7SM

Risk management and decision-making in relation to sustainable development Supplementary Material

Coordinating Lead Authors:
Margot Hurlbert (Canada), Jagdish Krishnaswamy (India)

Lead Authors:
Edouard Davin (France/Switzerland), Francis X. Johnson (Sweden), Carlos Fernando Mena (Ecuador), John Morton (United Kingdom), Soojeong Myeong (The Republic of Korea), David Viner (United Kingdom), Koko Warner (The United States of America), Anita Wreford (New Zealand), Sumaya Zakieldeen (Sudan), Zinta Zommers (Latvia)

Contributing Authors:
Rob Bailis (The United States of America), Brigitte Baptiste (Colombia), Kerry Bowman (Canada), Edward Byers (Austria/Brazil), Katherine Calvin (The United States of America), Rocio Diaz-Chavez (Mexico), Jason Evans (Australia), Amber Fletcher (Canada), James Ford (United Kingdom), Sean Patrick Grant (The United States of America), Darshini Mahadevia (India), Yousef Manialawy (Canada), Pamela McElwee (The United States of America), Minal Pathak (India), Julian Quan (United Kingdom), Balaji Rajagopalan (The United States of America), Alan Renwick (New Zealand), Jorge E. Rodríguez-Morales (Peru), Charlotte Streck (Germany), Wim Thiery (Belgium), Alan Warner (Barbados)

Review Editors:
Regina Rodrigues (Brazil), B.L. Turner II (The United States of America)

Chapter Scientist:
Thobekile Zikhali (Zimbabwe)

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Table of contents

SM7.1 Supplementary information to Section 7.2

The burning embers diagrams (Figure 7.1, 7.2 and 7.3) outline risks associated with climate change as a function of global warming, socio-economic development and mitigation choices. Diagrams indicate transitions between undetectable, moderate, high, and very high risks to humans and ecosystems. The method is based on a literature review of estimated impacts at different global mean surface temperature levels (O'Neill et al. 2017) on different components of desertification, land degradation and food security, including emerging literature on Shared Socio-economic Pathways (SSPs) as well as literature from IPCC AR5 and SR15.

Most studies focus on changes in hazards as a function of climate change (e.g. as represented by RCP scenarios or other climate change scenarios) or climate change superimposed on present-day exposure. Only a limited number of studies focus on changes in risk as a function of both RCPs and SSPs (climate and socio-economic change and adaptation decisions). This was addressed by splitting the embers into different figures. Figure 7.1 focuses on the impact of climate change on risk, under present-day exposure and vulnerability. Figure 7.2 examines the relationship between climate change and risks under two SSPs (SSP1 and SSP3). Figure 7.3 depicts risks to humans and ecosystems as a function of the land area employed for mitigation through bioenergy plantations.

Further, a formal expert elicitation protocol, based on the modified-Delphi technique (Mukherjee et al. 2015) and the Sheffield Elicitation Framework (Oakley and O'Hagan 2016; Gosling 2018), was followed to develop threshold judgments on risk transitions. Specifically, experts participated in a multi-round elicitation process, with feedback of group opinion provided after each round: the first two rounds involved independent anonymous threshold judgment, and the final round involved a group consensus discussion (von der Gracht 2012). To strengthen the rigor of developing expert consensus on risk transitions (Hasson and Keeney 2011), the protocol pre-specified the following prior to beginning the elicitation exercise (Grant et al. 2018): the research question, eligibility criteria and strategy to recruit experts, research materials, data collection procedure, and analysis plan. This systematic process of developing expert consensus on threshold judgments for risk transitions can better inform subsequent analytical approaches – an approach that may be further developed for use in future IPCC cycles (Bojke et al. 2010; Sperber et al. 2013). References for the current and past assessments are listed at the end of this document and by the relevant tables.

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

Table SM7.1 | Literature considered in the expert judgement of risk transitions for Figure 7.1.

Reference	Risk	Variable (unit)	Direction of impact	Climate scenario	Timeframe	Detection and attribution of current impact	Impact at 1 degree	Impact at 2 degrees	Impact at 3 degrees	Impact at 4 degrees	Impact at 4.5 degrees	Adaptation potential	Region (Including regional differences)
AVAILABILITY													
Rosenzweig 2014	Availability Yield	Yield	Strong negative effect on yields, especially at higher levels of warming and at lower latitudes	NA			See Figure 1 in paper. Maize mid to high latitude is –10 to +15% yield change	Maize – 20 to +5% yield change	Maize about –20 to +5% yield change in mid latitude and ALL negative in low latitude	Maize +15 to –20% yield change in mid latitude. Catastrophic in low latitude with –10 to –60% change!	Maize is now all negative in mid latitude	Between 3 and 4 degrees catastrophic declines in low latitudes for maize, wheat also significant declines around 4 degrees and same for rice. Adaptation potential limited at these temp.	Low latitudes
Zscheischler et al. 2018	Availability (crop failure)	Crop yield	"Increases the likelihood of such events considerably, and may make events of the rarity of the Russian event foreseeable and to some extent predictable"	Review	2010								
IPCC 2019	Availability (crop yields)	Yield	Decrease to yields	NA								Limiting global warming to 1.5°C compared to 2°C would result in a lower global reduction in crop yields	
Medina et al. 2017	Availability (increased loss of crops and livestock; increased pest burden, increased disease burden; higher post-harvest losses due to mycotoxins)	Infection of staple food commodities by fungal diseases pre-harvest and by spoilage fungi post-harvest	Reduced availability of food	NA									
Paterson and Lima 2011	Availability (increased loss of crops and livestock; increased pest burden, increased disease burden; higher post-harvest losses due to mycotoxins)	Crops after harvest	Reduced availability of food	NA	NA							Unclear. "Crops introduced to exploit altered climate may be subject to fewer mycotoxin producing fungi (the "Parasites Lost" phenomenon). Increased mycotoxins and UV radiation may cause fungi to mutate on crops and produce different mycotoxins"	
Magan et al. 2011	Availability (increased loss of crops and livestock; increased pest burden, increased disease burden; higher post-harvest losses due to mycotoxins)	Crops after harvest	Reduced availability of food	NA	NA								

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

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Rivera-Ferre et al. 2016	Availability (increased loss of crops and livestock; increased pest burden, increased disease burden; higher post-harvest losses due to mycotoxins)	Crop yield	Reduced availability of food	NA	NA							Local / traditional knowledge in agriculture (LTKA) is proposed in this article / has valid knowledge to ensure food availability under climate change, given its long experience in dealing with climate variability	
Zimmermann et al. 2017	Availability (increased yields if management assumptions hold, thermal management)	Crop yields in Europe	Increased yields	Three SRES climate change scenarios to 2050	Three SRES climate change scenarios to 2050								
Faye et al. 2018	Availability (modeled crop yield)	Crop yield	Negative	NA								Success of intensification the key factor making the difference	
Tesfaye et al. 2017	Availability (modeled crop yield)	Crop yield	Negative	NA				"At regional scale, they found maize yields declines in 2050 of up to 12% to 14% in rainfed and irrigated maize"					
Scheelbeek et al. 2018	Availability (modeled crop yield)	Crop yield	Negative	NA						Mean yield declines of fruits –31.5%			
Rippke et al. 2016	Availability (modeled crop yield)	Crop yield	Negative	NA	To end of 21st century			"30–60% of common bean growing area and 20–40% of banana growing areas in Africa will lose viability in 2078–2098 with a global temperature increase of 2.6 and 4.0"					
Bisbis et al. 2018	Availability (modeled fruit crop yield), and utilization (reduced quality, more spoilage, reduced nutrition)	Crop yield	Negative	NA									
Tebaldi and Lobell 2018	Availability (models relation between climate variables, CO_2 concentrations, and yields)	Crop yield	Negative	RCP4.5 and RCP8.5	Short (2021–2040), medium (2041–2060) and long (2061–2080) time horizons			"Critical or "lethal" heat extreme					
Schleussner et al. 2018	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Yield	Negative for half a degree additional warming (1.5 to 2)	HAPPI				"Half a degree warming will also lead to more extreme low yields, in particular over tropical regions"					
Ovalle et al. 2015	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Yield	Decrease in coffee yields	NA									
Bunn et al. 2015	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Yield	Decrease in coffee yields by 50%	NA									

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

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Roberts and Schlenker 2013	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Yield	Productivity of major crops will decline as a result of climate change, particularly from increasing warming	NA									
Peng et al. 2004	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Grain yields	Grain yield of rice declined 10% for each 1°C increase in night-time temperature during the dry season	NA			–10%	–20%	–30%	–40%	–50%		
Asseng et al. 2015	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Soy bean & maize yields	While maize and soy bean yields are expected to decline by 6% for each day above 30°C	NA			–6% / day above 30°C	–12% / day above 30°C	–18% / day above 30°C	–24% / day above 30°C	–30% / day above 30°C		
Asseng et al. 2017	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Wheat yields	Wheat yields are expected to decline by 6% for each 1°C increase	NA		Warming is already slowing yield gains at a majority of wheat-growing locations.	–0.06	–0.12	–0.18	–0.24	–0.3		
Porter et al. 2014	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Crop yields all crops	If global temperature increases beyond 3°C it will have negative yield impacts on all crops	NA					Negative yield impact				
Schleussner et al. 2016	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Competition for land	increasing competition for land from the expansion of bioenergy	NA									
Fischer et al. 2005	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)		Decrease in yields	NA			10%	10–20%	10–20%	10–20%		On-farm and via market mechanisms	
Smith et al. 2016	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Soil	Reduced yields	NA	NA								
Challinor et al. 2014	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Crop yield	Reduced yields	NA	2050 to end of century								
FAO 2018	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops)	Crop yield	Reduced yields	NA									
Roberts and Schlenker 2013	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops) (3crops)		Decrease in yields	NA			30–46%	30–46%	63–80%	63–80%			

