Chapter 14: North America
Supplementary Material

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SM14.1 Table for 14.4 Indigenous People and Climate Change

Table SM14.1: A summary of the observed impacts and projected risks and adaptation for Indigenous Peoples in North America, with evidence assessed.

Impact, Risk, and/or Adaptation	References
Indigenous knowledge and science Indigenous knowledge and science are resources for understanding climate change impacts and adaptive strategies (*very high confidence*).	(Battiste and Henderson, 2000; Houser et al., 2001; Maynard, 2002; Trosper, 2002; Davidson-Hunt and Berkes, 2003; Hassol, 2004; Simpson, 2004; Barrera-Bassols and Toledo, 2005; Mustonen, 2005; Berkes et al., 2007; Dodson, 2007; Cochran et al., 2008; Sakakibara, 2008; Toledo et al., 2008; Turner and Clifton, 2009; Wildcat, 2009; Lemelin et al., 2010; Sakakibara, 2010; Weatherhead et al., 2010; Alexander et al., 2011; McNeeley and Shulski, 2011; Sánchez-Cortés and Chavero, 2011; Colombi, 2012; Ford, 2012; McCarty et al., 2012; Campos et al., 2013; Cunningham Kain et al., 2013; Gearheard et al., 2013; Nancy and Spalding, 2013; Sena and UN Permanent Forum on Indigenous Issues Secretariat, 2013; Toledo, 2013; Bennett et al., 2014; CTKW, 2014; Intergovermental Panel on Climate Change, 2014; Maynard, 2014; Sena, 2014; Gadamus et al., 2015; Kootenai Culture Committee, 2015; Quispe and UNPFII, 2015; UNGA, 2015; Council of Athabascan Tribal Governments, 2016; Daniel et al., 2016; Dockry et al., 2016; Ford et al., 2016; Johnson et al., 2016a; Johnson et al., 2016b; Kermoal and Altamirano-Jiménez, 2016; Hiza-Redsteer and Wessells, 2017; Merculieff et al., 2017a; Merculieff et al., 2017b; Raymond-Yakoubian and Angnaboogok, 2017; UNGA, 2017; Behe et al., 2018; David-Chavez and Gavin, 2018; Ikaarvik, 2018; Jantarasami et al., 2018; McGregor, 2018; Nelson and Shilling, 2018; Seremata, 2018; UNGA, 2018; Bachelet, 2019; Bering Sea Elders Group, 2019; Billiot et al., 2019; Carter et al., 2019; FAQI, 2019; Greenwood and Lindsay, 2019; Ijaz, 2019; Mikraszewicz and Richmond, 2019; Ratima et al., 2019; Thompson et al., 2019; Tom et al., 2019; Donatuto et al., 2020; Ford et al., 2020; Gift Lake Métis Settlement, 2020; Kenote, 2020; Latulippe and Klenk, 2020; Lewis et al., 2020; Metcalfe et al., 2020; Popp et al., 2020; Timler and Sandy, 2020; Vogel and Bullock, 2020; Atlas et al., 2021; BIA, 2021b; Camacho-Villa et al., 2021; Cameron et al., 2021; Fast et al., 2021; Fischer et al., 2021; Hauser et al., 2021; Jones et al., 2021; Lake, 2021; Yua et al., 2021)
Indigenous livelihoods and economies Current and projected climate change impacts disproportionately harm Indigenous Peoples' livelihoods and economies (*very high confidence*).	(Ford et al., 2006; ICC Canada, 2008; Ellis and Brigham, 2009; Ford, 2009; Meakin and Kurtvits, 2009; Swinomish Indian Tribal Community, 2009; Hori, 2010; Kronik and Verner, 2010; Wesche and Chan, 2010; Confederated Salish and Kootenai Tribes of the Flathead Reservation, 2013; Cozzetto et al., 2013; Dittmer, 2013; Ford et al., 2013; Grah and Beaulieu, 2013; Lynn et al., 2013; St. Regis Mohawk Tribe, 2013; Tam et al., 2013; The Navajo Nation Department of et al., 2013; Barbaras, 2014; Brubaker et al., 2014b; Brubaker et al., 2014c; Chapin et al., 2014; Donatuto et al., 2014; Nania et al., 2014; Parlee et al., 2014; Durkalec et al., 2015; Berner et al., 2016; Brinkman et al., 2016; Stults et al., 2016; Yakama et al., 2016; Lewis and Peters, 2017; Medeiros et al., 2017; Melvin et al., 2017; Nyland et al., 2017; Petersen et al., 2017; Scott et al., 2017; Angel et al., 2018; Conant et al., 2018; Dupigny-Giroux et al., 2018; Great Lakes Indian Fish and Wildlife Commission, 2018; Hori et al., 2018a; Hori et al., 2018b; Jantarasami et al., 2018; Markon et al., 2018; May et al., 2018; McGregor, 2018; Oficina Internacional del Trabajo, 2018; Wall, 2018b; Agnew::Beck, 2019; Heeringa et al., 2019; ITK, 2019; Kapp, 2019a; Khalafzai et al., 2019; Marushka et al., 2019a; Shinbrot et al., 2019; Anderzén et al., 2020; Centre for Indigenous Environmental Resources et al., 2020; Cold et al., 2020; Hasbrouck et al., 2020; Human Rights Watch, 2020; ICC Alaska, 2020; Ross and Mason, 2020b; Ross and Mason, 2020a; Segal et al., 2020; Settee, 2020; Tangen, 2020; Gibson et al., 2021)
Indigenous Peoples' health Climate change impacts have harmful effects on Indigenous Peoples' public health, physical	(Norgaard, 2007; Pfeiffer and Huerta Ortiz, 2007; Pfeiffer and Voeks, 2008; Sakakibara, 2009; Bell et al., 2010; Swinomish Indian Tribe Community, 2010; Riley et al., 2011; Vanderslice, 2011; Ford, 2012; Cozzetto et al., 2013; Doyle et al., 2013; EPA, 2013; Jamestown S'Klallam Tribe and Adaptation International, 2013; Redsteer et al., 2013b 2013; Voggesser et al., 2013; Brubaker et al., 2014c; Ford et al., 2014; Hanrahan et al., 2014; Cunsolo Willox et al., 2015; Bad River Band of Lake Superior Tribe of Chippewa Indians and Abt Associates Inc., 2016; Chief et al., 2016; Confederated Salish and Kootenai Tribes of the Flathead Reservation, 2016; Gamble et al., 2016; Grand

health, and mental health, including harmful effects connected to the cultural and community foundations of health (*very high confidence*).	Traverse Band of Ottawa Chippewa Indians, 2016; Norton-Smith et al., 2016; Puyallup Tribe of Indians, 2016; Rosol et al., 2016; Yakama et al., 2016; Alexander et al., 2017; Scott et al., 2017; Udall and Overpeck, 2017; Bell and Brown, 2018; Blackfeet, 2018; Campo Caap, 2018; Chavarria and Gutzler, 2018; Conant et al., 2018; Edwin and Mölders, 2018; Gonzalez et al., 2018; Jantarasami et al., 2018; Kloesel et al., 2018; Markon et al., 2018; May et al., 2018; Meadow et al., 2018; Mihychuk, 2018; Peacock et al., 2018; Ratelle et al., 2018; Reo and Ogden, 2018; Rioja-Rodríguez et al., 2018; Stevenson, 2018; Tom et al., 2018; Wilson, 2018; Bisbal and Jones, 2019; Christianson et al., 2019; EPA, 2019; FAQI, 2019; Horn and Webel, 2019; ITK, 2019; Lac du Flambeau, 2019; Lee et al., 2019; Marks-Marino, 2019c 2020a; Mashpee Wampanoag, 2019; Norgaard and Tripp, 2019; Peralta and Scott, 2019; Ristroph, 2019; Tlingit and Haida, 2019; Billiot et al., 2020b 2020; Cunsolo et al., 2020; Gobler, 2020; Kirezci et al., 2020; Marks-Marino, 2020 2020a; Martin et al., 2020a; Middleton et al., 2020a; Middleton et al., 2020b; Mottershead et al., 2020; Palinkas, 2020; Stewart et al., 2020; Ute Mountain Ute Tribe, 2020; Woo et al., 2020; Adams et al., 2021; Arsenault, 2021; Donatuto et al., 2021; National Tribal Air Association, 2021; Preece et al., 2021; Schlinger et al., 2021; United States Federal Emergency Management, 2021; Walker, 2021; Whyte et al., 2021a 2021; Wiecks et al., 2021)
Climate-related disasters and extreme environmental events Indigenous Peoples are affected dramatically by climate hazards and other climate-related extreme environmental events (*very high confidence*).	(Delta Environmental Services and Wilbur Smith Associates, 2005; Knutson et al., 2007; Hennessy et al., 2008; ITF, 2008; GAO, 2009; Karl et al., 2009; Papiez, 2009; Swinomish Indian Tribal Community, 2009; Redsteer et al., 2010; Riley et al., 2011; Steinman and Vinyeta, 2012; Ballard and Thompson, 2013; Cohen et al., 2013; Cozzetto et al., 2013; Crimmins et al., 2013; Doyle et al., 2013; Jamestown S'Klallam Tribe and Adaptation International, 2013; Madrigano et al., 2013; Redsteer et al., 2013a 2013; Shinnecock Indian Nation, 2013; Southern Ute Indian Tribe and GAP Consulting LLC, 2013; Voggesser et al., 2013; Brubaker et al., 2014a; Brubaker et al., 2014b; Johnson and Gray, 2014; Maldonado et al., 2014; Nania et al., 2014 Druen, Tapp, & Eitner, 2014; Thompson et al., 2014; DOE, 2015; Golden et al., 2015; Maldonado, 2015; Marino, 2015; Chief et al., 2016; Citizen Potawatomi Nation et al., 2016; Confederated Salish and Kootenai Tribes of the Flathead Reservation, 2016; Confederated Tribes of the Umatilla Indian Reservation, 2016; Hoh Indian Tribe, 2016; Jamestown S'klallam Tribe, 2016; Norton-Smith et al., 2016; Oneida Nation Pre-Disaster Mitigation Plan Steering Committee and Bay-Lake Regional Planning Commission, 2016; Peterson et al., 2016; Port Gamble S'klallam Tribe, 2016 2021; Puyallup Tribe of Indians, 2016; Yakama et al., 2016; Burkett et al., 2017; Keene, 2017; Krueger, 2017; McNeeley, 2017; Patrick, 2017; Quinault Indian Nation, 2017; Wall, 2017; Bronen et al., 2018; Carter et al., 2018; Conant et al., 2018; Crepelle, 2018; Doyle et al., 2018; EPA, 2018; GAO, 2018; Goode, 2018; Haynes et al., 2018; IHS, 2018; Jantarasami et al., 2018; Kloesel et al., 2018; Maldonado, 2018; Markon et al., 2018; May et al., 2018; McNeeley et al., 2018; Patrick, 2018; Pershing et al., 2018; Redsteer et al., 2018; Wall, 2018a; Collins et al., 2019; Dannenberg et al., 2019; Emanuel, 2019; Jeo Consulting Group, 2019; Kapp, 2019b; La Jolla Band of Luiseno Indians, 2019; Lac du Flambeau, 2019; Marks-Marino, 2019a 2019c, 2020b, 2021; Marks-Marino, 2019b 2019c, 2020b, 2021; Mashpee Wampanoag, 2019; McKinley et al., 2019; Pala Band of Mission Indians, 2019; Ristroph, 2019; Sharp, 2019; Sioui, 2019; University of Alaska Fairbanks Institute of Northern Engineering et al., 2019; Ute Mountain Ute Tribe and Wood Environment Infrastructure Solutions Inc, 2019; Affiliated Tribes of Northwest Indians, 2020; Bamford et al., 2020; Beym and Jones, 2020; Billiot et al., 2020a 2020; Centre for Indigenous Environmental Resources et al., 2020; Cheung and Frölicher, 2020; Comardelle, 2020; Congressional Research Service, 2020; Cooley, 2020; Crepelle, 2020; Cunsolo et al., 2020; Fayazi et al., 2020; Hoell et al., 2020; LaDuke and Cowen, 2020; Laufkötter et al., 2020; Low, 2020; Lummi Indian Business, 2020; McNeeley et al., 2020; NIFC, 2020; NWAC, 2020; Palinkas, 2020; Port Gamble S'klallam Tribe, 2020 2021; Sauchyn et al., 2020; State of Alaska, 2020b; State of Alaska, 2020a; Thistlethwaite et al., 2020; Bridgeview Consulting L.L.C., 2021; Cozzetto et al., 2021a; Cozzetto et al., 2021b; Donatuto et al., 2021; Gaughen et al., 2021; Indigenous Climate Action et al., 2021; Jurkowski et al., 2021; Maldonado et al., 2021; Morales et al., 2021; Muckleshoot Tribal Council, 2021; National Tribal Air Association, 2021; Schlinger et al., 2021; United States Federal Emergency Management, 2021; Walker, 2021; Whyte et al., 2021a; Whyte et al., 2021b; Wiecks et al., 2021; Yellow Old Woman-Munro et al., 2021; Zambrano et al., 2021)

