April 11, 2018

Supplemental Climate Information for Bruce Peninsula National Park and Fathom Five National Marine Park

Prepared by:

Scott Parker, Ph.D.
Office of the Chief Ecosystem Scientist

Parks Canada Parcs Canada

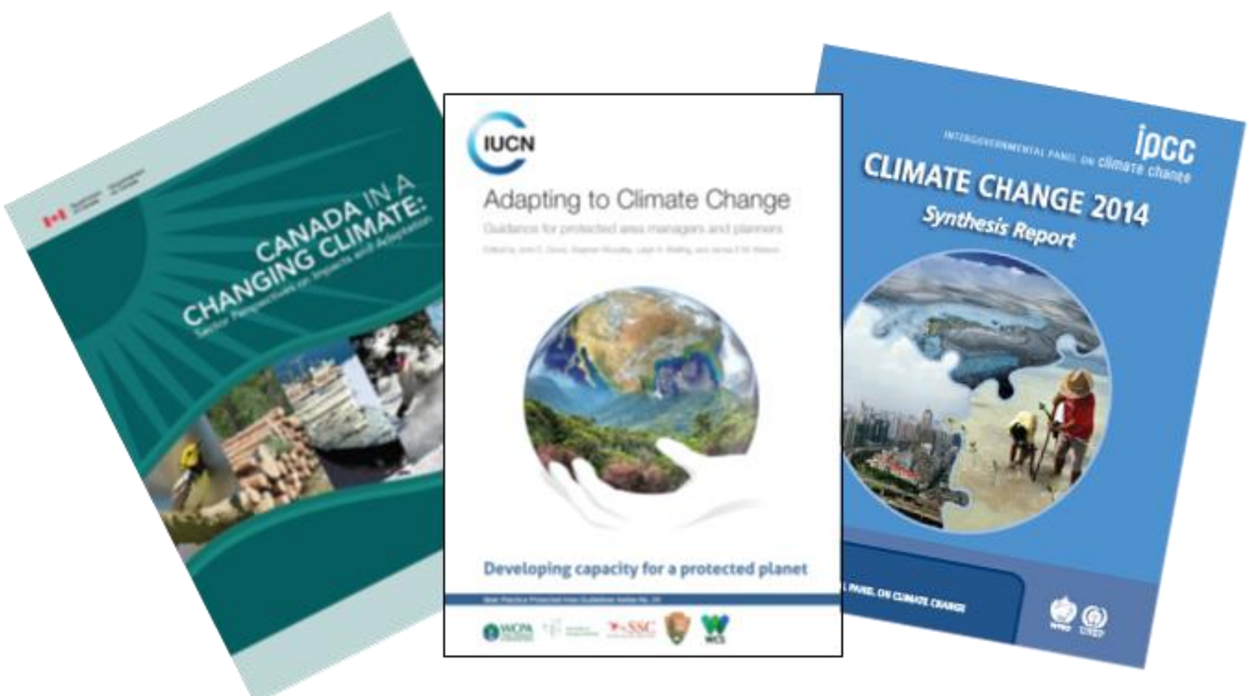
Contents

Preface

This is a supplement to the "Let's Talks about Climate Change: Great Lakes Region" report (Parker, 2017) and is intended to support climate change discussions at Bruce Peninsula National Park and Fathom Five National Marine Park.

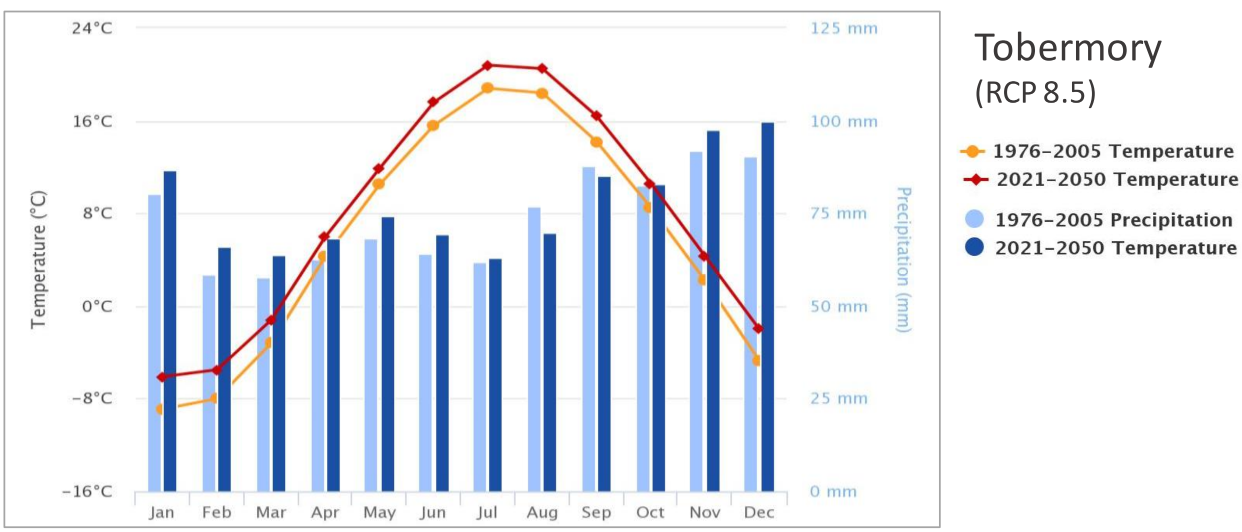
Future climate projections are modelled with several greenhouse gas concentration trajectories, called **Representative Concentration Pathways (RCP)** (Vuuren *et al.*, 2011). They describe possible climate futures and are named after respective radiative forcing values in the year 2100 relative to pre-industrial values (i.e., +2.6, +4.5 and +8.5 watts/m^2). **RCP 2.6** assumes we take action and greenhouse gas emissions peak in 2010-2020 and decline thereafter. **RCP 4.5** assumes emissions peak around 2040 and then decline. **RCP 8.5** assumes we take no action and emissions continue to rise "status quo" throughout the 21st century.

This is a site focussed document and to understand the larger climate change context please consult Canada's Changing Climate assessment reports (http://www.nrcan.gc.ca/environment/impacts-adaptation/10029) and the Intergovernmental Panel on Climate Change assessment reports (e.g., IPCC, 2014) With respect to adaptation and mitigation options, please review Gross *et al.* (2016) or Gray *et al.* (2017).



Highlights

- Mean annual air temperature in the region has increased by ~1˚C since 1916, with the greatest increase occurring during winter and nighttime periods.
- Mean annual temperature for the region is projected to increase by ~2.1˚C by 2021-2050 and ~4.3˚C by 2051-2080 (RCP 8.5).
- The number of extreme heat days (+30˚C) per year is projected to increase from 0.8 days to 21.3 days by 2051-2080 (RCP 8.5).
- Growing season has already increased by ~17 days since 1900 and is projected to increase an additional 86 days by 2100 (RCP 8.5).
- Precipitation is variable, most projections suggest a slight increase (9% by 2050-2080) with greater increase in winter and spring and a decrease in summer. More is expected to fall in intense events with associated flooding. The "one in 100 year" event is projected to be closer to a "one in 25 year" event and happen more unpredictably.
- Mean wind speed has decreased and is projected to continue to decrease, however, extreme events are projected to have higher wind speeds.
- Lake Huron is projected to warm by ~3˚C and the ice free period increase by 45-62 days by 2071-2100.
- Lake Huron levels are projected to fluctuate within historical range of variability, several models suggest the mean level may be lower, while at least one suggests higher.
- Wildfire season length is projected to increase by 20-40 days by 2040-2070. Conditions for more intense fire behaviour are projected.
- Climatic envelopes are projected to change (northward at 3 km/yr) and will no longer be suitable for many species, particularly those with northern affinities. For instance, a 42% turnover in bird species is projected by 2100. Plant hardiness zone will change and no longer be suitable for 1000 species.
- Visitation is expected to increase, particularly in the autumn.
- Human health issues include the impact of extreme heat events and the northward movement of vector-borne diseases such as Lyme disease and Ehrlichia.
- Assets and infrastructure will be exposed to more extreme weather events and wildfire.



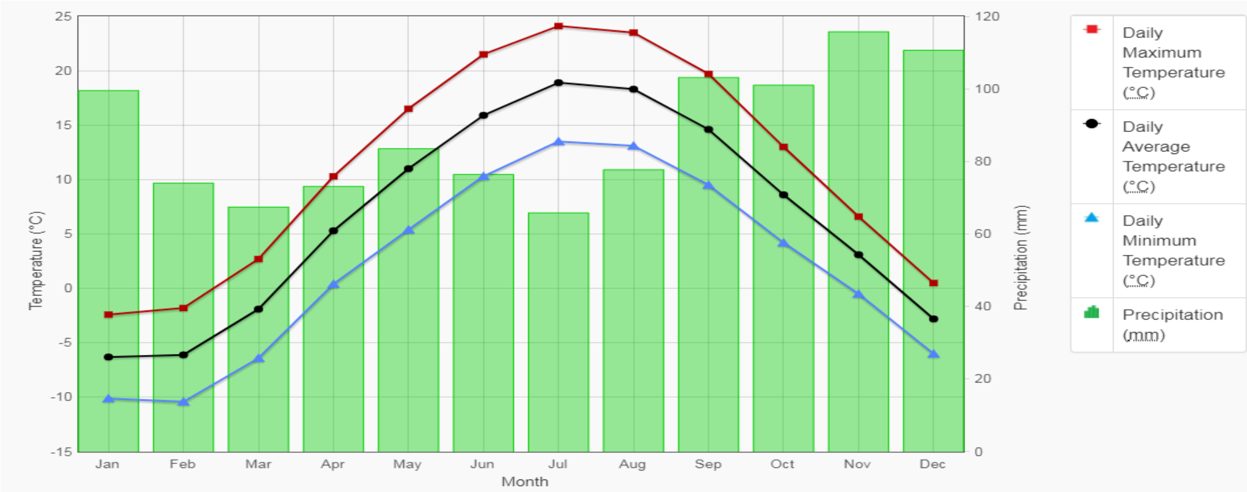
Climograph for Tobermory area. Modelled monthly mean temperature and total precipitation for the 1976-2005 baseline and 2021-2050 future projection (RCP 8.5). Figure source: Climate Atlas of Canada (https://climateatlas.ca/).

1. Historic Climate

Moderated by its maritime location, the climate of Bruce Peninsula National Park and Fathom Five National Marine Park (BP/FF) is humid and temperate with warm summers (daily mean of 18.5˚C) and cool winters (daily mean of -6.1˚C). The summer months are dominated by hot, humid air masses originating in the Pacific Ocean and the Gulf of Mexico (with extreme maximums reaching 35˚C). Winters have an increase in Pacific air which is displaced over the season by cold Arctic currents (with extreme minimums as low as -36˚C). The most prolonged cold periods occur when large Arctic high pressure air masses stall over Hudson Bay. Spring and autumn represent transitional periods; the autumn typically being the most turbulent with a relatively high frequency of storms.

Lake Huron tends to buffer macroclimatic extremes. In the spring and summer, the colder lake cools coastal areas by a few degrees. Conversely, in the autumn and winter the warmer lake moderates temperatures, often delaying frost for several weeks. Moisture picked up from the lake by prevailing winds can cause lake effect fog, rain or snow. The annual mean water temperature for Lake Huron is 8.8˚C, with a maximum mean of 21.1˚C and a minimum mean of 1.1˚C. Mean maximum ice cover for Lake Huron is 51.7%.

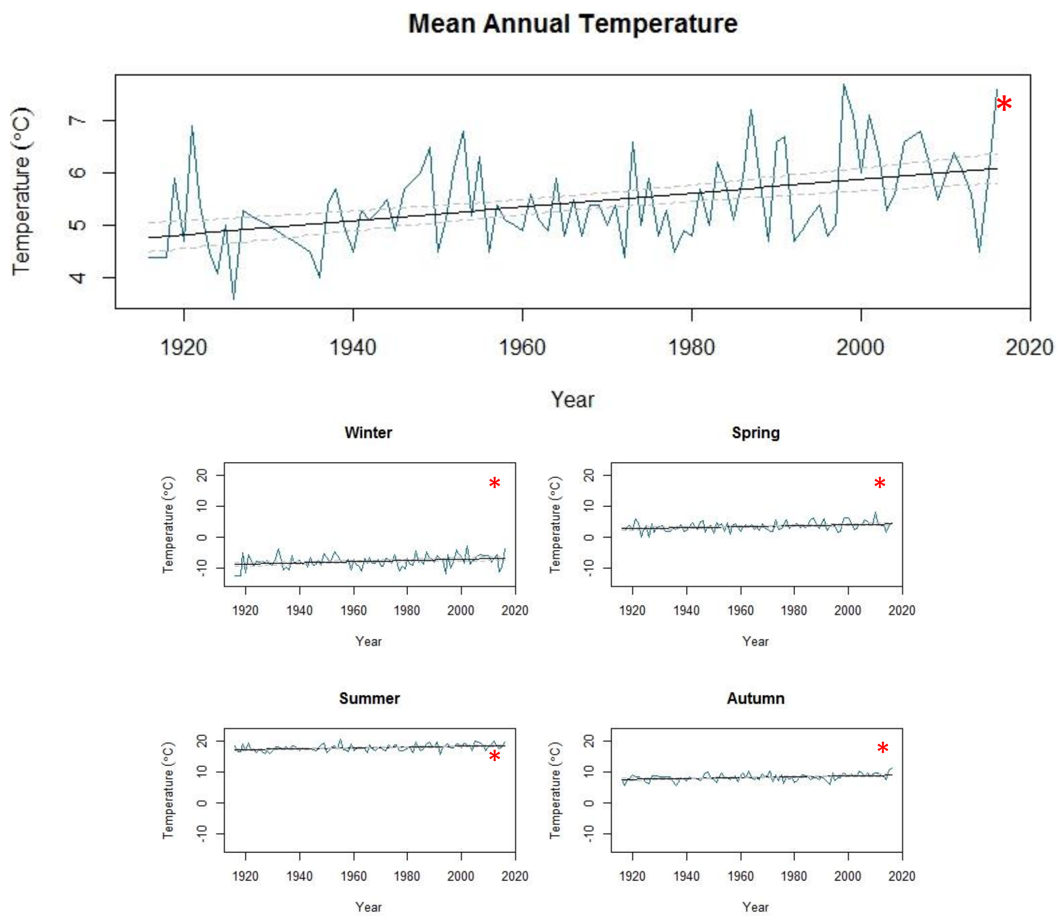
Winds are predominately from the southwest to west, with mean speeds of 10 km/hr in summer and 14 km/hr in the other seasons. Normal wave height is 0.7 m during the summer and may exceed 3 m during strong wind events. Some spectacular storms, especially in the autumn and winter, can experience winds >80 km/hr and wave heights >5 m.



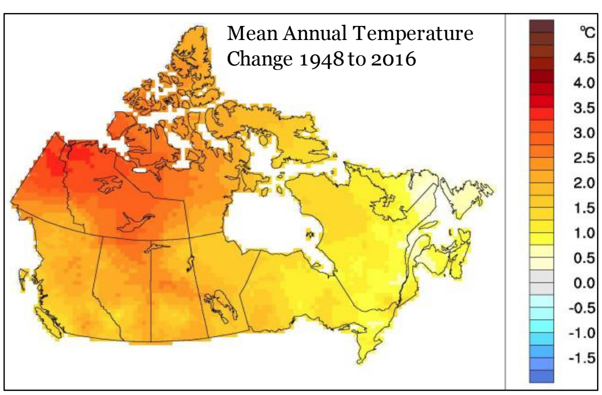
Climate "normals" (1981-2010) for Wiarton. Figure source: Environment and Climate Change Canada (http://climate.weather.gc.ca/climate_normals/)

1.1 Temperature

Gore Bay is the closest meteorological station (6092920) with long term temperature data in the AHCCD (ECCC, 2017). Trends from 1916 to 2016 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend ($P<0.05$).

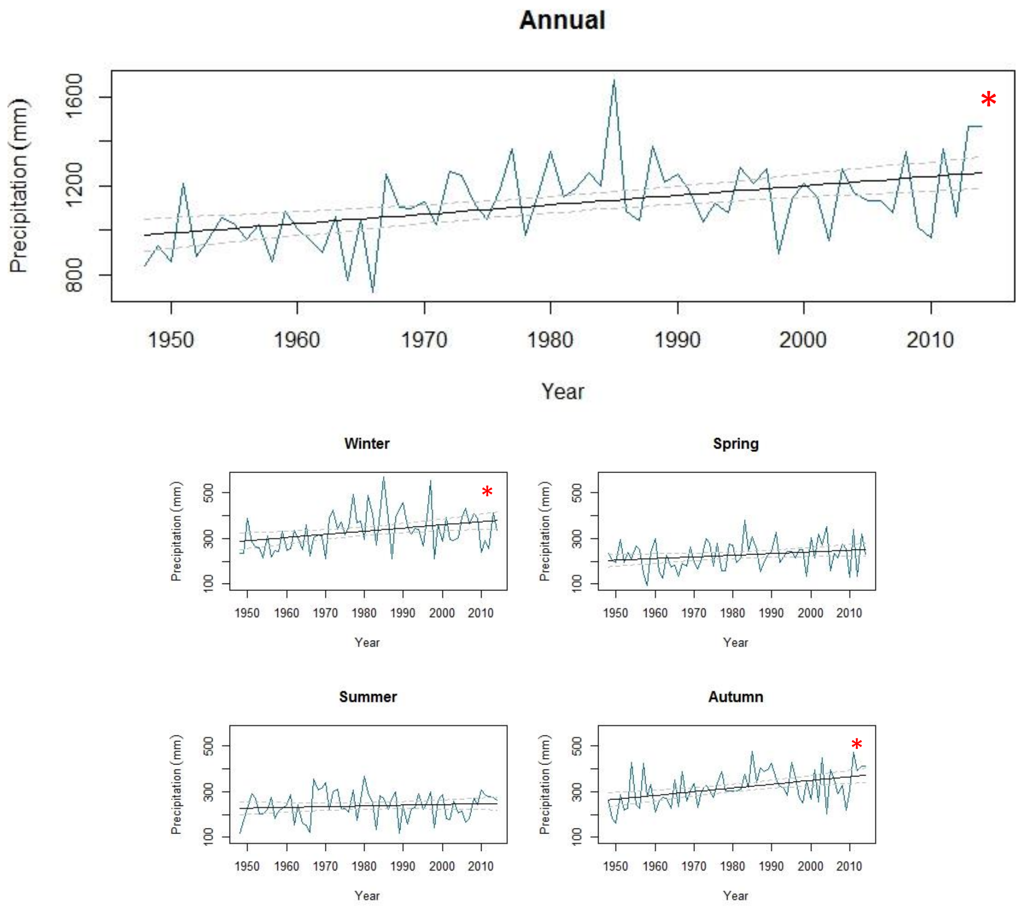


Gore Bay mean annual and seasonal temperature. A statistically significant ($P<0.05$) increase observed in mean annual and seasonal temperature. Mean annual temperature has increased by ~1°C since 1916. Of all the seasons winter temperature has increased the greatest, ~1.5°C since 1916.