7SM

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

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Betts et al. 2018	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops) (food crops)	Yield	Decrease	NA									
Tigchelaar et al. 2018	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops) (Maize)		Decrease in yields	NA				7–10%		87%			
Leng and Hall 2019	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops) (six crops)		Declining yield (but varies between crops and regions)	NA								Study doesn't consider adaptations	
Bocchiola et al. 2019	Availability (reduced yields and soil fertility and increased land degradation for some regions and crops) (wheat, rice, maize)		Declining	NA								Increasing altitude – increases yield for maize and rice slightly	
Rosenzweig et al. 2018	Availability (simulated wheat and maize yield changes)	Crop yield	Negative	AgMIP coordinated global and regional assessment (CGRA)								Between 1.5 and 2.0	
Parkes et al. 2018	Availability (simulated wheat and maize yield changes)	Crop yield	Negative	NA								Between 1.0 and 1.5	
Lombardozzi et al. 2018	Availability (Yield)	Yield	Positive effect of CO_2 on future crop yields muted by negative impacts of climate	CESM/CLM4.5 under RCP8.5	2006–2100					Corn: –10 to +20% Wheat +40 to +100%; Soy –10 to +5%; Rice +10 to +50%			
Chen et al. 2018	Availability (Yield)	Yield	Decrease in organic matter in soil, soil erosion	NA									
Leng 2018	Availability (Yield)	Yield		NA									
Byers et al. 2018	Availability (Yield)	Yield		NA									
Xie et al. 2018	Availability barley yields (beer)	Yield	Decrease in barley yield, consumption (and hence global beer supply)	NA				–3%	–10%	–17%			
Leng and Hall 2019	Availability Corn Yields	Yield	Decrease to yields	NA		2.5% decrease of corn yield for the historical period, which is reduced to 1.8% if accounting for the effects of corn growing pattern changes	Negative corn yield response to warmer growing season, largest yield reduction up to 20% by 1° increase of temperature	Majority of impacts will be driven by trends in temperature rather than precipitation				Negative corn yield response to warmer growing season. Corn yield is predicted to decrease by 20~40% by 2050s	
Leng 2018	Availability crop yields	Yield	Decrease in yields	NA									
Su et al. 2018	Availability crop yields	Yield	Decrease in yields	NA									
Zhao et al. 2017	Availability maize yields	Yield, production/ per hectare	Decrease in yield	NA									
Brisson et al. 2010	Availability Yield	Yield	Yield losses/plateauing	NA									
Lin and Huybers 2012	Availability Yield	Yield	Yield losses/plateauing	NA									
Grassini et al. 2013	Availability Yield	Yield	Yield losses/plateauing	NA									

7SM

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Myers et al. 2017	Availability yield declines	Yield		NA								Adaptation could lead to crop yields that are 7–15% higher. Gains will be highest in temperate areas but will be unlikely to help tropical maize and wheat production	
Hasegawa et al. 2018	Mitigation policy combined with climate effect on yields	Available land		NA									
ACCESS													
Schmidhuber and Tubiello 2007	Access Price (cereal)	Price	Increase in price	NA					80%	170%		Current period (timewise)	
Easterling et al. 2007	Access Price (cereal)	Price	Increase in price	NA			10–30%	10–30%	10–40%	10–40%	10–40%		
Parry et al. 2004	Access Price (food crops)	Price	Increase in price	NA				5–35%				Increase fertiliser and pesticide application, irrigation	
Fujimori et al. 2018	Access Price (food crops)	Price	Increase in price	NA								Food policy scenarios (international aid, domestic reallocation, bioenergy tax)	
Hertel et al. 2010	Access Price (major staples)	Price	Increase in price	NA		3.60%	10–15%					New crop varieties, significant expansion of irrigation Infrastructure	
UNCCD 2017	Access (disproportionate impact on low-income consumers, in particular women and girls, due to lack of resources to purchase food)	Soil health	Negative	NA								Low (soil health provides key adaptation option, without which lit reviewed by UNCCD points towards low adaptation potential)	
Vermeulen et al. 2012	Access (inability to invest in adaptation and diversification measures to endure price rises)	Agricultural yields and earnings, food prices, reliability of delivery, food quality, and, notably, food safety	Reduced access to food	NA									
Morris et al. 2017	Access (indirect impacts due to spatial dislocation of consumption from production for many societies)	Crop Yield	Reduced access to food	GGCMs								Strong negative effects of climate change, especially at higher levels of warming and at low latitudes	
FAO 2016a	Access (loss of agricultural income due to reduced yields and higher costs of production inputs, such as water, limits ability to buy food)	Crop Yield	Negative	NA								Likely 1.0 and 1.5	
Abid et al. 2016	Access (loss of agricultural income due to reduced yields and higher costs of production inputs, such as water, limits ability to buy food)	Farm income	Negative	NA								Likely 1.0 and 1.5	

Reference	Risk	Variable (unit)	Direction of impact	Climate scenario	Timeframe	Detection and attribution of current impact	Impact at 1 degree	Impact at 2 degrees	Impact at 3 degrees	Impact at 4 degrees	Impact at 4.5 degrees	Adaptation potential	Region (Including regional differences)
Harvey et al. 2014	Access (loss of agricultural income due to reduced yields and higher costs of production inputs, such as water, limits ability to buy food)	Farm income	Negative	NA								Likely 1.0 and 1.5	
Calvin et al. 2014	Access (Price)	Price	increase in price	NA						320%			
Kreidenweis et al. 2016	Access (Price)	Price	Increase in price	NA				60–80%				Increase investment in R&D, etc	
Tilman and Clark 2014	Access demand	Demand	Doubling of demands by 2050	NA									
Chatzopoulos et al. 2019	Access	Economic impacts				Negative. Large-scale events will 'very likely' occur more frequently, more intensely, and last longer	Key wheat-growing regions display yield reductions from −28% (Australia) to −6% (US and Ukraine). ...consumer prices increase by up to one third, most notably in Asian countries	"Besides Australia, three more regions exceed a reduction of −20%: Canada, Russia, and Kazakhstan."	"persistent large-scale harvest failures may deplete grain stocks and thus render future prices even more responsive."				
UTILIZATION													
Müller et al. 2014	Utilization (decline in nutritional quality resulting from increasing atmospheric CO_2)	Human migration	Negative (heat stress induced long-term migration of people)	NA									
Myers et al. 2014	Utilization (decline in nutritional quality resulting from increasing atmospheric CO_2)	Zinc and iron	Reduced nutrition	NA	2050 or 550 ppm							Low/Moderate. Differences between cultivars of a single crop suggest that breeding for decreased sensitivity to atmospheric CO_2 concentration could partly address these new challenges to global health	
Smith et al. 2017	Utilization (decline in nutritional quality resulting from increasing atmospheric CO_2)	Iron	Negative (iron deficiency)	NA				550 ppm					
Myers et al. 2015	Utilization (decline in nutritional quality resulting from increasing atmospheric CO_2)	Zinc deficiency under different CO_2 concentrations	Negative (zinc deficiency)	NA	2050			The total number of people estimated to be placed at new risk of zinc deficiency by 2050 was 138 million (95% CI 120–156)					
Moretti et al. 2019	Utilization (higher post-harvest losses due to mycotoxins)	Crops after harvest	Reduced availability of food	NA	Current to 2050								
Van der Fels-Klerx et al. 2016	Utilization (negative impact on food safety due to effect of increased temperatures on microorganisms, including increased mycotoxins in food and feed)	Crops after harvest	Reduced utilization of food	NA									

Reference	Risk	Variable (unit)	Direction of impact	Climate scenario	Timeframe	Detection and attribution of current impact	Impact at 1 degree	Impact at 2 degrees	Impact at 3 degrees	Impact at 4 degrees	Impact at 4.5 degrees	Adaptation potential	Region (Including regional differences)
Tirado and Meerman 2012	Utilization (negative impact on food safety due to effect of increased temperatures on microorganisms, including increased mycotoxins in food and feed)		Reduced utilization of food	NA	To midcentury								
Aberman and Tirado 2014	Utilization (negative impact on nutrition resulting from reduced water quantity and quality used to prepare food)	Food availability, utilization, access	Negative	NA	2020–end of century								
Thompson and Cohen 2012	Utilization (negative impact on nutrition resulting from reduced water quantity and quality used to prepare food)	Nutrition, distribution of food	Negative	NA									
IPCC 2018	Utilization (nutrition)	Nutrients	Decrease in nutritional content	NA		At 0.87, yellow – associated impacts are both detectable and attributable to climate change with at least medium confidence	Associated impacts are both detectable and attributable to climate change with at least medium confidence	Indicates closer to severe and widespread impacts				Limiting global warming to 1.5°C compared to 2°C would result in a lower global reduction in nutritional quality	
Bahrami et al. 2017	Utilization Nutrients	Nutrients	Above ground biomass production and yield will typically increase by 17–20% while concentrations of nutrients such as N will decrease by 9–15% in plant tissues. Here they found – The 12% loss in grain protein under e[CO_2]	NA								Grain yield per plant was greater under e[CO_2]. Irrigation treatment significantly enhanced grain yield by 128%. Grain protein concentration (%) decreased by 12% in e[CO_2] grown wheat compared to a[CO_2]. Grain protein concentration (%) was 15% higher in rain-fed than well-watered treatments but did not differ between the two wheat cultivars. Continuing favourable water supply conditions for photosynthesis during grain filling can prolong carbohydrate delivery to grains and thereby increase yield but depress grain protein, which is consistent with greater grain yield and lower grain protein concentrations in well watered compared to rain-fed crops in our study	