Indigenous self-determination and self-governance Indigenous self-determination and self-governance are the foundations of adaptive strategies that improve understanding and research on climate change, develop actionable community plans and policies on climate change, and have demonstrable influence in improving the design and allocation of national, regional, and international programs relating to climate change (*very high confidence*).	(Clinton, 2000; Grossman, 2008; Wildcat, 2008; Doolittle, 2010; Wilson and Smith, 2010; McInerney-Lankford et al., 2011; Sorenson, 2011; Kuslikis, 2012; Parker and Grossman, 2012; Campos et al., 2013; Kronk Warner and Abate, 2013; Callison, 2015; Warner, 2015b; Warner, 2015a; Maldonado et al., 2016; Angel et al., 2018; Dupigny-Giroux et al., 2018; Tribal Climate Adaptation Guidebook Writing Team et al., 2018; Whyte et al., 2018; Hepler and Kronk Warner, 2019; National Congress of American Indians, 2019; Reyes, 2019; Thompson et al., 2019; Tribal Adaptation Menu Team, 2019; AFN, 2020; Centre for Indigenous Environmental Resources et al., 2020; Donatuto et al., 2020; Ferguson and Weaselboy, 2020; Irlbacher-Fox and MacNeill, 2020; Metcalfe et al., 2020; Sloan Morgan, 2020; Whitney et al., 2020; BIA, 2021a; Cozzetto et al., 2021b 2021; Huntington et al., 2021; Jones et al., 2021; Maldonado et al., 2021; McClain, 2021; Morales et al., 2021; Sawatzky et al., 2021; Singletary et al., 2021; STACCWG, 2021; Whyte et al., 2021a 2021; Wiecks et al., 2021; Wildcat et al., 2021)

SM14.2 Tables for Section 14.5.4 Food & Fibre

Table SM14.2: Summary of observed impacts of and adaptation to climate change in agriculture in Mexico

Region	Impacted crop	Observed change	Comments	Adaptation	Reference
National	Soils (Environmental enabler)	Droughts, reduced soil fertility	Temperature in soils will increase, suitability loss from 22% to 18% Soil erosion and degradation		(Galloza et al., 2017)
National / south	All	ENSO has never been as variable as during the last few decades			(Li et al., 2013)
National	Wheat	(-5.5%) since 1980		i.e. increase area	(Hernandez-Ochoa et al., 2018)
National	Maize (production)	Low precipitation during 1997–1998 led to a 25% decrease in the total production of maize		use of genomic estimates for rapid breeding of drought-tolerant varieties; a shift in cultivation practices, particularly the planting time	(Murray-Tortarolo et al., 2018)
South (Oaxaca)	Maize	Changing rainfall patterns, soils had lost their ability to retain soil moisture	TK Traditional system cajete	agroecological resilience, agrobiodiversity minimize risk from climate and pests	(Rogé and Astier)

Centre (Guanajuato)	Maize	Maximum temperature rise of 0.092 °C per year (1961 a 2009)	Urban and periurban agriculture	change of crop, the use of native seeds, the incorporation of organic matter and reforestation with native species.	(Vélez-Torres et al., 2016)
Centre (mexico, Puebla, veracruz)	Maize, wheat, barley		Integrates climate change, soil degradation and water balance scenarios	Two adaptation actions were evaluated: changing planting date and increase of organic mulches	(Monterroso-Rivas et al., 2018b)
Centre (Guanajuato, Jalisco, State of Mexico, Michoacán and Querétaro)	Maize	Tmax (+0.8°C), Tmin (+0.74°C) Pcp june and sept (+131 mm) Hailstorm increase in frequency	Seasonal climate changes coincide with the most vulnerable stage or flowering period of maize	use of local, water deficit tolerant varieties, polycultives, opportune weeding or agroforestry	(Altieri and Nicholls; Mastachi-Loza et al., 2016)
Centre (Veracruz)	Coffee	During 1980-2011 decrease in tons per hectare harvested from 3.0 to 2.3 (-23%)			(Loreto et al.)
North and South America	Maize, Soybean, wheat	72%, 30% and 57%, respectively	During ENSO (Same sign NA and SA)		(Anderson et al.)
Chiapas, Oaxaca, Veracruz	Coffee	Tendency of the average annual temperature of the principal coffee production states in Mexico. Chiapas, Oaxaca, and Veracruz are the states evaluated from1985 to 2019. Since 2006, it is observed an marked increase in the temperature (over the average 24–25 °C) and remains above average.	instability in the flowering and fruit generation cycles and has favored the proliferation of HV (coffee rust) in coffee-growing areas, above 1400 m above sea level	Fundamental role of native biodiversity in H. vastatrix management, agroforestry systems and organic production schemes, Soil and plant nutrition for crop reinforcement	(Torres Castillo et al., 2020)
Centre (Veracruz)	Coffee	During 1980-2011 decrease in tons per hectare harvested from 3.0 to 2.3 (-23%)			(Loreto et al., 2017)
	Coffee	Droughts, heavy rains	Flowering reduction	Soil management	(Manson)

Table SM14.3: Projected impacts of climate change on agriculture in Mexico

Region	Crop	Projected impact	Scenarios	Comment	Reference
Change in suitability (% surface)					
semi-arid region of central Mexico	water	decline of up to 9.16% in the available water for groundwater recharge and runoff	7 models 2050s and 2080s	B1 and A1B	(Herrera-Pantoja and Hiscock, 2015)

National	Soils	soil moisture deficit, shift to the next drier regime	3 models, RCP4.5 RCP8.5	1.5°C warming scenario	(Gomez Diaz et al., 2019)
National	Maize suitability	(-57%) to (-2.4%)	HADGEM2-ES and MPI-ESM-LR RCP8.5 by 2075–2099	land suitability	(López-Blanco et al., 2018)
National	Maize in agricultural land suitability	(-18%) to (+5%) RCP4.5 (-16%) to (+11%) RCP8.5	GFDL, HAGDEM and REA; RCP4.5 and 8.5	Agricultural land suitability	(Gómez Díaz et al., 2020)
National	Sorghum in agricultural land suitability	(-16%) to (+12%) RCP4.5 (-11%) to (+7%) RCP8.5	GFDL, HAGDEM and REA; RCP4.5 and 8.5	Agricultural land suitability	(Gómez Díaz et al., 2020)
National	Wheat in agricultural land suitability	(-34%) to (-23%) RCP4.5 (-38%) to (-15%) RCP8.5	GFDL, HAGDEM and REA; RCP4.5 and 8.5	Agricultural land suitability	(Gómez Díaz et al., 2020)
Centre (Tlaxcala)	Barley	(-16%) to (+2%)	2 models, RCP4.5, RCP6.0 and RCP8.5		(Calderón-García et al., 2015)
Veracruz	Coffee				
Change (% in yields)					
National	Maize (production)	(+0.05) to (-30%)	14 models of the CMPI5 RCP2.6, 4.5, 6.0 and 8.5		(Murray-Tortarolo et al., 2018)
North Mx (Durango)	Maize	(-55%) to (-70%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099		(Arce Romero et al., 2020)
Centro Occidente (Jalisco, Mexico)	Maize	(+10%) to (-55%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099	Mex includes climate change, soil degradation and water balance scenarios	(Montiel-González et al., 2017; Reyer et al., 2017; Monterroso-Rivas et al., 2018a; Arce Romero et al., 2020)
South (Oaxaca)	Maize	(+5%) to (-10%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099		(Arce Romero et al., 2020)
North (zacatecas)	Beans	(+8%) to (-51%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099		(Arce Romero et al., 2020)

Centre (mexico)	Beans	(-80%) to (-100%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099		(Arce Romero et al., 2020)
North (Sonora)	Wheat	(-28%) to (+2%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099		(Arce Romero et al., 2020)
Centre (Guanajuato, Puebla)	Wheat	(-25%) to (-82%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099	Puebla Includes climate change, soil degradation and water balance scenarios	(Monterroso-Rivas et al., 2018a; Arce Romero et al., 2020)
National	Wheat	(-) 6. 9% to (-) 7.9%	5 GCms, 2 RCPs (4.5, 8.5; 2050	CO2 effect	Hernández-Ochoa, 2018}
South (Chiapas, Campeche)	Soybean	(-8%) to (+57%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099		(Arce Romero et al., 2020)
Norteast (Tams)	Sorghum	(-81%) to (+31%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099		(Arce Romero et al., 2020)
Centre (Gto)	Sorghum	(-60%) to (-14%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099		(Arce Romero et al., 2020)
Centre (Mexico, Hgo, Ver, Tlax)	Barley	(-92%) to (+56%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099	Tlax includes economic impacts Ver includes climate change, soil degradation and water balance scenarios	(Monterroso-Rivas et al., 2018a; Arce Romero et al., 2020)
Centre (Mex, Ver)	Potato	(-61%) to (+2%)	5 models, RCP4.5 and 8.5 2015-2039, 2045-2069 and 2075-2099		(Arce Romero et al., 2020)
Veracruz	Coffee		3 GCMs,		

South East (Tabasco)	Coffee	the mean potential yields would decrease by 41% by the year 2050 due to the effect of the increase in daytime temperatures on the maximum photosynthetic ratio.	Ensamble 23 GCMs, SRES A2, B1 and A1B	Increase Coffea canephora P (robusta variety)	(Navarro-Estupinan et al., 2018)
Veracruz	Coffee	(-34%)	3 models, RCP 4.5 and RCP 8.5	soil fertility and coffee production	(Brigido and Herrera, 2015)
		(-7%) to (-10%)	A2, A1B, B1	Includes soil and water balance	(Rivera-Silva et al., 2013)

Table SM14.4: Impacts to crops from climate impact drivers from recent * greenhouse, field and modeling studies in North America. (* Literature from 2012 to 2020).