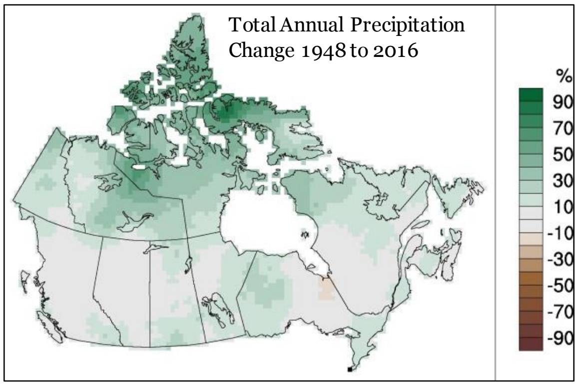


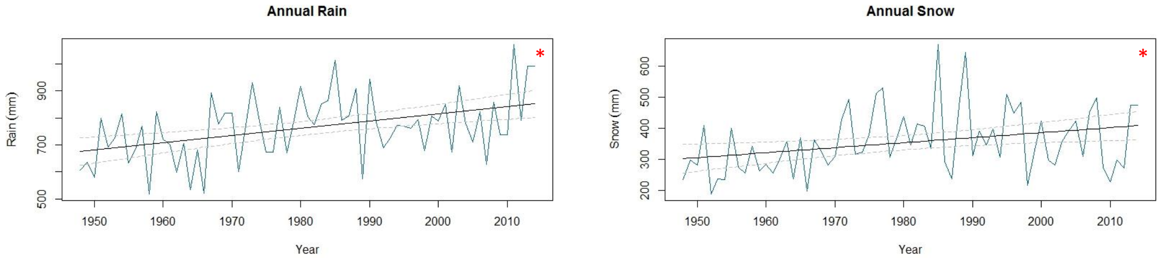
1.2 Precipitation

Wiarton is the closest meteorological station (6119500) with long term precipitation data in the AHCCD (ECCC, 2017). Trends from 1948 to 2014 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend ($P<0.05$).



Wiarton total annual and seasonal precipitation. Total annual precipitation demonstrated a statistically significant increase ($P<0.05$), ~281 mm (29%) since 1948. Winter (Dec, Jan, Feb) and autumn (Sep, Oct, Nov) demonstrated a statistically significant ($P<0.05$) increase, the greatest being observed for autumn, ~107 mm (41%).

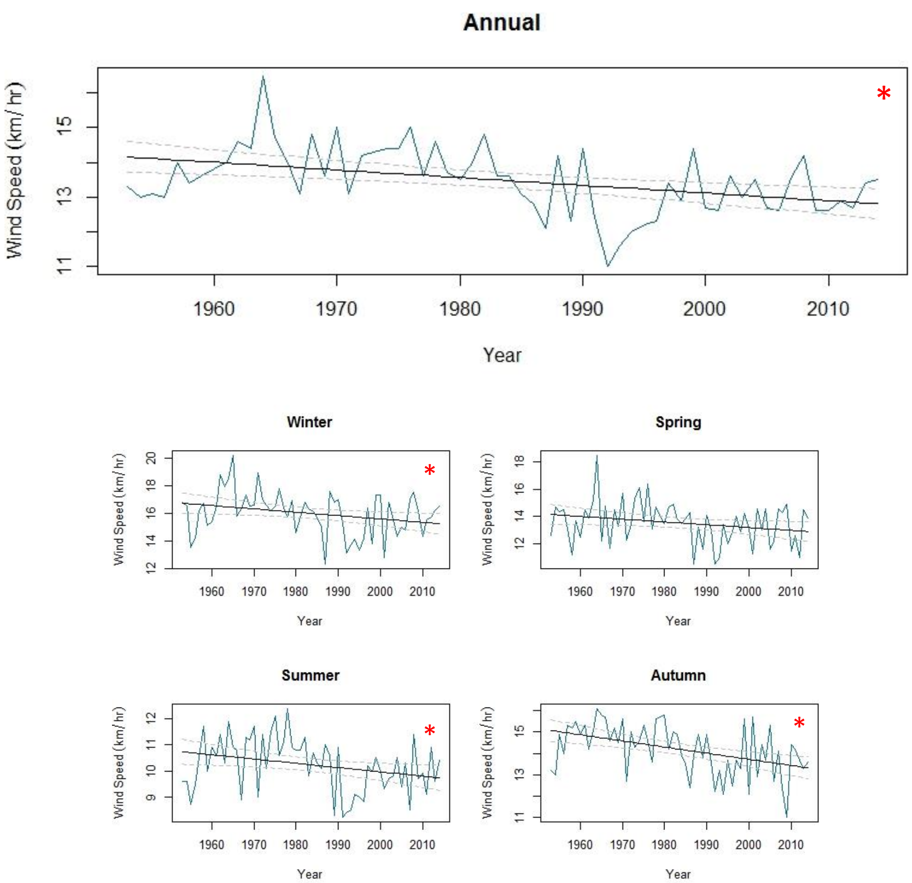




Wiarton total annual rain demonstrated a statistically significant (P<0.05) increase since 1948, ~175 mm (26%).
Wiarton total annual snow demonstrated a statistically significant (P<0.05) increase since 1948, ~105 mm (35%).

1.3 Surface Wind Speed

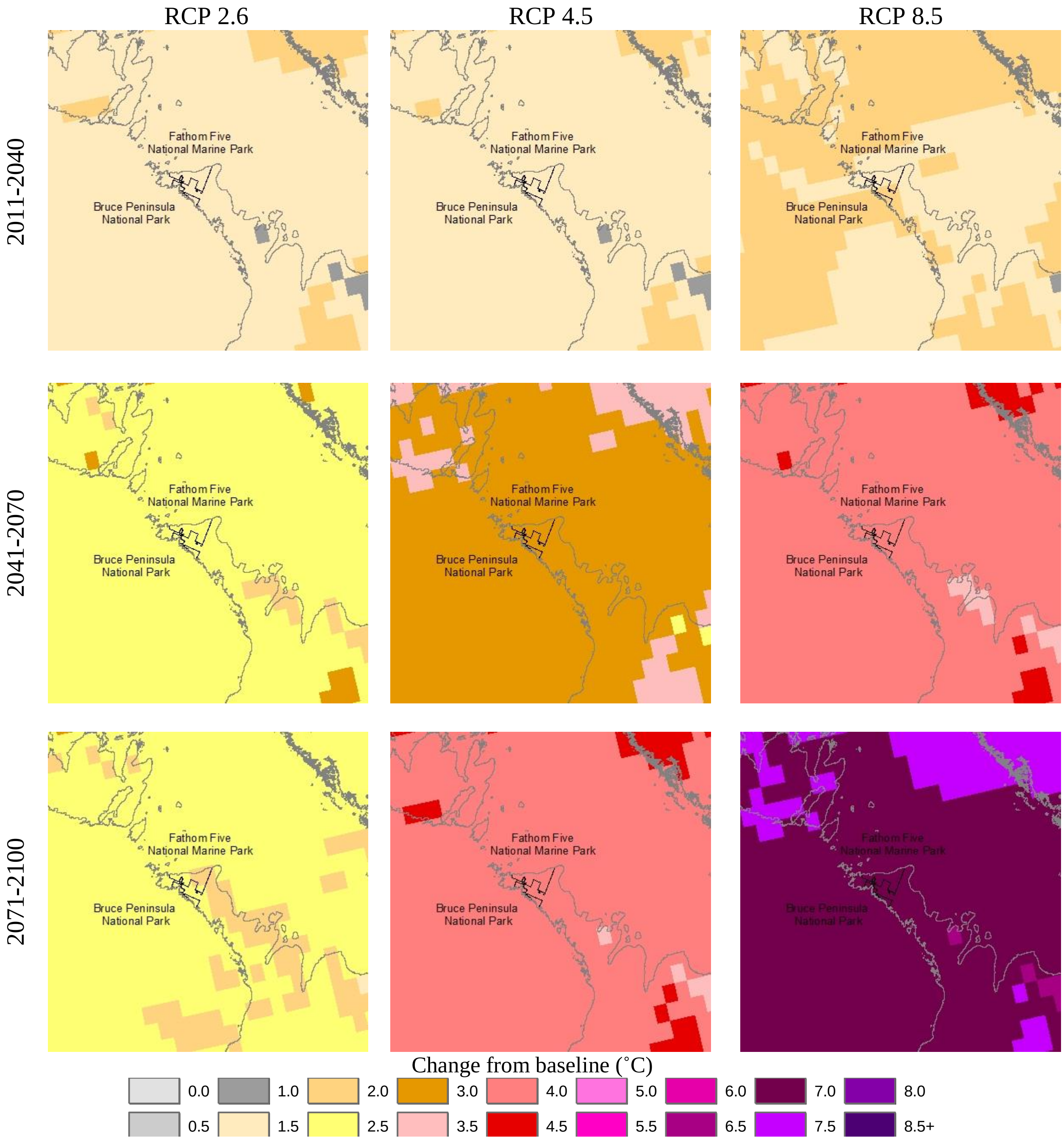
Wiarton is the closest meteorological station (6119500) with long term wind data in the AHCCD (ECCC, 2017). Trends from 1953 to 2014 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend (P<0.05).



Wiarton mean annual and seasonal wind speeds. Mean annual wind speeds have demonstrated a statistically significant (P<0.05) decrease, ~1.4 km/hr (10%) since 1953. Seasonally, winter (Dec, Jan, Feb), summer (Jun, Jul, Aug) and autumn (Sep, Oct, Nov) have all demonstrated a statistically significant (P<0.05) decrease, the greatest being observed for autumn, ~1.9 km/hr (13%) since 1953.

2. Projected Climate Trends

2.1 Temperature



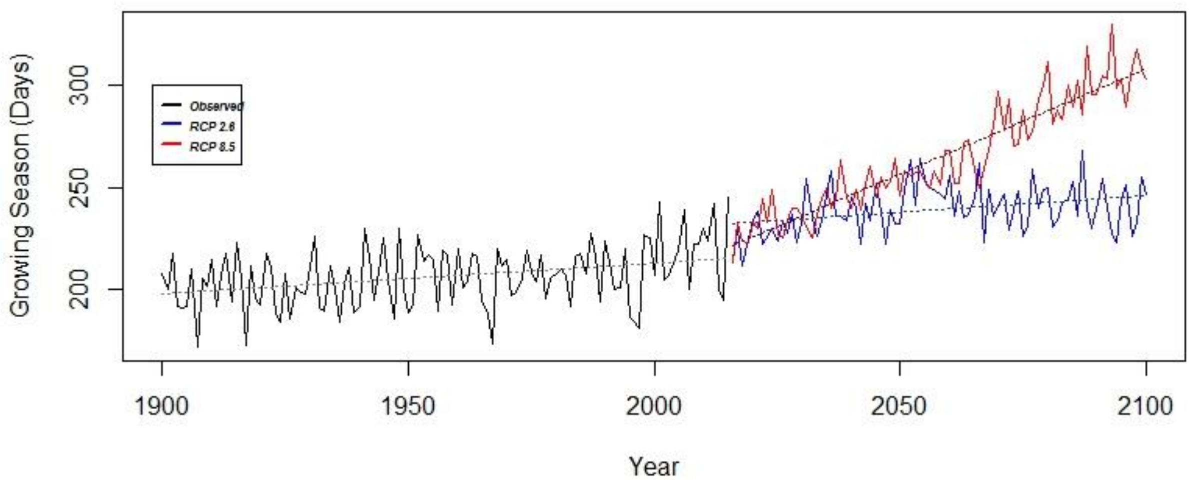
Projected mean annual temperature increase for the Bruce Peninsula from a 1980-2010 baseline. Composite projection of CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM. Data source: Natural Resources Canada, Canadian Forest Service, http://cfs.nrcan.gc.ca/projects/3 (Price *et al.*, 2011).

Temperature projections for the BP/FF area from PCIC (2014):

- Mean annual temperature is projected (RCP 4.5-RCP 8.5) to increase by 1.9-2.1°C by 2021-2050 and 2.9-4.3°C by 2051-2080.
- Winter time is projected to warm the greatest (e.g., 3.7-5.3°C by 2051-2080).
- The nighttime period is projected to warm faster than the daytime period.
- The number of +30°C days is projected to increase from 0.8 days/year (1976-2005 baseline) to between 9.4 (RCP 4.5) and 21.3 (RCP 8.5) days/year by 2051-2080.
- The number of -30°C days is projected to decrease from 0.8 days/year (1976-2005 baseline) to between 0.2 (RCP 4.5) and 0.1 (RCP 8.5) days/year by 2051-2080.

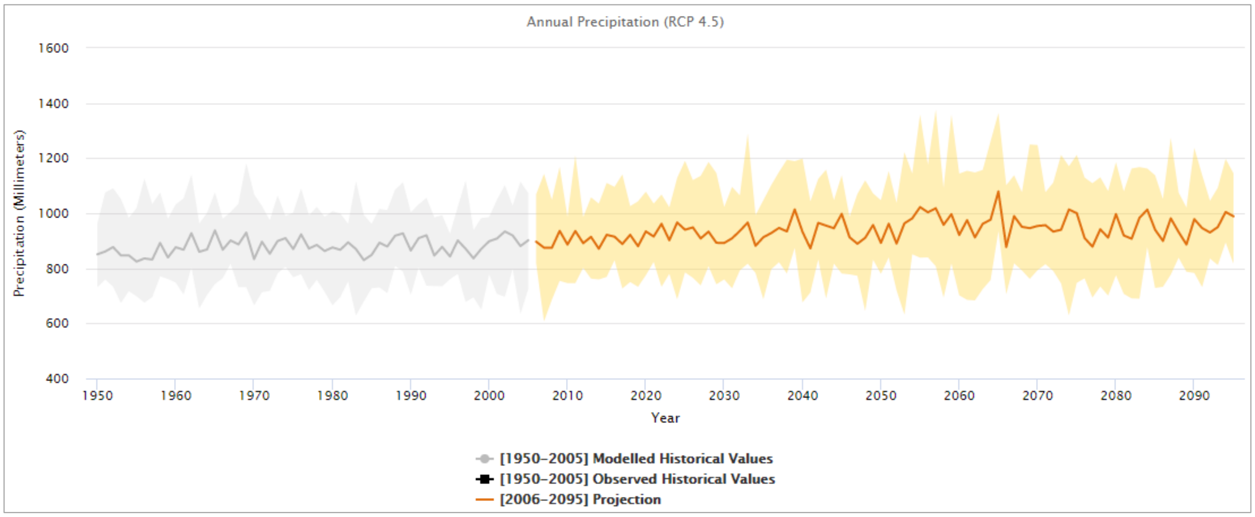
Growing Season

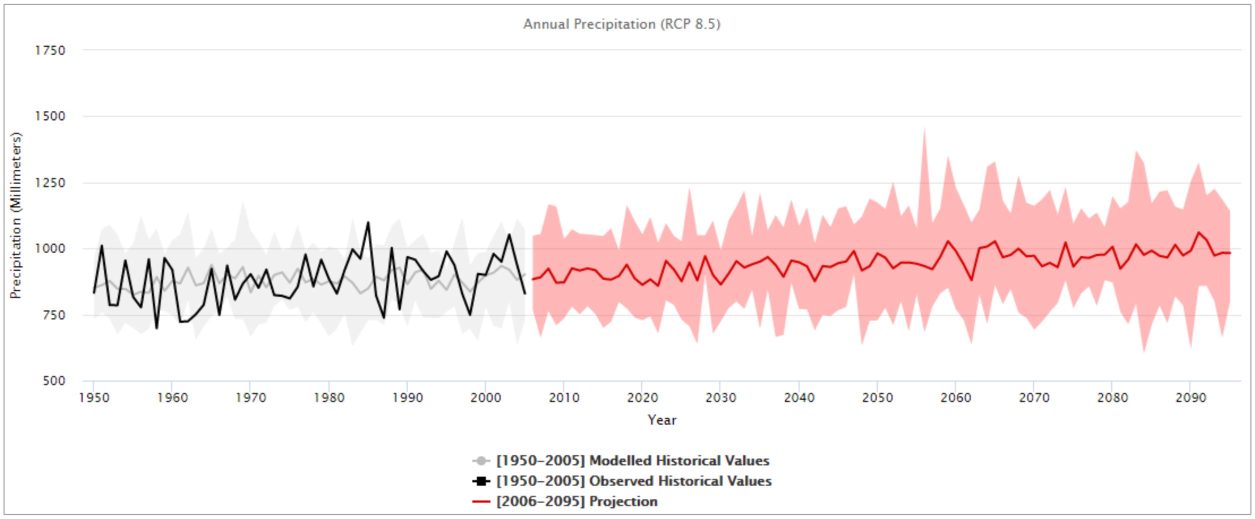
Growing Season is calculated as the number of days between the last occurrence of 0°C in spring and the first occurrence of 0°C in autumn. The metric is a widely used indicator of plant photosynthetic activity (http://www.nrcan.gc.ca/forests/climate-change/forest-change/18470). Data courtesy of Dan McKenney and John Pedlar, Canadian Forest Service. Generalized linear model developed in R (R Core Team, 2017).



Growing Season Length for Tobermory, ON. The historic period and the RCP 2.6 and 8.5 future scenarios all demonstrate a statistically significant (P<0.05) increase in growing season. Since 1900 growing season has increased by ~17 days and may increase an additional 86 days under RCP 8.5.

2.2 Precipitation





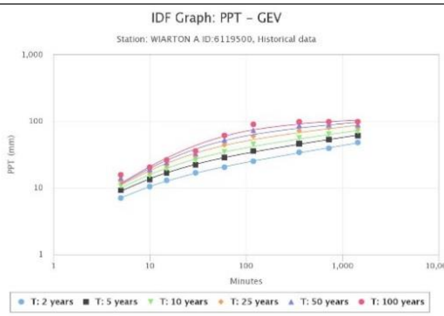
Observed and projected total annual precipitation for the Tobermory area. Statistically downscaled data derived from 12 CMIP5 global climate models (PCIC, 2014). Both the RCP 4.5 and RCP 8.5 scenarios project an increase in the mean estimate for total annual precipitation of 9% by 2051-2080. See Appendix 2 for scatterplot of model projections. Figure source: Climate Atlas of Canada, https://climateatlas.ca/.

Other precipitation projections:

- Wang *et al.* (2017) project that total annual precipitation will increase by 7.5%, 10.1% and 5.9% in the 2030s, 2050s and 2080s respectively relative to the 1961-1990 baseline.
- Precipitation patterns are expected to change, including more falling as rain than snow, an increase in the amount of spring time precipitation and an increase in the intensity of precipitation events (e.g., Cheng *et al.*, 2012a; Deng *et al.*, 2016; Wang *et al.*, 2015). It is projected that the mean number of days/year with heavier precipitation (+20 mm) will increase from 5.7 (1950-2005) to 6.4 (2021-2050) to 7.0 (2051-2080) (PCIC, 2014). As well, reduced ice cover and greater wind fetch enhances lake evaporation, resulting in greater lake-effect precipitation. Local air temperatures will determine if the precipitation falls as snow or rain (Kunkel *et al.*, 2009; Notaro *et al.*, 2015b; Notaro *et al.*, 2014).
- Summer drought conditions are projected to increase due to decreased summer rain and increased temperature and evapotranspiration (Bonsal *et al.*, 2011).