7SM

7SM

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Medek et al. 2017	Utilization nutrition	Protein content	Decrease Under eCO_2, rice, wheat, barley, and potato protein contents decreased by 7.6%, 7.8%, 14.1%, and 6.4%,respectively	NA									
Smith et al. 2017	Utilization nutrition	Nutrients	CO_2 concentrations of 550 ppm can lead to 3–11% decreases of zinc and iron concentrations in cereal grains and legumes and 5–10% reductions in the concentration of phosphorus, potassium, calcium, sulfur, magnesium, iron, zinc, copper, and manganese across a wide range of crops under more extreme conditions of 690 ppm CO_2	NA									
Puma et al. 2015	Utilization (disruptions to food storage and transportation networks)	Crops after harvest	Reduced utilization of food	NA	1992–2009	Moderate risk at present	Increased connectivity and flows within global trade networks suggest that the global food system is vulnerable to systemic disruptions, especially considering tendency for exporting countries to switch to non-exporting states during times of food scarcity in the global markets						
Wellesley et al. 2017	Utilization (disruptions to food storage and transportation networks)	Food prices	Reduced utilization of food	NA									
STABILITY													
Schmidhuber and Tubiello 2007	Stability		High Fluctuation (price, supply, yields)	NA		Negative. Increased fluctuations in crop yields and local food supplies and higher risks of landslides and erosion damage, they can adversely affect the stability of food supplies and thus food security	In semiarid areas, droughts can dramatically reduce crop yields and livestock numbers and productivity (most in sub-Saharan Africa and parts of South Asia) poorest regions with the highest level of chronic undernourishment will also be exposed to the highest degree of instability in food production					Food import, freer trade, investment (storage, irrigation, transport, communication)	

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Zheng et al. 2014	Stability (civil disturbance, social tension)	Social tension	Disruption food supply	NA			1. Extreme events will severely disrupt the food supply 2. Extreme events will escalate popular unrest, rebellions and wars 3. Extreme events will increase expenditure to 60 –70%						
Diffenbaugh et al. 2012	Stability (impacts on world market export prices that carry through to domestic consumer prices due to climate shocks)	Price of corn	Negative	NA									
Verma et al. 2014	Stability (impacts on world market export prices that carry through to domestic consumer prices due to climate shocks)	Price of corn	Likely negative	NA									
Willenbockel 2012	Stability (impacts on world market export prices that carry through to domestic consumer prices due to climate shocks)	Food price	Negative (potential food price impacts of a number of extreme weather event scenarios in 2030 for each of the main exporting regions for rice, maize and wheat)	NA	2030		1. Extreme events, such as flooding, can wipe out economic infrastructure; 2. Agricultural infrastructure will be affected 3. Weather-related yield shocks occurred will occur 4. Global crop production will drop						
Salmon et al. 2015	Stability (political and economic)	Rainfall, temperature	Disruption food supply, price fluctuation, decrease in production	NA								Agricultural intensification, changes in land use practices	
Medina-Elizalde and Rohling 2012	Stability (political and economic)	Rainfall	Low yields	NA									
Challinor et al. 2018	Stability (widespread crop failure contributing to migration and conflict)	Crop failure	Negative	NA								Moderate	
Hendrix 2018	Stability (widespread crop failure contributing to migration and conflict)	Crop failure	Negative	NA	Current							Moderate	

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

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Kelley et al. 2017	Stability (widespread crop failure contributing to migration and conflict)	Crop failure	Negative	NA	Current	Negative. severe drought 2006/2007 caused northeastern "breadbasket" region to collapse (zero or near-zero production, livestock herds lost)	"Multiyear drought episodes in the late 1950s, 1980s, and 1990s, (i) the total population of Syria grew from 4 million in the 1950s to 22 million in recent years; (ii) decline groundwater supply (iii) drought occurred shortly after the 1990s drought					Low to medium	
Kelley et al. 2015	Stability (widespread crop failure contributing to migration and conflict)	Crop failure	Negative, low yields and price increase	NA	Current		1. Extreme events will lead to unprecedented rise in food prices 2. Extreme events will obliterate livestock					Low	
Schmidhuber and Tubiello 2007	Stability production, supply chain, extreme events	Extreme events	Fluctuation (yield and supply), Reduction (labour, productivity), Increase (disease burden)	NA			1. Droughts can dramatically reduce crop yields and livestock productivity 2. Exposed to the highest degree of instability in food production					Food imports, Freer trade, Investment (storage, irrigation, transport, communication)	
Chatzopoulos et al. 2019	Stability (variability in supply, price)	Yield, market, price	Fluctuation (yield, market and price)	NA		Negative. climate extremes collide with major drivers (population growth, dietary shifts, environmental degradation, and trade interdependence	Key wheat-growing regions display yield reductions –28% (Australia) to –6% (US and Ukraine).	Besides Australia, three more regions exceed a reduction of –20%: Canada, Russia, and Kazakhstan. The highest absolute drops, corresponding to –0.9 tha^{-1} and –0.7 tha^{-1}, were found in Canada and Russia.	The transmission of domestic prices to global markets is visible in most scenarios with large shocks in key exporters and importers being responsible for the most pronounced effects.			Buffer stock schemes for stabilizing supply and prices of major staple commodities in food-insecure regions may mitigate some of the induced price volatility but are generally difficult to achieve and sustain in practice	
Bellemare 2015	Stability (trade)	Trade, supply, price	Negative, trade in situations where global grain production is reduced does not distribute world food stocks/ inadequate and counter to modeling results (in reality producing countries protect domestic grain reserves; prices spike upwards in times of reduced yields but do not fall as much in times of normal or increased yields)	NA	2007–2010	Negative	2009–2011 food price increases led to increases in social unrest, food price volatility has not been associated with increases in social unrest					Medium in SSP1-like world	
Zampieri et al. 2017	Stability (variability in supply, price)	Yield, market, price	Fluctuation (yield, market and price)	NA		Negative							

7SM

7SM

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Donati et al. 2016	Stability (trade)	Trade, supply, price	Negative, trade in situations where global grain production is reduced does not distribute world food stocks/ inadequate and counter to modeling results (in reality producing countries protect domestic grain reserves; prices spike upwards in times of reduced yields but do not fall as much in times of normal or increased yields)		2007–2010	Negative	Open trade helps improve access to food at lower prices, combined with observations in other articles about impact of market speculation (US) combined with export restraints (Russia, Ukraine, India, Vietnam) in 2007–2011 drought periods.						
Gilbert and Morgan 2010	Stability (trade)	Trade, supply, price	Negative, trade in situations where global grain production is reduced does not distribute world food stocks/ inadequate and counter to modeling results (in reality producing countries protect domestic grain reserves; prices spike upwards in times of reduced yields but do not fall as much in times of normal or increased yields)		2007–2010	Negative. not yet clear if trend in food price volatility is permanent	"World dollar prices of major agricultural food commodities rose dramatically from late 2006 through to mid-2008. Prices collapsed dramatically in the second half of 2008 with the onset of the financial crisis. periods of high volatility have been relatively short and interspaced with longer periods of market tranquillity. It would therefore be wrong simply to extrapolate recent and current high volatility levels into the future. However, it remains valid to ask whether part of the volatility rise may be permanent."					Moderate	Global
Gilbert 2010	Stability (trade)	Trade, supply, price	Negative, trade in situations where global grain production is reduced does not distribute world food stocks/ inadequate and counter to modeling results (in reality producing countries protect domestic grain reserves; prices spike upwards in times of reduced yields but do not fall as much in times of normal or increased yields)		2007–2010	Negative. not yet clear if trend in food price volatility is permanent	Index-based investment in agricultural futures markets is seen as the major channel through which macroeconomic and monetary factors generated the 2007–2008 food price rise					Moderate depending on exposure to market speculation	

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Headey 2011	Stability (trade)	Trade, supply, price	Negative, trade in situations where global grain production is reduced does not distribute world food stocks/ inadequate and counter to modeling results (in reality producing countries protect domestic grain reserves; prices spike upwards in times of reduced yields but do not fall as much in times of normal or increased yields)			Negative	When food prices peaked in June of 2008, they soared well above the new equilibrium price. observations that international rice prices surged in response to export restrictions by India and Vietnam suggested that trade-related factors could be an important basis for overshooting, especially given the very tangible link between export volumes and export prices	"In all cases except soybeans, we find that large surges in export volumes preceded the price surges. The presence of these large demand surges, together with back-of-the-envelope estimates of their price impacts, suggests that trade events played a much larger and more pervasive role than previously thought."					
Marchand et al. 2016	Stability (trade)	Trade, supply, price	Negative, trade in situations where global grain production is reduced does not distribute world food stocks/ inadequate and counter to modeling results (in reality producing countries protect domestic grain reserves; prices spike upwards in times of reduced yields but do not fall as much in times of normal or increased yields)		2007–2010	Negative. Without coordinated and effective international and domestic risk management of food stocks	Supply shocks driven not only by the intensification of trade, but as importantly by changes in the distribution of reserves. trade dependency may accentuate the risk of food shortages from foreign production shocks	Increased number and volume of trade links (relative to production), decrease and a more even distribution of global reserves (still relative to production). – ->distribution of reserves matters more than their aggregate quantity in terms of conferring resilience to shocks.	Possibility of multiple supply side shocks across different regions of the world (multi-breadbasket failure)	"Compounded risk: greater reliance on imports increases the risk of critical food supply losses following a foreign shock, notably in the case of several Central American and Caribbean countries that import grains from the United States"		Medium. Trade dependency has substantially increased in the last few decades and more than doubled since the mid-1980s likely as a result of liberalization and the associated removal of subsidies and trade protections in developing countries	
Sternberg 2012	Stability (trade, political)	Trade, supply, price	Negative, trade in situations where global grain production is reduced does not distribute world food stocks/ inadequate and counter to modeling results (in reality producing countries protect domestic grain reserves; prices spike upwards in times of reduced yields but do not fall as much in times of normal or increased yields)		2007–2010	"Chinese drought contributed to a doubling of global wheat prices. The drought affected the price of bread in Egypt which influenced political protest. The process exemplifies the potential global consequences of climate hazards today."						Depends on food reserves, trade policy (risk management) and if multi-breadbasket failure is present	