Climate Impact Driver	Impact to Crops	Location	References
Decreased irrigation water (simulated -25% reduction) for irrigated crops (projected)	Change in yield from 25% water supply reduction:Alfalfa (- 4%), Apples (-4%), Barley (-9%), Broccoli (-0.5%), Cauliflower (- 0.3%), Citrus (- 1.0%), Corn (- 1.5%), Cotton (- 23.6%), Grapes (- 0.5%), Lettuce (-1.0%), Melons (-0.7%), Onions (-0.2%), Potatoes (-0.5%),Sugar beets (-2.4%) Wheat (-9.2%)	Southern Mountain Region, U.S.	(Frisvold and Konyar, 2012)
-50% water availability (greenhouse experiment)	Bell pepper (Capsicum annuum L.) (- 65%)	Canada	(Aladenola and Madramootoo, 2014)
-50% water availability (deficit irrigation field experiment)	Onion: -22%	Southern Plains, U.S.	(Leskovar et al., 2012)
Extreme heat: Increase in daily maximum temperatures and heat waves (projected)	Maize (-18 to -27%) Cotton (-26 to -38%)	Southwest U.S. Southwest U.S.	(Elias et al., 2018)
Increased ozone (+25%) / Increased CO2 (+250ppm)	Snap bean: -24.4% (O3) + 6.5% (CO2)	U.S.	(Burkey et al., 2012)
Increased CO2 (+250ppm) / Increased temp (+4°C) (greenhouse experiment)	Habanero Pepper: Changes in flowering and fruiting of Habanero pepper in response to higher temperature and CO2 CO2: (+) 32.4% Temperature: (-)36.4%	Mexico	(Garruña-Hernández, 2012)
Weather extremes impacting crops (observed)	Crop losses and insurance payments to compensate farmers for drought, heat, hail, frost and other extreme events.	Midwest U.S. U.S.	(Kistner et al., 2018; Reyes and Elias, 2019)
Longer growing seasons and warmer winters (projected)	Increased weed and pest pressure	Northern U.S.	(Wolfe et al., 2018)

Table SM14.5: Projected changes in North American livestock

Climate Impact Driver	Impact to livestock	Location	References
Extreme Heat: Increase in daily maximum temperatures and heat waves	Livestock Heat Stress (Temperature-Humidity-Index (THI); Slow livestock growth, reduce profitability, reduce fertility, increase parasites and pathogens	Southeastern US and southern Great Plains, Northeast, Puerto Rico	(St-Pierre et al., 2003; Key and Sneeringer, 2014; Hristov et al., 2018; Ortiz-Colón et al., 2018)
Drought: increase in drought area, intensity, severity	Diminished water sources; diminished forage production	Varies across North America, varies seasonally and annually	(Havstad et al., 2018)
Increased CO2 concentrations	Reduce forage quality and benefit invasive plant species	North Central and northern US Great Plains	(Derner et al., 2018)
Increased frequency and magnitude of weather extremes	Require greater adaptive capacity to maintain viable production systems	Northern Great Plains	(Derner et al., 2018)
Temperature and precipitation change	Reduce net primary production and biomass for livestock feeding	Mexico	(Monterroso Rivas et al., 2011)

Table SM14.6: Observed and projected climate change impacts on aquaculture.

Subregion	Time period of impact / reference period	Stressor	Taxa	Environment	Impact	Evdience/source	Type of study (experimental, Risk/vulnerabilty assessment, adaptation evaluation, review)	Citation
North America; US & Canada	past	OA	(calcifying) molluscs	marine	growth, clacifcation, mortality, reduced attachment	negative responses reported in majority of experiment & reported in the industry; also agreeance across CC modelling in vulnerability & production assessments robust	Review; current risk assessment; RCP 8.5 2100; furture risk assessment	(Handisyde et al.; Froehlich et al.; Food Agriculture Organization of the United Nations; Reid et al., 2019; Stewart-Sinclair et al.)
Global	experimental	OA	finfish	both	metabolism	limited	Review	(Froehlich et al., 2018; Food Agriculture Organization of the United Nations; Reid et al., 2019; Clements et al., 2020)
Global	past	OA	seaweed	marine	mixed; clacifiers *likely*	limited (largely experimental); more solution/mitigation than impact oriented in the literature of farmed production.	Review & experimental	(Food Agriculture Organization of the United Nations;

					impacted, non-califiers benefit			Froehlich et al., 2019; Reid et al.)
North America; US & Canada; Global	past, current, furutre (2100)	temperature	finfish	both	growth & mortality	lots of literature on the effects temperature, but the exact response, pos v negative is mixed; new ENSO/La Nina extreme temps marine declines, cooler temps declines in prod; freshwater no effect. Large-scale climatic effects on traditional Hawaiian fishpond aquaculture; New farmed cobia experiments of marine heatwaves and HAB, he waves driving impact of growth & feeding. robust	Review; time-series estimation; model projections; vulnerability assessments	(McCoy et al., 2017; Froehlich et al., 2018; Ahmed et al., 2019; Food Agriculture Organization of the United Nations; Reid et al., 2019; Bertrand et al., 2020; Le et al., 2020)
North America; US & Canada; Global	past, current, furutre (2100)	temperature	mollusc	both	growth & mortality	lots of literature on the effects temperature, but the exact response, pos v negative is mixed; robust	Reviews	(Food Agriculture Organization of the United Nations; Froehlich et al., 2019; Reid et al., 2019; Weiskerger et al., 2019)
North America; US & Canada; Global	past, current, furutre (2100)	temperature	seaweed	marine	growth & mortality	some literature on the effects temperature, but the exact response, pos v negative is mixed; robust	Reviews	(Food Agriculture Organization of the United Nations; Froehlich et al., 2019; Reid et al., 2019)
Glboal/regional	past	storms/extremes	all	freshwater	growth & mortality	extremes from current and past events (e.g., extreme ENSO events) limited evidence of impact on freshwater declines aquaculture and vulnerability comparatively low.	Vulnerability assessment; Reviews	(Handisyde et al., 2017; Froehlich et al., 2018; Food Agriculture Organization of the United Nations; Froehlich et al.)
Glboal/regional	past	storms/extremes	all	freshwater	growth & mortality	extremes from current and past events (e.g., extreme ENSO events) limited evidence of impact on freshwater declines aquaculture and vulnerability comparatively low.	Vulnerability assessment; Reviews	(Handisyde et al., 2017; Froehlich et al.; Food Agriculture Organization of the United Nations)
Glboal/regional	past	storms/extremes	all	freshwater	growth & mortality	extremes from current and past events (e.g., extreme ENSO events) limited evidence of impact on freshwater	Vulnerability assessment; Reviews	(Handisyde et al., 2017; Froehlich et al., 2018; Food Agriculture Organization of the

						declines aquaculture and vulnerability comparatively low.		United Nations; Froehlich et al.)
Glboal/regional	past	sea level/floods	all	marine	growth & mortality	Increased events and vulnerability, especially low-lying pond systems and hatcheries.	Vulnerability assessment; Reviews	(Handisyde et al., 2017; Froehlich et al.; Food Agriculture Organization of the United Nations; Reid et al., 2019)
Glboal/regional	past	sea level/floods	seaweed	marine	growth & mortality	limited evidence	Reviews	(Froehlich et al., 2018)
Glboal/regional	past	storms/extremes	finfish	marine	growth & mortality	extremes from current and past events (e.g., extreme ENSO events) have negatively impacted marine aquaculture	Reviews	(Bertrand et al., 2020; Sippel et al., 2020)
Glboal/regional	past							
Glboal/regional	past	storms/extremes	mollusc	marine	growth & mortality	extremes from current and past events (e.g., extreme ENSO events) have negatively impacted marine aquaculture	Reviews	(Froehlich et al., 2018; Sippel et al., 2020)
Glboal/regional	past	storms/extremes	seaweed	marine	growth & mortality	limited evidence	Reviews	(Froehlich et al., 2018; Sippel et al., 2020)
global	future	hypoxia	mollusc		growth & mortality	limited evidence	Reviews	(Froehlich et al., 2018; Food Agriculture Organization of the United Nations; Reid et al., 2019)
global	future	hypoxia	seaweed	marine	growth & mortality	limited evidence	Reviews	(Froehlich et al., 2018; Food Agriculture Organization of the United Nations; Reid et al., 2019)
global	future	HAB	finfish		growth & mortality	limited evidence	Reviews	(Handisyde et al., 2017; Froehlich et al., 2018; Food Agriculture Organization of the United Nations; Reid et al., 2019)
global	future	HAB	mollusc		growth & mortality	limited evidence	Reviews	(Handisyde et al., 2017; Froehlich et al., 2018; Food Agriculture Organization of the

								United Nations; Reid et al., 2019)
global	future	HAB	seaweed	marine	growth & mortality	limited evidence	Reviews	(Froehlich et al., 2018; Food Agriculture Organization of the United Nations; Reid et al., 2019)

Table SM14.7: Adaptation in aquaculture

Subregion	Time period of impact / reference period	Type	Adaptation	Taxa	Agreement	Evidence	Language to use	Source
US, Canada, Global	past (last decade)	Aquaculture	Clear adaptive & intregated policy	all	high	Review of social and policy literature; surveys & interviews of stakeholders and experts; farm-level and community technical coping most common; US OA centric; knowledge sharing needed	medium	(Sanchez-Jerez et al., 2016; Froehlich et al., 2018; Brugère et al., 2019; Food Agriculture Organization of the United Nations, 2019; Ford et al., 2020; Galparsoro et al., 2020)
Global	experimental future conditions	Aquaculture	Genetic	Bivalve	medium	Limited for OA; some evidence of long-term adaptive potential exists potnetial (e.g., epi-genentics, cryopreservation, selective breeding; hybridization and polyploidization short-term coping; technologies exist but uptake slow; linked consideration for disease and growth	low	(Sae-Lim et al., 2017; Food Agriculture Organization of the United Nations, 2019; Reid et al., 2019; Clements et al., 2020)
Global	past (last decade) & future	Aquaculture	Genetic	Finfish	medium	Temperature and associated extremes most studied; hybridization and polyploidization short-term coping; longer-term selective breeding and technologies exist but uptake slow; linked consideration for disease and growth	medium	(Food Agriculture Organization of the United Nations)
North America, Global	current	Aquaculture	Mitigation	farmed seaweed	emerging	Local buffering of OA and hypoxia; high biophysical potential, cost and scale prohibitive	low	(Duarte et al., 2017; Froehlich et al., 2019)
North America, Global	current; 2050	Aquaculture	Set production goals	all	high	aquaculture will fill climate driven "production gaps" in the furture	medium	(Food Agriculture Organization of the United Nations, 2019; Gentry et al., 2019; Costello et al., 2020)
Global	2100	Aquaculture	Expansion	finfish	medium	conditions to support finfish production in artic regions will expand; medium	medium	(Troell et al., 2017; Klinger et al., 2018; Froehlich et al., 2019)

