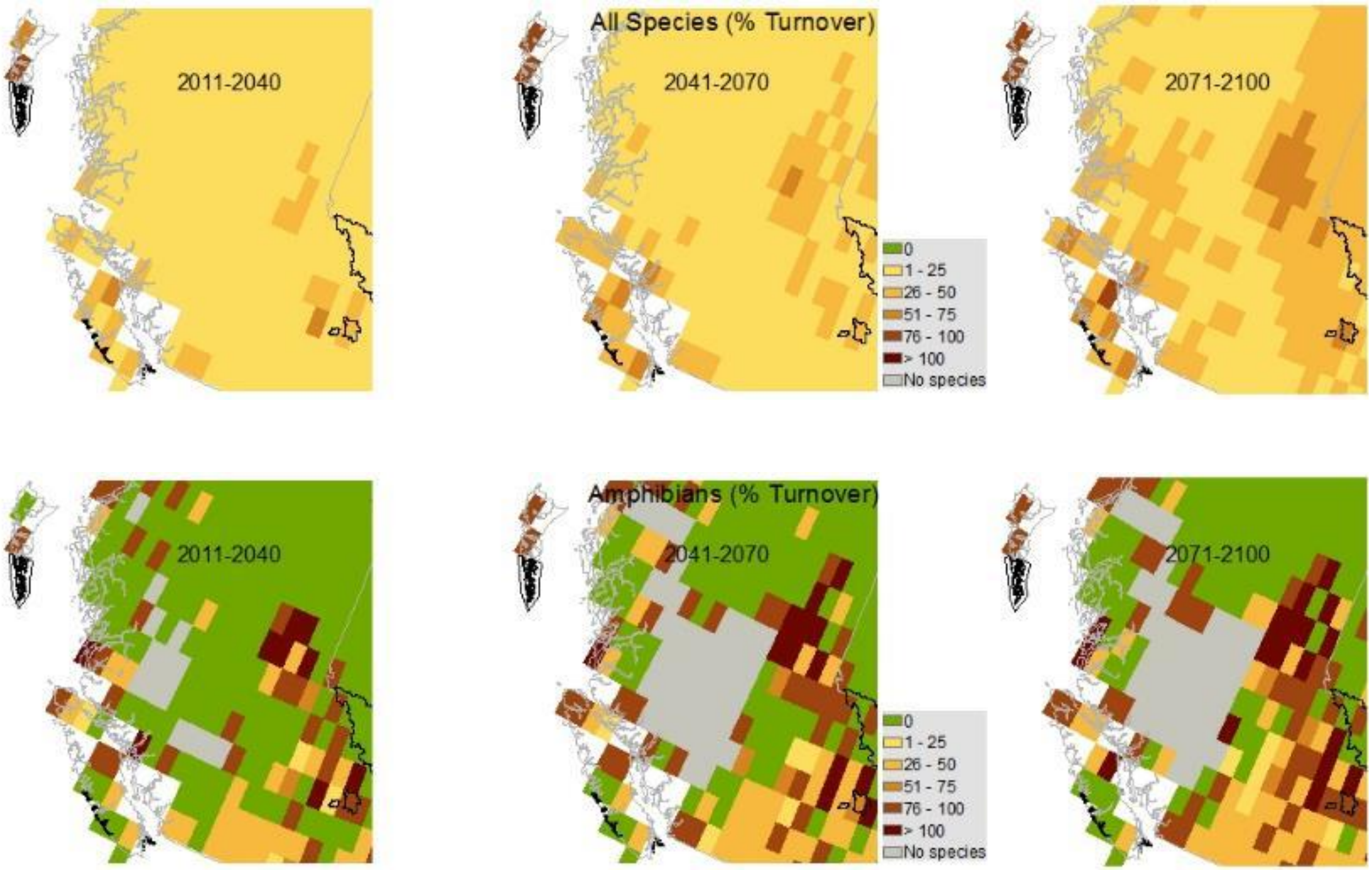


Figure 5. The complex ecosystem linkages and interactions to climate change (from Nantel *et al.*, 2014)


All Species (% Turnover)
2011-2040
2041-2070
2071-2100
0
1 - 25
26 - 50
51 - 75
76 - 100
> 100
No species
Amphibians (% Turnover)
2011-2040
2041-2070
2071-2100
0
1 - 25
26 - 50
51 - 75
76 - 100
> 100
No species