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Permafrost degradation													
Chadburn et al. 2017	Permafrost degradation	Permafrost area change (million km^2)	Increased loss of permafrost, leading to radical changes in high-latitude hydrology and biogeochemical cycling. Estimated sensitivity of permafrost area loss to global mean warming at stabilization of 4.0 ± 1.1 million $km^2 °C^{-1}$	CMIP5, multiple RCPs	1850–2300	Indirectly	13	9	6	4	2		Global
Burke et al. 2018	Permafrost degradation	Increased land carbon emissions at stabilization Gt C yr^{-1}	Additional emissions between 225 and 345 GtC (10th to 90th percentile) from permafrost thaw under 2°C stabilised warming. 60–100 GtC less in a 1.5°C world	JULES-IMOGEN intermediate complexity climate model	1.5° and 2°C stabilization		1.5: 0.08 to 0.16 GtC yr^{-1} (10th to 90th percentile)	0.09 to 0.19 GtC yr^{-1} (10th to 90th percentile)					Global
Jorgenson & Osterkamp 2005	Permafrost degradation	Water erosion	Increased water erosion	Review									Global
Gauthier et al., 2015	Permafrost degradation	Tree mortality	Permafrost thawing in dry continental Siberia may trigger widespread drought-induced mortality in dark coniferous forests and larch forests that cover 20% of the global boreal forest	Review									Fennoscandia, Siberia and the northern reaches of North America
FAO 2012	Permafrost degradation	Damage to forest hydrological regimes	Permafrost thawing will reinforce the greenhouse effect and induce irreversible damage to forest hydrological regimes, especially across regions receiving little rainfall	Review	2012–2030					Carbon release by 2100 could be several times that of current tropical deforestation			Siberia
Price et al., 2013	Permafrost degradation	Permafrost thaw	Increases in nearsurface permafrost temperatures during 2007–2009 are up to 2°C warmer compared to 2–3 decades, and there is a concurrent trend in its degradation and disappearance. Overall transient responses of permafrost to warming are likely to be nonlinear	Review	1995–2100		Permafrost is now warming at almost all sites across the North American permafrost zones, except for site where the permafrost is already close to 0°C and vertical ground temperature profiles are isothermal, indicating ongoing phase changes		Rapid degradation and disappearance over extensive areas within next 50–100 years. Accelerated degradation by 2050 likely in several regions	16%–35% of Canadian permafrost area in 2000 may be lost by 2100			Canada

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

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Hjort et al. 2018	Permafrost degradation	Proportion of all residential, transportation, and industrial infrastructure in areas of nearsurface permafrost thaw (a) and high hazard (b) in the pan-Arctic permafrost area (%)	Arctic infrastructure at risk from degrading permafrost by mid-century	Infrastructure hazard computations	2041–2060			4 million people, 70% of current infrastructure					Global
Fire													
Bajocco et al. 2011	Fire	Area burned	Multidirectional relationships between climate, land degradation and fire may be amplified under future land use change and climate scenarios		1990–2000								Mediterranean
Marlon et al. 2016	Fire	Biomass burning	Increase in charcoal influx (i.e. biomass burning) during the industrial period (probably not related to climate but human activities)	Paleoclimate reconstruction	Last 22,000 years								Global
Giglio et al. 2013	Fire	Area burned	Trends in land area burnt have varied regionally	Recent observations	1995–2011	Regionally varying trends			–				Northern Hemisphere Africa has experienced a fire decrease of 1.7 Mha yr^{-1} (–1.4% yr^{-1}) since 2000, while Southern Hemisphere Africa saw an increase of 2.3 Mha yr^{-1} (+1.8% yr^{-1}) during the same period. Southeast Asia witnessed a small increase of 0.2 Mha yr^{-1} (+2.5% yr^{-1}) since 1997, while Australia experienced a sharp decrease of about 5.5 Mha yr^{-1} (–10.7% yr^{-1}) during 2001–11, followed by an upsurge in 2011 that exceeded the annual area burned in the previous 14 years

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Andela et al. 2017	Fire	Area burned	A recent analysis using the Global Fire Emissions Database v.4 that includes small fires concluded that the net reduction in land area burnt globally during 1998–2015 was –24.3± 8.8% (–1.35 ± 0.49% yr^{-1}). However, from the point of fire emissions it is important to consider the land cover types which have experienced changes in area burned; in this instance, most of the declines have come from grasslands, savannas and other non-forest land cover types (Andela et al. 2017)	Remote sensing	1998–2015	Global decline						High in the tropics	Global
Abatzoglou and Williams 2016	Fire	Forest area burned	Significant recent increases in forest area burned (with higher fuel consumption per unit area) recorded in western and boreal North America	Detection/attribution	1979–2015	+100% cumulative forest fire area, CC accounted for 55% of increase in fuel aridity						Moderate (rise in forest fires despite increasing adaptation measures)	Western and boreal north America
Ansmann et al. 2018	Fire	Forest area burned	Clear link between the western Canadian fires and aerosol loading over Europe	Aerosols, case study	2017–2017								Western and boreal north America
Pechony and Shindell 2010	Fire	Fire activity (% relative to pre-industrial)	Temperature increase and precipitation decline may become the major driver of fire regimes under future climates as evapotranspiration increases and soil moisture decreases	Driving forces, A2, A1B, B1 scenarios; single GCM	800–2100		0–10%	0–10%	5–10%	10–35%	15%	Low under high warming levels	Global with strong regional variations.
Aldersley et al. 2011	Fire	Fire regimes	Temperature increase and precipitation decline may become the major driver of fire regimes under future climates as evapotranspiration increases and soil moisture decreases	Random forest on data sets	2000–2000								Global

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Fernandes et al. 2017	Fire	Fire regimes	Temperature increase and precipitation decline may become the major driver of fire regimes under future climates as evapotranspiration increases and soil moisture decreases	Logistic regression	1995–2015	Yes, for Indonesia during moderate to wet years							Indonesia
Liu et al. 2010	Fire	Probability of fire	The risk of wildfires in future could be expected to change, increasing significantly in North America, South America, central Asia, southern Europe, southern Africa, and Australia	KBDI on GCM data	2070–2100								North America, South America, central Asia, southern Europe, southern Africa, and Australia
Jolly et al. 2015	Fire	Fire weather season length	Fire weather season has already increased by 18.7% globally between 1979 and 2013, with statistically significant increases across 25.3% but decreases only across 10.7% of Earth's land surface covered with vegetation; even sharper changes have been observed during the second half of this period	Weather analysis	1979–2013	Yes, global	plus18.7%						Global
Jolly et al. 2015	Fire	Area experiencing long weather fire season	Global area experiencing long weather fire season has increased by 3.1% per annum or 108.1% during 1979–2013	Weather analysis	1979–2013	Yes, global	plus108.1%						Global
Huang et al. 2014	Fire	Fire frequencies	Fire frequencies by 2050 are projected to increase by ~27% globally, relative to the 2000 levels, with changes in future fire meteorology playing the most important role in enhancing the future global wildfires, followed by land cover changes, lightning activities and land use, while changes in population density exhibits the opposite effects	A1B	2000–2050				19%				Global

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

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Knorr et al. 2016a	Fire	Area burned	Climate is only one driver of a complex set of environmental, ecological and human factors in influencing fire. Interplay leads to complex projections of future burnt area and fire emissions (Knorr et al. 2016a,b), yet human exposure to wildland fires is projected to increase because of population expansion into areas already under high risk of fires	SIMFIRE+LPJGUESS model; RCP4.5/8.5 scenarios	1971–2100		No change	No change	No change	5%	10%		Global
Knorr et al. 2016a	Fire	Exposure (number of people)	Climate is only one driver of a complex set of environmental, ecological and human factors in influencing fire. Interplay leads to complex projections of future burnt area and fire emissions (Knorr et al. 2016a,b), yet human exposure to wildland fires is projected to increase because of population expansion into areas already under high risk of fires	SIMFIRE+LPJGUESS model RCP4.5/8.5 scenarios	1971–2100		413		497–646		527–716		Global
Knorr et al. 2016b	Fire	Greenhouse gas emissions from fire	Climate is only one driver of a complex set of environmental, ecological and human factors in influencing fire. Interplay leads to complex projections of future burnt area and fire emissions (Knorr et al. 2016a,b), yet human exposure to wildland fires is projected to increase because of population expansion into areas already under high risk of fires	SIMFIRE+LPJGUESS model; RCP4.5/8.5 scenarios	1971–2100		–15%						Global