Global	future	Aquaculture	all	1) Provide incentives (e.g., flexible leasing and permitting, increase access to ‘crop’ insurance) for aquaculture enterprises to assess risks to infrastructure so that farming operations and facilities can be “climate-proofed” and relocated if necessary. 2) Strengthen environmental impact assessments for coastal aquaculture activities to include the additional risks posed by climate change. 3) Develop partnerships with regional technical agencies to provide support for development and monitoring of sustainable aquaculture.	AR5 Table 30-2 Oceans chapter

Table SM14.8: Observed and projected climate change impacts on fisheries

Climate Driver	Type	Summary	Observed Change	Evidence	Agreement	Summary	Projected change
Climate shocks; variability	flatfish	Climate change and extreme events have impacted fisheries	Climate shocks reduce catch, revenue and county-level wages and employment among commercial harvesters in US-NE; climate variability 1996 - 2017 is responsible for a 16% (95% CI: 10% to 22%) decline in county-level fishing employment in New England; impacts mediated by local biology and institutions (Oremus, 2019)	Robust	High		
Extreme heat	multiple species	Climate change and extreme events have impacted fisheries	In the EBS, GOA, and N-CC, declines in fish biomass and shifts in distribution were 4 times higher and greater during MHWs than that of general warming over the same period; pelagic fish showed largest decrease in biomass (7%), as did Sockeye salmon and California anchovy (Cheung and Frölicher, 2020)	Robust	High	Marine Heatwaves amplify climate change impacts on fisheries	Projected doubling of impact levels by 2050 amongst the most important fisheries species over previous assessments that focus only on long-term climate change (Cheung and Frölicher, 2020)
HAB; climate shocks	Shellfish	Climate change and extreme events have	Fishery closures during the 2014-2016 MHW and HAB event, closed multiple fisheries along the west coast (US-NW, US-SW), differentially impacted small	Robust	High		

		impacted fisheries	and large vessels with greatest impacts on small vessel revenue and participation in the fishery; impacts were highest for ports in the northern California current region and least for fishing communities diverse harvest portfolios and livelihoods supported adaptation (Jardine et al., 2020; Fisher et al., 2021)				
Mean temperature increase	Fish and shellfish	Climate change has caused declines in fisheries yield and productivity	Changes in mean MSY of fisheries in multiple regions are associated with warming temperatures over the last century (2001-2010) -(1930-1939)) including declines along the entire west coast of North America That range from -14% in the EBS to -29% in the southern california current. Along the east coast, declines of -3% to -9% were observed in the GOMX and US-SE, while increased of 8-15% were observed in the US-NE and CA-CQ) (Free et al., 2019).	High	High	Climate change will reduce fishery catches and North American subsistence resources; impacts will be higher under high emission scenarios.	Estimated 17% decrease in (CA-WA) Arctic cod populations due to habitat loss by 2100 under RCP8.5 (high emission scenario), and greater declines in catch under RCP 8.5 relative to SSP2.6, but potential increases in abundance for other Arctic and sub-Arctic species (Steiner, 2019); In CA-BC, projected declines in abundance of key Indigenous subsistence resources (e.g., salmon, halibut, herring, rockfish and shellfish) are greater for RCP8.5 than 2.6 (-20.8%- -15.0%, respectively) (Weatherdon et al., 2016).
Mean temperature increase	Shellfish	Climate change has caused declines in fisheries yield and productivity	Juvenile red king crab survival decreased significantly with exposure to higher temperatures; after 150 d only 3% of crabs survived treatments of ambient + 4 deg C and 7.8pH (Swiney et al., 2017). American Lobster abundances declined (78%) in South New England and have increased (515%) in the Gulf of Maine due to water temperature changes and differing conservation measures (between 1985 and 2014 for GOM and 1997 and 2014 for Southern New England) (Le Bris et al., 2018)			Climate change will reduce the yeild and productivity of fish and shellfish with greater impacts at RCP8.5 than 2.6	Modest increases (up to 10%) in landings of CA-QC and CA-AT surf clams and shrimp under RCP2.6 by 2100 while projected declines in snow crab up to 16% (RCP2.6 &8.5); minor changes projected for lobster and scallop, while mussels projected to increase 21%. (Wilson et al., 2020)
Mean temperature increase	Shellfish					Climate change will shift fisheries poleward and to depth	Projected redistributions poleward and changes to access including decreases in access to shellfisheries in CA-QC

			(Wilson et al., 2020); Poleward distributional shifts (10.3 - 18.0 km decade-1) are greater under RCP 8.5 than 2.6 for multiple important Indigenous subsistence species in CA-BC and reduce availability of subsistence species by 28%under RCP8.5 by 2100), with impacts declining poleward (Weatherdon et al., 2016).
Multiple	fish and shellfish	Climate change will impact fisheries livelihoods and increase fishery losses	By end of century, under RCP 2.6 North America fish biomass (9.1%), and fishery catch potential (9.7%), and fishery revenue (9.1) are higher while household costs are lower (by 3.4%) under low emissions scenarios (relative to RCP 8.5); gains under lower emissions are greatest for US fisheries (Sumaila et al., 2019)
Multiple	flatfish	Climate change will alter transboundary stocks	Climate change (RCP8.5) is projected to shift the relative % of catch and profits for US - Canada transboundary stocks of Atlantic cod (CA>US) and yellowfin flounder (Canada >>US), but has little effect on Pacific halibut; effects are reduced or minimal under RCP2.6 (Palacios-Abrantes et al., 2020; Sumaila et al., 2020).
Multiple	fish and shellfish	Climate change will reduce the yeild and productivity of fish and shellfish with greater impacts at RCP8.5 than 2.6	Climate change drives declines in productivity and catch potential for 24 of 25 evaluated fishery species in Mexico with largest declines for abalone (-35%, -44% respectively) and pacific sardine; Impacts are greatest for artisanal species (Cisneros-Mata et al.); Projected climate driven changes to food webs and marine conditions are associated with declines in fish community biomass across all North American coasts except US-SW and the Canadian Arctic; declines are greatest in

			from CA-BC to the EBS (Carozza et al., 2019)
Multiple	flatfish	Climate change will shift fisheries poleward and to depth	67% of flatfish in the N Atlantic and N Pacific are projected to shift poleward 39.1 km decade-1 under RCP8.5 (Cheung, 2018)
Multiple	flatfish	Climate change will reduce the yeild and productivity of fish and shellfish with greater impacts at RCP8.5 than 2.6	Declines in North American catch potential of flatfish species are projected under RCP8.5 for the EBS, GOA, GOMX, US-SE, and US-NE (Cheung, 2018)
Multiple	multiple species	Climate change will reduce the yeild and productivity of fish and shellfish with greater impacts at RCP8.5 than 2.6	Projected biomass of historically large fisheries in the US-NA and CA-QC region increased until ~2030 after which declines were observed; under RCP 8.5 declines of 5-40% were projected by 2090 for most NAFO divisions; biomass increases between 20-70% were projected for Arctic and subarctic divisions with lower historical landings (Bryndum-Buchholz et al., 2020)
Multiple	multiple species	Climate change will reduce the yeild and productivity of fish and shellfish with greater impacts at RCP8.5 than 2.6	Assuming status quo management, projected declines in multiple groundfish species in the EBS due to climate effects on fish and food webs with most groups near or below recent historical (1991–2017) biomass levels by 2080 (Whitehouse and Aydin, 2020)
Multiple	multiple species	Climate change will reduce the yeild and productivity of fish and shellfish with greater impacts at RCP8.5 than 2.6	Under RCP 8.5, end-of-century (2080–2100 average) community spawner stock biomass, catches, and mean body size decreased by 36% (±21%), 61% (±27%), and 38% (±25%), respectively. Climate variability drove uncertainty in projections for 85% of species. (Reum et al., 2020)
Multiple drivers	Shellfish	Climate change will shift fisheries poleward and to depth	Shifting distributions poleward and changes to access including decreases in

							access to shellfisheries in CA-QC (Wilson et al., 2020)
Multiple drivers	All	Climate change has altered the distribution of fish and fisheries	Species distributions have shifted poleward and phenology has shifted earliier with strongest effects on bony fish (Poloczanska et al., 2016; Miller et al., 2018)	Very High	High		
Multiple drivers	Shellfish					Climate change will reduce the yeild and productivity of fish and shellfish with greater impacts at RCP8.5 than 2.6	Declines in landings are twice as high under RCP 8.5 as RCP 2.6 and include 54%, 48%, and 42% declines in landings of lobster, sea scallop and northern shrimp under RCP 8.5 by 2090.; Total shellfish landings (primarily that of snow crab) projected to decline in CA-QC and CA-QT, and increase after 2050; declines under RCP 8.5 are double that of RCP 2.6. (Wilson et al., 2020); Climate change reduced the probability of observing recovery in simulations of blue king crab in the Bering Sea (Reum et al., 2019)
Multiple drivers (O_2, Temp., NPP)	Multiple					Climate change will reduce the yeild and productivity of fish and shellfish with greater impacts at RCP8.5 than 2.6	Projected declines of global catch of 3 mt per oC of GMWL with disparities in magnitude and direction across North American regions and strongest benefits of RCP2.6 relative to RCP8.5 (>30%) along the coasts of Mexico; species turnover is more than halved between between RCP8.5 and RCP2.6 (Cheung et al., 2016); Using the same modeling approach (DBEM), increases of 70% in catch potential in the Canadian Arctic were projected under RCP 8.5 versus minimal increases under RCP2.6; however present catch potential is >10 fold higher than actual catch and estimates are sensitive to model assumptions (Tai et al., 2019).