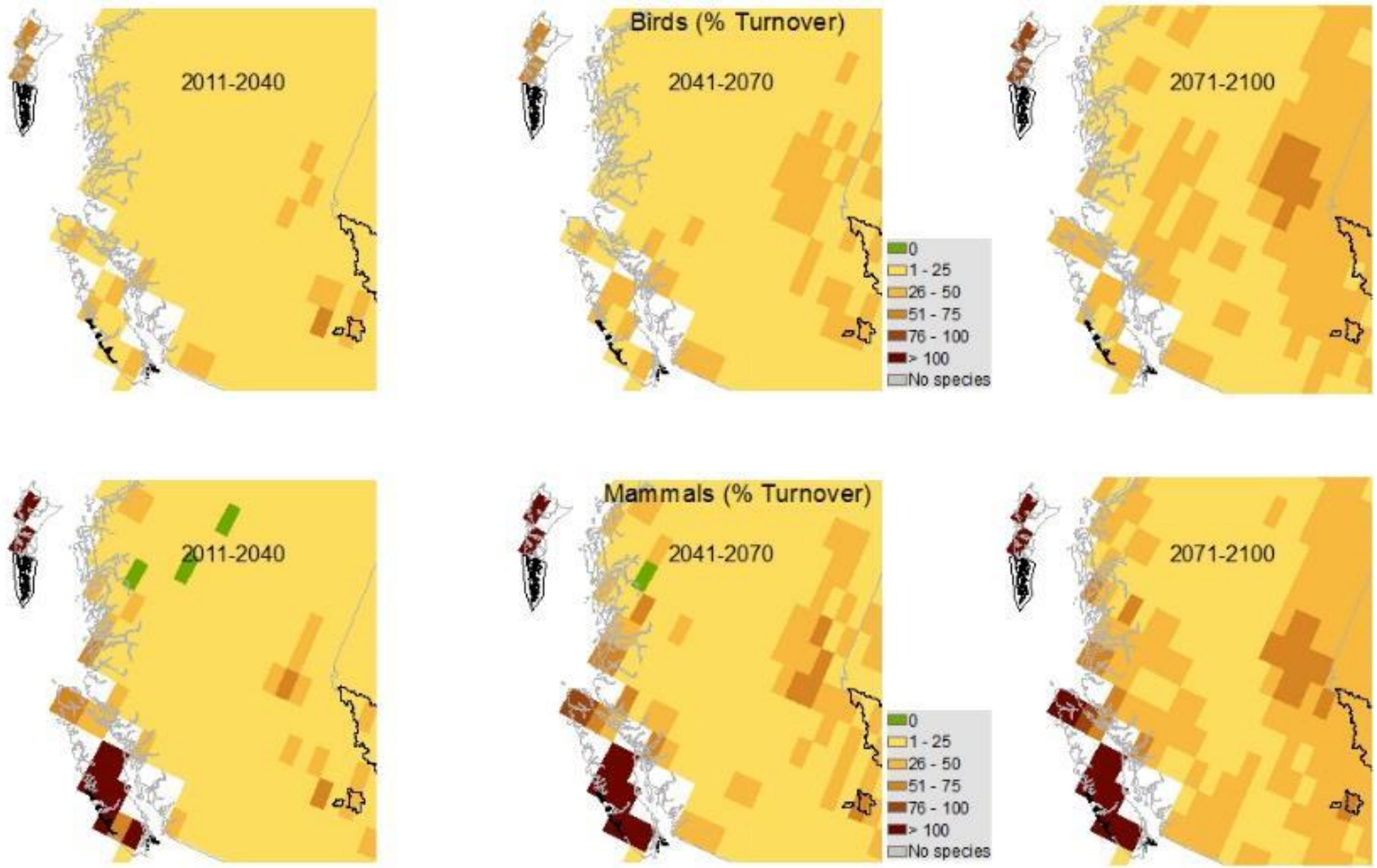
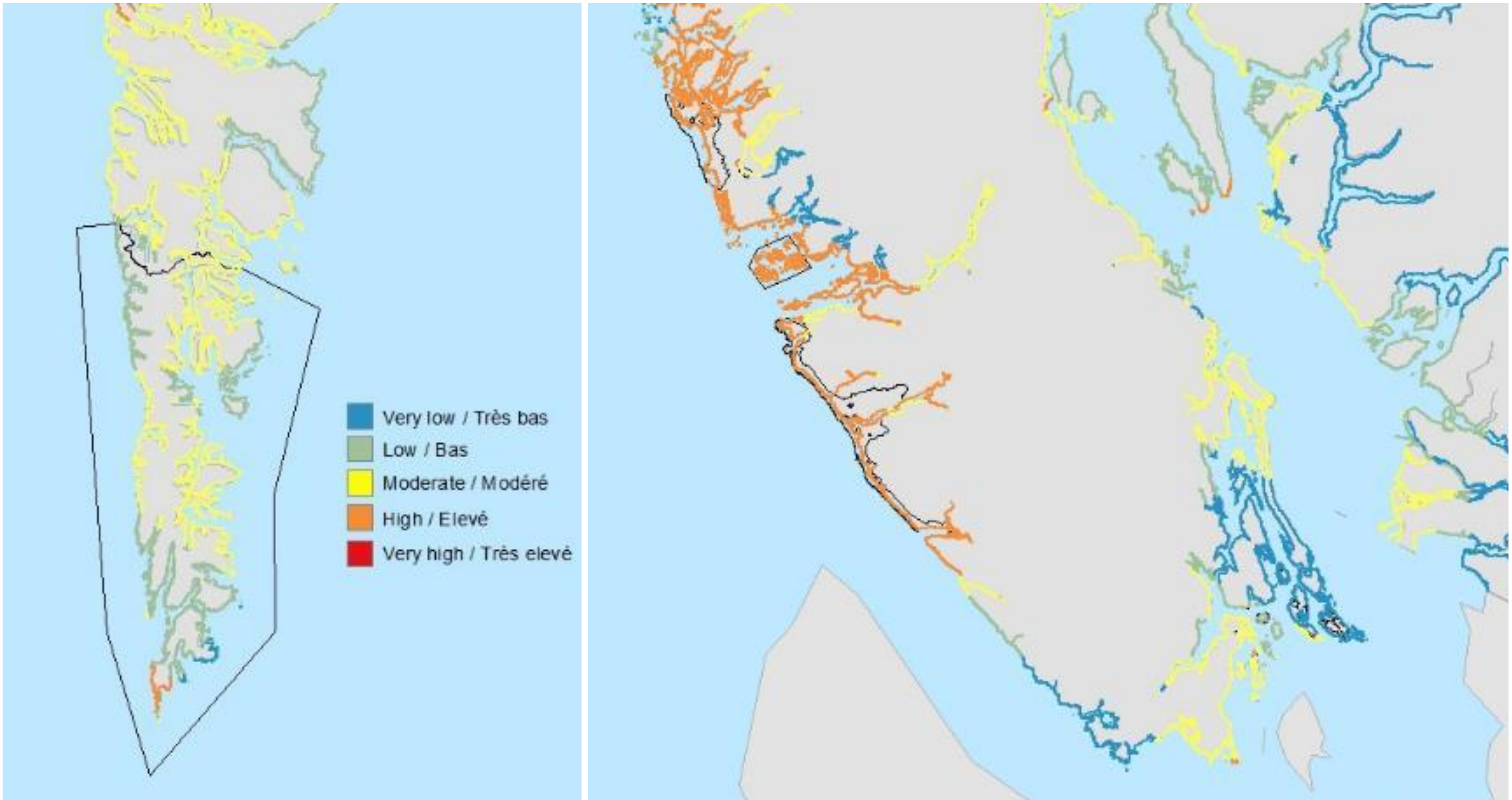


Figure 6. Percentage of projected species turnover (50 km x 50 km grid) relative to current species occurrence, assuming full dispersal (i.e., species can move into new areas) using ten coupled atmosphere-ocean general circulations models (AOGCMS) as in Lawler *et al.* (2009) and the A2 emission scenario. **Species turnover** is calculated as a composite measure of **species loss** (i.e., % of species currently in a cell whose projected future range does not include the cell) and **species gain** (i.e., % increase in species due to range expansion). Data and analysis discussed further in Lindsay *et al.* (2016). Does not illustrate species turnover for Gwaii Haanas or Gulf Islands because of the resolution of the analysis.



Gwaii Haanas | Pacific Rim and Gulf Islands

Figure 7. Preliminary map of coastal sensitivity to climate change. Sensitivity is based on coastal materials, landforms, relief, ground ice, wave height, tidal range, recent trends in sea ice concentration, and projected sea level rise to 2050. Data provided by Natural Resources Canada (Couture and Manson, 2016).