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

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Flannigan et al. 2009	Fire	Area burned, fire season length	General increase in area burned and fire occurrence but a lot of spatial variability, with some areas of no change or even decreases in area burned and occurrence. Fire seasons are lengthening for temperate and boreal regions and trend will continue in a warmer world. Future trends of fire severity and intensity are difficult to determine owing to the complex and non-linear interactions between weather, vegetation and people	Review	Present to 2100								Review of regional studies
Abatzoglou et al. 2019	Fire	Multimodel median proportion of burnable terrestrial surfaces for which emergence occurs (%)	Anthropogenic increases in extreme Fire Weather Index days emerge for an increasingly large fraction of burnable land area under higher global temperatures	Fire Weather Index on 17 CMIP5 climate models	1861–2099	Yes, on 22% of burnable land	0–3%	15–30%	30–50%				Global (pronounced effects in Mediterranean and Amazon)
Westerling et al. 2006	Fire	Wildfire frequency and duration	Higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons	Fire reports	1970–2003	Yes, for Western US							Western US
Yang et al. 2014	Fire	Area burned	Global decline in recent burned area $(1.28 \times 104 km^2 yr^{-1})$, driven significant decline in tropics and extratropics caused by human factors. warming and droughts are expected to increase wildfire activity towards the future	DLEM-Fire	1901–2007								Global
Turco et al. 2018	Fire	Area burned	Increase in burned area scales with warming levels. Substantial benefits from limiting warming to well below 2°C	SM and NSM under RCP2.6 and RCP8.5	1981–2100			+50–75%	+75–175%				Mediterranean
Flannigan et al., 2005	Fire	Area burned	Increase burned area under enhanced CO_2 scenarios	$2xCO_2$, $3xCO_2$	1975–1995; 2050; 2100				+78%		+143%		Canada

7SM

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

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Coastal degradation													
Mentaschi et al. 2018	Coastal degradation	Coastal erosion area (km^2)	Substantial global-scale increases in coastal erosion in recent decades	Remote sensing	1984–2015	No	28,000 km^2 eroded globally						Global
Neumann et al. 2015	Coastal degradation	Number of people exposed to a 1-in-100 year flood event in coastal regions million	Increased population exposure to 1-in-100 year storm surge. Strongest changes in exposure in Egypt and sub-Saharan countries in Western and Eastern Africa	Population projections	2000–2060	No	625	879–949	1,053–1,388				Coastal regions are also characterised by high population density, particularly in Asia (Bangladesh, China, India, Indonesia, Vietnam) whereas the highest population increase of coastal regions is projected in Africa (East Africa, Egypt, and West Africa)
Nicholls et al. 2011	Coastal degradation	Number of people displaced (million)	Increases in coastal erosion	DIVA model framework	2000–2100	No					72–187 (0.9–2.4%)	High: most of the threatened population could be protected.	Global
Cazenave and Cozannet 2014	Coastal degradation		Increases in coastal erosion	Review, mostly qualitatively	2000–2100	No							Global (with Southeast Asia concentrating many locations highly vulnerable to relative sea level rise)
Rahmstorf 2010	Coastal degradation		Increases in coastal erosion	Commentary	2000–2100	Yes							Global
Meeder and Parkinson 2018	Coastal degradation	Coastal erosion	Increases in coastal erosion	Sedimentary record	1900–2000								Everglades, USA
Shearman et al. 2013	Coastal degradation	Coastal erosion	Net contraction in mangrove area	Land cover classification	1980s-2000s	Indirectly	−0.28%						Asia-Pacific Region
McInnes et al. 2011	Coastal degradation	Coastal erosion	CMIP3 wind speed exhibit low skill over land areas	CMIP3 evaluation wind speed, SRES	1981–2100								Global
Mori et al. 2010	Coastal degradation	Coastal erosion	Wave heights increase in future climates across mid-latitudes and the Antarctic Ocean	GCM combined with a wave model under SRES	1979–2099								Global (rise in wave height in midlatitudes and southern ocean, decrease in tropics)
Savard et al. 2009	Coastal degradation	Coastal erosion	Increases in coastal erosion	Stakeholder discussions	2005–2007								Canada
Tamarin-Brodsky and Kaspi 2017	Coastal degradation	Tropical cyclones	Poleward shift in the genesis latitude and increased latitudinal displacement of tropical cyclones under global warming	Storm tracking algorithm to CMIP5	1980–2099								Midlatitudes
Ruggiero 2013	Coastal degradation	Total water level	Increases in wave height (and period), increasing the probability of coastal flooding/erosion more than sea level rise alone	Simple total water level model	1965–2010								U.S. Pacific Northwest
Elliott et al. 2014	Coastal degradation	Nexus	Nexus of climate change and increasing concentration of people	Review, mostly qualitatively									Global

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

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Knutson et al. 2010	Coastal degradation	Tropical cyclone intensity	Increased intensity and frequency of high-intensity hurricanes with higher warming levels	Review	1950–2100	Yes globally, regionally difficult							Tropical cyclone regions
Bender et al. 2010	Coastal degradation	Atlantic hurricane category 4 frequency	Increased intensity and frequency of high-intensity hurricanes with higher warming levels	CMIP3 downscaling with hurricane model under SRES A1B	2001–2020; 2081–2100				+75–81%				Atlantic (with the largest increase projected over the Western Atlantic, north of 20°N)
Vecchi et al. 2008	Coastal degradation	Hurricane Power Dissipation Index Anomaly (10^{11} m^3 s^{-2})	Increased intensity and frequency of high-intensity hurricanes with higher warming levels	Statistical regression SST PDI applied to CMIP	1950–2100		+1	–1 to +4	–1 to +6				Atlantic
Bhatia et al. 2018	Coastal degradation	Tropical cyclone category 4 frequency (# TCs)	Frequency, intensity, and intensification distribution of TCs all shift to higher values during the twenty-first century	RCP4.5, single GCM	2016–2035; 2081–2100		+26–67%	+27–133%					Tropical cyclone regions
Bhatia et al. 2018	Coastal degradation	Tropical cyclone category 5 frequency (# TCs)	Frequency, intensity, and intensification distribution of TCs all shift to higher values during the twenty-first century	RCP4.5, single GCM	2016–2035; 2081–2100		+46–50%	+85–200%					Tropical cyclone regions
Tu et al. 2018	Coastal degradation	Tropical cyclones	Regime shift in the destructive potential of tropical cyclones around 1998, with regional regulation by the ElNiño/ Southern Oscillation and the Pacific Decadal Oscillation	PDI on observations	1979–2016	No							Western North Pacific
Sharmila and Walsh 2018	Coastal degradation	Tropical cyclones paths	Tropical cyclones paths shift poleward	Reanalysis	1980–2014	Indirectly: hadley cell expansion has been linked to climate change							Tropical cyclone regions
Kossin 2018	Coastal degradation	Tropical cyclones translation speed	Over the last seven decades, the speed at which tropical cyclones move has decreased significantly as expected from theory, exacerbating the damage on local communities from increasing rainfall amounts	Best-track data from IBTrACS	1949–2016	Indirectly: trend analysis							Tropical cyclone regions

7SM

7SM

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Luke et al. 2016	Coastal degradation	Forest composition	The heterogeneity of land degradation at coasts that are affected by tropical cyclones can be further enhanced by the interaction of its components (for example, rainfall, wind speed, and direction) with topographic and biological factors (for example, species susceptibility)	Case studies of TC impacts on vegetation	2004–2007								West Indies
Emmanuel 2005	Coastal degradation	Tropical cyclone Power Dissipation Index	Potential destructiveness of hurricanes has increased markedly since the mid-1970s due to both longer storm lifetimes and greater storm intensities	'Best track' tropical data sets	1930–2010	Indirectly: consistency with increase in SST							Global
Emmanuel 2017	Coastal degradation	Tropical cyclone precipitation	Increase in intense precipitation associated with tropical cyclones	Downscaling of large numbers of tropical cyclones from three climate reanalyses and six climate models	1981–2000; 2081–2100		×6 increase in probability since late 20th century		×18 increase in probability since late 20th century				Texas
Wehner et al. 2018	Coastal degradation	Tropical cyclone counts of category 4/5	Increase in frequency and intensity of most intense tropical cyclones under 1.5°C and 2°C warming levels	single GCM, HAPPI protocol	HAPPI		At 1.5°C: +2.1 / +1.2	+1.4 / +1.2					Tropical cyclone regions
Hanson et al. 2011	Coastal degradation	People exposed to 1-in-100-year coastal flooding (# people)	Enhanced exposure to extreme coastal flooding, with total population exposure possibly increasing threefold by 2070	Global rise of 0.5 m above current levels by 2070, +10% increase in extreme water levels	2005; 2070s		38.5 million people (0.6%)	150 million people				High! "This research shows the high potential benefits from risk-reduction planning and policies at the city scale to address the issues raised by the possible growth in exposure." (paper)	Global
Hanson et al. 2011	Coastal degradation	Assets exposed to 1-in-100-year coastal flooding (% global GDP of that period)	Enhanced exposure to extreme coastal flooding, with total population exposure possibly increasing threefold by 2070	Global rise of 0.5 m above current levels by 2070, +10% increase in extreme water levels	2005; 2070s		5%	9%				High! "This research shows the high potential benefits from risk-reduction planning and policies at the city scale to address the issues raised by the possible growth in exposure." (paper)	Global
Vousdoukas et al. 2016	Coastal degradation	Extreme storm surge levels	The anticipated increase in relative sea level rise can be further enforced by an increase in extreme storm surge levels	RCP4.5 + 8.5, 8 CMIP5 models	1970–2100							Present and needed	Europe