Multiple drivers (SLR, Warming, OA)	Fisheries & Fisheries Management					Climate change will increase fishery management challegnes	Multiple effects of climate change on fisheries (e.g., fish distributions, productivity, declines in catch, novel opportunities for new fisheries, changes in fish growth) can result in increased conflict drivers including changes in fishery yields, more or less fishers, opportunistic exploration, food insecurity, resource allocation trade offs, changing fishery locations, changes to fishing livelihoods (Mendenhall et al., 2020).
Multiple drivers (Temperature, OA)	Shellfish					OA will negatively impact future fisheries catch	Climate change reduced the probability of observing recovery in simulations of blue king crab in the Bering Sea (Reum et al., 2019)
Ocean and lake acidification	Shellfish	OA has reduced yield an impacted fish and shellfish fisheries	No appreciable effects of pH on larval growth of walleye pollock in the lab (Hurst et al., 2013).	Limited	Low	OA will negatively impact future fisheries catch	Ocean acidification reduced maximum sustainable yield, catch and profits of EBS Tanner crab in simulations, with projected declines >50% over 20 yr due to OA impacts on larval hatching and survival (Punt et al., 2016); Survival of larval and juvenile red king crab (RKC) in the lab decreased 97-100% with decreasing pH (Long et al., 2013; Swiney et al., 2017) while projected economic impacts of OA on Bering Sea red king crab fisheries are sensitive to assumptions around OA effects and global RKC prices (Seung et al., 2015). OA declines projected for some shellfisheries fisheries but are less than impacts of temperature (Wilson et al., 2020)
Ocean and lake acidification	Mollusc					OA will negatively impact future fisheries catch	Projected OA conditions under RCP 8.5 are anticipated to reach critical risk thresholds for mollusc harvests earlier in northern regions than southern areas, e.g., between present day and 2030 in northern regions of North America (US-

							AK, US-NW, and northern US-NE) and after 2099 in the Gulf of Mexico and Hawaiian Islands; combined risk is highest in the Northern California Current (Ekstrom et al., 2015).
Ocean and lake acidification	Groundfish					OA will negatively impact future fisheries catch	Population declines of 17% were projected due to temperature, while an additional 1% decline in Arctic cod populations by 2100 under RCP8.5 was due to the effects of OA (Steiner, 2019);OA influences biological reference points used for setting target harvest limits for Northern Rock sole (Punt et al., 2021); Projected declines of flatfish declined up to 20%-80% in California Current ecosystem projections with OA due to loss of shelled prey items.
Temperature	shellfish					Climate change will shift fisheries poleward and to depth	Projected increases in suitable thermal habitat for American lobster in Nova Scotia (CA-QC) is greater under RCP2.6 than RCP8.5 (note different base models used for each projection; (Greenan et al., 2019).
Temperature	multiple species						
Temperature	multiple species					Climate change will shift fisheries poleward and to depth	Poleward shifts of ~20.6 km per decade projected for multiple north American fisheries based on changes in thermal habitat under RCP 2.6 and 8.5; changes were greater under RCP8.5 than RCP 2.6 and largest along the west coast of north America (Morley et al., 2018).
Multiple drivers	fish and shellfish		Seafood is an important source of nutrients and protein for Indigenous Peoples in CA-BC (Marushka, 2019) (14.5.6 Health); polices that incorperate nutrition in fisheries management are limited in North America (Kohen, 2021)	Robust	High	Climate change poses a risk to the health and nutrition of Indigenous Peoples in North America	Projected climate change (2050) reduced essential nutrient intake by Indigenous Peoples in CA-BC by 21% and 31% under RCP2.6 and RCP 8.5, respectively; substitution of seafood with selected alternative non-traditional foods did not meet nutritional needs (Marushka et al.,

2019b); CA-BC, projected declines in abundance of key Indigenous subsistence resources (e.g., salmon, halibut, herring, rockfish and shellfish) are greater for RCP8.5 than 2.6 (-20.8%--15.0%, respectively) (Weatherdon et al., 2016).

SM14.3 Supplemental Table of Case Studies for Section 14.6, Figure 14.11

Table SM14.9: Key risk assessment for North America. Results were used to identify topic areas for burning embers and the full risk assessment of available literature; see corresponding section text for full assessment.

Key Risk	Sector	Citation	Sub-Region	Climate scenario	Time period	Hazard score	Vulnerability score	Exposure score	Risk Assessment
KR1		(Bolsen and Shapiro, 2018)				3			High
		(Ding et al., 2011)							High
		(Drews and Van den Bergh, 2016)				3			High
		(Morton et al., 2017)				0			High
		(Supran and Oreskes, 2017)				3			High
		(van der Linden et al., 2015)							High
		(Aklin and Urpelainen, 2014)							High
KR2	Cities and Infrastructure: Cities	(Castro and De Robles, 2019)	Mexico		current	2	3	3	High
	Terrestrial and Freshwater: Land species	(EPA, 2017)	US: All	RCP 4.5	2099 (cumulative costs)	3			Med
			US: All	RCP 8.5	2099 (cumulative costs)	3			Med
KR3	Health and Communities: Morbidity	(Greene, 2018)	California		During the 2012-2016 California drought.	3	3	3	High*
			California		During the 2012-2016 California drought.	3	3	3	High*

	Health and Communities: Mortality	(Mach et al., 2019)	Global	RCP 8.5	2100	2	2		Undetectable
	Conflict, Crime, Violence, Security	(Mach et al., 2019)	Global	RCP 4.5	2100	1	1		Undetectable
	Terrestrial and Freshwater: Land species	(Hope et al., 2016)	Canada Ontario	RCP 8.5	2070-2100	3			High
			Canada Ontario	RCP 2.6	2070-2100	1			Low

KR4	Oceans: Coastal ecosystem	(Vousdoukas et al., 2020)	North West	RCP 4.5	2050				Med
	Poverty and Livelihoods: Marine transportation	(Smith and Stephenson, 2013)	All Arctic	RCP 4.5	2040-59				Medium
			All Arctic	RCP 8.5	2040-59				High
KR5	Food and Fibre: Fisheries & Aquaculture	Tables SI_14.5-7	Potential risk evaluated in Tables 5-7						High*
	Terrestrial and Freshwater: Land species	(Allen et al., 2015)	Global			2	3	3	Very High*
		(Gauthier et al., 2015)	Canada Ontario			2	2	3	High
		(McIntyre et al., 2015)	US Southwest			2	3	3	Very High*
		(Weiskopf et al., 2019)				2	2	2	High*
		(Zaifman et al., 2017)					2	2	Undetectable
	Terrestrial and Freshwater: Mountain ecosystem	(Halofsky et al., 2020)	US Northwest			2	2	2	High*

KR6	Energy Resources: Fossil resources	(Bartos and Chester, 2015)	South West		2040-60	1	2	3	Med
	Energy Resources: Hydro resources	(Bartos and Chester, 2015)	North West		2040-60	1	2	3	Med
	Terrestrial and Freshwater: Mountain ecosystem	(Fell et al., 2017)	Global		future	2	3	3	Very High*

	Water: Freshwater resource	(Bonsal et al., 2019)	Canada		current and mid century	1	1	1	Med
		(Brown et al., 2019)	South West	RCP 4.5	2046-2070 and 2071-2095		2	2	Med
			South West	RCP 8.5	2046-2070 and 2071-2095		3	3	High
		(Cook et al., 2019)	South West	RCP 8.5	2048–57				Low
		(Duran-Encalada et al., 2017)	Mexico Northeast		2010-2080	3	3	3	High*
		(Li et al., 2017)	South West	RCP 4.5	2100	2	3	2	High
		(Paredes-Tavares et al., 2018)	Mexico North	RCP 4.5	(1980-2009 base) v. (2075-2099 future)	2	3	3	Medium to High*
			Mexico North	RCP 8.5	(1980-2009 base) v. (2075-2099 future)	3	3	3	High*
		(Schwarz, 2018)	South West		2050	2	3	3	High
	Water: Water quality	(Chapra et al., 2017)	US: All	RCP 8.5	2050 (2040−2059)	3	3	2	Med
			US: All	RCP 4.5	2090 (2080−2099)	3	3	2	High
			US: All	RCP 8.5	2050 (2040−2059)	2	3	2	Med
			US: All	RCP 4.5	2090 (2080−2099)	2	3	2	High
		(Duran-Encalada et al., 2017)	Mexico Northeast		2010-2080	3	2	2	High
		(Lewandowsky et al., 2019)	US: All			3	3	3	High
			US coastal areas			2	2		Low
KR7	Health and Communities: Morbidity	(Cunsolo Willox et al., 2012)	Arctic Canada		Lifetime of community members, conducted 2009-2010	3	2	3	High
		(Cunsolo Willox et al., 2013)	Arctic Canada		Lifetime of community members, conducted 2009-2010	3		3	High
		(Dodd et al., 2018)	Arctic Canada		Lived experiences of the 2014 wildfire season	3		3	High
		(Durkalec et al., 2015)	Arctic Canada			3		3	High
		(Greene, 2018)	California		During the 2012-2016 California drought.	3	3	3	High

		(Obradovich et al., 2018)	US	RCP 8.5	2002-2012	3		3	High
		(Schwartz et al., 2017)	NY, US		2012-2016	3	3	2	High
		(Vida et al., 2012)	Quebec, Canada		1995-2007	3		2	Med
		(Yusa et al., 2015)			1993-2013	3			High
	Health and Communities: Mortality	(Burke et al., 2018)	US	RCP 8.5	2000 (reference period) to 2050 (projection timeframe)	3		3	High
			Mexico	RCP 8.5	2000 (reference period) to 2050 (projection timeframe)	3		3	High
		(Fernández-Arteaga et al., 2016)	Mexico		2005-2012	3	3		High
		(Ford et al., 2018)	North West	RCP 4.5	2100	3	3	3	High*
KR8	Food and Fibre: Fisheries and aquaculture	(Gaichas et al., 2014)	US Northeast	RCP 8.5	2075-2100	2	2	3	High
	Health and Communities: Morbidity	(Dodd et al., 2018)	Arctic Canada		Lived experiences of the 2014 wildfire season	3		3	High
		(Greene, 2018)	California		During the 2012-2016 California drought.	3	2	3	High
	Health and Communities: Mortality	(Kohler et al., 2014)	US Southwest		CE 600-1760	1	3	3	High
KR9	Cities and Infrastructure: Transportation	(Espinet et al., 2016)	Mexico Northeast		2031-2050				High
			Mexico Northwest		2031-2050				Low
			Mexico Centre		2031-2050				Low
			Mexico Southwest		2031-2050				Medium
			Mexico Southeast		2031-2050				Medium

	Poverty and Livelihoods: Marine transportation	(Smith and Stephenson, 2013)	Arctic Canada	RCP 8.5	2075-2100	3	1	2	High
	Poverty and Livelihoods: Recreation and tourism	(Lithgow et al., 2019)	Mexico: All		Current/Present	3	3	3	High*
KR10	Cities and Infrastructure: Cities	(Dunning et al., 2012)	Mexico Southeast		CE 100-900	2	2	2	Medium
			Mexico Southwest		CE 100-900	2	2	2	Medium
		(Hauer et al., 2016)	US: All		2100	3	2	3	High
	Health and Communities: Morbidity	(Harp and Karnauskas, 2018)	Global		1979-2016	2	1	1	Medium
		(Mares, 2013)	US Midwest		1990-2009 monthly	1	1	1	Low
		(Ranson, 2014)	US: All		1960-2009	1	2	2	Medium
	Poverty and Livelihoods: Recreation and tourism	(Dundas and Haefen, 2020)	US: All	RCP 2.6	2020-49	1	1	3	Low
			US: All	RCP 4.5	2020-49	1	1	3	Low
			US: All	RCP 8.5	2020-49	1	1	3	Low
			US: All	RCP 2.6	2050-79	1	1	3	Low
			US: All	RCP 4.5	2050-79	1	1	3	Low
			US: All	RCP 8.5	2050-79	1	1	3	Low
			US: All	RCP 2.6	2080-99	1	1	3	Low
			US: All	RCP 4.5	2080-99	1	1	3	Low
			US: All	RCP 8.5	2080-99	1	1	3	Low
		(Fisichelli et al., 2015)	US: All	RCP 4.5	2041-2060	2	1	3	Med
			US: All	RCP 8.5	2041-2060	3	1	3	High
		(Groulx et al., 2017)	Canada Prairies			3	3	3	High
		(Hestetune et al., 2018)	US Midwest	RCP 4.5	2035	0	1		Low