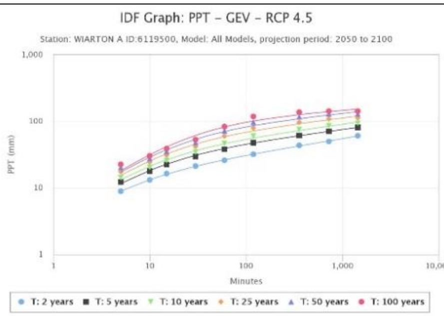
Rainfall Intensity, Duration and Frequency (IDF)

These rainfall IDF values are calculated with IDF_CC Tool 3.0 (http://idf-cc-uwo.ca/; Simonovic *et al.* (2017)) using Generalized Extreme Values (GEV). The Ontario Ministry of Transport also maintains an accessible IDF database, http://www.mto.gov.on.ca/IDF_Curves/terms.shtml.



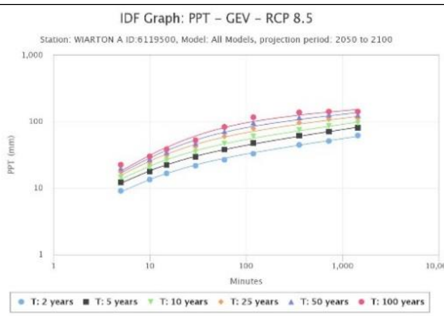
Baseline total precipitation amounts (mm) for Wiarton from 1973-2007.

T (years)	2	5	10	25	50	100
5 min	7.02	9.19	10.68	12.64	14.15	15.69
10 min	10.44	13.35	15.18	17.38	18.93	20.41
15 min	12.95	16.77	19.19	22.12	24.21	26.21
30 min	16.85	22.22	25.67	29.90	32.96	35.92
1 h	20.41	28.55	34.92	44.29	52.34	61.39
2 h	25.11	35.79	44.97	59.70	73.44	90.04
6 h	34.23	46.18	56.32	72.41	87.26	98.45
12 h	39.27	53.17	64.07	80.11	89.70	98.45
24 h	47.97	60.89	69.67	81.05	89.70	98.45



Projected (2050-2100) precipitation (mm) for Wiarton using an ensemble of models and **RCP 4.5**.

T (years)	2	5	10	25	50	100
5 min	8.88	12.25	14.25	17.46	20.27	22.54
10 min	13.18	17.83	20.32	24.26	27.57	30.27
15 min	16.35	22.38	25.67	30.86	35.24	38.82
30 min	21.27	29.64	34.32	41.67	47.90	53.05
1 h	25.92	38.04	46.43	59.95	71.98	83.26
2 h	31.97	47.53	59.99	79.23	97.25	118.24
6 h	43.46	61.18	75.46	96.78	116.79	137.20
12 h	49.82	70.74	85.41	108.59	128.97	141.98
24 h	60.62	81.13	93.04	112.21	128.97	141.98



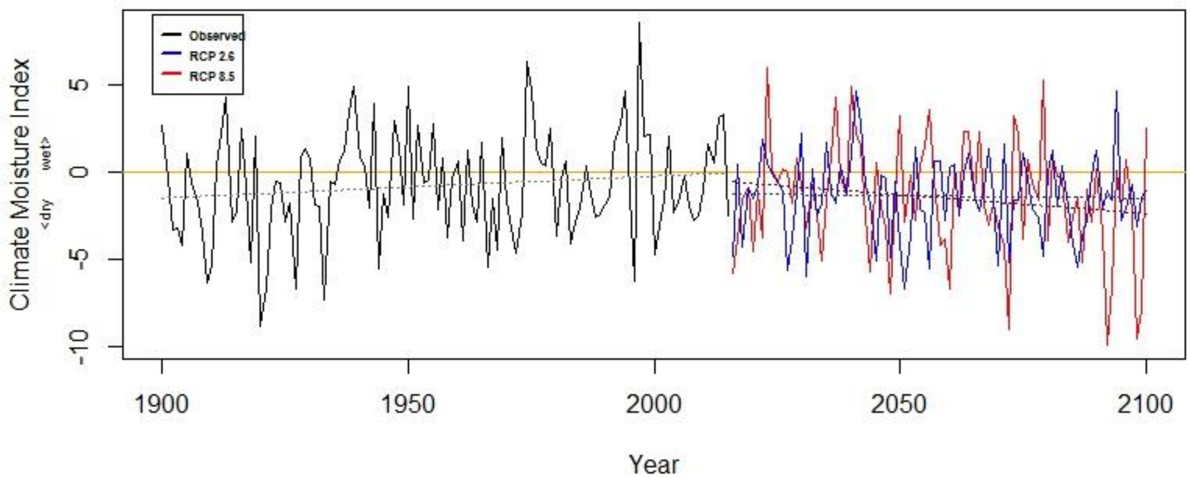
Projected (2050-2100) precipitation (mm) for Wiarton using an ensemble of models and **RCP 8.5**.

T (years)	2	5	10	25	50	100
5 min	9.07	12.21	14.45	17.49	19.90	22.43
10 min	13.42	17.73	20.63	24.35	27.14	29.95
15 min	16.65	22.27	26.07	30.97	34.67	38.40
30 min	21.67	29.50	34.85	41.80	47.09	52.46
1 h	26.54	37.99	46.88	59.84	70.90	83.25
2 h	32.84	47.68	59.95	78.95	96.10	116.21
6 h	44.61	61.44	75.25	96.45	115.42	137.53
12 h	51.01	70.74	86.05	108.39	126.60	141.40
24 h	61.86	80.89	94.35	112.40	126.60	141.40

Wiarton IDF observations and projections. Observe that today's "one in 100 year" rainfall event (i.e., 61.39 mm/hr) is projected to be closer to a "one in 25 year" event by 2050-2100 for both RCP scenarios and the future "one in 100 year" rainfall event is projected to increase in intensity (i.e., ~83 mm/hr).

Climate Moisture Index

The Climate Moisture Index (CMI) is calculated as the difference between annual precipitation and potential evapotranspiration. A positive CMI value indicates wet conditions and a negative value indicates dry conditions (http://www.nrcan.gc.ca/forests/climate-change/forest-change/17772). Data courtesy of Dan McKenney and John Pedlar, Canadian Forest Service. Generalized linear model developed in R (R Core Team, 2017).



Climate Moisture Index (CMI) for Tobermory, ON. No statistically significant (P<0.05) trend observed for CMI values over the historic period or RCP scenarios. Future CMI projections are estimated to be negative (dry) 68-72% of years, an increase from 60% for the historic period (1900-2015).

2.3 Wind

Wind is an important variable in ecosystem dynamics as it influences evaporation, water currents, ice cover, erosion, thermoclines, etc… It is difficult to model and results from a few studies suggest that wind speeds will become more variable.

- Cheng *et al.* (2014) project a 30-50% increase in wind gust events in excess of 70km/yr by 2081-2100 for Wiarton.
- Projections for BP/FF illustrate a decrease in mean wind speeds of 1-3% for the Lake Huron side and an increase of 1-3% for the Georgian Bay side (Yao *et al.*, 2012), regardless of the trend extreme events are projected to have higher wind speeds (McDermid *et al.*, 2015).

3. Climate Change Impacts

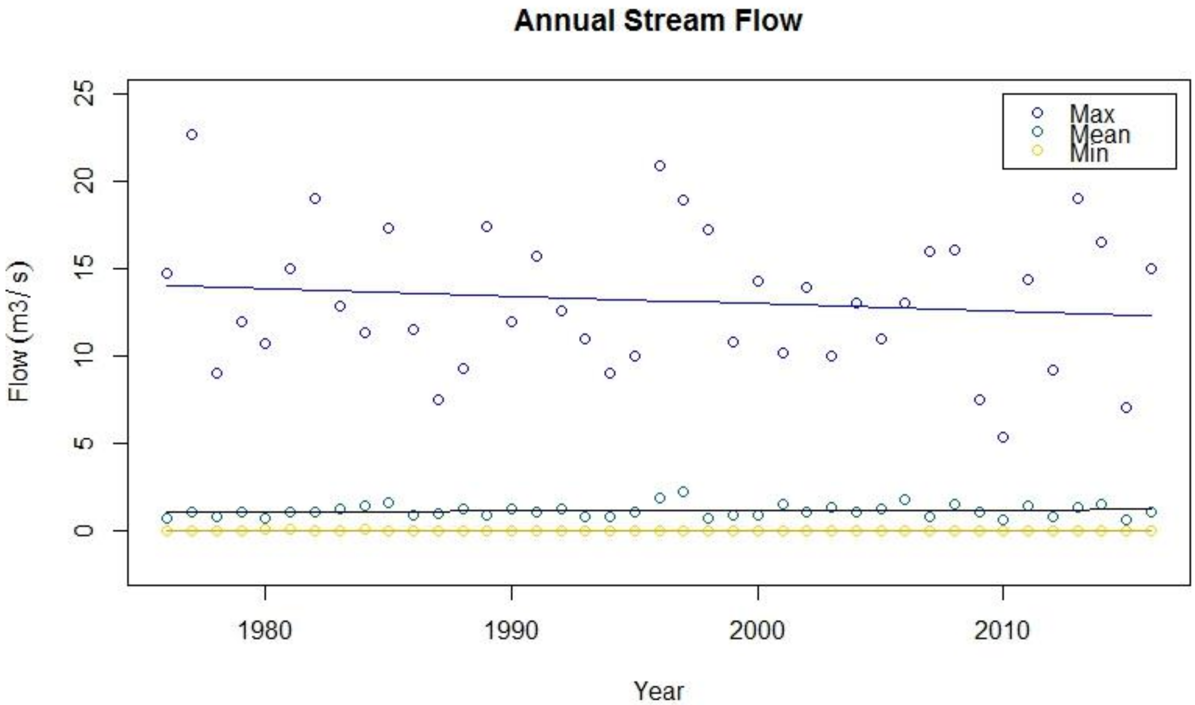
3.1 Water Temperature and Levels

Lake Huron

- Lake summer surface water temperature for eastern Lake Huron and Georgian Bay has increased by 0.11 and 0.07˚C/year respectively from 1994 to 2013 (Mason *et al.*, 2016).
- Surface water temperatures for Lake Huron are projected to increase 2.6-3.9°C by 2071-2100 relative to a 1971-2000 baseline (Trumpickas *et al.*, 2009).
- An earlier onset and longer period of thermal stratification is expected (Zhong *et al.*, 2016). For instance, the number of days with a surface water temperature greater than 4°C is projected to increase by 45-62 days by 2071-2100 relative to a 1971-2000 baseline (Dove-Thompson *et al.*, 2011; Trumpickas *et al.*, 2008).
- Wang *et al.* (2012) report that the spatial extent of ice coverage on Lake Huron has declined by 62% from 1973 to 2010. Mason *et al.* (2016) also report that a significant decline in ice cover duration of -0.67 days/year has occurred for Lake Huron.
- Ice cover is projected to continue to decline (e.g., by half, see figure 8 in Notaro *et al.*, 2015b).
- Lake level data is available for the Tobermory Hydrographic Station (02FA003) from 1962 to present day (e.g., http://collaboration.cmc.ec.gc.ca/cmc/hydrometrics/www/ or http://tides.gc.ca). Although no analysis was undertaken for this report, the data does highlight the variability in lake levels across times scales from hours to decades, with a recorded minimum/maximum difference of 2.2 m at this station.
- Lake precipitation, basin runoff and lake evaporation are the primary drivers of water levels (IJC, 2009).
- Many of the earlier studies predicted lower lake levels due to climate change (e.g., Croley, 1990). More recent studies suggest that future lake levels will fluctuate within the historical range of variability but with a lower mean level (e.g., -14 to -25 cm from current) (IJC, 2012; Lofgren and Rouhana, 2016; MacKay and Seglenieks, 2013; Music *et al.*, 2015) and one study suggests that lake levels will be higher (+42 cm from current) (Notaro *et al.*, 2015a).
- Phosphorus loading into lake is expected to be higher in spring due to increased precipitation and runoff from agricultural fields and decrease in summer (Collingsworth *et al.*, 2017).

Inland Waters

While there are a few discrete water flow and level records for some lakes and streams in BP/FF, there is no long term dataset on which to assess trends. The closest hydrographic station is maintained by Environment and Climate Change Canada, located on the Stokes River at Hwy. 6 (Station ID: 02FA002, summary data link).

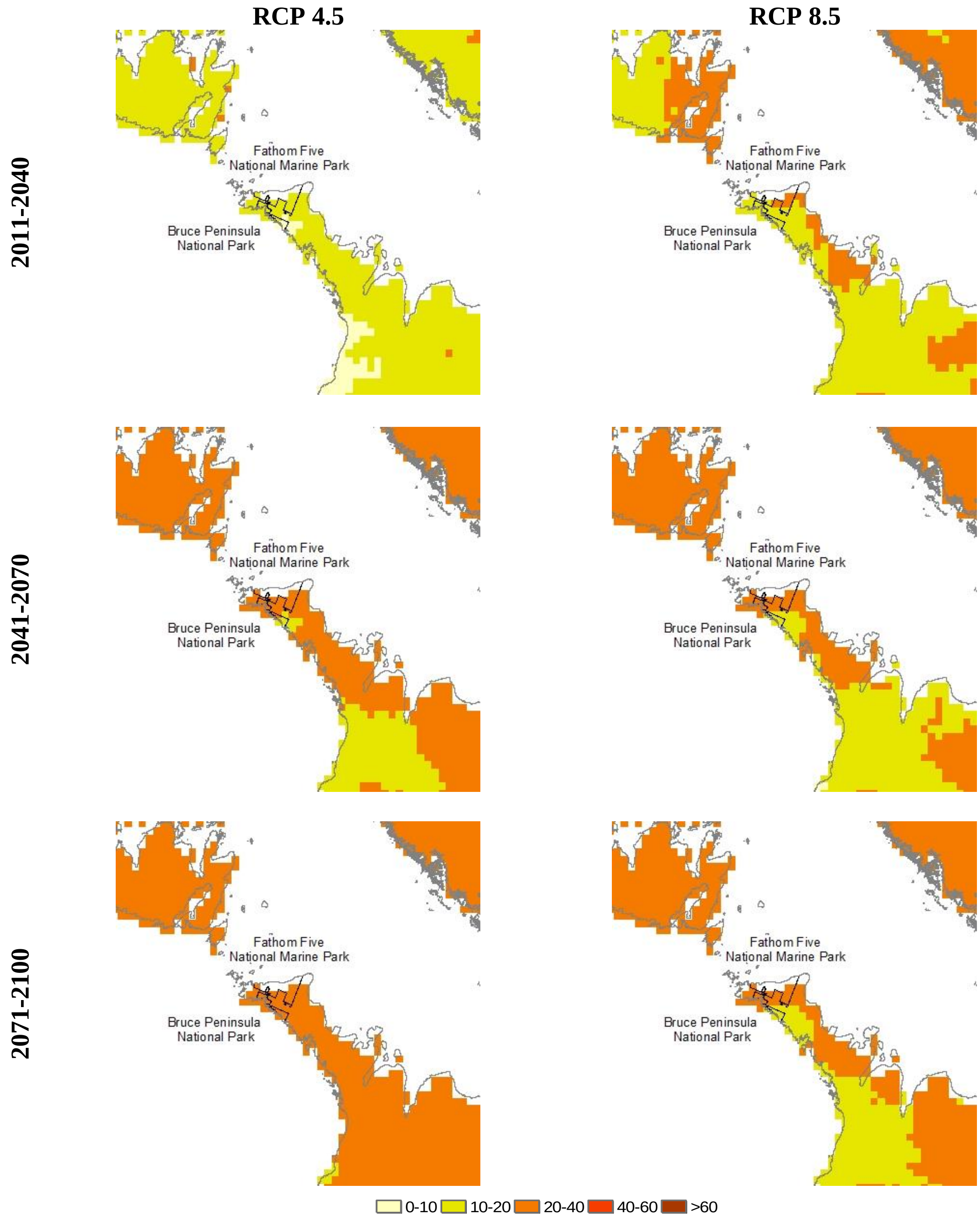


Stokes River annual flow data (HYDAT database, Jan. 17, 2018 release). Although a statistically significant ($P<0.05$) trend was not demonstrated for mean, max or min values, a slight declining trend is noted for maximum and minimum annual flows while mean flow shows a slight increase. Changing land use patterns may be a factor in this context. It is worth noting that 3 of the top 10 maximum peak flows on record (1976-2016) have occurred since 2010, the highest flow was recorded on January 30, 2013 (coincided with a thunderstorm and temperatures >8˚C). The majority of peak flows occur in March or April and may be attributed to rain on snow events.

Additional information on inland waters:

- The ice free period for the inland waters of Bruce County is projected to increase by 9.6 to 22.6 days by 2041-2070, with spring break-up occurring 1.7 to 7.2 days earlier and freeze-up 7.9 to 15.4 days later (Minns *et al.*, 2014).
- Stream temperatures are expected to increase as air temperatures increase (Chu, 2015). Brook Trout is an example of a species in BP/FF already vulnerable to stream temperature maximums in Willow and Dorcas Creeks and are known to occupy groundwater discharge and shaded riparian areas as refugia during summer. This cooling benefit could be reduced as groundwater warms or riparian areas are opened (e.g., beavers, logging, etc…) (Meisner *et al.*, 1988).
- Maximum spring runoff is occurring earlier and with a lower amplitude, flooding from more extreme precipitation events is expected to increase (Adamowski *et al.*, 2013; Cheng *et al.*, 2012b; Cunderlik and Ouarda, 2009; Jones *et al.*, 2015; Karl *et al.*, 2009).
- Chu (2015) indicates (Figure 3) that the wetlands in BP/FF area have a high vulnerability to drying due to changes in air temperature and precipitation by the 2080s.

3.2 Wildfire



Projected increase in wildfire season for the Bruce Peninsula area. Increased length in days from baseline (1981-2010) under RCP 4.5 and RCP 8.5 scenarios. Data source: Natural Resources Canada, http://cfs.nrcan.gc.ca/fc-data-catalogue.