2.2.2 Other Effects

Ecosystems and Biodiversity

- Species response to climate change will vary with abiotic (e.g., isolated by fragmented landscape or island context, thermal conditions, etc…), biotic (e.g., competition, habitat) and physiological stresses. Some species, or variant forms, will survive and adapt, while others may move or face extinction (e.g., Pecl *et al.*, 2017).
- Rising levels of atmospheric CO_2 are also increasing the amount of CO_2 absorbed by the oceans. This causes the oceans to become more acidic, affecting the ability of marine organisms to form calcareous skeletal structures and fix carbon (Doney *et al.*, 2009; Fabry *et al.*, 2008; Orr *et al.*, 2005). Haigh *et al.* (2015) explore the impact to marine ecosystems and fisheries in the region. In general, this a serious concern and the need for more regional data is cited (e.g., Christian and Foreman, 2013).
- The total turnover (loss and gain) of marine fishes and invertebrates is expected to be high throughout the region due to climate change (Cheung *et al.*, 2011). As examples, there is some evidence of a contributing link to jellyfish population explosions (Purcell, 2012) as well as on the distribution of Humboldt squid (and associated impact on groundfish species (Zeidberg and Robison, 2007). Hare and Mantua (2000) provide evidence of climate driven regime shifts in the North Pacific in 1977 and 1989. A northward movement of many pelagic fish species is projected (Cheung *et al.*, 2015).
- Increasing inland water temperatures may exceed the thermal tolerance for some species (e.g., salmon) and cause behavioural changes, increase incidence of disease, etc… (e.g., Martins *et al.*, 2011; Poesch *et al.*, 2016).
- From a global perspective, vertebrate population abundances have declined by 58% between 1970 and 2012 (WWF, 2016). Projections estimate that ~60% of plants and ~35% of animals will lose over half of their range by 2080 due to climate change (Warren *et al.*, 2013). The median rate of northward migration, for those species where migration is even attainable, is ~16.9 km/decade (Chen *et al.*, 2011).
- Coastal marshes can migrate landward, however, this can be blocked by natural slopes or human structures, a situation known as "coastal squeeze" (Pontee, 2013).
- Sea-level rise and increases in the frequency and magnitude of storm surges are potential threats to waterbird nests and breeding habitat on low-lying landforms, such as barrier islands and beaches (e.g., Bourque *et al.*, 2015; Craik *et al.*, 2015; Tremblay *et al.*, 2006).
- First Nation fishery catch potentials are projected to decline (Weatherdon *et al.*, 2016).
- Wildlife species will continue to experience range shifts and changes in abundance. (e.g., National Audubon Society, 2015).
- Climate change will influence environmental chemistry and pollutants, including an exacerbation of the effects of acid deposition (lower pH due to higher CO_2 levels), nutrient loading (precipitation events), and mercury toxicity (released under anoxic conditions, warmer waters increase the rate of methylation) (e.g., Michalak, 2016; Noyes *et al.*, 2009). No significant change in the regions ocean surface water pH has been observed since 1934 (DFO, 2012).
- Asynchrony between life history events has been observed. Although photoperiod is not changing, other ecological cues are changing, such as temperature, river flow, etc… Earlier peaks in insect and plant biomass have been observed and this may mismatch

migrant bird hatchling growth and development (Knudsen et al., 2011; Nituch and Bowman, 2013). As an example, the timing of Cassin's and Rhinoceros auklet nestlings and peak populations of its copepod prey are beginning to mismatch (i.e., warmer oceans have advanced copepod populations) (Bertram, 2001).

- The distribution and impacts of pathogens and parasites are expected to increase with warmer temperatures and the northward migration of species (Marcogliese, 2008; 2016; Pickles *et al.*, 2013).
- "Temperature velocities" for forest biomes are estimated to move northward, however, colonization success will vary with (micro)topography, permafrost conditions, dispersal competition, soil, precipitation patterns, disturbance regimes, pollinators and many other factors (e.g., Hamann and Wang, 2006; Jacobs *et al.*, 2014; Lafleur *et al.*, 2010; McKenney *et al.*, 2007; Warren *et al.*, 2013). Nationally, it is suggested that vegetation distribution (biomes) will change in over half of Canada`s national park (Scott *et al.*, 2002).
- To facilitate Garry oak conservation in the context of climate change, Pellatt *et al.* (2012) developed bioclimatic models for future habitat distribution. They discuss the need to maintain connectivity.
- Conditions, including milder winters and summer drought, may be more favourable for invasive species colonization (Langor *et al.*, 2014; Walther *et al.*, 2009) and for more extensive forest insect and disease outbreaks (e.g., spruce budworm, forest tent caterpillar, gypsy moth) (Warren and Lemmen, 2014; Warren *et al.*, 2013; Weed *et al.*, 2013).
- The alpine tree line is projected to move upslope. For example the current coastal western hemlock and mountain hemlock climate zones are predicted to move upwards by 200-300 m in elevation by 2050 (FLNR, 2016; Wang *et al.*, 2012). Of note, the impact is compounded by the fact increasing deposition of atmospheric nitrogen is facilitating (through fertilization) plant species colonization (including invasive species) of the alpine tundra through (Bobbink *et al.*, 2010; Porter *et al.*, 2011).
- Conditions, including milder winters and summer drought, may be more favourable for invasive species colonization (Walther *et al.*, 2009) and for more extensive forest insect and disease outbreaks (e.g., spruce beetles, Swiss needle cast, western hemlock loopers)(Warren and Lemmen, 2014).
- Length of the wildfire season and area burned is expected to increase (Boulanger *et al.*, 2013; Wang *et al.*, 2015; Whitman *et al.*, 2015).