		(Hestetune et al., 2018)	US Midwest	RCP 8.5	2035	0	1		Low
		(Hewer and Gough, 2019)	Canada Ontario	RCP 4.5	2050 (Fall only; SON)	2	1	3	Low
		(Jedd et al., 2018)	US Northwest		Current	1			Low
		(Rutty et al., 2015)	Canada Ontario			3	1	3	med
			Canada Ontario	RCP 8.5	2050	3	3	3	High
KR 10, continued	Poverty and Livelihoods: Recreation and tourism, cont.	(Scott et al., 2019)	Canada Ontario	RCP 2.6	2050	3	3	3	High
			Canada Ontario	RCP 4.5	2050	3	3	3	High
			Canada Ontario	RCP 8.5	2050	3	3	3	High
			Canada Ontario	RCP 2.6	2080	3	3	3	High
			Canada Ontario	RCP 4.5	2080	3	3	3	High
			Canada Ontario	RCP 8.5	2080	3	3	3	High
		(Scott et al., 2020)	Canada Ontario	RCP 4.5	2050	3	3	3	Very High
			Canada Ontario	RCP 8.5	2050	3	3	3	Very High
			Canada Québec	RCP 4.5	2050	3	3	3	Very High
			Canada Québec	RCP 8.5	2050	3	3	3	Very High
			US Northeast	RCP 4.5	2050	3	3	3	Very High
			US Northeast	RCP 8.5	2050	3	3	3	Very High
			Canada Ontario	RCP 4.5	2080	3	3	3	Very High
			Canada Ontario	RCP 8.5	2080	3	3	3	Very High
			Canada Québec	RCP 4.5	2080	3	3	3	High
			Canada Québec	RCP 8.5	2080	3	3	3	High

			US Northeast	RCP 4.5	2080	3	3	3	High
			US Northeast	RCP 8.5	2080	3	3	3	High
		(Seekamp et al., 2019)	US Southeast						Low
		(Wilkins et al., 2018)	US Northeast		2050		1	3	med
KR 10, continued	Poverty and Livelihoods: Recreation and tourism, cont.	(Wobus et al., 2017)	US: All	RCP 4.5	2050	3	3	3	High
			US: All	RCP 8.5	2050	3	3	3	High
			US: All	RCP 4.5	2090	3	3	3	High
			US: All	RCP 8.5	2090	3	3	3	High
			US: All	RCP 4.5	2050	3	3	3	High
			US: All	RCP 4.5	2090	3	3	3	High
			US: All	RCP 8.5	2050	3	3	3	High
			US: All	RCP 8.5	2090	3	3	3	High

Table Notes:
* indicates weighting of risk assessment based on confidence assessment of papers (i.e. level of agreement, robustness, quality of methods, etc.)

SM14.4 Detailed Methods for Burning Ember Diagrams

The burning embers diagrams in Chapter 14 (North America) (14.3, 14.10 and 14.11) outline risks associated with climate change as a function of global warming by degrees warming above pre-industrial. The first two burning embers (14.3 - water, 14.10 - economic sectors) focus only on risk by global warming level without adaptation, whereas the third burning ember (14.11 - tourism activities) includes risk without adaptation and risk with adaptation. The exclusion of risk with adaptation in the first two embers is due to a lack of available literature that would enable valid assessment. The method used to develop the embers was adapted from Zoomers et al. 2020 to include an extensive analysis of key risks and the development of a risk assessment database that helped to reveal appropriate ember focus areas. Once focus areas for ember development were established within the author team a formal expert elicitation protocol based on Zommers et al. (2020) and Oakley and O'Hagen (2016). Gosling et al. (2018) was used to develop threshold judgements on risk transitions. Figure SM14.1 outlines the formal five-step process used to generate the burning ember diagrams.

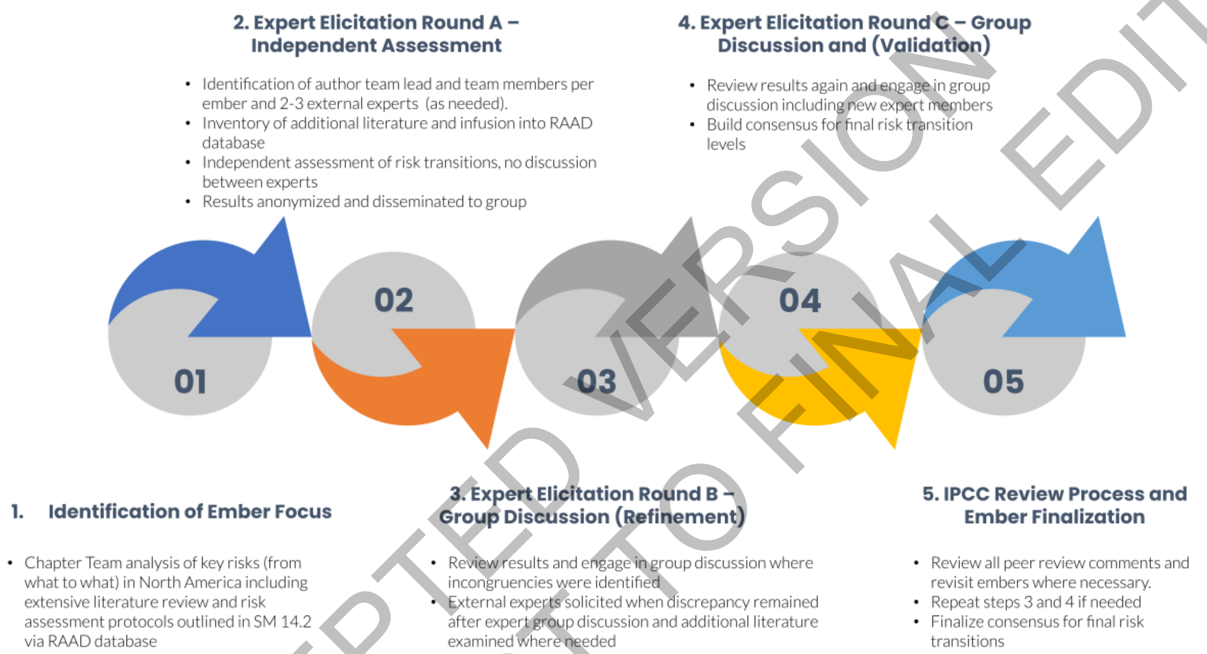

Figure SM14.1: Expert elicitation process for burning ember development

Using the expert opinion of a subset of the Chapter 14 author team (6 authors across a range of expertise) we conducted a rapid risk assessment of sectors by WGI hazards in order to identify potential key risks. Authors were asked to identify the risk of a (climate change) caused increase in a hazard on a given sector for all of North America. These key risks were then evaluated further during the assessment and results of the rapid assessment are in Fig. 14.11. A subset of case studies from the rapid assessment were evaluated for burning ember diagrams. For each unique combination, the hazard by sector risk was ranked as very high (very high risk & *high confidence*), high (significant impacts and risk, *high to medium confidence*), medium (impacts are detectable and attributable to climate change, *medium confidence*), low/ not detected /positive (risk is low or not detectable). Blank cells are those where the assessment was not applicable or not conducted.

Based on chapter team risk assessment and key risks identification protocols (see SM14.3) it was decided that existing literature would enable robust assessments of risks to; 1) freshwater, 2) major economic sectors, and 3) key tourism activities across North America. References for the current and past assessments are listed in Table SM14.10 (also see Table SM14.9).

Table SM14.10: Authors and references associated with burning embers figures in Chapter 14.

Burning Ember	Main Authors Involved	Key References Utilized*
Freshwater	Kathleen Miller, Linda Mortsch, Dave Gutzler	*Scarcity* – (Molina-Navarro et al., 2016; Prein et al., 2016; Dibike et al., 2017; Paredes-Tavares et al., 2018; Brown et al., 2019; Bonsal et al., 2020; Martin et al., 2020b; Overpeck and Udall, 2020; Bureau of Reclamation, 2021) *Snow/ice decline, streamflow & summer water* - (Schwarz, 2018; Ullrich et al., 2018; Bai et al., 2019; Bonsal et al., 2020; Milly and Dunne, 2020; Ray et al., 2020) *Pluvial and flash flooding* *Water Quality* – (Chapra et al., 2017; Lee et al., 2018; Ballard et al., 2019; Coffey et al., 2019)
Economic Sectors	Jackie Dawson, Libby Jewett, Kirstin Holsman, Michelle Rutty, Jeff Hicke	*Energy and Mining* – (Cruz and Krausmann, 2013; Kinniburgh et al., 2015; Leong and Donner, 2015; McFarland et al., 2015; Clark et al., 2017) *Construction* – (Kinniburgh et al., 2015; Rogers et al., 2015; Schulte et al., 2016; Hsiang et al., 2017) *Forestry* – (Brecka et al., 2018; D'Orangeville et al., 2018; Chaste et al., 2019) *Agriculture* – (Lant et al., 2016; Janssens et al., 2020b) *Fisheries* – (Beaugrand et al., 2015; Lam et al., 2016; Holsman et al., 2020) *Transportation* – (EPA; Palko and Lemmen, 2017; Chinowsky et al., 2019; Koks et al.; Lemmen et al., 2021)
Tourism Activities	Jackie Dawson, Michelle Rutty, Chris Lemieux	*Nordic Skiing and Snowmobiling* – (Wobus et al., 2017; Chin et al., 2018) *Alpine Skiing* - (Dawson et al., 2009; Rutty et al., 2017; Scott et al., 2019; Scott et al., 2020) *Beach Tourism and Coral Reef Snorkelling* – (EPA; Groulx et al., 2017; Atzori et al., 2018; Lithgow et al., 2019; Seekamp et al., 2019) *Parks and Protected Areas Visitation* – (Fisichelli et al., 2015; Lemieux et al., 2015; Hestetune et al., 2018; Jedd et al., 2018; Wilkins et al., 2018; Hewer and Gough, 2019; Dundas and Haefen, 2020)

Table Notes:
* North America risk assessment RAAD database also utilized for all risk transition assessments (see SM14.3 and Table SM14.9). Summary of analysis is provided below. Other analysis notes are also available upon request.