Additional information on wildfire:

- Lightening has a positive correlation with temperature, increasing risk of wildfire ignitions (e.g., Veraverbeke *et al.*, 2017; Woolford *et al.*, 2014).
- Flannigan *et al*. (2016) demonstrate that seasonal precipitation must increase 15% to offset every 1˚C rise in temperature. Wotton *et al.* (2005) project drier forest floor conditions for Ontario, including the Bruce Peninsula, and predict a province-wide increase in the number of wildfires. In considering the climate projections for BP/FF, spring precipitation is only projected to increase by 5.6% for every degree warming and summer precipitation is projected to decline by 0.7% per every degree warming, thus an increase risk due to drier conditions is possible.
- More severe fire weather (heat and drought) may create conditions (i.e., intensity >10,000 kW/m) where fire suppression is no longer feasible or effective (Colombo, 2008; Podur and Wotton, 2010; Wotton *et al.*, 2017). In the context of BP/FF and in particular maturing jackpine (S2) and assumed increase in dead balsam fir (M3) stands, a potential increase in fuel types/loads to support more intense conditions may have occurred since last assessed using 1994 imagery (Del Degan and Masse et Associes Inc., 2007).
- Provincially, Fire Weather Index and Fire Severity values are projected to increase (Lemieux *et al.*, 2007; Podur and Wotton, 2010; Wotton *et al.*, 2017; Wotton *et al.*, 2005).
- An increase in deciduous species may reduce the amount of crown fire and total fuel consumption (Terrier *et al.*, 2013). However, spring time before leaf-out, still remains a potentially higher risk wildfire period in BP/FF (Del Degan and Masse et Associes Inc., 2007).

3.3 Biodiversity

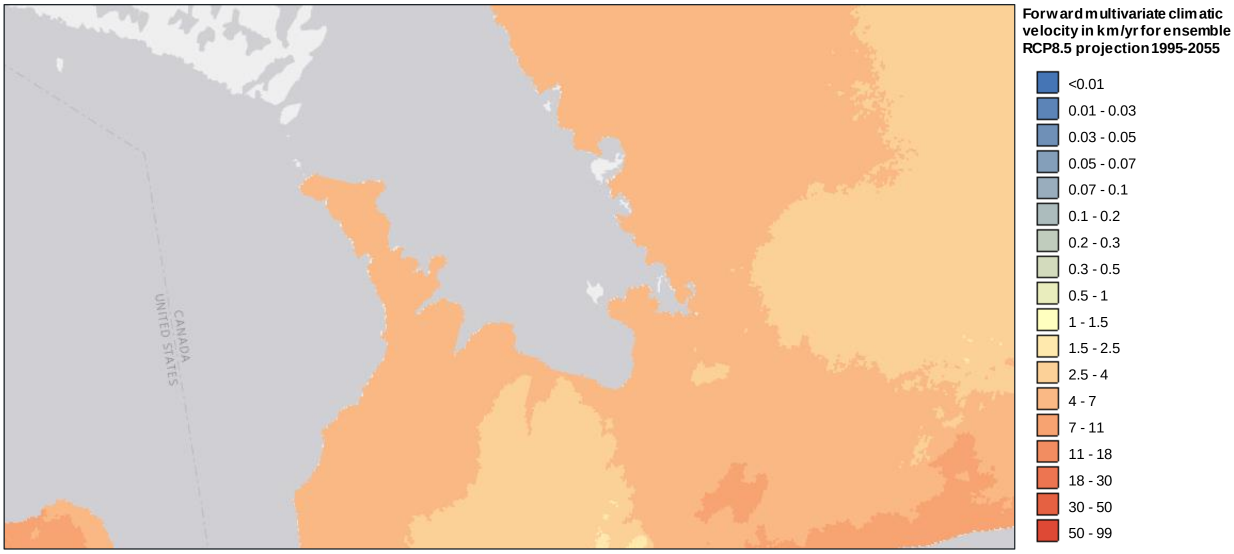
Biodiversity is the variety of genes, species and ecosystems and is essential to our social, economic and ecological well-being. "Agricultural expansion, over-exploitation and introduction of invasive alien species have been the main drivers of biodiversity loss in the recent past, but several lines of research suggest that climate change could become a prominent, if not leading, cause of extinction over the coming century" (Pacifici *et al.*, 2015; Thomas *et al.*, 2004). The latest "Living Planet Report" (WWF, 2017), cites climate change as a key driver of wildlife loss and reports that half of Canada's monitored species (451 of 903) are in decline, and of those, the average decline is 83%.

The effects of climate change on biodiversity are fairly well documented and include (e.g., Nantel *et al.*, 2014; Nituch and Bowman, 2013):

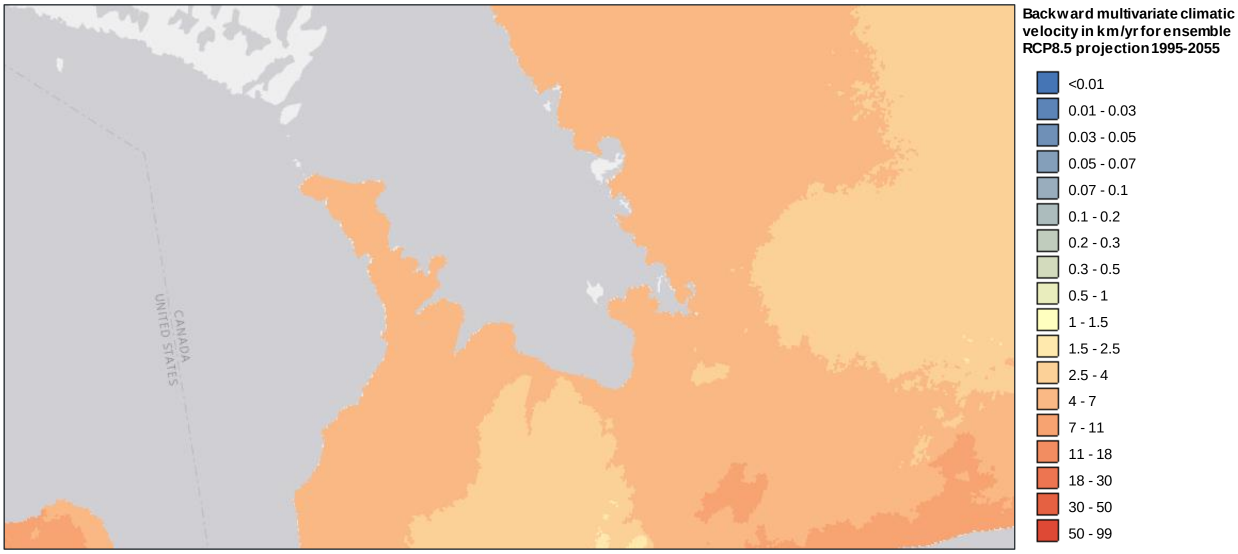
- Shifts in species distribution.
- Changes in phenology.
- Decoupling of interactions (plant-pollinator)
- Reductions in population size.
- Species extinction and extirpation.
- Habitat loss.
- Increased disease and spread of invasive species.
- Competitive exclusion.
- Change to ecosystem services.

Climate Velocity

AdaptWest (https://adaptwest.databasin.org/) provides integrative tools that can inform conservation planning, including the following analysis on climate velocity.

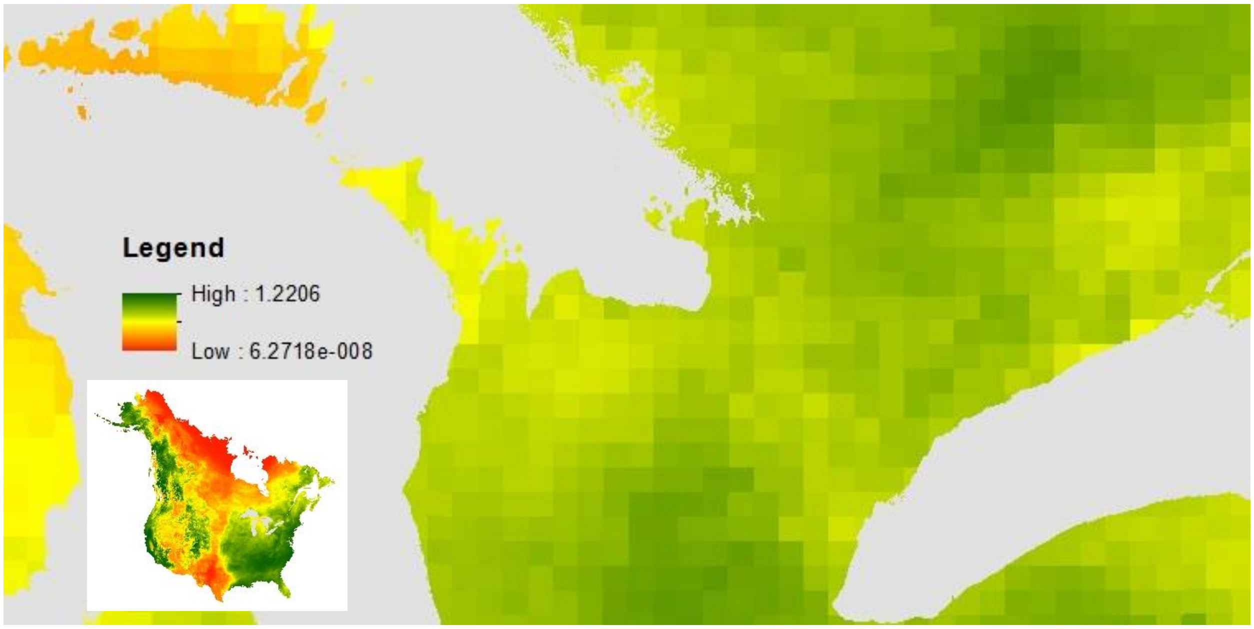


Forward climate velocity (km/yr). The rate at which an organism in the current landscape has to migrate to maintain constant climate conditions. For BP/FF the projected rate is **3 km/yr** for 1995-2055 (RCP 8.5).



Backward climate velocity (km/yr). Given the projected future climate habitat of a grid cell, it is the minimum rate of migration for an organism from equivalent climate conditions to colonize this climate habitat. For BP/FF the projected rate is 5 km/yr for 1995-2055 (RCP 8.5).

Plant Species

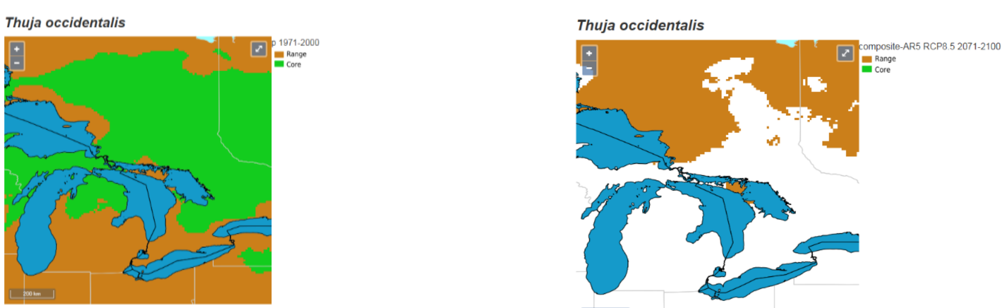


Projected climate refugia areas for tree species. Refugia index based on niche-based velocities for 324 tree species derived from McKenney *et al*. (2011). The refugia values for BP/FF are moderate (0.1 – 0.13). Inset image of Canada/USA. Date source: AdaptWest (https://adaptwest.databasin.org/), for study details see Stralberg *et al.* (2018).

Plant Hardiness is associated with probabilities of plant survival in relation to average, broad scale climatic conditions. As the climate changes, habitat suitability for plant species also changes. Natural Resources Canada maintains a database that includes future projections of plant hardiness (http://www.planthardiness.gc.ca/). A query of this database revealed a future decline in the number of species in BP/FF (45.2N, -81.6W), see Table 1.

Table 1. Potential plant species richness for BP/FF based on current and future plant hardiness projections.

	1971-2000	2011-2040	2041-2070	2071-2100
Full Range	1291	1230	664	245
Core Range	550	390	102	26

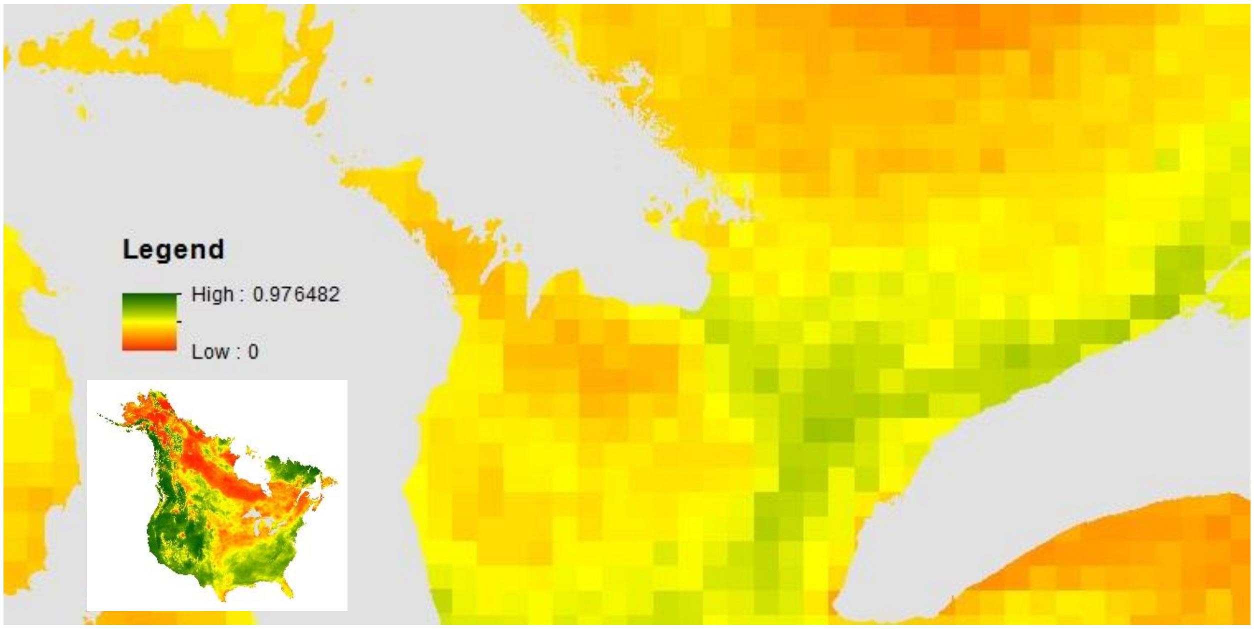


Eastern white cedar (*Thuja occidentalis*) is an example of a species whose core and full range is projected to change. Currently the Bruce Peninsula includes core range, but by the end of century it is projected to decline. More models and information for this species at: http://planthardiness.gc.ca/index.pl?m=9b&lang=en&speciesid=1001217. Most of the tree species in BP/FF considered dominant or co-dominnant will experience similar declines, e.g., balsam fir and american beech will no longer be within their climate envelopes (core or full rnage), and sugar maple will no longer be within its core range, but will still be within its full range.

Additional information on plants:

- BP/FF is a transition zone with species at both their northern and southern range. As the climate envelope for boreal tree species (e.g., black spruce, white spruce, jack pine, balsam fir, trembling aspen) becomes less suitable (see reference to "deborealize" in Taylor *et al.*, 2017), conditions will become more favourable for Great Lakes-St. Lawrence species (e.g., white pine, red pine, sugar maple, red oak) (e.g., McKenney *et al.*, 2010; Walker *et al.*, 2002; Warren *et al.*, 2013).
- Using future climatic envelopes for 63 native tree species in Ontario, Crowe and Parker (2011) modelled the optimal location for additional reserves, both with and without the need for migration, to protect these representative species. The base of the Bruce Peninsula (5) was identified as one potential location.
- Plant productivity may increase due to increased CO_2, that is, if species are not otherwise limited by habitat conditions (e.g., soil, moisture, nutrients, light, or pollinators) or disturbances (e.g., fire, flooding, or drought) (Warren *et al.*, 2013).
- Climate change could create conditions which are more favourable for invasive species, and coupled these two impacts presents an important threat to BP/FF's biodiversity (e.g., Mainka and Howard, 2010; Walther *et al.*, 2009). For instance, beech are already sensitive to climate change (e.g., flooding/drought events) and are now facing high rates of mortality from invasive beech bark disease (Stephanson and Ribarik Coe, 2017). The invasive emerald ash borer doubled its rate of infestation in Toronto during a recent hot summer, further devastating trees already stressed by warm and dry conditions (https://toronto.ctvnews.ca/hot-dry-weather-accelerated-toronto-s-emerald-ash-borer-tree-crisis-1.3044828) (DeSantis *et al.*, 2013). There is strong association between warmer temperatures and invasive gypsy moth distribution (potential threat to hardwood forests) (Regniere *et al.*, 2009).

Bird Species

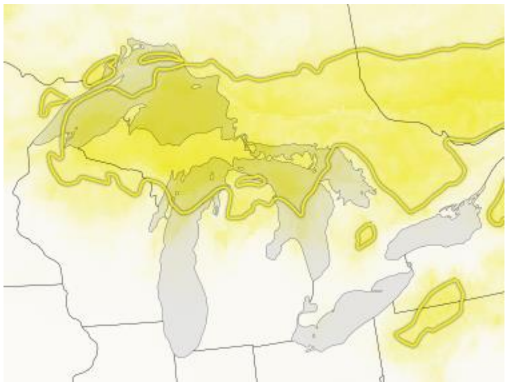
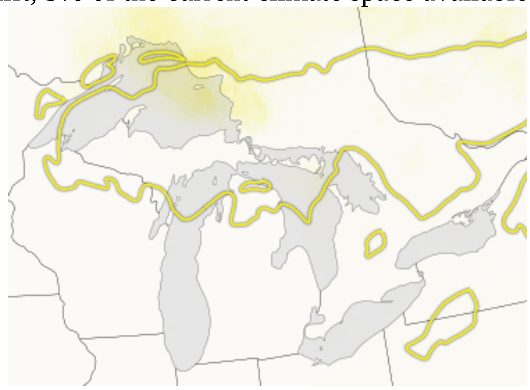


Projected climate refugia areas for songbird species. Refugia index based on niche-based velocities for 268 songbirds derived from Distler *et al.* (2015). The refugia values for BP/FF are moderate to low (0.18 – 0.2). Inset image of Canada/USA. Data source: AdaptWest (https://adaptwest.databasin.org/), for study details see Stralberg *et al.* (2018).

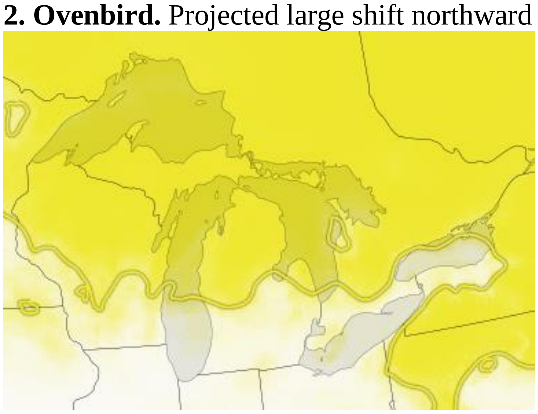
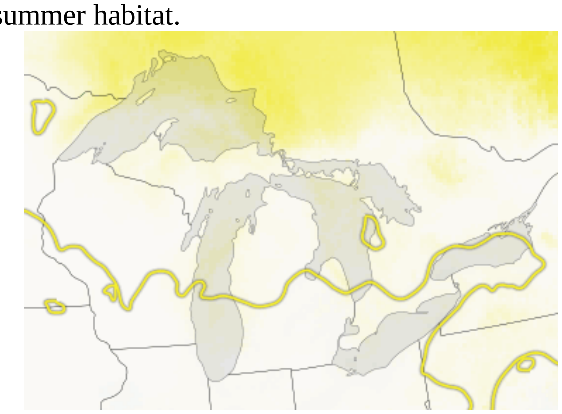
The following figures are clipped from the National Audubon Society's online "The Climate Report" (Audubon, 2015). Yellow indicates summer range and the darker the shading, the more likely the bird species will find suitable climatic conditions to survive. The year 2000 and 2080 are presented here, but intermediate years are also provided. Maps are available for 314 climate threatened (may lose 50% of current rage by 2080) or climate endangered (may lose over 50% of current range by 2050) bird species.