Visitor Experience

- Visitation may increase due to an earlier spring and warmer summer and autumn conditions. For example, Scott and Jones (2006) project a 13-37% increase in visitation at Pacific Rim NPR by 2050.
- When temperatures exceeded 25-30˚C, a strong decrease in visitation has been observed in some parks (Fisichelli *et al.*, 2015; Hewer *et al.*, 2016).
- It may be necessary to extend the operating season to accommodate visitor safety and demand.
- There are concerns to human health from increased disease risks. For example, Lyme disease (bacterial disease transmitted by an infected tick) which was formerly restricted

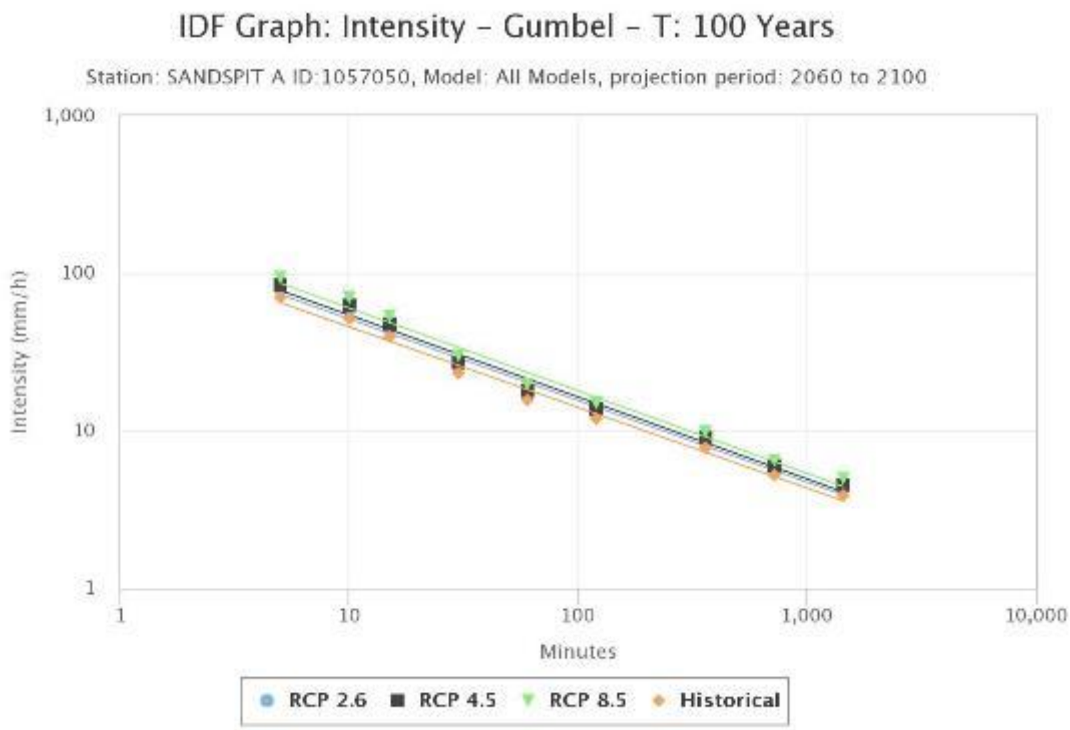
to localized areas by temperature and relative humidity, is expected to expand by mid-century (Eisen *et al.*, 2016; Ogden *et al.*, 2006). Some mosquito-borne diseases also show a connection to climate change, including West Nile virus (Chen *et al.*, 2013; Kulkarni *et al.*, 2015).
- A longer and more intense fire season will affect visitor safety and experience (e.g., possible area closures, no campfires, or evacuations).

Assets and Infrastructure

- Increased storm surge intensity increases the risk of coastal flooding and erosion (PCIC, 2016). Projected sea level rise (see vertical allowance projection within each site summary) will damage and destroy coastal infrastructure (Lemmen *et al.*, 2016), with associated maintenance or relocation costs.
- Saltwater intrusion of aquifers may impact potable water sources.
- Some facilities may be more vulnerable to the expected increase in wind gust events (Cheng *et al.*, 2014).
- Intense rainfall can result in flooding and landslides, which potentially can damage assets and infrastructure and overwhelm stormwater system capacities (PCIC, 2013a).
- There is an increasing risk to assets and infrastructure by wildfire damage in some areas. More severe fire weather (heat and drought) may also create conditions where fire suppression is no longer feasible or effective (Colombo, 2008; Flannigan *et al.*, 2005).
- Designing or retrofitting stormwater systems and hydraulic structures to accommodate new "normal" precipitation and temperature patterns will be necessary. Larger structures can serve both a drainage and road "ecopassage" function, thus making landscape more permeable to water flow and species movements.

Cultural Resources

- Increased damage or loss of cultural resources is possible during and post- flood, storm-surge, and wildfire events as well as by sea level rise (e.g., Marissa *et al.*, 2016; Walker and Barrie, 2006).
- Coastal erosion plays both a disturbance and discovery role with archaeological sites, raising fundamental issues about salvage, identification, protection and site management.
- There is a potential for increased deterioration of facilities and collections (e.g., non-mechanically ventilated interiors, HVACs) from increased temperature, humidity, and precipitation, e.g., increased mold, rot and fungal decay; increased corrosion, etc… (Brimblecombe, 2014; Brimblecombe and Brimblecombe, 2016; Horowitz *et al.*, 2016; Marissa *et al.*, 2016).
- Socio-economic impacts through lose or damage to cultural resources may occur.
- Micro-climates which allow historic gardens to flourish at some cultural sites may be affected (e.g., Percy *et al.*, 2015).
- Longer growing seasons and warmer conditions may lead to increased presence and abundance of invasive plant species and pests (Marissa *et al.*, 2016).