SM14.4.1 Freshwater

SM14.4.1.1 Water Scarcity

There is large literature on projected declines in water availability for portions of North America, primarily in the US Southwest, Northern Mexico and the Canadian Prairies. Other research focuses on more widespread increases in water scarcity relative to projected future water demands (Brown et al., 2019). Assessment for this ember considered the latter type of scarcity while focusing primarily on the consequences of increased physical aridification. Papers providing explicit assessments of risks for different climate change scenarios informed the calculations of risk transitions with respect to changes in global average temperatures. For Mexico, (Paredes-Tavares et al., 2018) projects increasingly water-short conditions in the Rio Bravo Basin over the 21st century, while (Molina-Navarro et al., 2016) projects roughly a 60% decline in streamflow by end-of-century for the Guadalupe River Basin. For the Canadian Prairies, (Bonsal et al., 2020) used multiple GCMs and emissions scenarios to estimate projected increases in the frequency of severe droughts. (Dibike et al., 2017) assessed changes in the summer water balance (P-PET) across western Canadian river basins, further supporting projections of greater drought severity. Material for the US includes an analysis of climate change impacts on the major multi-purpose water projects operated by the US Bureau of Reclamation across the17 western states (Bureau of Reclamation, 2021). Projections of aridification in the US SW are summarized by (Overpeck and Udall, 2020). A study of the Missouri River Basin documents the increasing role of extreme heat and higher evapotranspiration in driving low flows (Martin et al., 2020b), and an analysis by (Prein et al., 2016) uses the observed relationship between specific weather types and droughts in the US SW to support GCM projections of future US SW drying due to poleward extension of the subtropical dry zones leading to increasing anticyclonic conditions.

SM14.4.1.2 Snow/Ice Decline, Streamflow & Summer Water

Many North American rivers are characterized by strong streamflow seasonality that is driven by the accumulation of snow and ice over the winter season, followed by spring and summer melting. Water use and management are tuned to this natural cycle. The likelihood of both early-season riverine flooding and low summer water availability will increase as warming erodes natural snow and ice reservoirs. This presents difficult challenges for management of human-constructed reservoirs that are operated for both winter flood protection and summer water deliveries. The risk assessment for this ember reflects these dual risks, while following the available literature in emphasizing the significance of low summer streamflows in areas heavily dependent on irrigated agriculture. Earlier snowmelt runoff is projected to harm small communities relying on traditional irrigation systems (acequias) in the US SW by reducing the availability of both irrigation water and upland forage (Bai et al., 2019). Milly and Dunne (2020) evaluated the combined impacts of changes in snow albedo, precipitation and temperature on Upper Colorado River flows, to estimate annual flow reductions of 5-24% by mid-century under RCP4.5. Ray, 2020 uses a decision scaling approach in combination with GCM projections to evaluate the likely future performance of California's Central Valley Water System across a range of potential future climate conditions. The approach finds a 93 percent likelihood of diminished water exports through the Sacramento-San Joaquin Delta to cities and farms in Central and Southern California by 2050. Ullrich (2018) assessed how a midcentury (2042–2046) drought in California would differ if the same dynamical conditions emerged as those for the 2012–2016 drought, finding much larger losses in snow water storage and total water availability. Bonsal, 2020 evaluated the impacts of earlier snowmelt and declining glacier mass on seasonal streamflow patterns & water availability in Western Canada. Late century impacts under RCP 4.5 are projected to include 60% summer streamflow declines on Vancouver Island while winter flows will possibly double for the Fraser and Columbia Rivers.

SM14.4.1.3 Pluvial and Flash Flooding

Heavier precipitation events are projected for many parts of North America, increasing the potential for flooding, including flash flooding in areas distant from existing stream channels. Papers estimating projected damages from flooding and/or changes in precipitation intensity as a function of climate change were used to inform construction of this ember. Emanuel (2017) presents projections of end-of-century changes in the frequency of heavy precipitation events over the Houston, TX metropolitan area for the RCP 8.5 scenario. Results indicate that the current 100yr return frequency event would increase to a 1 in 5.5yr frequency, while the frequency of extremely destructive rainfall akin to that produced by Hurricane Harvey would increase from an estimated 1 in 2000yr to a 1 in 100yr event. Thistlethwaite (2018) used an existing insurance-industry catastrophe model for Halifax, Canada to estimate changes in damages that would be produced by increasingly heavy rainfall events. The study found that: "…average annual losses could increase by 137% by mid-century and 300% by late-century due to climate change alone. But increasing exposure and value of capital at risk could more than double those figures. Prein (2017) examines future changes in total rain volume delivered by mesoscale convective systems (MCS) over North America, finding that increases in MCS size and maximum precipitation rates will combine to result in large increases in total rainfall and potential for flooding. Wobus (2019) calculates current and projected future expected annual flood damages (EAD) for hydrologic basins across CONUS based on current-day exposed assets and projected changes in return intervals for floods of various magnitudes. Increased expected damages occur in all regions, with the largest impacts in US-NE; US-MW; US-SP & US-NP.: "EAD from flooding typically increases by 25–50% under a 1 °C warming scenario and in most regions more than double under a 3 °C warming scenario." Gaur and Simonovic (2018) assessed changes in the return frequency of major fluvial floods across Canada, focusing on current 100yr & 250yr events based on multiple end-of-century GCM projections. They found increased frequencies for northern Canadian river basins, with current 100yr events becoming 1 in ~50yr events, while estimated frequencies tended to decrease for southern Canadian basins. A survey of methods for estimating probable maximum precipitation (PMP) for dam-safety is presented by Mahoney, 2018, concluding that: "Multiple modeling studies have produced results … showing increases of 15 to 50% in PMP later in the 21st century."

SM14.4.1.4 Water Quality

The majority of the papers published on the impacts of climate change on water quality focus on the US with results for individual and regional watersheds, and the continental US (CONUS) (see synthesis by Coffey et al., 2019; Paul et al., 2019). Coffey, 2019 provide an authoritative survey of the effects of climate drivers (e.g., temperature increase and more intense precipitation) on water quality (i.e., increase in issues related to nutrients, algal blooms, sediments, pathogens) and summarizes climate change assessments (primarily SRES scenarios and some RCPs) into maps of impacts for much of the CONUS. This research provides a strong foundation for the linkage between current observed and modelled climate and the relationship to water quality as well future impact assessment modelling based on scenarios. Sinha (2019) produced an assessment of projected increase in Nitrogen loading for CONUS for middle-of-the century (2031-2060) and end-of-the-century (2071-2100). Results, percentage change in mean total nitrogen flux from base of 1976-2005, from Supplementary Figure 1 were based on climate scenarios (all 4 RCPs) interacting with historical land use and show mean percentage increase in nutrient flux mid-century (+5 to +9 %) and end-of-century (+9 to +15%). Chapra (2017) addressed the issue of Hazardous Algal Blooms (HABs) and reported on current conditions (i.e., strong relationship between cyanobacteria growth and temperature) and assessed future impacts using 4.5 and 8.5RCP-based scenarios from 5 GCMs. The 100 000 cells/mL threshold (WHO guidance) represents a "very high" risk of harmful consequences to people. This assessment for CONUS (300 reservoirs and 10 natural lakes important for recreation) reported a projected increase from 0 days for the base period 1986–2005 to +10.4 day (RCP4.5) and +11.2 days (RCP8.5) for 2050, and for 2090 +11.0 days (RCP4.5) and +18.2 days (RCP 8.5). Wagena and Easton (2018) used multi-model climate scenarios to assess the effect on water quality in the Susquehanna River Basin for the base period 1990–2014 and future scenario periods (2041–2065 and 2075–2099). Compared against the historical baseline and with no conservation practices, there were increases in flow and surface runoff linked with increases in mid-Century total Nitrogen export of +9% (+4% to +14%) and sediment of +26% (+9% to +60%) and late Century total Nitrogen +12% (+5% to +20%) as well as sediment +31% (+14% to +72%). Average Nitrate, dissolved Phosphorus, and total Phosphorus export decreased (but this is not a consistent across modelling assessments in the literature (see Coffey et al., 2019) but reflects local hydrology, geology and land use). The water quality Burning Ember was developed using studies discussed above all using RCP scenarios and three of five based on CONUS assessments.

Table SM14.11: Burning Ember Risk Transitions for Freshwater Resources

	Risk Transition	Global mean surface temperature change above pre-industrial levels °C		Confidence
Snow & Ice decline -seasonal flows	Undetectable to Moderate	Min	0.6	*Medium*
		Max	0.9	
	Moderate to High	Min	1.2	*Medium*
		Max	2.0	
	High to Very High	Min	3.2	*Medium*
		Max	4.0	
Heavy Precipitation - flooding	Undetectable to Moderate	Min	0.9	*Medium*
		Max	1.5	
	Moderate to High	Min	2.5	*Medium*
		Max	3.0	
	High to Very High	Min	3.7	*Medium*
		Max	4.0	
Water Quality Impacts	Undetectable to Moderate	Min	0.20	*Medium*
		Max	1.30	
	Moderate to High	Min	1.45	*Medium*
		Max	2.90	
	High to Very High	Min	2.95	*Medium*
		Max	4.20	

SM14.4.2 Economic Sectors

Risks to economic sectors and activities were sometimes assessed across all of North America (3, 4), within specific regions (1, 2), and for specific crops or species (1 - corn and soybean, 2 – cod and pollock). The assessment is informed by literature on economic damage projections (Box 14.6, Cross-Working Group Box ECONOMIC in Chapter 16). However, these risks are not translated into estimates of economic damages, do not address interactions between sectors nor adjustments due to future shifts in demand that could amplify or moderate economic impacts across an economy. The economic impact of the changes in any given sector depends on the relative importance of that sector to a national, regional or local economy.

SM14.4.2.1 Energy & Mining

Analysis was focused on several case studies (observed and modelled) in remote regions of operational mines (onshore oil fields in Mexico and Texas, Kansas, and Oklahoma in the US, Athabasca oil sands and mines in northern and Prairie regions in Canada) (Cruz & Krausmann, 2013; Leng, 2015; OCCIAR 2015; Clark, 2017) and urban and rural regions of energy generation and transmission (US northwest, northeast and southeast) (Kinniburgh et al., 2015; McFarland et al., 2015). Increased average temperature will lead to an increase in cooling degree days (which will outweigh the decrease in heating degree days), creating more pressure on energy systems to meet peak demands (*high confidence*). In turn, costs will increase (both in terms of production/supply, transmission, and energy prices for consumers) *(high confidence)*. Changes in hydrological regimes will have negative implications for energy infrastructure and generation in the future (decreased streamflow, flooding, storm surges, SLR) (*medium confidence*). Elevated temps diminish thermal power plant efficiency and capacity (including transmission lines) (*medium confidence*)

SM14.4.2.2 Construction

Existing literature is mostly focused on the US and suggests that warming temperatures will reduce labour productive (*medium confidence*) (Kinniburgh et al., 2015; Rogers et al., 2015; Schulte et al., 2016) and could negatively impact the health and wellbeing of workers (Hsiang et al., 2017) especially in southern US and Mexico (*medium confidence*) (also see Dong et al., 2019).

SM14.4.2.3 Forestry

Forestry in North America will be disproportionately impacted by geographic region. Analysis here is focused on case studies of the US, Canada, eastern Canada, northern Canada, and the Boreal Forest including changes due to biome shifts, reduced productivity, drought events, insects, elevated ozone levels, and fire for forestry. Changes in the quality and quantity of timber yields are expected whereby total yield could potentially increase until 2 °C warming in conjunction with increased CO2 and fertilization but the quality could decrease depending on the extent of disturbance from insects, drought, and extreme events (*medium confidence*) (Attavanich and McCarl, 2014; Tian et al., 2016; Brecka et al., 2018; D'Orangeville et al., 2018; Chaste et al., 2019). After 2 °C warming most models reveal a reversal of total yield trends and continuation of potential reductions in yield quality exacerbated by reductions in water availability and increased disturbance events from fire, insects, and other events (*medium confidence*) (Beach et al., 2015; McKenney et al., 2016; D'Orangeville et al., 2018; Chaste et al., 2019).