2000 **2080**

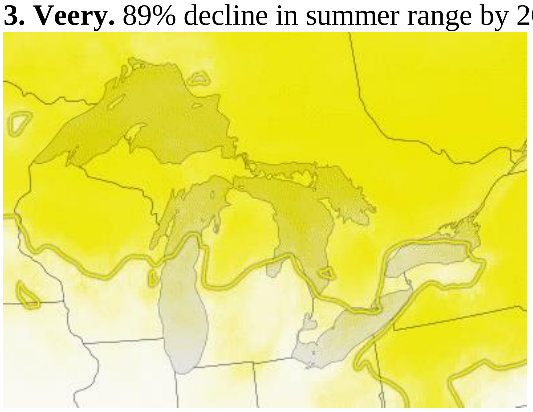
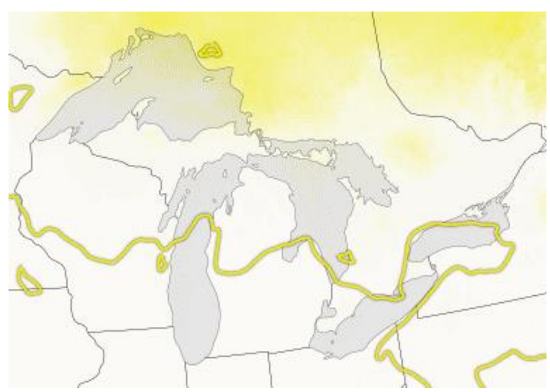
1. Black-throated Green Warbler. Northward shift, 3% of the current climate space available.

2. Ovenbird. Projected large shift northward in summer habitat.

3. Veery. 89% decline in summer range by 2080.

Additional information on birds:

- A query of Audubon (2015) revealed: **A. BP/FF may become less suitable** for species such as: American bittern (summer), bank swallow (summer), pine grosbeak (winter), ruffed grouse (winter), bohemian waxwing (winter), mourning warbler (summer), least flycatcher (summer), etc… **B. BP/FF may become more suitable** for species such as: Bufflehead (winter), black-crowned night heron (winter), dunlin (winter), gadwall (winter), laughing gull (summer), short-eared owl (winter), hermit thrush (winter), etc… Season of range change in brackets ().ArcGIS geodatabases for these and 610 other bird species are available from the USGS ScienceBase-Catalog (https://www.sciencebase.gov/catalog/item/55897deae4b0b6d21dd61c9d).
- Wu *et al.* (2018) report that by 2050 on average 23% of bird species in found in a given US national park could be completely different.
- Based on changing climatic conditions Lindsay *et al.* (2016) project that for the BP/FF area the **percent species turnover for migratory bird species** could increase from 12% in 2011-2040 to 35% by 2071-2100. The **percent species turnover for all bird species** could increase from 16% in 2011-2040 to 42% by 2071-2100. 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).
- Earlier peaks in insect populations and plant biomass have been observed and may mismatch with migrant bird hatchling growth and development (e.g., **asynchrony** between wood warbler and eastern spruce budworm) (Knudsen *et al.*, 2011; Nituch and Bowman, 2013).
- Rempel and Hornseth (2017) completed a climate change vulnerability assessment for **wood thrush** and **eastern meadowlark**. While the assessment confirmed that these species are highly vulnerable to climate change, their persistence in the BP/FF area was projected through to 2100.

Other Terrestrial Species

- Community level effects from climate change to terrestrial biodiversity in Ontario, including a summary of effects to 181 terrestrial vertebrate species, is discussed by Nituch and Bowman (2013). Documented effects include population expansion for 68 species (e.g., wood frog, gray treefrog, American woodcock, northern rough-winged swallow, little brown bat, meadow vole, opossum), population contraction for 11 species (e.g., painted turtle, black-capped chickadee, alder flycatcher, northern flying squirrel) and equivocal for the other 102 species assessed.
- A vulnerability assessment for the **eastern massasauga rattlesnake** predicts that the northern Bruce Peninsula population will experience high persistence and is stable/least decline in the face of climate change (Pomara *et al.*, 2014). In addition to land cover (habitat) change, winter drought and summer flooding (i.e., extreme fluctuations in water table, especially near hibernacula) were strongly associated with population declines throughout its range.
- The distribution and impacts of pathogens and parasites are expected to increase with warmer temperatures and the northward migration of species (Marcogliese, 2008; 2016).

Aquatic Species

- A recent shift to smaller **diatom** species in the Great lakes may be attributed to warming waters (Bramburger *et al.*, 2017), however, it appears Lake Huron is not responding to climatic drivers as quickly as Lakes Ontario and Superior (Reavie *et al.*, 2016; Wang *et al.*, 2012).
- Prolonged periods of low lake levels with minimal fluctuations is shown to reduce **coastal wetland** area and species diversity (Langer *et al.*, 2018; Midwood and Chow-Fraser, 2012; Mortsch *et al.*, 2006). During the 1999-2014 low period experienced in FF coastal wetlands

became stranded, disconnecting potential spawning and nursery habitats, and exposed lakebeds were more vulnerable to invasive phragmites and narrow-leaved cattail (Parker *et al.*, 2015).

- In Ontario, fish distribution has been observed to move northward at a rate of 12-17 km/decade. Cold-water fishes (e.g., brook trout, lake trout, lake whitefish) are seeking refuge further north and in deeper waters, while cool- and warm-water fishes (e.g., walleye, smallmouth bass) are moving into vacated habitats and warmer waters (Alofs *et al.*, 2014; Chu, 2015; Dove-Thompson *et al.*, 2011). While species fish richness is projected to increase, functional diversity is expected to decline (Biswas *et al.*, 2017).
- The first record of white bass in FF occurred in 2013 (pers. com. S. Campbell). This is a temperate species known to prefer warmer waters.
- As a response to warmer waters, 27 species of fish, including non-native species, may move northward into Ontario (Mandrak, 1989).
- Phenological mismatches including changes in the timing of larval fish emergence and zooplankton production are possible and in need of further study (Collingsworth *et al.*, 2017).
- Ice cover can protect incubating eggs (e.g., lake trout, lake whitefish) by ameliorating wave action on shallow spawning shoals (Brown *et al.*, 1993). The potential impact of less ice cover on spawning shoals in FF is uncertain.
- Warmer spring and summer temperatures have been shown to have a positive influence on yellow perch and walleye recruitment in Lake Huron (Collingsworth *et al.*, 2017; Honsey *et al.*, 2016).
- While water temperatures in the inland lakes are projected to increase there is a high probability that conditions will remain thermally suitable for smallmouth bass in the 2050s and 2080s, there is, however, a very low probability they will remain suitable for walleye (e.g., in Cyprus Lake) (Van Zuiden *et al*., 2016).

3.4 Visitor Experience and Operations

Visitor Experience

Visitation Patterns

Although visitation patterns are monitored in BP/FF during the operational season, assessing and predicting the influence of climate change on total visitation or park specific activities has not been explicitly studied. However, it is expected that visitation will increase due to an earlier spring and warmer summer and autumn conditions. Naturally, knowledge from other studies may help to inform management actions in this regard, for example:

- Visitation is projected to increase in Ontario’s provincial parks by the 2020s (11–27%) due to a warmer climate, and this increase may be even higher (23-41%) when combined with demographic changes (Jones and Scott, 2006b).
- Maximum and minimum temperature were determined to be most influential climate variable for predicting visitation in 15 national parks (these parks accounted for 86% of Parks Canada’s visitation at the time) (Jones and Scott, 2006a).
- At Pinery Provincial Park critical temperature thresholds for visitation were revealed as being less than 11˚C and above 29˚C during the shoulder season and above 33˚C during the peak season. Modelled projections resulted in a 3.1% increase in annual visitation for every degree of warming (+1 to +5), despite increases in precipitation. Shoulder season visitation, particularly the autumn, is expected to increase (Hewer *et al.*, 2016; Hewer *et al.*, 2015; Hewer *et al.*, 2017a; 2017b).
- The US National Park Service examined visitation response across their network and found that it generally increased as mean monthly temperatures increased, but decreased strongly as temperatures exceeded 25˚C. Future climate/visitation projections suggest that there is a complex

and cascading effect and a need to develop park and neighbouring community adaptation strategies (Fisichelli *et al.*, 2015).

Recreational Opportunities

- Although not specific to BP/FF, Hewer and Gough (2018) reviewed 30 years of climate change impacts on outdoor recreation in Canada, including increased risks to cold-weather activities and opportunities for warm weather activities.
- Dorcas Bay and other recreational beaches may face closures due to poor recreational water quality from warmer waters and increased nutrient and bacteria loads (e.g., stormwater runoff). Harmful algal blooms and filamentous algae growth will increase under such conditions as well (Barton *et al.*, 2013; Reavie *et al.*, 2014).
- Low water levels may affect vessel access to Flowerpot Island and navigational safety near the islands and shoals (Shlozberg *et al.*, 2014).
- Decreased snowpack will negatively impact winter recreational activities such as snowshoeing, skiing, ice fishing, ice travel and snowmobiling.
- A longer and more intense fire season will affect visitor safety and experience (e.g., area closures, no campfires).

Human Health

- Lyme disease (tick carrying the borrelia pathogen), which was formerly restricted to localized areas by temperature and relative humidity, is expected to expand to the entire Great Lakes region including BP/FF by mid-century (Eisen *et al.*, 2016; Ogden *et al.*, 2006). Other pathogens associated with black legged ticks include arboviruses (encephalitis), Anaplasma, Ehrlichia, Babesia, Rickettsia and Bartonella (Nelder *et al.*, 2016). Lyme disease and arbovisruses are reportable in Ontario. Companion animals are also at risk to Lyme and other tick-borne diseases (e.g., Public Health Ontario, 2017).
- Increasing incidences of West Nile Virus (mosquito vector) have been linked to climate change, including the temperature for mosquito development (14-35˚C) and the extrinsic incubation period (Chen *et al.*, 2013; Soverow *et al.*, 2009).
- The literature suggests that climate change will increase the northward expansion of mosquito's and associated pathogens (Wudel and Shadabi, 2016). The range of *Aedes albopictus* which is a vector for Zika virus, Dengue virus, Yellow fever and other diseases, is projected to expand into parts of Ontario, including BP/FF, by 2041-2070 (Ogden *et al.*, 2014).
- Heat waves in the Grey Bruce Health Unit region are projected to increase from 0.10/year to 2.21/year by the 2080s (Gough *et al.*, 2016).
- Changing weather and increased temperature can affect the rate of photochemical smog formation (e.g., ozone). However, future ozone exceedances (>80 ppb) for the Grey Bruce Health Unit region only suggests an increase from todays 9 days/year to 10 days/year by the 2080s (Gough *et al.*, 2016).
- Extreme weather events are the top risk globally in terms of likelihood and the second highest risk in terms of impact (after weapons of mass destruction) (World Economic Forum, 2018). At BF/FF intense rainfall, lightning storms, hail, extreme winds and wildfire events are all potential hazards whose risks are projected to increase (e.g., Brimelow *et al.*, 2017; Cheng *et al.*, 2012a; IPCC, 2012). Besides a potential role in emergency preparedness and response, protected areas are increasingly being recognized as a "natural solution" in terms of disaster risk reduction (e.g., flood control, protection from storm surge, etc…) (e.g., Dudley *et al.*, 2015; Lo, 2016; Murti and Buyck, 2014).

Interpretation and Communication

Climate change is a theme in Parks Canada's communication and interpretation programs (e.g., https://www.pc.gc.ca/en/nature/science/climat-climate). By engaging and inspiring the public, Parks Canada is able to build support for its mandate and adaptation actions. A place for "natural solutions" is a concept used to frame and present Parks Canada's response to climate change mitigation and adaptation, as it highlights the importance and effectiveness of ecosystem-based approaches (e.g., CPC, 2013; NAWPA, 2012)

"The changing climate surrounds us, compelling us to tell the story" (US NPS). Of related interest, is the US National Park Service climate change interpretation and education strategy (US NPS, 2016) and climate change interpreter training (http://idp.eppley.org/training/specialist/interpreting-climate-change). Parks Canada staff have found this training to be very helpful.

Assets and Infrastructure

The impacts to Canada's assets and infrastructure from climate change are well documented (e.g., Boyle *et al.*, 2013; Canada, 2017; Palko and Lemmen, 2017; Warren and Lemmen, 2014) and are explicitly mentioned as a concern in Parks Canada's Departmental Plan (Parks Canada, 2017). Although an assessment of vulnerabilities and risks to infrastructure has not been completed at BP/FF, in light of the information in this report, expected concerns could include:

- Flooding from intense rainfall and winter rain events, overwhelming surface drainage capacity, particularly undersized or debris filled culverts, and damaging facilities, washing out roads, etc…
- Freezing rain or hail damage to buildings and power/communication lines.
- Longer wildfire season and more intense burns, especially given the high urban interface.
- Increased lake storm intensity and less ice cover increases risk of coastal flooding and erosion. Although BP/FF has relatively little coastal infrastructure, there may be a need to clean up debris washed in from other areas.
- Longer seasonal use of trails and roads (one benefit, less frost damage to roads in milder winters).
- Increased temperatures could lead to premature weathering. Similarly, increased spring rains could lead to premature weathering and deterioration (e.g., building foundations, corrosion, and mold).
- Summer drought increases water demands and may exceed system capacity.
- The energy demands for cooling buildings will increase.

Of related interest, the "Public Infrastructure Engineering Vulnerability Committee" (PIEVC, 2008) undertook an assessment of risks to the water supply system near Point Pelee National Park (Genivar, 2013) and surface drainage near Rouge National Urban Park (Genivar, 2010; 2011). Concerns with freezing rain (e.g., transmission lines) and culvert capacity are highlighted in these reports.

An assessment of greenhouse gas (GHG) emissions was not in the scope of this report. However, it is important to observe that throughout the document different RCP scenarios were presented and if we meet (and celebrate) RCP 2.6 or continue to track (and mourn) RCP 8.5, depends entirely on our actions to address and reduce GHG emissions today. Federally the government is committing to reducing GHG emissions by 80% below 2005 levels by 2050 (https://www.canada.ca/en/treasury-board-secretariat/services/innovation/greening-government/strategy.html). Also see Parks Canada's 2015 Master Plan to reduce GHG emissions (Parks Canada, 2015).

4. References

Adamowski, J., Adamowski, K., and Prokoph, A. (2013). Quantifying the spatial temporal variability of annual streamflow and meteorological changes in eastern Ontario and southwestern Quebec using wavelet analysis and GIS. *Journal of Hydrology, 499*, 27-40. doi:10.1016/j.jhydrol.2013.06.029.

Alofs, K. M., Jackson, D. A., and Lester, N. P. (2014). Ontario freshwater fishes demonstrate differing range-boundary shifts in a warming climate. *Diversity and Distributions, 20*(2), 123-136. doi:10.1111/ddi.12130.

Audubon. (2015). *Audubon's Birds and Climate Change Report*. National Audubon Society. Contributors: Gary Langham, Justin Schuetz, Candan Soykan, Chad Wilsey, Tom Auer, Geoff LeBaron, Connie Sanchez, Trish Distler, New York. http://climate.audubon.org/.

Barton, D. R., Howell, E. T., and Fietsch, C. L. (2013). Ecosystem changes and nuisance benthic algae on the southeast shores of Lake Huron. *Journal of Great Lakes Research, 39*(4), 602-611. doi:10.1016/j.jglr.2013.09.010.

Biswas, S. R., Vogt, R. J., and Sharma, S. (2017). Projected compositional shifts and loss of ecosystem services in freshwater fish communities under climate change scenarios. *Hydrobiologia, 799*(1), 135-149. doi:10.1007/s10750-017-3208-1.

Bonsal, B. R., Wheaton, E. E., Chipanshi, A. C., Lin, C., Sauchyn, D. J., and Wen, L. (2011). Drought Research in Canada: A Review. *Atmosphere-Ocean, 49*(4), 303-319. doi:10.1080/07055900.2011.555103.

Boyle, J., Cunningham, M., and Dekens, J. (2013). *Climate Change Adaptation and Canadian Infrastructure. A review of the literature*. International Institute for Sustainable Development (IISD). http://www.iisd.org/sites/default/files/publications/adaptation_can_infrastructure.pdf.

Bramburger, A. J., Reavie, E. D., Sgro, G. V., Estepp, L. R., Shaw Chraïbi, V. L., and Pillsbury, R. W. (2017). Decreases in diatom cell size during the 20th century in the Laurentian Great Lakes: A response to warming waters? *Journal of Plankton Research*, *39*(2), 199-210. doi:10.1093/plankt/fbx009.

Brimelow, J. C., Burrows, W. R., and Hanesiak, J. M. (2017). The changing hail threat over North America in response to anthropogenic climate change. *Nature Clim. Change, advance online publication*. doi:10.1038/nclimate3321 http://www.nature.com/nclimate/journal/vaop/ncurrent/abs/nclimate3321.html#supplementary-information.

Brown, R. W., Taylor, W. W., and Assel, R. A. (1993). Factors Affecting the Recruitment of Lake Whitefish in Two Areas of Northern Lake Michigan. *Journal of Great Lakes Research, 19*(2), 418-428. doi:10.1016/s0380-1330(93)71229-0.

Canada. (2017). *Pan-Canadian Framework on Clean Growth and Climate Change first annual report*. Government of Canada. https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework/first-annual-report.html.

Chen, C. C., Jenkins, E., Epp, T., Waldner, C., Curry, P. S., and Soos, C. (2013). Climate Change and West Nile Virus in a Highly Endemic Region of North America. *International Journal of Environmental Research and Public Health, 10*(7), 3052-3071. doi:10.3390/ijerph10073052.

Cheng, C. S., Auld, H., Li, Q., and Li, G. L. (2012a). Possible impacts of climate change on extreme weather events at local scale in south-central Canada. *Climatic Change, 112*(3-4), 963-979. doi:10.1007/s10584-011-0252-0.

Cheng, C. S., Li, Q., Li, G., and Auld, H. (2012b). Climate Change and Heavy Rainfall-Related Water Damage Insurance Claims and Losses in Ontario, Canada. *Journal of Water Resource and Protection, 4*, 49-62. doi:http://dx.doi.org/10.4236/jwarp.2012.42007.