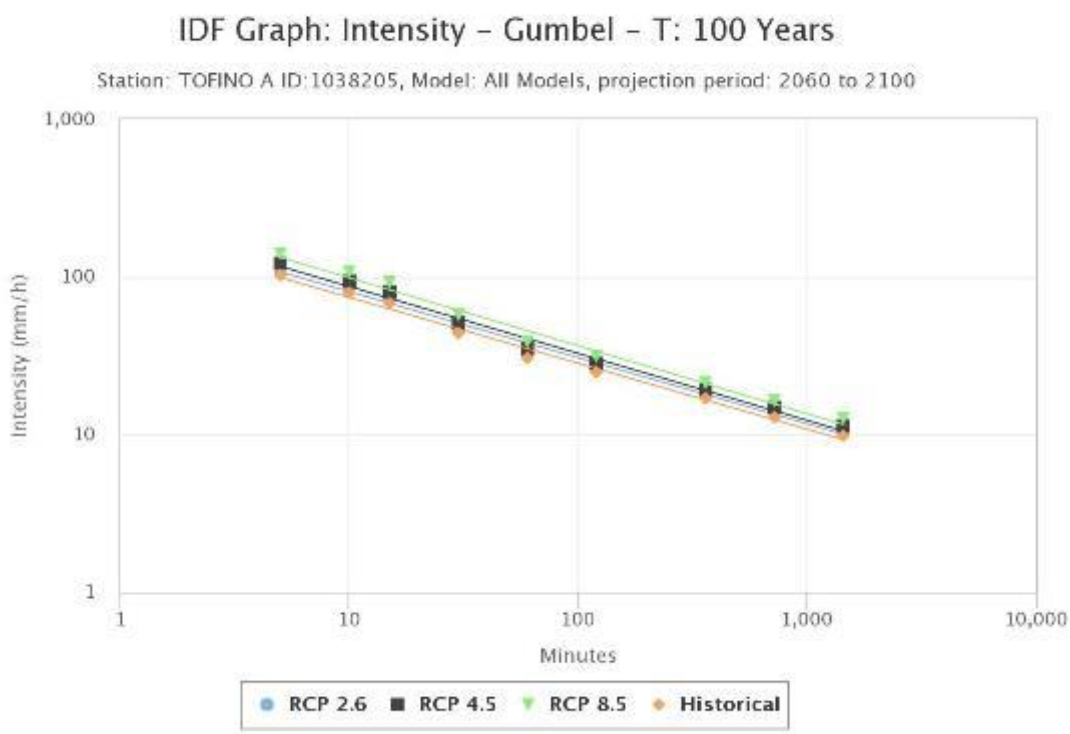


Figure 83. Example of rainfall intensity-duration-frequency curves for future climate scenarios. As illustrated, rainfall intensity for the “1 in a 100 year” event at Sandspit (Gwaii Haanas) is projected to increase from 64mm/hr to as much as 86mm/hr (5 minute duration) and at Tofino (Pacific Rim NPR) from 102mm/hr to as much as 133mm/hr (5 minute duration). The IDF_CC Tool (https://www.idf-cc-uwo.ca) permits user driven analysis of future projections for climatological stations across the country.

3. Climate Change Actions

In general, most protected area agencies in Canada are only beginning to consider and develop climate change policies, planning tools, and management frameworks (Lemieux *et al.*, 2011) (note: a draft Parks Canada climate change strategy, version 4.4, was last revised in 2008). There are, however, examples of adaptation and mitigation actions already underway in individual sites and within other jurisdictions that may inspire and guide actions (e.g., Gross *et al.*, 2016; Lemieux *et al.*, 2010; US NPS, 2010).

3.1 Adaptation

Adaptation is an adjustment in natural or human systems in response to actual or expected climate change impacts. Adaptation in protected areas often involves the implementation of established ecosystem-based management practices. These actions can represent "**no regrets**" since they broadly benefit the ecological and commemorative integrity at a site, regardless of the rate of climate change. This includes working with regional partners to manage landscape level disturbances; protecting and restoring ecosystems to build resilience; preventing the spread of invasive species; protecting species at risk; conserving built heritage at historic sites; replacing storm damaged resources and infrastructure with more sustainable and resilient designs; and, responding to changing visitor interests and needs.

Other more regionally specific examples:

- The Pacific Climate Impacts Consortium provides on-line climate analysis tools, including "Regional Analysis Tool" and the easy to use "Plan2Adapt" (https://www.pacificclimate.org/analysis-tools).
- The Pacific Institute for Climate Solutions provides accessible climate change information for the region (http://www.pics.uvic.ca/).
- Many of "natural solution" concepts are already embedded in Biosphere Reserves, included the Clayoquot Sound.
- The "Joint Canada-US Pacific Marine Protected Area Vulnerability Assessment" assessed vulnerabilities to coastal ecosystems, including those in Pacific Rim NPR. The project was organized by the Commission for Environmental Cooperation (CEC) and involved Parks Canada staff. The final report is due in 2017. This assessment and other reports (Sloan, 2004; Steneck *et al.*, 2002) reinforced the importance of improving the resilience of kelp forests to climate disturbance by reducing the added stress of urchin grazing (e.g., control urchin populations, sea otter recovery).
- The Coastal Archaeological Resources Risk Assessment (CARRA) project helps managers respond to coastal hazard impacts to archaeological resources (Pollard-Belsheim *et al.*, 2014).