SM14.4.2.4 Agriculture

Similar to forestry in North America, agricultural crop yields and quality will be highly dependent on local geography and vary across the region. Warming temperature and lack of freshwater availability are key hazards for crop production and can lead to economic loss. Analysis here is focused on corn and soybeans, which are two of the largest crops in North America (Lant et al., 2016). Modeling studies indicate that high risk to the agricultural sector begins just before 2C warming, which is expected to be mid-century and beyond (*medium confidence*). The high relative importance of agriculture to the North America economy and the role food exports play in the global food system was considered in the risk transition analysis (see Janssens et al., 2020a).

SM14.4.2.5 Fisheries

Risk transition analysis was focused on cod and pollock species in the Bering Sea under scenarios that include status quo Ecosystem Based measures including a limit on total groundfish yields (Holsman et al., 2020). These fisheries represent the largest (pollock) and one of the most valuable (Pacific cod) fisheries in the US. Warming temperatures and change in sea ice, circulation and shifts in trophic pathways to less energy efficient food chains (Huntington et al., 2020; Suryan et al., 2021) were used to drive changes in survival (predation), growth, and recruitment under future scenarios, and subsequent catch.

SM14.4.2.6 Transportation

The focus of this assessment was on road (including ice roads in the Arctic) and rail and transportation infrastructure such as bridges, airstrips, pipelines, and port facilities. Extreme events, warming, storm surge, flooding, and SLR are expected to present high risks to transportation infrastructure, especially in coastal and Arctic areas of North America by 2C of global warming (EPA, 2017; Chinowsky et al., 2019; Koks et al., 2019). North America is a large geographic region that relies heavily on transportation infrastructure for economic sustainability and health and well being. Near term impacts to transportation infrastructure are expected to be incremental and albeit expensive to repair, are not anticipated to present irreversible or catastrophic risks. However, in the absence of strong adaptation planning, transportation related infrastructure will be at high risk before 4C global warming and could amount to hundreds of billions in needed repairs (EPA; Palko and Lemmen, 2017; Chinowsky et al., 2019; Lemmen et al., 2021) (also see Koetse and Rietveld, 2009; Markolf et al., 2019).

Table SM14.12: Burning Ember Risk Transitions for Economic Sectors in North America

Name	Risk Transition	Global mean temperature change		Confidence
Agriculture	Undetectable to Moderate	Min	0.0	*Low*
		Max	1.0	
	Moderate to High	Min	1.0	*Medium*
		Max	1.6	
	High to Very High	Min	4.2	*Medium*
		Max	6.0	
Forestry	Undetectable to Moderate	Min	0.0	*High*
		Max	1.5	
	Moderate to High	Min	1.7	*Medium*
		Max	2.0	
	High to Very High	Min	2.2	*Low*
		Max	4.0	
Tourism	Undetectable to Moderate	Min	0.5	*High*
		Max	0.9	
	Moderate to High	Min	1.7	*High*
		Max	2.2	
	High to Very High	Min	2.3	*Low*
		Max	3.9	

Transportation	Undetectable to Moderate	Min	0.8	*High*
		Max	1.1	
	Moderate to High	Min	1.8	*Medium*
		Max	2.2	
	High to Very High	Min	2.5	*Low*
		Max	3.8	
Fisheries	Undetectable to Moderate	Min	1.1	*High*
		Max	1.8	
	Moderate to High	Min	2.0	*Medium*
		Max	2.5	
	High to Very High	Min	3.0	*Medium*
		Max	4.2	
Energy and Mining	Undetectable to Moderate	Min	0.0	*Medium*
		Max	1.1	
	Moderate to High	Min	1.5	*Low*
		Max	2.5	
	High to Very High	Min		Does not reach this threshold
		Max		
Construction	Undetectable to Moderate	Min	0.0	*Medium*
		Max	1.5	
	Moderate to High	Min		Does not reach this threshold
		Max		
	High to Very High	Min		Does not reach this threshold
		Max		

SM14.4.3 Tourism Activities (with and without adaptation)

SM14.4.3.1 Nordic Skiing and Snowmobiling

Nordic skiing and snowmobiling are at the highest risk to climate change compared to other tourism activities considering there are hard limits to adaptation for participating in the activity. Reduction of natural snowfall and increased precipitation events falling as rain will severely limit nordic skiing and snowmobiling activities. Chin et al. (2018) project the following season length reductions: RCP 4.5 2050s (1.5C) = 14 days; 2080s (2C) = 13 days. RCP 8.5 2050s (1.8C) = 10 days; 2080s (4C) = 5 days. Wobus et al. (2017) project the following snowmobiling season lengths: 139 of 247 (56%) sites would have a snowmobile season of <75 days. RCP 4.5 2050s (1.5C) = 179 of 247sites (72%) would have <75 days; 2080s (2C) = 192 of 247 (78%) sites would have <75 days. RCP 8.5 2050s (1.8C) = 190 sites of 247 (77%) would have <75 days; 2080s (4C) = 228 of 247 (92%) sites would have <75 days.

SM14.4.3.2 Alpine Skiing

There is high agreement that winter/snow-based tourism is already experiencing negative impacts from climate change even with adaptation efforts through machine made snow. As conditions warm, further impacts are anticipated given the high dependence on natural snowfall and low temperatures (e.g., for snowmaking, snow farming, etc). High altitude mountains are not as impacted as low-lying resorts (which there are more of) and we are already seeing impacts (e.g., resort closures, shortened season lengths, etc). Threshold for economic viability is 100 day season length in North America (Scott et al., 2020) and this was used to assess overall risk with and without adaptation. Making machine made snow is economical to +5 degrees C. 171 ski areas in Ontario, Quebec and US Northeast even with advanced snowmaking, as only 29 ski areas in Quebec and high elevation areas of the US Northeast will be able to maintain a 100-day ski season (Scott et al., 2020).

SM14.4.3.3 Beach Tourism and Coral Reef Snorkelling

Impacts on beach and coral reef tourism are highly location dependent. There is limited literature linking climate change and beach tourism specifically but many papers outlining impacts on coral reefs, coastal regions, and tourism generally that can be assessed collectively in order to understanding sector risks. Based on this literature Mexico at high risk (coastal squeeze and flooding - Litgow, 2019), with US at risk to coral bleaching (EPA, 2017): "extensive loss of shallow corals is projected by 2050s for major US reef locations [South Florida, Puerto Rico]...near complete loss by 2100...modest loss in Hawaiian coral cover with declines from 38% in 2010 to 11% by 2050 with further declines thereafter." Loss is greater for 8.5 vs 4.5. Demand may diminish with proposed adaptation strategies because it can reduce perceived naturalness. E.g., Glacier Tourism (Groulx et al., 2017): photorealistic visualizations to assess perceptions of environmental change on tourists visiting the Athabasca Glacier (Jasper, AB). Demand to substantially diminish, with proposed adaptations to further decrease demand as it reduces perceived naturalness. E.g., Beach tourism (Atzori et al., 2018; Seekamp et al., 2019).

SM14.4.3.4 Parks and Protected Areas Visitation

Adaptation options for Parks and Protected Areas are numerous but it has been found that intrusive structures or infrastructure limiting access to natural environment is undesirable for tourists and therefore may have limited effect in impacting future visitation (Lemieux et al., 2015).The impact of climate change on nature-based tourism (e.g. parks) and outdoor recreation in protected areas is dependent on geographic location. Overall, it is widely agreed that shoulder seasons (spring and fall) will improve as temperatures warm and increase the tourism season, however increased precipitation and storm events, particularly in the spring, could limit opportunities for longer seasons (e.g., Wilkins et al., 2018; Hewer and Gough, 2019; Dundas and Haefen, 2020). It is also possible that the summer season could be longer and more ideal (particularly in upper latitude locations), but decline in southern and mid-latitude locations (as it becomes 'too hot') (e.g., Fisichelli et al., 2015) or where there's increased risk for drought (Jedd et al., 2018) and fire (e.g., Hestetune et al., 2018). Time series analysis of climate and visitation data for US NW National Parks (1991-2012) reveal visitors are more sensitive to extreme dry (drought) conditions, though findings are mixed (e.g., during a climatically dry season, visitor numbers declined in Yellowstone in 2001, but increased in 2012) (Jedd et al., 2018). Fisichelli (2015) suggest that as temperatures increase, overall growth in visitor numbers across parks system is projected (+8 to 23%), noting visitation strongly declines at temps >25C (which represents a small portion of parks across the system). Wilkins (2018) show through regression analysis between weather variables and tourism spending in Maine revealing increasing temps is an opportunity for increased tourism spending in summer and fall.

Table SM14.13: Burning Ember Risk Transitions for Tourism Activities in North America

Nordic Skiing and Snowmobiling

	Risk Transition	Global mean temperature change		Confidence
Without Adaptation	Undetectable to Moderate	Min	0.2	*High*

		Max	0.5	
	Moderate to High	Min	0.8	*High*
		Max	1.5	
	High to Very High	Min	1.8	*Low*
		Max	2.0	
With Adaptation	Undetectable to Moderate	Min	0.2	*High*
		Max	0.5	
	Moderate to High	Min	0.8	*High*
		Max	1.5	
	High to Very High	Min	1.8	*Low*
		Max	2.0	

Alpine Skiing

	Risk Transition	Global mean surface temperature change		Confidence
Without Adaptation	Undetectable to Moderate	Min	0.5	*High*
		Max	0.8	
	Moderate to High	Min	1.2	*Medium*
		Max	1.8	
	High to Very High	Min	2.5	*Medium*
		Max	3.0	
With Adaptation	Undetectable to Moderate	Min	0.5	*High*
		Max	1.1	
	Moderate to High	Min	2.0	*High*
		Max	2.5	
	High to Very High	Min	3.0	*Medium*
		Max	4.0	

Beach Tourism and Coral Reef Snorkeling

	Risk Transition	Global mean surface temperature change		Confidence
Without Adaptation	Undetectable to Moderate	Min	0.5	*High*
		Max	1.1	
	Moderate to High	Min	2.5	*Low*
		Max	3.0	

	High to Very High	Min	3.2	*Low*
		Max	5.5	
With Adaptation	Undetectable to Moderate	Min	0.8	*High*
		Max	1.1	
	Moderate to High	Min	3.0	*Medium*
		Max	3.5	
	High to Very High	Min	3.5	*Low*
		Max	6.0	

Parks and Protected Areas Visitation

	Risk Transition	Global mean surface temperature change		Confidence
Without Adaptation	Undetectable to Moderate	Min	0.5	*Medium*
		Max	1.1	
	Moderate to High	Min	2.0	*Low*
		Max	3.0	
	High to Very High	Min	3.5	*Low*
		Max	6.0	
With Adaptation	Undetectable to Moderate	Min	0.5	*Medium*
		Max	1.1	
	Moderate to High	Min	2.0	*Low*
		Max	3.0	
	High to Very High	Min	3.0	*Low*
		Max	5.0	

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