Cheng, C. S., Lopes, E., Fu, C., and Huang, Z. Y. (2014). Possible Impacts of Climate Change on Wind Gusts under Downscaled Future Climate Conditions: Updated for Canada. *Journal of Climate, 27*(3), 1255-1270. doi:10.1175/jcli-d-13-00020.1.

Chu, C. (2015). *Climate Change Vulnerability Assessment for Inland Aquatic Ecosystems in the Great Lakes Basin, Ontario*. Ontario Ministry of Natural Resources and Forestry. http://www.climateontario.ca/MNR_Publications/CCRR-43.pdf.

Collingsworth, P. D., Bunnell, D. B., Murray, M. W., Kao, Y. C., Feiner, Z. S., Claramunt, R. M., Lofgren, B. M., Hook, T. O., and Ludsin, S. A. (2017). Climate change as a long-term stressor for the fisheries of the Laurentian Great Lakes of North America. *Reviews in Fish Biology and Fisheries, 27*(2), 363-391. doi:10.1007/s11160-017-9480-3.

Colombo, S. J. (2008). *Ontario's Forests and Forestry in a Changing Climate*. Ontario Ministry of Natural Resources. https://www.ontario.ca/document/ontarios-forests-and-forestry-changing-climate.

CPC. (2013). *Canadian Parks and Protected Areas: Helping Canada Weather Climate Change*. Parks Canada Agency on behalf of the Canadian Parks Council. http://www.parks-parcs.ca/english/CPC%20Climate%20Change%20Report%20FINAL%20engLR.pdf.
Croley, T. E. (1990). Laurentian Great Lakes double-CO2 climate change hydrological impacts. *Climatic Change, 17*(1), 27-47. doi:10.1007/bf00148999.
Crowe, K. A. and Parker, W. H. (2011). Conserving the diversity of Ontario tree species under multiple uncertain climatic futures. *Canadian Journal of Forest Research, 41*(3), 533-542. doi:10.1139/x10-228.
Cunderlik, J. M. and Ouarda, T. (2009). Trends in the timing and magnitude of floods in Canada. *Journal of Hydrology, 375*(3-4), 471-480. doi:10.1016/j.jhydrol.2009.06.050.
Del Degan and Masse et Associes Inc. (2007). *Bruce Peninsula National Park of Canada and Fathom Five National Marine Park of Canada Wildfire Risk Analysis*. Prepared for Parks Canada
Deng, Z. W., Qiu, X., Liu, J. L., Madras, N., Wang, X. G., and Zhu, H. P. (2016). Trend in frequency of extreme precipitation events over Ontario from ensembles of multiple GCMs. *Climate Dynamics, 46*(9-10), 2909-2921. doi:10.1007/s00382-015-2740-9.
DeSantis, R. D., Moser, W. K., Gormanson, D. D., Bartlett, M. G., and Vermunt, B. (2013). Effects of climate on emerald ash borer mortality and the potential for ash survival in North America. *Agricultural and Forest Meteorology, 178*, 120-128. doi:10.1016/j.agrformet.2013.04.015.
Distler, T., Schuetz, J. G., Velásquez-Tibatá, J., and Langham, G. M. (2015). Stacked species distribution models and macroecological models provide congruent projections of avian species richness under climate change. *Journal of Biogeography, 42*(5), 976-988. doi:10.1111/jbi.12479.
Dove-Thompson, D., Lewis, C., Gray, P. A., Chu, C., and I., D. W. (2011). *A Summary of the Effects of Climate Change on Ontario's Aquatic Ecosystems*. Ontario Ministry of Natural Resources. http://files.ontario.ca/environment-and-energy/aquatics-climate/stdprod_088243.pdf.
Dudley, N., Buyck, C., Furuta, N., Pedrot, C., Renaud, F., and Sudmeier-Rieux, K. (2015). *Protected areas as tools for disaster risk reduction : a handbook for practitioners*. MOEJ and IUCN, Tokyo and Gland, Switzerland. https://portals.iucn.org/library/node/45054.
ECCC. (2017). *Adjusted and Homogenized Canadian Climate Data (AHCCD)*. Environment and Climate Change Canada. https://www.ec.gc.ca/dccha-ahccd/.
Eisen, R. J., Eisen, L., Ogden, N. H., and Beard, C. B. (2016). Linkages of Weather and Climate with *Ixodes scapularis* and *Ixodes pacificus* (Acari: Ixodidae), Enzootic Transmission of *Borrelia burgdorferi*, and Lyme Disease in North America. *Journal of Medical Entomology, 53*(2), 250-261. doi:10.1093/jme/tjv199.
Fisichelli, N. A., Schuurman, G. W., Monahan, W. B., and Ziesler, P. S. (2015). Protected Area Tourism in a Changing Climate: Will Visitation at US National Parks Warm Up or Overheat? *PLoS ONE, 10*(6), 13. doi:10.1371/journal.pone.0128226.
Flannigan, M. D., Wotton, B. M., Marshall, G. A., de Groot, W. J., Johnston, J., Jurko, N., and Cantin, A. S. (2016). Fuel moisture sensitivity to temperature and precipitation: climate change implications. *Climatic Change, 134*(1), 59-71. doi:10.1007/s10584-015-1521-0.
Genivar. (2010). *Toronto and Region Conservation Authority Flood Control Dam Water Resources Infrastructure Assessment*. Engineers Canada. https://pievc.ca/toronto-and-region-conservation-authority-claireville-and-g-ross-water-control-dams.
Genivar. (2011). *Climate Change Vulnerability Assessment for Culverts, City of Toronto*. Engineers Canada. https://pievc.ca/city-toronto-study-three-road-culverts.
Genivar. (2013). *Union Water Supply System Climate Risk Assessment*. Engineers Canada. https://pievc.ca/sites/default/files/uwss_climate_risk_assessment_final_report_may_2013.pdf.
Gough, W., Anderson, V., and Herod, K. (2016). *Ontario Climate Change and Health Modelling Study: Report*. Ontario Ministry of Health and Long-Term Care. http://www.health.gov.on.ca/en/common/ministry/publications/reports/climate_change_toolkit/climate_change_health_modelling_study.pdf.
Gray, P. A., Perdeaux, S., and Cobb, P. (2017). *Approaches for Integrating Climate Change into Natural Resource Management and Management Planning for Protected Areas. A Review of the Literature*. Ontario Ministry of Natural Resources and Forestry
Gross, J. E., Woodley, S., Welling, L. A., and Watson, J. E. M. (Eds.). (2016). *Adapting to Climate Change. Guidance for protected area managers and planners.* (Vol. No. 24). Gland, Switzerland: IUCN. https://portals.iucn.org/library/node/46685.

Hewer, M., Scott, D., and Fenech, A. (2016). Seasonal weather sensitivity, temperature thresholds, and climate change impacts for park visitation. *Tourism Geographies, 18*(3), 297-321. doi:10.1080/14616688.2016.1172662.

Hewer, M. J. and Gough, W. A. (2018). Thirty years of assessing the impacts of climate change on outdoor recreation and tourism in Canada. *Tourism Management Perspectives, 26*(Complete), 179-192. doi:10.1016/j.tmp.2017.07.003.

Hewer, M. J., Scott, D., and Gough, W. A. (2015). Tourism climatology for camping: a case study of two Ontario parks (Canada). *Theoretical and Applied Climatology, 121*(3-4), 401-411. doi:10.1007/s00704-014-1228-6.

Hewer, M. J., Scott, D. J., and Gough, W. A. (2017a). Differences in the importance of weather and weather-based decisions among campers in Ontario parks (Canada). *International Journal of Biometeorology*. doi:10.1007/s00484-017-1364-7.

Hewer, M. J., Scott, D. J., and Gough, W. A. (2017b). Differential temperature preferences and thresholds among summer campers in Ontario's southern provincial parks: a Canadian case study in tourism climatology. *Theoretical and Applied Climatology*. doi:10.1007/s00704-017-2248-9.

Honsey, A. E., Bunnell, D. B., Troy, C. D., Fielder, D. G., Thomas, M. V., Knight, C. T., Chong, S. C., and Hook, T. O. (2016). Recruitment synchrony of yellow perch (Perca flavescens, Percidae) in the Great Lakes region, 1966-2008. *Fisheries Research, 181*, 214-221. doi:10.1016/j.fishres.2016.04.021.

IJC. (2009). *Impacts on Upper Great Lakes Water Levels: St. Clair River*. International Upper Great Lakes Study. http://www.ijc.org/files/publications/IUGLS%20St%20Clair%20Report.pdf.

IJC. (2012). *Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels*. International Joint Commission, Upper Great Lakes Study. http://www.ijc.org/files/publications/Lake_Superior_Regulation_Full_Report.pdf.

IPCC. (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK, and New York, NY, USA. https://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf.

IPCC. (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Intergovernmental Panel on Climate Change (IPCC). The Summary for Policymakers of the Working Group II contribution to the Fifth Assessment Report. http://www.ipcc.ch/index.htm.

Jones, B. and Scott, D. (2006a). Climate Change, Seasonality and Visitation to Canada's National Parks. *Journal of Park and Recreation Administration; Vol 24, No 2 (2006)*. http://js.sagamorepub.com/jpra/article/view/1407

Jones, B. and Scott, D. (2006b). Implications of climate change for visitation to ontario's provincial parks. *Leisure/Loisir, 30*(1), 233-261. doi:10.1080/14927713.2006.9651350.

Jones, N. E., Petreman, I. C., and Schmidt, B. J. (2015). *High Flows and Freshet Timing in Canada: Observed Trends*. Ontario Ministry of Natural Resources and Forestry. http://www.climateontario.ca/MNR_Publications/CCRR42.pdf.

Karl, T. R., Melillo, J. M., and Peterson, T. C. (Eds.). (2009). *Global Climate Change Impacts in the United States*. New York: Cambridge University Press. https://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.

Knudsen, E., Linden, A., Both, C., Jonzen, N., Pulido, F., Saino, N., Sutherland, W. J., Bach, L. A., Coppack, T., Ergon, T., Gienapp, P., Gill, J. A., Gordo, O., Hedenstroom, A., Lehikoinen, E., Marra, P. P., Moller, A. P., Nilsson, A. L. K., Peron, G., Ranta, E., Rubolini, D., Sparks, T. H., Spina, F., Studds, C. E., Saether, S. A., Tryjanowski, P., and Stenseth, N. C. (2011). Challenging claims in the study of migratory birds and climate change. *Biological Reviews, 86*(4), 928-946. doi:10.1111/j.1469-185X.2011.00179.x.

Kunkel, K. E., Ensor, L., Palecki, M., Easterling, D., Robinson, D., Hubbard, K. G., and Redmond, K. (2009). A New Look at Lake-Effect Snowfall Trends in the Laurentian Great Lakes Using a Temporally Homogeneous Data Set. *Journal of Great Lakes Research, 35*(1), 23-29. doi:10.1016/j.jglr.2008.11.003.

Langer, T. A., Cooper, M. J., Reisinger, L. S., Reisinger, A. J., and Uzarski, D. G. (2018). Water depth and lake-wide water level fluctuation influence on alpha- and beta-diversity of coastal wetland fish communities. *Journal of Great Lakes Research, 44*(1), 70-76. doi:10.1016/j.jglr.2017.11.001.

Lemieux, C. J., Scott, D. J., Gray, P. A., and Davis, R. G. (2007). *Climate Change and Ontario's Provincial Parks: Towards an Adaptation Strategy*. Ontario Ministry of Natural Resources, Sault Ste. Marie, ON. http://www.climateontario.ca/MNR_Publications/276924.pdf.

Lindsay, K., Gobeil, J.-F., Lawler, J. L., Schloss, C., Beazley, K. F., and Beechey, T. J. (2016). *Wildlife Conservation, Protected Areas and Climate Change in Canada: Implications of Projected Species Range*

Shifts. Canadian Council on Ecological Areas, CCEA Secretariat, Ottawa, Ontario. http://www.ccea.org/wp-content/uploads/2015/10/CCEA_WildlifeConservationProtectedAreasandClimateChangeinCanada_Digital.pdf.

Lo, V. (2016). *Synthesis report on experiences with ecosystem-based approaches to climate change adaptation and disaster risk reduction*. Secretariat of the Convention on Biological Diversity (SCBD), Montreal. https://www.cbd.int/climate/.

Lofgren, B. M. and Rouhana, J. (2016). Physically Plausible Methods for Projecting Changes in Great Lakes Water Levels under Climate Change Scenarios. *Journal of Hydrometeorology, 17*(8), 2209-2223. doi:10.1175/jhm-d-15-0220.1.

MacKay, M. and Seglenieks, F. (2013). On the simulation of Laurentian Great Lakes water levels under projections of global climate change. *Climatic Change*, *117*(1), 55-67. doi:10.1007/s10584-012-0560-z.

Mainka, S. A. and Howard, G. W. (2010). Climate change and invasive species: double jeopardy. *Integrative Zoology, 5*(2), 102-111. doi:10.1111/j.1749-4877.2010.00193.x.

Mandrak, N. E. (1989). Potential Invasion of the Great Lakes by Fish Species Associated with Climatic Warming. *Journal of Great Lakes Research, 15*(2), 306-316.

Marcogliese, D. J. (2008). The impact of climate change on the parasites and infectious diseases of aquatic animals. *Revue Scientifique Et Technique-Office International Des Epizooties*, *27*(2), 467-484.

Marcogliese, D. J. (2016). The Distribution and Abundance of Parasites in Aquatic Ecosystems in a Changing Climate: More than Just Temperature. *Integrative and Comparative Biology, 56*(4), 611-619. doi:10.1093/icb/icw036.

Mason, L. A., Riseng, C. M., Gronewold, A. D., Rutherford, E. S., Wang, J., Clites, A., Smith, S. D. P., and McIntyre, P. B. (2016). Fine-scale spatial variation in ice cover and surface temperature trends across the surface of the Laurentian Great Lakes. *Climatic Change, 138*(1), 71-83. doi:10.1007/s10584-016-1721-2.

McDermid, J. L., Dickin, S. K., Winsborough, C. L., Switzman, H., Barr, S., Gleason, J. A., Krantzberg, G., and Gray, P. A. (2015). *State of Climate Change Science in the Great Lakes Basin: A Focus on Climatological, Hydrological and Ecological Effects.* Ontario Climate Consortium and Ontario Ministry of Natural Resources and Forestry. http://climateconnections.ca/our-work/the-state-of-climate-change-science-in-the-great-lakes/.

McKenney, D. W., Pedlar, J. H., Lawrence, K., Gray, P. A., Colombo, S. J., and Crins, W. J. (2010). *Current and Projected Future Climatic Conditions for Ecoregions and Selected Natural Heritage Areas in Ontario*. Ontario Ministry of Natural Resources, Sault Ste. Marie, ON. http://www.climateontario.ca/MNR_Publications/stdprod_088016.pdf.

McKenney, D. W., Pedlar, J. H., Rood, R. B., and Price, D. (2011). Revisiting projected shifts in the climate envelopes of North American trees using updated general circulation models. *Global Change Biology, 17*(8), 2720-2730. doi:10.1111/j.1365-2486.2011.02413.x.

Meisner, J. D., Rosenfeld, J. S., and Regier, H. A. (1988). The Role of Groundwater in the Impact of Climate Warming on Stream Salmonines. *Fisheries*, *13*(3), 2-8. doi:10.1577/1548-8446(1988)013<0002:Trogit>2.0.Co;2.

Midwood, J. D. and Chow-Fraser, P. (2012). Changes in aquatic vegetation and fish communities following 5 years of sustained low water levels in coastal marshes of eastern Georgian Bay, Lake Huron. *Global Change Biology, 18*(1), 93-105. doi:10.1111/j.1365-2486.2011.02558.x.

Minns, C. K., Shuter, B. J., and Fung, S. R. (2014). *Regional Projections of Climate Change Effects on Ice Cover and Open-Water Duration for Ontario Lakes Using Updated Ice-Date Models*. Ontario Ministry of Natural Resources. http://www.climateontario.ca/MNR_Publications/ccrr40.pdf.

Mortsch, L., Ingram, J., Hebb, A., and Doka, S. (Eds.). (2006). *Great Lakes Coastal Wetlands Communities: Vulnerabilities to Climate Change and Response to Adaptation Strategies*: Environment Canada. http://www.publications.gc.ca/pub?id=9.689486&sl=0.

Murti, R. and Buyck, C. (2014). *Safe Havens: Protected Areas for Disaster Risk Reduction and Climate Change Adaptation*. International Union for Conservation of Nature and Natural Resource (IUCN), Gland, Switzerland. https://portals.iucn.org/library/sites/library/files/documents/2014-038.pdf.

Music, B., Frigon, A., Lofgren, B., Turcotte, R., and Cyr, J.-F. (2015). Present and future Laurentian Great Lakes hydroclimatic conditions as simulated by regional climate models with an emphasis on Lake Michigan-Huron. *Climatic Change, 130*(4), 603-618. doi:10.1007/s10584-015-1348-8.