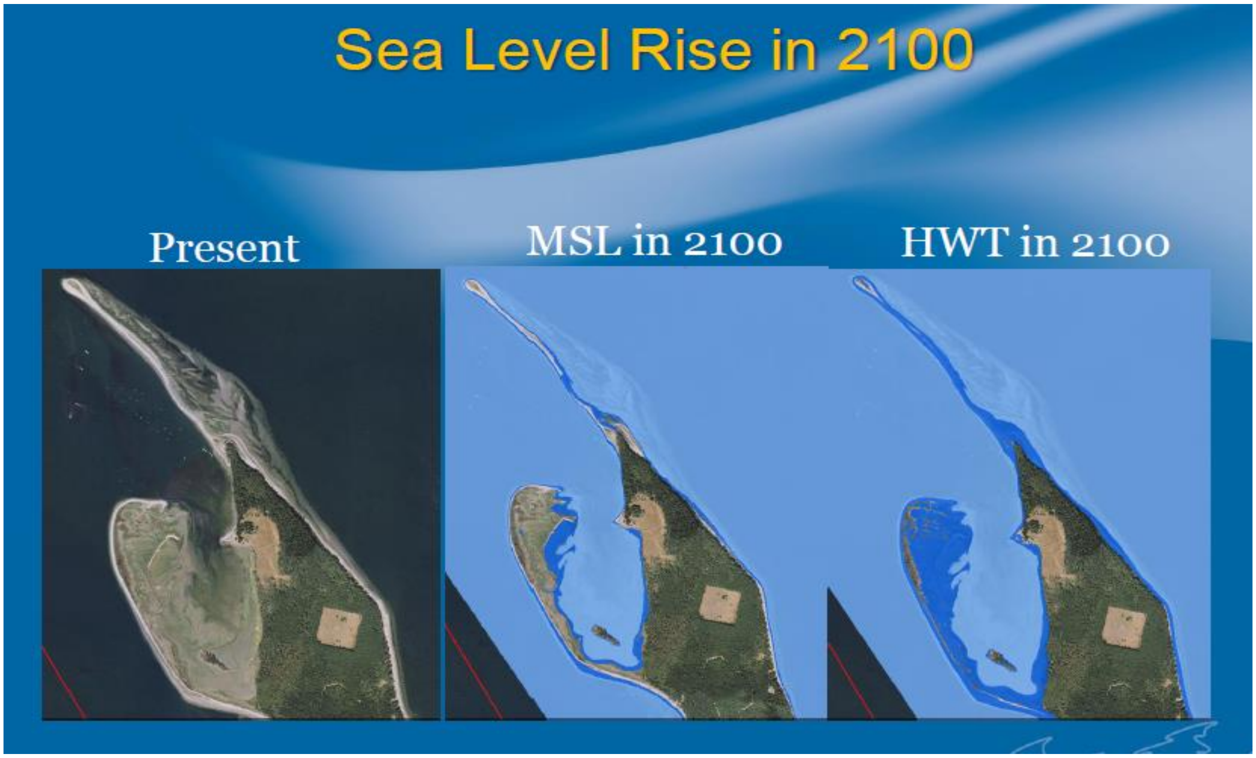


Figure 9. Sea-level rise impacts and adaptation in Gulf Islands National Park Reserve (GINPR). GINPR used a digital elevation model derived from airborne light detection and ranging (LiDAR) to map inundation of its lands for a scenario of 1m rise in sea level by 2100. This scenario was based on extreme high estimate of global sea level rise (SLR) projected for Victoria, BC. Mapping was done to represent conditions under two levels of tide – mean sea level and high tide level. Impacts of SLR on species at risk, sensitive ecosystems, archaeological sites and park infrastructure were assessed to help planning for adaptation. Projected Sea Level Rise at Sidney Spit in GINPR from 2016 to the year 2100. Inundated areas are shown in dark blue colour. MSL= Mean Sea Level; HWT= High Water Tide. Prepared by T. Sharma.

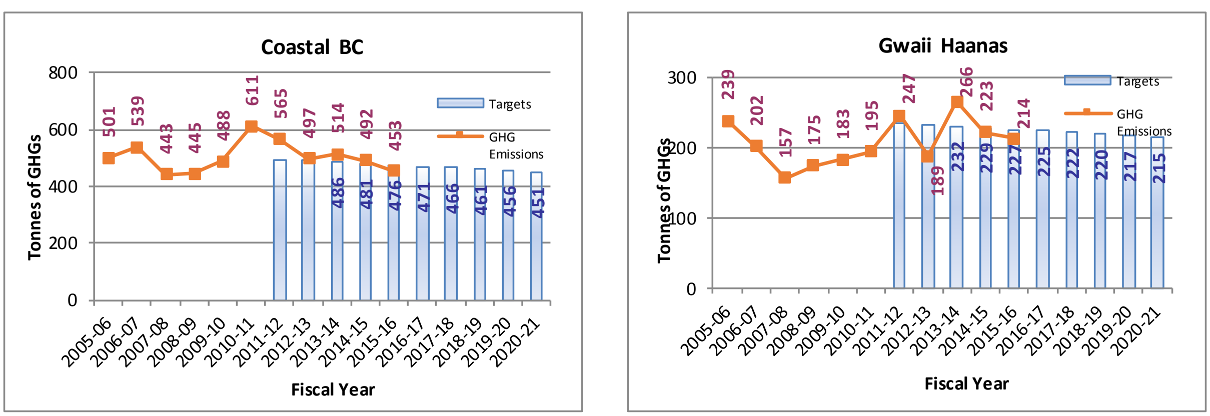


Figure 10. Greenhouse Gas Emissions per Field Unit. Emissions are calculated from energy (e.g., heating, electricity) and fuel expenditures, excluding travel, air charters, and some other sources. GHG emissions from energy cost are adjusted for source (e.g., coal, hydro, diesel, etc...). The targets in these figures are from 2015 reduction targets (Parks Canada, 2015). Revised, lower targets to be communicated in 2017 (Canada, 2016).

3.2 Mitigation

Mitigation refers to human interventions that reduce the source or enhance the sinks of GHG emissions. Carbon dioxide, methane, nitrous oxide, water vapour and ozone are the primary GHGs in the earth's atmosphere, in addition to human-made chlorine- and bromine-containing substances. Parks Canada's Asset and Environmental Management team provides national functional leadership, expertise and support related to GHG reductions. Sites interested in working on GHG reduction and more sustainable operations should confer with this team. As an example, this team annually tracks all Field Unit energy expenditures and GHG emissions and reports progress towards federal government reduction targets. The current target is 40% reduction in GHG emissions from federal buildings and fleets below the 2005 levels by 2030 (Canada, 2016); it is clear that this will require an ambitious and concerted effort on the part of all.

Mitigation examples include:

- Evaluate progress towards Parks Canada / Field Unit GHG reduction targets.
- Specify "green" and energy efficient designs for construction and renovation projects (e.g., LEED, R-2000, and Green Buildings BC).
- Reduce the number and/or size of park vehicles and vessels to match need and maximize efficiency. Provide hybrid or electric where possible.
- Electric utility and lawn vehicles for campground maintenance.
- Anti-idling and cabin heat-recovery systems in trucks.
- Use energy efficient products, promote energy efficiency and water conservation, reduce waste and support alternative transportation.
- Review Parks Canada (2015) and US NPS (2012a).

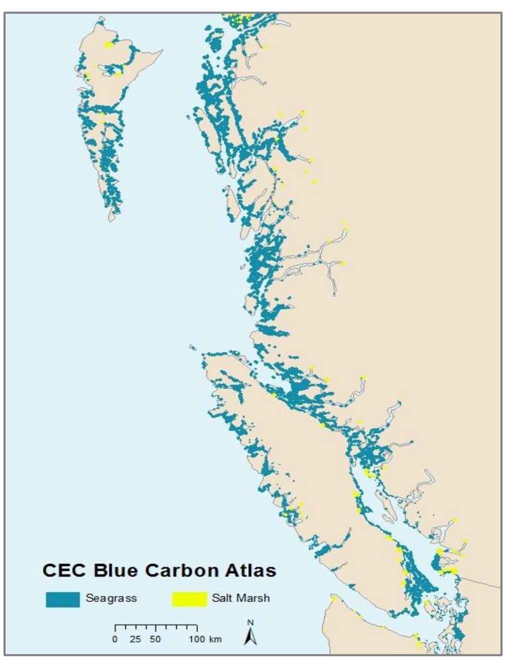


Figure 11. CEC Blue Carbon

Blue Carbon is the carbon captured and stored in marine and freshwater ecosystems. Coastal ecosystems, including seagrass meadows and salt marshes, are especially important for climate mitigation as they sequester CO2 at significantly higher rates, per unit area, than terrestrial forests.

In addition these ecosystem provide numerous benefits and services essential for climate change adaptation (e.g., coastal protection, water quality, habitat, food security, etc…).

The Commission for Environmental Cooperation's (CEC) Blue Carbon map shows the distribution of salt marsh, mangrove, and seagrass ecosystems in North America. This is available at: http://www.cec.org. The CEC has also supported Blue Carbon research in and around national parks, e.g., at Pacific Rim NPR (CEC, 2017a; 2017b).