7SM

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Vousdoukas et al. 2017	Coastal degradation	Extreme sea level change compared to present-day	100-year extreme sea level along Europe's coastlines is on average projected to increase by 57/81 cm for RCP4.5/8.5	RCP4.5 + 8.5, 6 CMIP5 models	1980–2014; 2100			+57cm		+81cm			Europe
Vousdoukas et al. 2017	Coastal degradation	Extreme sea level return period affecting 5 million Europeans	100-year extreme sea level along Europe's coastlines is on average projected to increase by 57(81) cm for RCP4.5(8.5)	RCP4.5 + 8.5, 6 CMIP5 models	1980–2014; 2100		100 year	3 year		1 year			Europe
Vousdoukas et al. 2018	Coastal degradation	Extreme sea level change compared to present-day	By 2050, extreme sea level rise would annually expose a large part of the tropics to the present-day 100-year event. Unprecedented flood risk levels by the end of the century unless timely adaptation measures are taken	RCP4.5 + 8.5, 6 CMIP5 models	1980–2014; 2100			+34–76 cm		+58–172cm			Global
Rasmussen et al. 2018	Coastal degradation	Human population exposure under 2150 local SLR projections (millions)	Increased permafrost melt, increased coastal erosion	1.5K, 2.0K, 2.5K stabilisation scenarios	2010; 2150		1.5: 56.05 32.54–112.97	61.84 (32.89–138.63)	2.5: 62.27 34.08–126.95				Global
Moftakhari et al. 2017	Coastal degradation	Coastal flooding	Compound flooding from river flow and coastal water level enhances risk derived from univariate assessments	RCP4.5 + 8.5	2030; 2050								Global
van den Hurk et al. 2015	Coastal degradation	Coastal flooding	Compound flooding from river flow and coastal water level enhances risk derived from univariate assessments	800 simulation years with an RCM	2012–2012								The Netherlands
Zscheischler et al. 2018	Coastal degradation	Coastal flooding	Interaction between multiple climate drivers and/or hazards play a major role in coastal extremes	Review									USA
Jevrejeva et al. 2018	Coastal degradation	Coastal flooding	Rising global annual flood costs with future warming	1.5K, 2.0K, stabilisation scenarios + RCP8.5 in CMIP5	2100		1.5°C: 1	1.2		14–27		"Adaptation could potentially reduce sea level induced flood costs by a factor of 10" (paper)	Global, "Upper middle income countries are projected to experience the largest increase in annual flood costs (up to 8% GDP) with a large proportion attributed to China. High income countries have lower projected flood costs, in part due to their high present-day protection standards." (paper)

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Brown et al. 2018	Coastal degradation	Decadal average of land inundated by flooding (km^2)	Increased soil erosion, increased soil salinity, subsiding land with future warming	1.5, 2.0 and 3.0 stabilisation scenarios from SRES A1B, with Delta Dynamic Integrated Emulator Model	1986–2005; 2050; 2100		1.5°C: 1,000–1,500	1,500–1,700	2,000–2,500			"With slow rates of sea-level rise, adaptation remains possible, but further support is required" (paper)	Ganges-Brahmaputra-Meghna and other vulnerable deltas
Nicholls et al. 2011	Coastal degradation	Expected people flooded (millions yr^{-1})	Increase in coastal inundation and number of people exposed under future warming levels	1.5K, 2.0K, stabilisation scenarios + RCP8.5 in CMIP5; Warming Acidification and Sea Level Projector Earth systems model, large ensembles	1986–2300		1.5°C: 150 (100–230)	170 (120–270)			400 (220–700)	"Adaptation remains essential in densely populated and economically important coastal areas under climate stabilization. Given the multiple adaptation steps that this will require, an adaptation pathways approach has merits for coastal areas." (paper)	Global
Mentaschi et al. 2017	Coastal degradation	Extreme wave energy flux in 100 yr return level	More extreme wave activity in the southern hemisphere towards the end of the century	Spectral wave model forced by 6 CMIP5 models under RCP8.5	1980–2010; 2070–2100					up to +30%			Southern hemisphere
Villarini et al. 2014	Coastal degradation	Coastal flooding	Flooding from tropical cyclones affects large areas of the United States	Discharge measurements	1981–2011								Eastern US
Woodruff et al. 2013	Coastal degradation	Coastal flooding	Increase in future extreme flood elevations	Review of global and regional studies	1981–2100								Global
Brecht et al. 2012	Coastal degradation	Coastal flooding	Strong inequalities in the risk from future disasters	Implications of tropical storm intensification for 31 developing countries and 393 of their coastal cities with populations greater than 100,000	2000–2100								Selected cities across the world
Hallegatte et al. 2013	Coastal degradation	Flood losses (Billion US$ yr^{-1})	Increasing global flood future warming	Quantification of present and future flood losses in the 136 largest coastal cities.	2005; 2050 (20 and 40 cm sea level rise; assume 2°C but no info in paper)		6	1,000 without adaptation, 60–63 with adaptation keeping constant flood probability				Huge challenge: "To maintain present flood risk, adaptation will need to reduce flood probabilities below present values" (paper)	Global
Jongman et al. 2012	Coastal degradation	People and value of assets in flood-prone regions (Trillion US$ in 1/00 coastal flood hazard areas)	Increased people and asset exposure in 1-in-100-year coastal flood hazard areas	Population density and GDP per capita estimate; land-use estimate	2010; 2050		27–46	80–158					Global (largest population exposure increase in Asia (absolute) and Sub-Saharan + North Africa (relative))
Muis et al. 2018	Coastal degradation	Coastal flooding	Significant correlations across the Pacific between ENSO and extreme sea levels	Tides and storm surge reanalysis	1979–2014	No							Global
Reed et al., 2015	Coastal degradation	Return period of 1/500yr pre-industrial flood height (yr)	Mean flood heights increased by ~1.24 m from ~A.D.850 to present.	Proxy sea level records and downscaled CMIP5	850–1800; 1970–2005	Yes	24 year						New York

Reference	Risk	Variable (unit)	Direction of impact	Climate scenario	Timeframe	Detection and attribution of current impact	Impact at 1 degree	Impact at 2 degrees	Impact at 3 degrees	Impact at 4 degrees	Impact at 4.5 degrees	Adaptation potential	Region (Including regional differences)
Wahl et al. 2015	Coastal degradation	Return period of 1/100yr pre-industrial flood height (yr)	Increase in the number of coastal compound events over the past century	Statistical analyses	1900–2012	Yes	42 year						USA & New York
Loucks et al. 2009	Coastal degradation	Number of breeding tiger species	Tiger habitat loss under future climate change. High agreement that the joint effect of climate change and land degradation will be very negative for the area	Sea level rise scenarios of 0, 12, 28cm (assumed 1,2,3K)	2000–2090		115	105	5				Sundarban, Bangladesh
Payo et al. 2016	Coastal degradation	Mangrove area loss (km²)	Increasing mangrove area losses by 2100 relative to 2000 due to sea level rise	Sea level rise scenarios of 0.46, 0.75 and 1.48m	2000; 2100				81–1,391 km² lost				Sundarban, Bangladesh
Vegetation degradation													
Allen et al. 2010	Vegetation changes	Tree mortality	Increases in tree mortality	Global assessment of recent tree mortality attributed to drought and heat stress.	1970–2008	Yes but not formally							Quasi-Global
Trumbore et al. 2015	Vegetation changes	Forest health	Intensification of stresses on forests	Review									
Hember et al. 2017	Vegetation changes	Net ecosystem biomass production (NEBP)	A 90% increase in NEBP driven by environmental changes	Observations at 10,307 plots across southern ecozones of Canada	1501–2012	Yes but not formally	Rise in wet climates, decline in dry climates						Canada
Midgley and Bond 2015	Vegetation changes	Vegetation structure	Climate, atmospheric CO_2 and disturbance changes are able to shift vegetation between states	Review									Africa
Norby et al. 2010	Vegetation changes	Net Primary Productivity (NPP, kg dry matter m² yr⁻¹)	Increasing N limitation, expected from stand development and exacerbated by elevated CO_2	FACE: CO_2 vs N	1998–2008		Reduction in NPP difference between ambient and elevated CO_2 experiments						High latitudes
Gauthier et al. 2015	Vegetation changes	Boreal forest shift to woodland/shrubland biome	Increase in drought-induced mortality, changes in climate and related disturbances may overwhelm the resilience of species and ecosystems, possibly leading to important biome-level changes	Review			Climate zones shift faster than adaptation capacity						Fennoscandia, Siberia and the northern reaches of North America
FAO 2012	Vegetation changes	Boreal forest productivity	Enhanced dieback and timber quality decrease despite increase in forest productivity	Review	2012–2030		"Higher forest mortality is already being observed in practically all areas of the boreal belt."				Mass destruction of forest stands.	"The state of knowledge regarding adaptive potential and the regional vulnerability of forests to climate change is insufficient" (paper)	Siberia (highest risks for Southern regions and forest steppe)