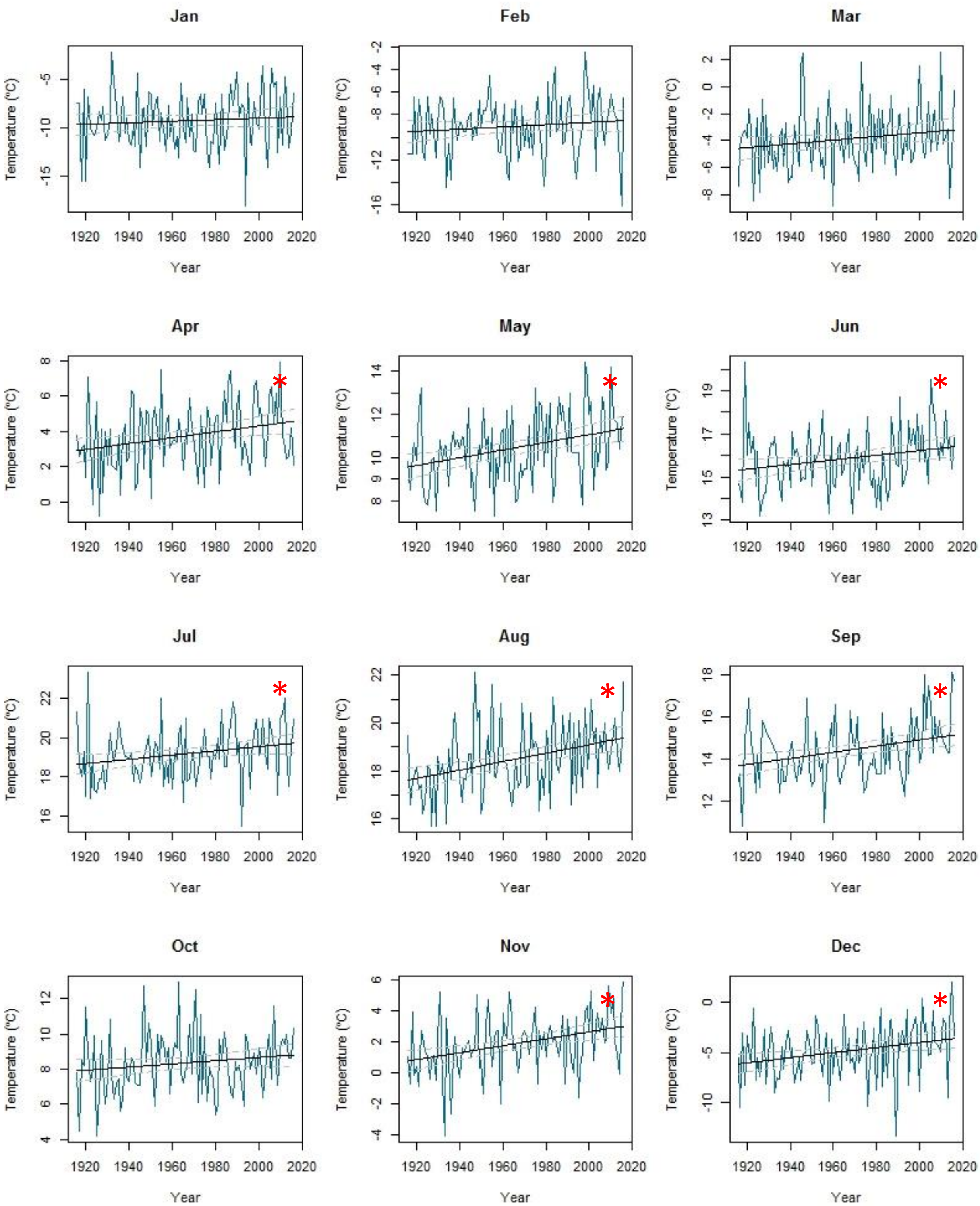
Nantel, P., Pellatt, M. G., Keenleyside, K. A., and Gray, P. A. (2014). Biodiversity and Protected Areas. In F. J. Warrenand D. S. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and*

Adaptation (pp. 159-190). Ottawa, ON: Government of Canada. http://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2014/16309.
NAWPA. (2012). *North American Protected Areas as Natural Solutions for Climate Change*. North American Intergovernmental Committee on Cooperation for Wilderness and Protected Area Conservation. http://nawpacommittee.org/wp-content/uploads/2012/08/NAWPA-CCWG-Brochure.pdf.
Nelder, M. P., Russell, C. B., Sheehan, N. J., Sander, B., Moore, S., Li, Y., Johnson, S., Patel, S. N., and Sider, D. (2016). Human pathogens associated with the blacklegged tick Ixodes scapularis: a systematic review. *Parasites & Vectors, 9*, 14. doi:10.1186/s13071-016-1529-y.
Nituch, L. A. and Bowman, J. (2013). *Community-Level Effects of Climate Change on Ontario's Terrestrial Biodiversity*. Ontario Ministry of Natural Resources. http://www.climateontario.ca/MNR_Publications/CCRR-36.pdf.
Notaro, M., Bennington, V., and Lofgren, B. (2015a). Dynamical Downscaling–Based Projections of Great Lakes Water Levels. *Journal of Climate, 28*(24), 9721-9745. doi:10.1175/jcli-d-14-00847.1.
Notaro, M., Bennington, V., and Vavrus, S. (2015b). Dynamically Downscaled Projections of Lake-Effect Snow in the Great Lakes Basin. *Journal of Climate, 28*(4), 1661-1684. doi:10.1175/jcli-d-14-00467.1.
Notaro, M., Lorenz, D., Hoving, C., and Schummer, M. (2014). Twenty-First-Century Projections of Snowfall and Winter Severity across Central-Eastern North America. *Journal of Climate, 27*(17), 6526-6550. doi:10.1175/jcli-d-13-00520.1.
Ogden, N. H., Maarouf, A., Barker, I. K., Bigras-Poulin, M., Lindsay, L. R., Morshed, M. G., O'Callaghan, C. J., Ramay, F., Waltner-Toews, D., and Charron, D. F. (2006). Climate change and the potential for range expansion of the Lyme disease vector Ixodes scapularis in Canada. *International Journal for Parasitology, 36*(1), 63-70. doi:10.1016/j.ijpara.2005.08.016.
Ogden, N. H., Milka, R., Caminade, C., and Gachon, P. (2014). Recent and projected future climatic suitability of North America for the Asian tiger mosquito Aedes albopictus. *Parasites & Vectors, 7*, 14. doi:10.1186/s13071-014-0532-4.
Pacifici, M., Foden, W. B., Visconti, P., Watson, J. F. M., Butchart, S. H. M., Kovacs, K. M., Scheffers, B. R., Hole, D. G., Martin, T. G., Akcakaya, H. R., Corlett, R. T., Huntley, B., Bickford, D., Carr, J. A., Hoffmann, A. A., Midgley, G. F., Pearce-Kelly, P., Pearson, R. G., Williams, S. E., Willis, S. G., Young, B., and Rondinini, C. (2015). Assessing species vulnerability to climate change. *Nature Climate Change, 5*(3), 215-225. doi:10.1038/nclimate2448.
Palko, K. and Lemmen, D. S. (Eds.). (2017). *Climate risks and adaptation practices for the Canadian transportation sector 2016*. Ottawa, ON: Government of Canada. http://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2017/19623.
Parker, S. (2017). *Let's Talk about Climate Change: Great Lakes Region*. Office of the Chief Ecosystem Scientist, Parks Canada
Parker, S. R., Harpur, C., and Murphy, S. D. (2015). Monitoring for resilience within the coastal wetland fish assemblages of Fathom Five National Marine Park, Lake Huron, Canada. *Natural Areas Journal, 35*(3), 378-391. doi:dx.doi.org/10.3375/043.035.0302.
Parks Canada. (2015). *Master Plan For the Reduction of Greenhouse Gas (GHG) Emissions within Parks Canada's Operations*. http://intranet2/media/2163749/master_plan_for_ghg_reduction_2015.pdf
Parks Canada. (2017). *Parks Canada Agency, 2017–18 Departmental Plan*. http://www.pc.gc.ca/en/agence-agency/bib-lib/plans/dp/dp2017-18/index.
PCIC. (2014). *Statistically Downscaled Climate Scenarios*. Pacific Climate Impacts Consortium, University of Victoria. https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios.
PIEVC. (2008). *Adapting to Climate Change Canada's First National Engineering Vulnerability Assessment of Public Infrastructure, April 2008*. Engineers Canada, Public Infrastructure Engineering Vulnerability Committee (PIEVC). https://pievc.ca/documents.
Podur, J. and Wotton, M. (2010). Will climate change overwhelm fire management capacity? *Ecological Modelling, 221*(9), 1301-1309. doi:10.1016/j.ecolmodel.2010.01.013.
Pomara, L. Y., Zuckerberg, B., LeDee, O., and Martin, K. J. (2014). *A Climate Change Vulnerability Assessment for the Eastern Massasauga Rattlesnake an Endemic of the Upper Midwest and Great Lakes Region*. Upper Midwest and Great Lakes Landscape Conservation Cooperative
Price, D. T., McKenney, D. W., Joyce, L. A., Siltanen, R. M., Papadopol, P., and Lawrence, K. (2011). *High-Resolution Interpolation of Climate Scenarios for Canada Derived from General Circulation Model*

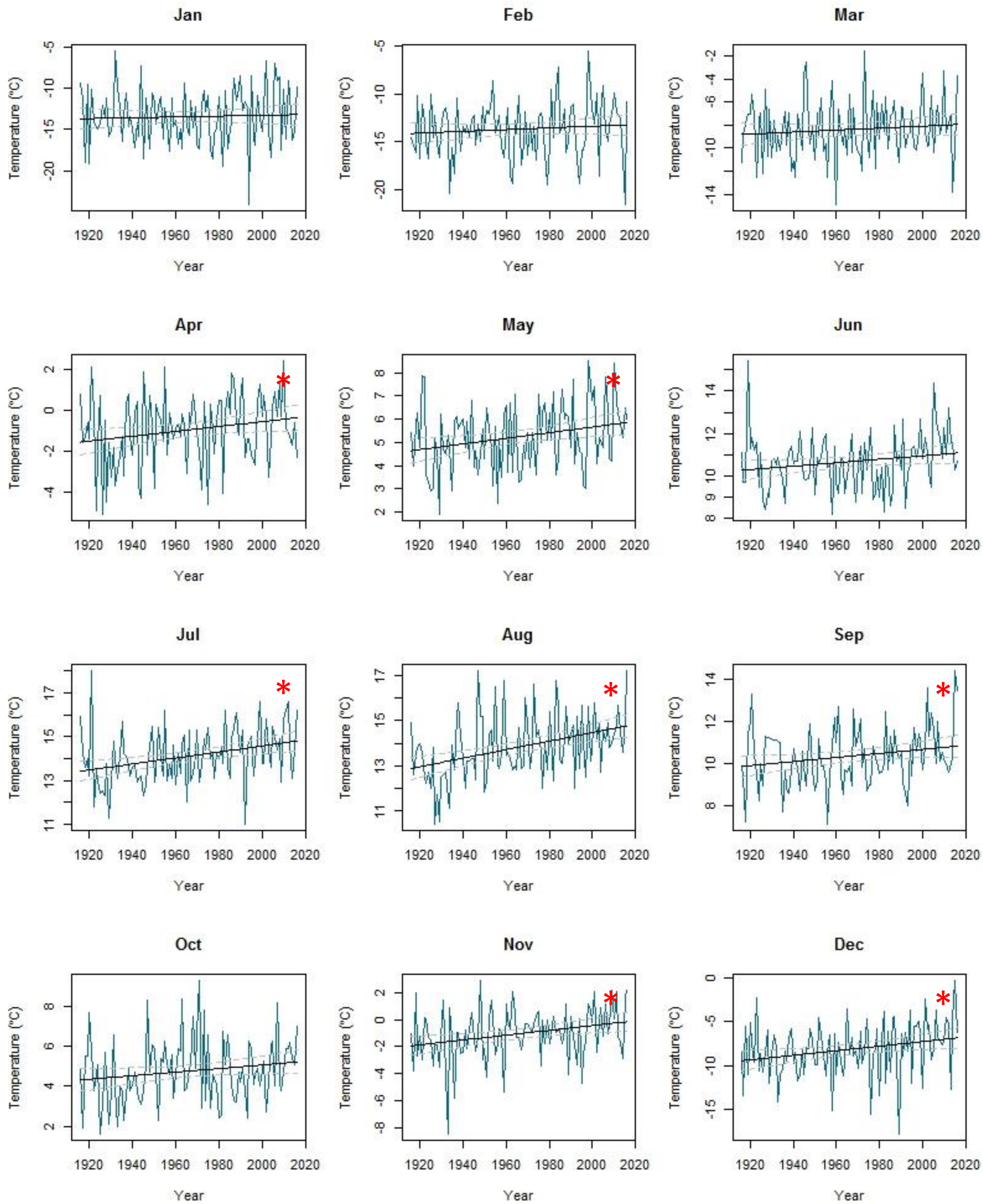
Simulations. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. http://cfs.nrcan.gc.ca/publications?id=32971.
Public Health Ontario. (2017). *Companion animals and tick-borne diseases: A systematic review*. Ontario Agency for Health Protection and Promotion, Toronto, ON. http://www.publichealthontario.ca/en/eRepository/Companion_Animals_Systematic_Review.pdf.
R Core Team. (2017). R: A Language and Environment for Statistical Computing (ver. 3.4.3). http://www.R-project.org
Reavie, E. D., Barbiero, R. P., Allinger, L. E., and Warren, G. J. (2014). Phytoplankton trends in the Great Lakes, 2001-2011. *Journal of Great Lakes Research, 40*(3), 618-639. doi:10.1016/j.jglr.2014.04.013.
Reavie, E. D., Sgro, G. V., Estepp, L. R., Bramburger, A. J., Shaw Chraïbi, V. L., Pillsbury, R. W., Cai, M., Stow, C. A., and Dove, A. (2016). Climate warming and changes in *Cyclotella sensu lato* in the Laurentian Great Lakes. *Limnology and Oceanography*. doi:10.1002/lno.10459.
Regniere, J., Nealis, V., and Porter, K. (2009). Climate suitability and management of the gypsy moth invasion into Canada. *Biological Invasions, 11*(1), 135-148. doi:10.1007/s10530-008-9325-z.
Rempel, R. S. and Hornseth, M. L. (2017). Binational climate change vulnerability assessment of migratory birds in the Great Lakes Basins: Tools and impediments. *PLoS ONE, 12*(2), e0172668. doi:10.1371/journal.pone.0172668.
Shlozberg, R., Dorling, R., and Spiro, P. (2014). *Low Water Blues. An Economic Impact Assessment of Future Low Water Levels in the Great Lakes and St. Lawrence River*. Council of the Great Lakes Region (CGLR) and Mowat Centre. https://mowatcentre.ca/low-water-blues/.
Simonovic, S. P., Schardong, A., and Sandink, D. (2017). Mapping Extreme Rainfall Statistics for Canada under Climate Change Using Updated Intensity-Duration-Frequency Curves. *Journal of Water Resources Planning and Management, 143*(3), 12. doi:10.1061/(asce)wr.1943-5452.0000725.
Soverow, J. E., Wellenius, G. A., Fisman, D. N., and Mittleman, M. A. (2009). Infectious Disease in a Warming World: How Weather Influenced West Nile Virus in the United States (2001-2005). *Environmental Health Perspectives, 117*(7), 1049-1052. doi:10.1289/ehp.0800487.
Stephanson, C. and Ribarik Coe, N. (2017). Impacts of Beech Bark Disease and Climate Change on American Beech. *Forests, 8*(5), 155.
Stralberg, D., Carroll, C., Wilsey, C., Pedlar, J., McKenney, D., and Nielsen, S. (2018). Macrorefugia for North American trees and songbirds: climatic limiting factors and multi-scale topographic influences. *Global Ecology and Biogeography*. doi:https://doi.org/10.1111/geb.12731.
Taylor, A. R., Boulanger, Y., Price, D. T., Cyr, D., McGarrigle, E., Rammer, W., and Kershaw, J. A. (2017). Rapid 21st century climate change projected to shift composition and growth of Canada's Acadian Forest Region. *Forest Ecology and Management, 405*, 284-294. doi:10.1016/j.foreco.2017.07.033.
Terrier, A., Girardin, M. P., Périé, C., Legendre, P., and Bergeron, Y. (2013). Potential changes in forest composition could reduce impacts of climate change on boreal wildfires. *Ecological Applications, 23*(1), 21-35. doi:10.1890/12-0425.1.
Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., Erasmus, B. F. N., de Siqueira, M. F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A. S., Midgley, G. F., Miles, L., Ortega-Huerta, M. A., Peterson, A. T., Phillips, O. L., and Williams, S. E. (2004). Extinction risk from climate change. *Nature, 427*(6970), 145-148. doi:10.1038/nature02121.
Trumpickas, J., Shuter, B., and Minns, C. (2008). *Potential Changes in Future Surface Water Temperatures in the Ontario Great Lakes as a Result of Climate Change* (Vol. Climate Change Research Information Note CCRN-07): Ontario Ministry of Natural Resources. http://files.ontario.ca/environment-and-energy/aquatics-climate/276900.pdf.
Trumpickas, J., Shuter, B. J., and Minns, C. K. (2009). Forecasting impacts of climate change on Great Lakes surface water temperatures. *Journal of Great Lakes Research, 35*(3), 454-463. doi:10.1016/j.jgir.2009.04.005.
US NPS. (2016). *National Climate Change Interpretation and Education Strategy*. https://www.nps.gov/subjects/climatechange/nccies.htm.
Van Zuiden, T. M., Chen, M. M., Stefanoff, S., Lopez, L., and Sharma, S. (2016). Projected impacts of climate change on three freshwater fishes and potential novel competitive interactions. *Diversity and Distributions, 22*(5), 603-614. doi:10.1111/ddi.12422.
Veraverbeke, S., Rogers, B. M., Goulden, M. L., Jandt, R. R., Miller, C. E., Wiggins, E. B., and Randerson, J. T. (2017). Lightning as a major driver of recent large fire years in North American boreal forests. *Nature Climate Change, 7*(7), 529-+. doi:10.1038/nclimate3329.

Vuuren, D., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S., and Rose, S. (2011). The representative concentration pathways: an overview. *Climatic Change, 109*(1-2), 5-31. doi:10.1007/s10584-011-0148-z.
Walker, K. V., Davis, M. B., and Sugita, S. (2002). Climate change and shifts in potential tree species range limits in the Great Lakes region. *Journal of Great Lakes Research, 28*(4), 555-567.
Walther, G. R., Roques, A., Hulme, P. E., Sykes, M. T., Pysek, P., Kuhn, I., Zobel, M., Bacher, S., Botta-Dukat, Z., Bugmann, H., Czucz, B., Dauber, J., Hickler, T., Jarosik, V., Kenis, M., Klotz, S., Minchin, D., Moora, M., Nentwig, W., Ott, J., Panov, V. E., Reineking, B., Robinet, C., Semenchenko, V., Solarz, W., Thuiller, W., Vila, M., Vohland, K., and Settele, J. (2009). Alien species in a warmer world: risks and opportunities. *Trends in Ecology & Evolution, 24*(12), 686-693. doi:10.1016/j.tree.2009.06.008.
Wang, J., Bai, X. Z., Hu, H. G., Clites, A., Colton, M., and Lofgren, B. (2012). Temporal and spatial variability of Great Lakes ice cover, 1973-2010. *Journal of Climate, 25*(4), 1318-1329. doi:10.1175/2011jcli4066.1.
Wang, X. Q., Huang, G. H., Baetz, B. W., and Zhao, S. (2017). Probabilistic projections of regional climatic changes over the Great Lakes Basin. *Climate Dynamics*, *49*(7-8), 2237-2247. doi:10.1007/s00382-016-3450-7.
Wang, X. Q., Huang, G. H., Liu, J. L., Li, Z., and Zhao, S. (2015). Ensemble Projections of Regional Climatic Changes over Ontario, Canada. *Journal of Climate*, *28*(18), 7327-7346. doi:10.1175/jcli-d-15-0185.1.
Warren, F. J. and Lemmen, D. S. (Eds.). (2014). *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation*. Ottawa, ON: Government of Canada. http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report_Eng.pdf.
Warren, R., VanDerWal, J., Price, J., Welbergen, J. A., Atkinson, I., Ramirez-Villegas, J., Osborn, T. J., Jarvis, A., Shoo, L. P., Williams, S. E., and Lowe, J. (2013). Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. *Nature Climate Change, 3*(7), 678-682. doi:10.1038/nclimate1887.
Woolford, D. G., Dean, C. B., Martell, D. L., Cao, J. G., and Wotton, B. M. (2014). Lightning-caused forest fire risk in Northwestern Ontario, Canada, is increasing and associated with anomalies in fire weather. *Environmetrics*, *25*(6), 406-416. doi:10.1002/env.2278.
World Economic Forum. (2018). *The Global Risks Report 2018, 13th Edition*, Geneva, Switzerland. http://wef.ch/risks2018.
Wotton, B. M., Flannigan, M. D., and Marshall, G. A. (2017). Potential climate change impacts on fire intensity and key wildfire suppression thresholds in Canada. *Environmental Research Letters, 12*(9), 12. doi:10.1088/1748-9326/aa7e6e.
Wotton, M., Logan, K., and McAlpine, R. (2005). *Climate Change and the Future Fire Environment in Ontario: Fire Occurrence and Fire Management Impacts*. Ontario Ministry of Natural Resources. http://www.climateontario.ca/MNR_Publications/276920.pdf.
Wu, J. X., Wilsey, C. B., Taylor, L., and Schuurman, G. W. (2018). Projected avifaunal responses to climate change across the U.S. National Park System. *PLoS ONE, 13*(3), e0190557. doi:10.1371/journal.pone.0190557.
Wudel, B. and Shadabi, E. (2016). *A Short Review of Literature on the Effects of Climate Change on Mosquito-Bourne Illness in Canada*. National Collaborating Centre for Infectious Disease. https://nccid.ca/wp-content/uploads/sites/2/2016/07/RapidReviewClimateMosquito-EN.pdf.
WWF. (2017). *Living Planet Report Canada. A National Look at Wildlife Loss*. World Wildlife Fund. http://assets.wwf.ca/downloads/WEB_WWF_REPORT.pdf?_ga=2.153875768.1853188321.1505385810-246620452.1505385810.
Yao, Y., Huang, G. H., and Lin, Q. (2012). Climate change impacts on Ontario wind power resource. *Environmental Systems Research*, *1*(1), 2. doi:10.1186/2193-2697-1-2.
Zhong, Y. F., Notaro, M., Vavrus, S. J., and Foster, M. J. (2016). Recent accelerated warming of the Laurentian Great Lakes: Physical drivers. *Limnology and Oceanography, 61*(5), 1762-1786. doi:10.1002/lno.10331.