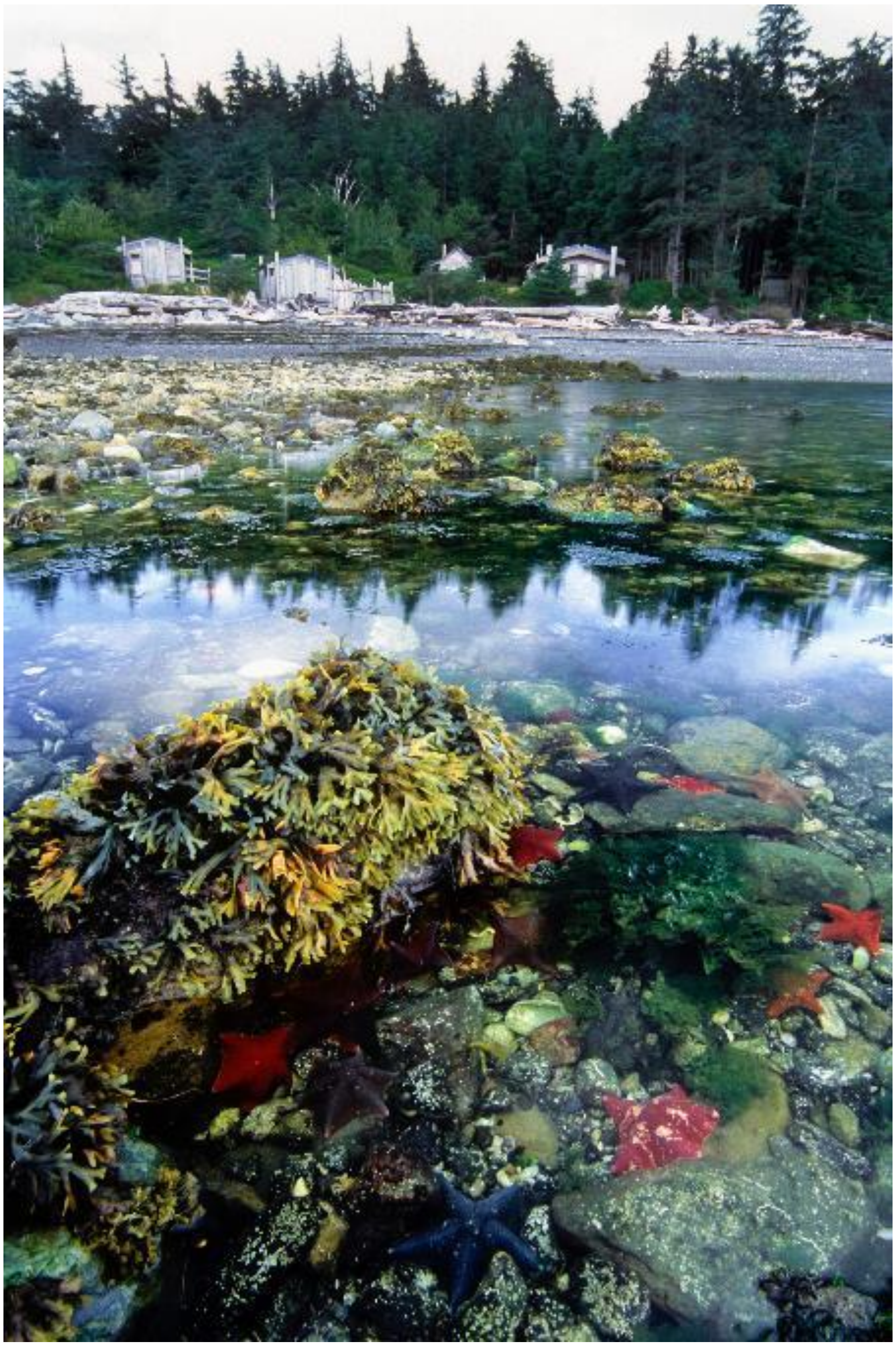
3.3 Possible Next Steps

This report is intended to be a stepping off point, from here individuals and sites are encourage to consider how best to advance climate change actions in their own context. Here is a checklist of ideas that others have considered that may be of particular interest or relevance.

- ☑ Enhance workforce climate literacy (e.g., Peterson *et al.*, 2011; US NPS, 2012b).
- ☑ Undertake more detailed analysis of climate trends, including impact models (e.g., hydrology, wildfire, infrastructure at risk, coastal visualization) and extreme weather events (e.g., Charron, 2016).
- ☑ Conduct future scenario planning and explore operations under novel and equally plausible future conditions. Use scenarios to test ("wind tunnel") strategic decisions and inform contingency plans (e.g., Gross *et al.*, 2016; US NPS, 2013).
- ☑ Conduct vulnerability assessments of species, ecosystems or governance structures. Vulnerability is the degree to which a system is susceptible to, and unable to cope with, the impacts of climate change (e.g., Edwards *et al.*, 2015; Gleeson *et al.*, 2011; Gross *et al.*, 2016).
- ☑ Incorporate climate change impacts and adaptation strategies into management planning. Recalibrate management objectives in the face of ecosystem change, system novelty and loss of resilience (e.g., Lemieux *et al.*, 2011).
- ☑ Revise visitor management and operational plans in response to changing visitor patterns and use (e.g., Fisichelli *et al.*, 2015; Hewer *et al.*, 2016). Diversify visitor experiences to provide alternatives to weather-dependent activities.
- ☑ Quantify and understand carbon stocks and dynamics (e.g., US NPS, 2012a).
- ☑ Evaluate and communicate the value of ecological goods and services (e.g., clean water/air, provision of food, maintain biodiversity, nature-based tourism, carbon storage, etc…) and manage for the sustainability of these services (e.g., Gross *et al.*, 2016).
- ☑ Maintain a list of climate science and management actions to help inform and influence park messaging.
- ☑ Build networks and collaborate across multiple scales (e.g., Waterton Lakes NP, crownmanagers.org).
- ☑ Consider the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol (https://pievc.ca/protocol) in climate change vulnerable infrastructure projects.
- ☑ "Explicitly recognize climate change as a management issue in state of the park reporting and monitoring frameworks". This adaption option was one of two from 165 options

deemed as necessary and "definitely implementable" by senior decision-makers for the Ontario park system (Lemieux and Scott, 2011).

Please contact the Office of the Chief Ecosystem Scientist if you have any questions or would like to explore any of these next steps further. In addition, PDF copies of all references and the climate data are freely available upon request.