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

Reference	Risk	Variable (unit)	Direction of impact	Climate scenario	Timeframe	Detection and attribution of current impact	Impact at 1 degree	Impact at 2 degrees	Impact at 3 degrees	Impact at 4 degrees	Impact at 4.5 degrees	Adaptation potential	Region (Including regional differences)
Price et al. 2013	Vegetation changes	Boreal forest productivity	Where precipitation is generally nonlimiting, warming coupled with increasing atmospheric carbon dioxide may stimulate higher forest productivity. Increase in large wildfires. Risk of endemic forest insect pests population outbreaks in response to relatively small temperature increases	Review	1995–2100								Canada
Girardin et al. 2016	Vegetation changes	Boreal forest productivity	Tree growth dependence on soil moisture in boreal Canada since the mid-20th century. Projections of future drying pose risk to forests especially in moisture-limited regimes	Dendrochronology	1950–2015	Drought and heat control boreal tree growth	No change						North America
Beck et al. 2011	Vegetation changes	Boreal forest productivity	Growth increases at the boreal–tundra ecotones in contrast with drought-induced productivity declines throughout interior Alaska. Initiating biome shift.	Dendrochronology and remote sensing	1982–2010	Drought-induced productivity declines							North America
Lewis et al. 2004	Vegetation changes	Tropical forest health	Widespread changes observed in mature tropical forests	Review	1900–2001								Global
Bonan 2008	Vegetation changes	Forest health	Forests under large pressure from global change	Review									Global
Miles et al. 2004	Vegetation changes	Species becoming non-viable (%)	Little change in the realized distributions of most species due to delays in population responses	HADCM2GSa1 1%CO_2 (old ref)	1990–2095						43% by 2095		Amazonia (highest risks over lowland and montane forests of Western Amazonia)
Anderegg et al. 2012	Vegetation changes	Tree mortality	Increased tree mortality	Review									Global
Sturrock et al. 2011	Vegetation changes	Tree mortality	Increased tree mortality	Review								Adaptation requires modified suite of forest management approaches	Global

Risk management and decision-making in relation to sustainable development Chapter 7 Supplementary Material

Reference	Risk	Variable (unit)	Direction of impact	Climate scenario	Timeframe	Detection and attribution of current impact	Impact at 1 degree	Impact at 2 degrees	Impact at 3 degrees	Impact at 4 degrees	Impact at 4.5 degrees	Adaptation potential	Region (Including regional differences)
Bentz et al. 2010	Vegetation changes	Tree mortality	Increased tree mortality	Population models forced with CRCM climate projections under A2	1961–2100				"By the end of the century, the change in temperatures across the boreal forests of central Canada may cause markedly higher probability of spruce beetle outbreak potential, based on developmental timing alone."				North America
McDowell et al. 2011	Vegetation changes	Tree mortality	Increased tree mortality	Synthetic theory	1850–2100								Global
Lindner et al. 2010	Vegetation changes	Tree mortality	Positive effects on forest growth and wood production from increasing atmospheric CO_2 content and warmer temperatures especially in northern and western Europe. Increasing drought and disturbance (e.g. fire) risks will cause adverse effects, outweighing positive trends in southern and eastern Europe	Review	2000–2100	Some changes already detected (e.g. in Pyrenees)							Europe
Mokria et al. 2015	Vegetation changes	Tree mortality	Decreasing trend in tree mortality with increasing elevation	Dendrochronology	2006–2013								Northern Ethiopia, dry afromontane forest
Shanahan et al. 2016	Vegetation changes	Abrupt woodland-grassland shifts	Interactions between climate, CO_2 and fire can make tropical ecosystems more resilient to change, but systems are dynamically unstable and potentially susceptible to abrupt shifts between woodland and grassland dominated states in the future	28,000-year integrated record of vegetation, climate and fire from West Africa	15–28Ka								West Africa
Ferry Slik et al. 2002	Vegetation changes	Tree mortality	Reduction in number of trees and tree species per surface area directly after disturbance (fire)	Forest plot monitoring	1970–2002								Indonesia
Dale et al. 2001	Vegetation changes	Tree mortality	Altered frequency, intensity, duration and timing of fires, droughts, introduced species and other disturbances can affect forests	Review									Global

Reference	Risk	Variable (unit)	Direction of impact	Climate scenario	Timeframe	Detection and attribution of current impact	Impact at 1 degree	Impact at 2 degrees	Impact at 3 degrees	Impact at 4 degrees	Impact at 4.5 degrees	Adaptation potential	Region (Including regional differences)
Schlesinger and Jasechko 2014	Vegetation changes	ratio of transpiration over evapotranspiration (%)	Changes in transpiration due to rising CO_2 concentrations, land use changes, shifting ecozones and climate warming	Review									Global
Song et al. 2018	Vegetation changes	Land change	60% of all recent land changes are associated with direct human activities whereas 40% with indirect drivers such as climate change	Remote Sensing	1982–2016		40% of land change from indirect drivers such as climate change						Global
McKee et al. 2004	Vegetation changes	Salt marsh dieback (ha)	Vegetation dieback and soil degradation	Areal and ground surveys	2000–2001		More than 100,000 ha affected, with 43,000 ha severely damaged						USA
Soil erosion													
Li and Fang 2016	Soil erosion	Soil erosion rates (t ha^{-1} yr^{-1})	More often than not studies project an increase in erosion rates (+1.2 to +1600%, 49 out of 205 studies project more than 50% increase)	Review	1990–2100	Indirectly: close links demonstrated regionally, no formal D&A	0–73.04						Global
Serpa et al. 2015	Soil erosion	Sediment export change in humid/dry catchment (%)	Decrease in streamflow (2071–2100)	SWAT + ECHAM SRES A1B and B1	1971–2000; 2071–2100			−22/+5%	−29/+222%				Mediterranean
Neupane and Kumar 2015	Soil erosion	Change in river flow	Dominant effect of LULCC	SWAT under SRES B1, A1B, A2	1987–2001; 2091–2100								Big Sioux River
Mullan et al. 2012	Soil erosion	Change in soil erosion	Erosion rates without land management changes would decrease by 2020s, 2050s and 2100s, dominant effect of land management	WEPP under SRES	2020s; 2050s; 2080s								Northern Ireland
Burt et al. 2016	Soil erosion	Extreme precipitation indices	Soil erosion may increase in a warmer, wetter world, yet land management is first-order control.	Commentary	1900–2016								India
Capolongo et al. 2008	Soil erosion	Climate erosivity	Influence on soil erosion in Mediterranean	Simplified rainfall erosivity model	1951–2000								Mediterranean
Bärring et al. 2003	Soil erosion	Wind erosion	No clear trend in wind erosion	Review	1901–2000								Sweden
Munson et al. 2011	Soil erosion	Wind erosion	Enhanced wind erosion	Wind erosion model	1989–2008								USA
Allen and Breshears 1998	Soil erosion	Water erosion	Increased water erosion	Observations	1950–1990								USA
Shakesby 2011	Soil erosion	Water erosion	Water erosion after wildfire not notably distinct in Mediterranean, likely due to land use effects	Review									Mediterranean

Reference	Risk	Variable (unit)	Direction of impact	Climate scenario	Timeframe	Detection and attribution of current impact	Impact at 1 degree	Impact at 2 degrees	Impact at 3 degrees	Impact at 4 degrees	Impact at 4.5 degrees	Adaptation potential	Region (Including regional differences)
Pruski and Nearing 2002	Soil erosion	Water erosion	Complex interactions between several factors that affect erosion	HadCM3	1990–2099								USA
Jiang et al. 2014	Soil erosion	Soil erosion rates (t ha^{-1} yr^{-1})	No significant change in soil erosion during one decade	Revised Universal Soil Loss Equation (RUSLE)	2000; 2006; 2012								Mount Elgon
Vanmaercke et al. 2011	Soil erosion	Sediment yield	High sediment yield indicates desertification	Review									Europe
Vanmaercke et al. 2016	Soil erosion	Volumetric gully headcut retreat rate change (%)	Increase in headcut retreat rates	Gully headcut retreat sensitivity to climate			Gully erosion already forms an important problem in many regions		plus 27–300%				Global
de Vente et al. 2013	Soil erosion	Soil erosion and sediment yield	Importance of spatial and temporal scales when considering erosion processes.	Review									Global
Broeckx et al. 2018	Soil erosion	Landslide susceptibility	Precipitation not a significant driver of landslide susceptibility, but is significant in non-arid climates	Review									Africa
Gariano and Guzzetti 2016	Soil erosion	Landslide susceptibility	Increase in the number of people exposed to landslide risk in regions with future enhanced frequency and intensity of severe rainfall events	Review									Global
Water scarcity in drylands													
IPCC 2014	Water scarcity	Drough		Observations	Historical	High confidence in observed trends in some regions of the world, including drought increases in the Mediterranean and West Africa and drought decreases in central North America and northwest Australia							
Hoegh-Guldberg et al. 2018	Water scarcity	Drought		Observations	Historical	Medium confidence that greenhouse forcing has contributed to increased drying in the Mediterranean region (including southern Europe, northern Africa and the Near East)							
Greve and Seneviratne 2015	Water scarcity	P-ET (mm)	Generally a decrease in P-ET in dryland regions but not statistically significant	RCP8.5	2080–2099 compared to 1980–1999								Global
Byers et al. 2018	Water scarcity	Water stress index (population exposed and vulnerable in drylands, in millions and in percentage of drylands population)	Increased water stress with temperature	Time sampling approach using a combination of RCPs	2050			391 (11%)	418 (12%)				Drylands particularly impacted, including southwestern North America, southeastern Brazil, northern Africa, the Mediterranean, the Middle East, and western, southern and eastern Asia