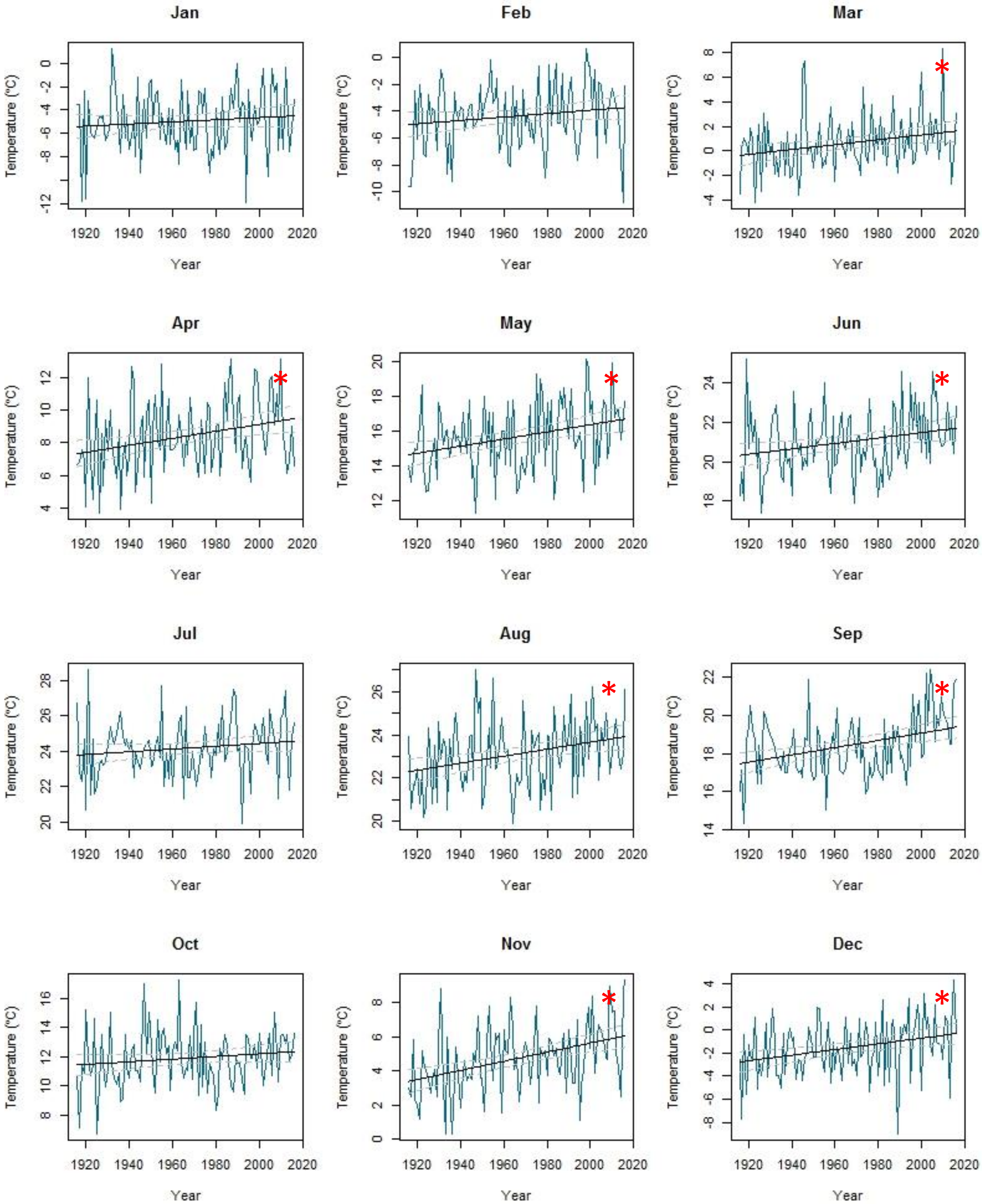
Appendix 1. Additional Climate Trends



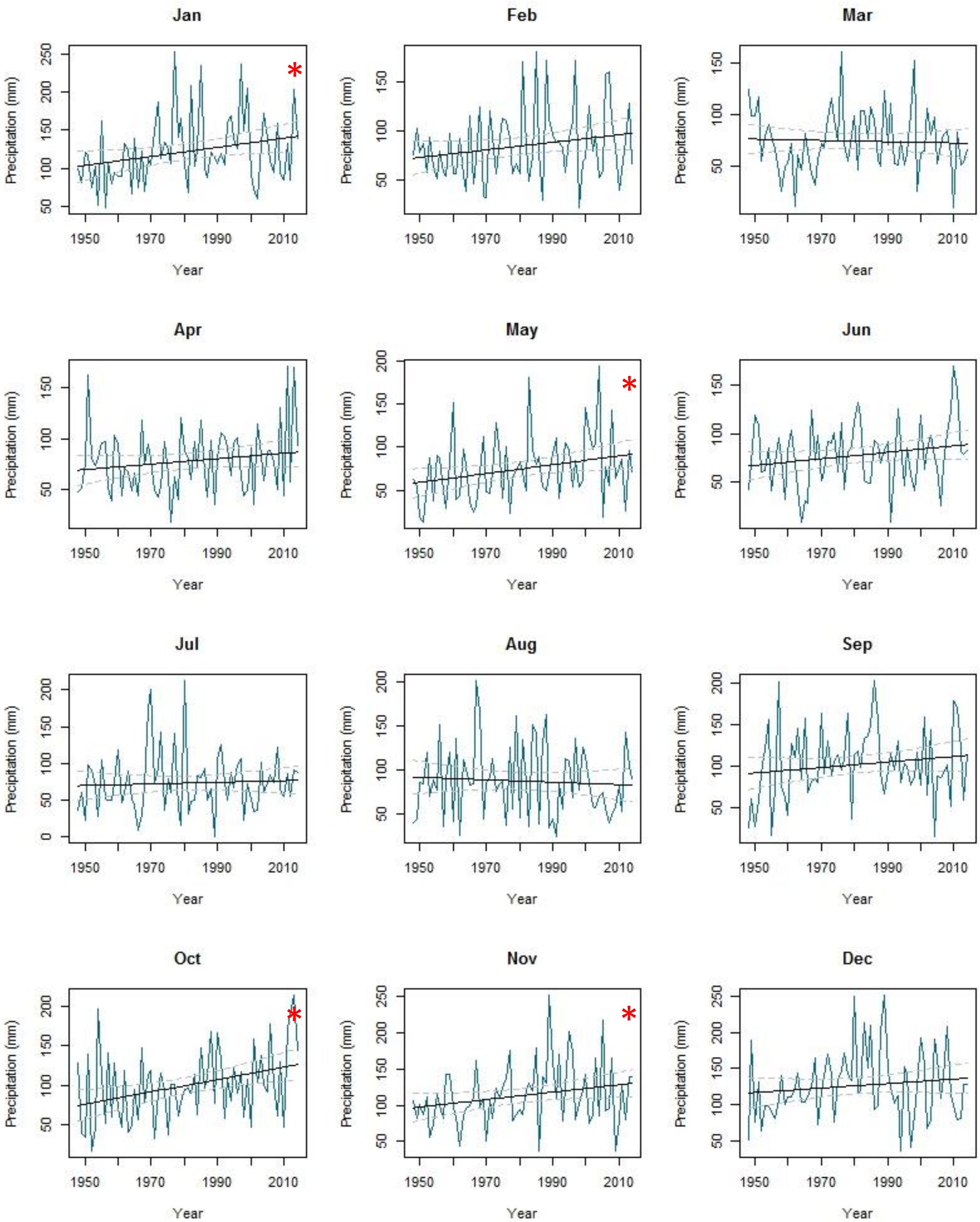
Gore Bay mean monthly temperature. Jan, Feb, Mar and Oct did not demonstrate a statistically significant ($P<0.05$) increase. Dec demonstrated the greatest increase, ~2°C since 1916.



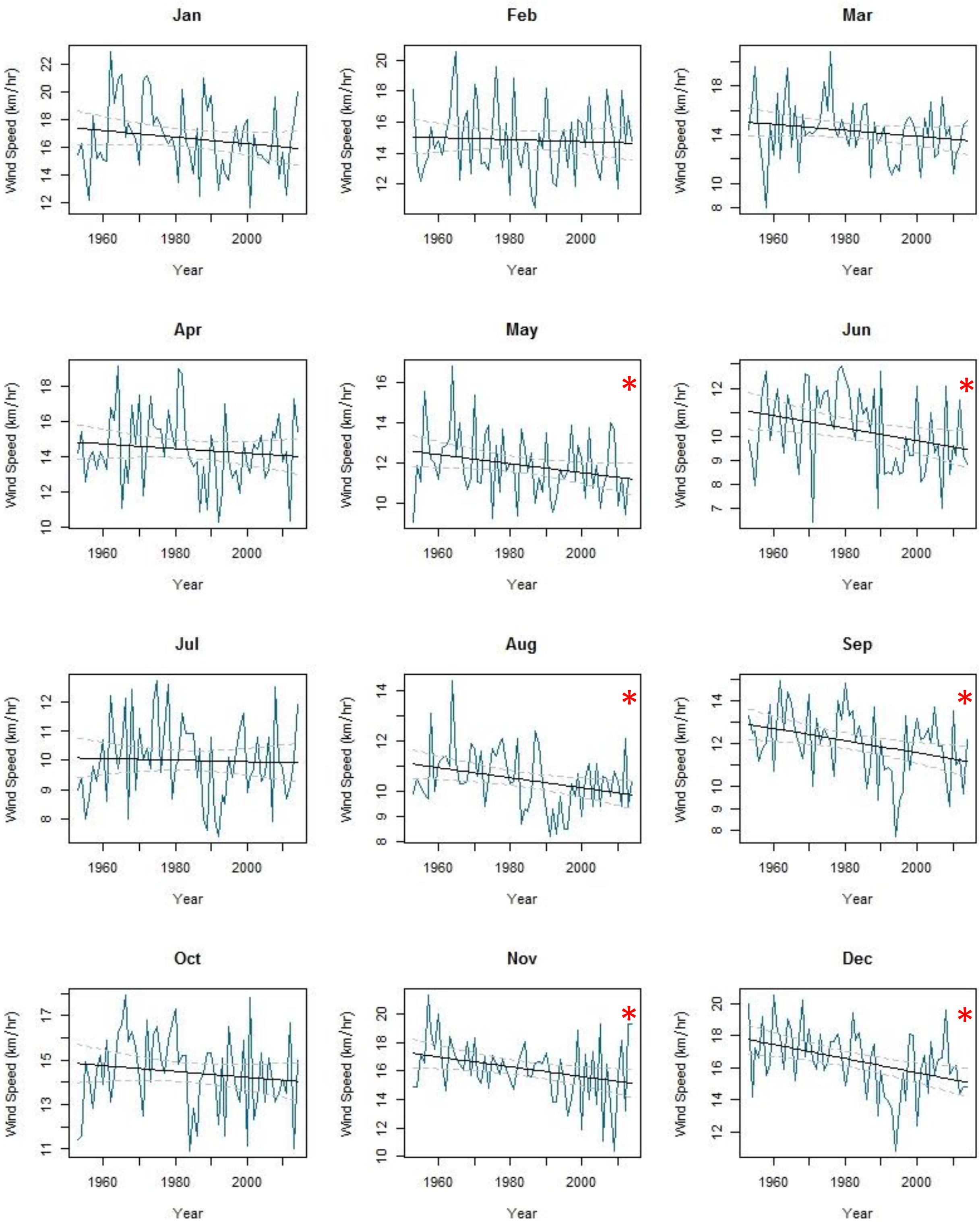
Gore Bay mean monthly <u>minimum</u> temperature. Jan, Feb, Mar, Jun and Oct did not demonstrate a statistically significant (P<0.05) increase in mean monthly minimum temperatures (i.e., nighttime). Dec demonstrated the greatest increase, ~2°C since 1916.



Gore Bay mean monthly <u>maximum</u> temperature. Jan, Feb, Jul and Oct did not demonstrate a statistically significant (P<0.05) increase in mean monthly maximum temperatures (i.e., daytime). Nov demonstrated the greatest increase, ~2.1°C since 1916.

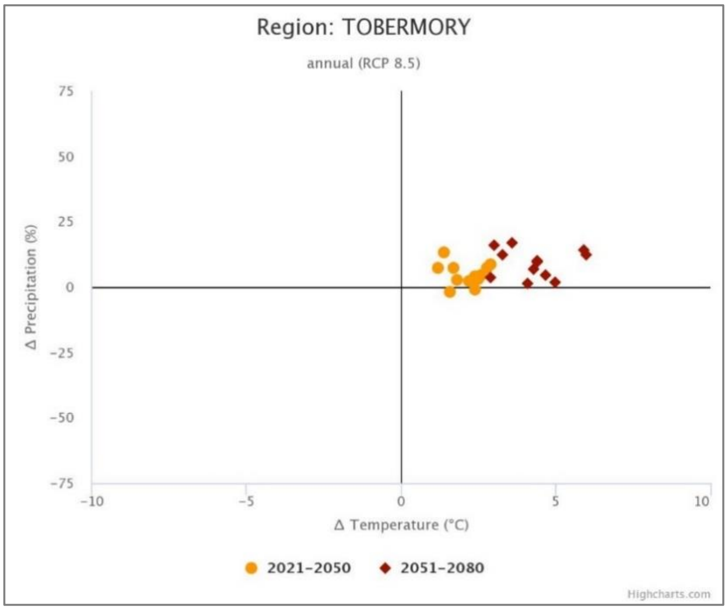


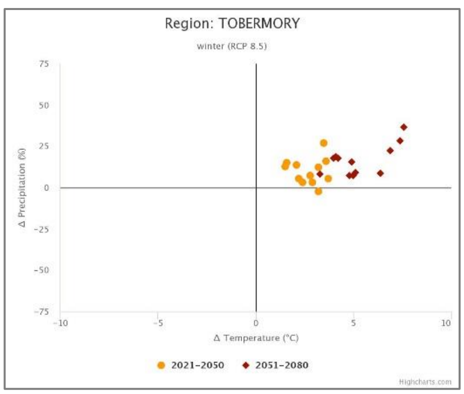
Wiarton total monthly precipitation. Total monthly precipitation has demonstrated a statistically significant increase (P<0.05) in Jan, May, Oct and Nov since 1948. The greatest increase being observed in Oct, ~51 mm (69%). Although not statistically significant (P<0.05), Mar and Aug both demonstrated a declining trend.

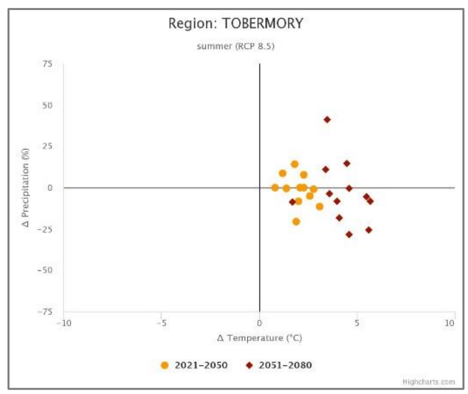


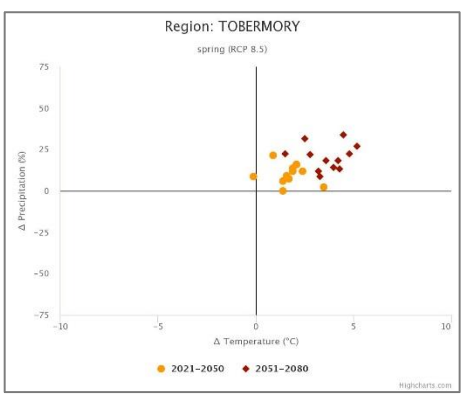
Wiarton mean monthly wind speeds. Mean monthly wind speeds have demonstrated a statistically significant ($P<0.05$) decrease in May, Jun, Aug, Sep, Nov and Dec since 1953. The greatest decrease being observed for Dec, ~2.9 km/hr (16%) since 1953.

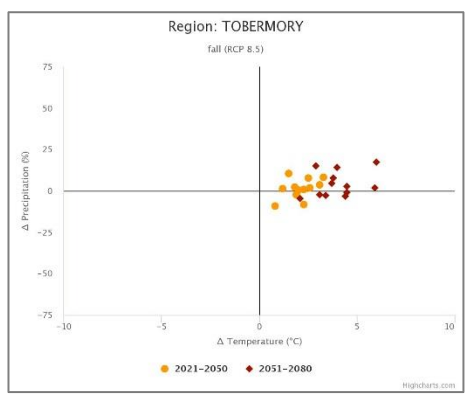
Appendix 2. Model Scatterplots for Temperature and Precipitation











Climate models for Tobermory area (10km x 10km grid). Each point represents a single model-simulated temperature/precipitation response to the RCP 8.5 scenario. Statistically downscaled data (Bias Corrected Spatial Disaggregation; BCSD) derived from 12 CMIP5 global climate models: ACCESS1.0, CanESM2, CCSM4, CNRM-CM5, CSIRO-Mk3-6.0, GFDL-ESM2G, HadGEM2-CC, HadGEM2-LR, INM-CM4, MPI-ESM-LR, MRI-CGCM3, MIROC5 (PCIC, 2014). Summer precipitation appears to have the most uncertainty, i.e., it may be wetter or drier.