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Appendix 1. Climate Change Projections

Climate change summaries were determined for the geo-centroid[1] of each national park and national marine conservation area. The method used to prepare the map followed Price *et al.* (2011) and used greenhouse gas (GHG) concentration scenarios adopted by the IPCC (2014) and General Circulation Models (GCMs)[2].

Of the four IPCC GHG concentration scenarios, the lowest and highest Representative Concentration Pathways (RCP), RCP 2.6 and RCP 8.5 were chosen. These are named after possible radiative forcing values in the year 2100 relative to pre-industrial values (i.e., +2.6 and +8.5 watts/m^2, respectively). RCP 2.6 assumes that global annual GHG emissions (measured in CO_2-equivalents) peak in 2010-2020, with emissions declining substantially thereafter. In RCP 8.5, emissions continue to rise throughout the 21st century.

To produce a high-resolution climate map, monthly time-series data were obtained for each GCM representing both the 20th century (1981–2010) and the scenarios of GHG concentration for the 21st century. Each monthly value at each GCM grid node was normalized either by subtracting (for temperature variables) or dividing by (for other climate variables) the mean of that month's values for the 30-year baseline period 1981–2010. The GCM projected changes in temperature and precipitation were averaged over 30-year periods and then interpolated using ANUSPLIN to the locations of climate stations in Canada and the USA. These data were then combined with observed station normals for the period 1981–2010 to create projected normals for three consecutive 30-year periods: 2011–2040, 2041–2070 and 2071–2100.

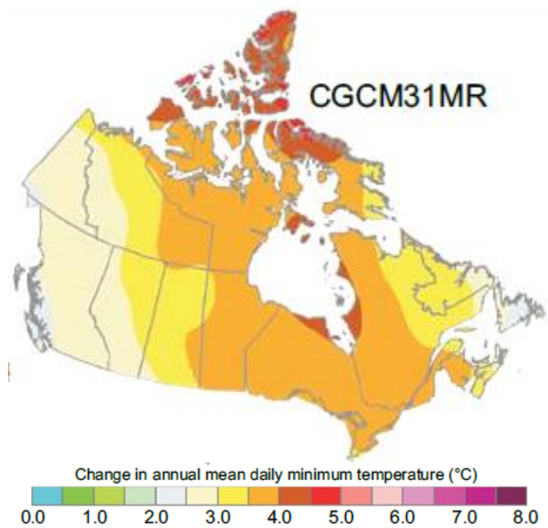

Figure A1. Projected change in annual daily minimum temperature for 2041-2070, relative to 1961-1990 (Price *et al.*, 2011).

A Bessel interpolation scheme was used to generate daily temperature and precipitation sequences that pass monotonically through the monthly values. This allowed for a suite of bioclimatic indicator variables to be estimated for these periods, including for example, mean growing season duration and precipitation during the growing season (Table A1). A set of composite maps averaging the values of the four GCMs was created and used to extract the projected climatic data for the parks and NMCAs at each geo-centroid.

No model driven by scenarios of future climate can ever provide definitive answers to questions about specific outcomes (e.g., how much change will occur at a specified location by a specified date?). However, temperature projections aligned with recent trends and there appears

[1] In the cases of parks for which the geo-centroid is located in the sea, we extracted the data for 5 sets of coordinates determined to be on the land using Google maps.
[2] CANESM2, CESM1CAM5, HADGEM2ES, and MIROCESM.

to be strong agreement on the magnitude of warming to be expected in the short term (until 2030–2040), independent of the RCP scenarios. This is because much of the warming projected for the next two to three decades is "committed warming" resulting from GHG emissions that have already occurred. It is only after ca. 2040 that the warming trajectories diverge, when early mitigation efforts (RCP 2.6 scenario) would evidently begin to have a positive effect. Further into the future, the range of possible warming increases, largely because of the divergence among the different GHG emission trajectories.

Table A1. Bioclimatic variables mapped for past and future climates[a]

No.	Variable[b]	Description
1	Annual mean temperature	Annual mean of monthly mean temperatures
2	Mean diurnal temperature range	Annual mean of monthly mean daily temperature ranges
3	Isothermality	Variable 2 ÷ variable 7
4	Temperature seasonality	Standard deviation of monthly mean temperature estimates, expressed as a percentage of their mean
5	Maximum temperature of warmest period	Highest monthly maximum temperature
6	Minimum temperature of coldest period	Lowest monthly minimum temperature
7	Annual temperature range	Variable 5 – variable 6
8	Mean temperature of wettest quarter	Mean temperature of three wettest consecutive months
9	Mean temperature of driest quarter	Mean temperature of three driest consecutive months
10	Mean temperature of warmest quarter	Mean temperature of three warmest months
11	Mean temperature of coldest quarter	Mean temperature of three coldest months
12	Annual precipitation	Sum of monthly precipitation values
13	Precipitation of wettest period	Precipitation of wettest month
14	Precipitation of driest period	Precipitation of driest month
15	Precipitation seasonality	Standard deviation of monthly precipitation estimates, expressed as a percentage of their mean
16	Precipitation of wettest quarter	Total precipitation of three wettest consecutive months
17	Precipitation of driest quarter	Total precipitation of three driest consecutive months
18	Precipitation of warmest quarter	Total precipitation of three warmest months
19	Precipitation of coldest quarter	Total precipitation of three coldest months
20	Start of growing season	Date when daily mean temperature first meets or exceeds 5°C for five consecutive days in spring
21	End of growing season	Date when daily minimum temperature first falls below –2°C after 1 August
22	Growing season length	Variable 21 – variable 20
23	Total precipitation in the three months before start of growing season	Total precipitation in the three months before variable 20
24	Total growing season precipitation	Total precipitation during variable 22
25	Growing degree-days during growing season	Total degree-days during variable 22, accumulated for all days where mean temperature exceeds 5°C
26	Annual minimum temperature	Annual mean of monthly minimum temperatures
27	Annual maximum temperature	Annual mean of monthly maximum temperatures
28	Mean temperature during growing season	Mean temperature during variable 22
29	Temperature range during growing season	Highest minus lowest temperature during variable 22
30	Climate Moisture Index (monthly)	Precipitation minus potential evapotranspiration

[a] In all cases, the descriptions should be considered estimates rather than actual values.
[b] Variables 1–19 were generated by ANUCLIM; variables 20–29 were generated by SEEDGROW. The approach used creates a daily sequence of minimum and maximum temperature and precipitation, with the values forced monotonically through the monthly values. The resulting values are intended to represent mean conditions only, as the weather in any given year would be expected to produce different results, because of interannual variability.