Reference	Risk	Variable (unit)	Direction of impact	Climate scenario	Timeframe	Detection and attribution of current impact	Impact at 1 degree	Impact at 2 degrees	Impact at 3 degrees	Impact at 4 degrees	Impact at 4.5 degrees	Adaptation potential	Region (Including regional differences)
Hanasaki et al. 2013	Water scarcity	Percentage of population under severely water-stressed conditions based on Cumulative Abstraction to Demand ratio CAD≤0.5	Increase with time and RCP	RCP2.6, 4.5, 8.5	(2071–2100 compared to 1971–2000			3.6% – 12%	6.2% – 16%		12.3% – 22.4%		Global
Huang et al. 2017	Impact of temperature increase	Temperature	Higher temperature increase in drylands compared to rest of the world					44% more warming over drylands than humid lands					Drylands / global
Zeng and Yoon 2009	Increase desert area	Expansion of desert area (i.e. LAI less than 1)	Increase in desert area	A1B	2099 compared to 1901						2.5 million km^2 (10% increase)/ with vegetation-albedo feedback: +8.5 million km^2 (34% increase)		Drylands / global
Liu et al. 2018	Water scarcity	Increase in population exposed to severe drought	Increase in exposed population globally	Time sampling approach at 1.5 and 2 degree				1,94.5±276.5 million					Global
Naumann et al. 2018	Water scarcity	Drought magnitude	Increase in drought magnitude	Time sampling approach at 1.5 and 2 degree				Doubling of drought magnitude for 30% of global landmass					Global
Schewe et al. 2014	Water scarcity	River runoff as a proxy for water resources	Increase in population confronted to water scarcity	RCP8.5				Severe reduction in water resources for about 8% of the global population	Severe reduction in water resources for about 14% of the global population				Global
Haddeland et al. 2014	Irrigation water scarcity	Percentage of population under worsened water-stressed conditions based on Cumulative Abstraction to Demand ratio	Irrigation water scarcity increases with temperature in most regions										Global

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Table SM7.2 | Literature considered in the expert judgement of risk transitions for figure 7.2.

Reference	Risk	Variable (unit)	Climate scenario	Timeframe	GMST level	Direction of impact	SSP1	SSP2	SSP3	SSP4	SSP5	Region (Including Regional Differences)
Food security												
Palazzo et al. 2017	Food availability	Percent deviation from 2010 Kilocalorie	RCP8.5	2050		Increase	Up to 30%		Only up to 10%			West Africa
Hasegawa et al. 2018	Change in crop yield combined with exposure and vulnerability based on prevalence of the undernourishment (PoU) concept	Population at risk of hunger (million)	RCP2.6	2050		Increasing population at risk of hunger	Approx. 2 million	Approx. 5 million	Approx. 24 million			Sub-Saharan Africa and South Asia have highest impacts
Hasegawa et al. 2018	Change in crop yield combined with exposure and vulnerability based on prevalence of the undernourishment (PoU) concept	Population at risk of hunger (million)	RCP6.0	2050		Increasing population at risk of hunger	Approx. 5 million (0–30 million) (RCP to GMT conversion based on SM SR15 ch3)	24 million (2–56million) (RCP to GMT conversion based on SM SR15 ch3)	Approx. 80 million (2–190 million)			Sub-Saharan Africa and South Asia have highest impacts
Byers et al. 2018	Crop yield change	Crop yield change (Number of exposed and vulnerable people)	time sampling approach using a combination of RCPs	2050	1.5		2	8	20			
Byers et al. 2018	Crop yield change	Crop yield change (Number of exposed and vulnerable people)	time sampling approach using a combination of RCPs	2050	2		24	81	178			
Byers et al. 2018	Crop yield change	Crop yield change (Number of exposed and vulnerable people)	time sampling approach using a combination of RCPs	2050	3		118	406	854			
Wiebe et al. 2015	Economic access	% change in price	RCP4.5	2050		Increase in price	~3% to ~17% (interquartile range)					
Wiebe et al. 2015	Economic access	% change in price	RCP6.0	2050		Increase in price		0 to ~12% increase (interquartile range)				
Wiebe et al. 2015	Economic access	% change in price	RCP8.5	2050		Increase in price			~5% to 30% (interquartile range), median by crop varies from 10% to 30%; restricting trade increases effects			
van Meijl et al. 2018	Crop production	% change in production	RCP6.0	2050		Decrease in production	2–3% decline		1–4% decline			
van Meijl et al. 2018	Economic access	% change in price	RCP6.0	2050		Increase in price	Up to 5%		Up to 20%			
Ishida et al. 2014	Undernourishment	DALYs attributable to childhood underweight (DAtU)	Used RCP 4.5 for BAU	2050 compared to 2005		Generally decrease in undernourishment	Health burden decreases by 36.4 million DALYS by 2030 and to 11.6 DALYS by 2050	Decrease by 30.4 DALYS by 2030 and 17.0 DALYS by 2050	Decrease by 16.2 DALYS by 2030 but increase to 43.7 by 2050			These are global statistics but there are regional differences. E.g. sub-Saharan Africa has higher DALYS
Ishida et al. 2014	Undernourishment	DALYs attributable to childhood underweight (DAtU)	Used RCP 2.6	2050 compared to 2005		Generally decrease in undernourishment, although there are some climate impacts	Difference in health burden of 0.2% compared to BAU	Difference of 0.5% in 2050 compared to BAU	Difference of 2.0% compared to BAU			These are global statistics but there are regional differences. E.g. sub-Saharan Africa has higher DALYS
Fujimori et al. 2018	Economic access	GDP loss	RCP8.5	2100		Decline in GDP	0%	0.04%	0.57% decrease in "GDP change rate"			
Springmann et al. 2016	Deaths due to changes in dietary and weight-related risk factors	Climate-related deaths	RCP2.6 to RCP8.5	2050			More avoided deaths compared to SSP2 and 3	Intermediate	Fewer avoided deaths			

Reference	Risk	Variable (unit)	Climate scenario	Timeframe	GMST level	Direction of impact	SSP1	SSP2	SSP3	SSP4	SSP5	Region (Including Regional Differences)
Land degradation												
Byers et al. 2018	Habitat degradation	Population (Million) exposed and vulnerable in relation to share of land area within a pixel being converted from natural land to agricultural land	Time sampling approach using a combination of RCPs	2050	1.5		88	88	107			Non-drylands only; data provided by authors
Byers et al. 2018	Habitat degradation	Population (Million) exposed and vulnerable in relation to share of land area within a pixel being converted from natural land to agricultural land	Time sampling approach using a combination of RCPs	2050	2		257	551	564			Non-drylands only; data provided by authors
Byers et al. 2018	Habitat degradation	Population (Million) exposed and vulnerable in relation to share of land area within a pixel being converted from natural land to agricultural land	Time sampling approach using a combination of RCPs	2050	3		652	1,068	1156			Non-drylands only; data provided by authors
Hinkel et al. 2014	Flooding and sea level rise, Coastal erosion	Number of people exposed to annual flooding		2100			Lowest number of people flooded		Highest number of people flooded			
Hinkel et al. 2014	Flood costs, Coastal erosion	Cost of flooding (% GDP)		2100		The global costs of protecting the coast with dikes are significant with annual investment and maintenance costs of US$ 12–71 billion in 2100, but much smaller than the global cost of avoided damages even without accounting for indirect costs of damage to regional production supply			Lowest costs under constant protection but highest under enhanced protection!		Highest costs under constant protection	
Zhang et al. 2018	Extreme precipitation	Population exposed to precipitation extremes (RX5day events exceeding 20-year return values)	Time sampling approach on RCP8.5 and RCP4.5	2100	2	Exposed population steadily increases with temperature, with only marginal differences between SSPs						
Knorr et al. 2016a	Fire	Exposure (number of people)	RCP4.5 transient	2071–2100 vs 1971–2000	2			560	646		508	Globally
Knorr et al. 2016a	Fire	Exposure (number of people)	RCP8.5 transient	2071–2100 vs 1971–2000	4			610	716		527	Globally
Knorr et al. 2016b	Fire	Emissions (Pg C yr^{-1})	RCP4.5 transient	2071–2100 vs 1971–2000	2			1.22	1.11		1.31	Globally
Knorr et al. 2016b	Fire	Emissions (Pg C yr^{-1})	RCP8.5 transient	2071–2100 vs 1971–2000	4			1.33	1.22		1.43	Globally
Desertification												
Zhang et al. 2018	Extreme precipitation	Population exposed to precipitation extremes (RX5day events exceeding 20-year return values)	Time sampling approach on RCP8.5 and RCP4.5	2100	2	Exposed population steadily increases with temperature, with only marginal differences between SSPs						
Byers et al. 2018	Water scarcity	Water stress index (2050); population exposed and vulnerable in drylands (Units: Million and percentage of drylands population)	Time sampling approach using a combination of RCPs	2050	1.5		76 (2%)	349 (10%)	783 (20%)			Dryland only: data provided by authors

7SM

Reference	Risk	Variable (unit)	Climate scenario	Timeframe	GMST level	Direction of impact	SSP1	SSP2	SSP3	SSP4	SSP5	Region (Including Regional Differences)
Byers et al. 2018	Water scarcity	Water stress index (2050); population exposed and vulnerable in drylands (Units: Million and percentage of drylands population)	Time sampling approach using a combination of RCPs	2050	2		82 (3%)	391 (11%)	864 (22%)			Dryland only: data provided by authors
Byers et al. 2018	Water scarcity	Water stress index (2050); population exposed and vulnerable in drylands (Units: Million and percentage of drylands population)	Time sampling approach using a combination of RCPs	2050	3		91 (3%)	418 (12%)	919 (24%)			Dryland only: data provided by authors
Arnell and Lloyd-Hughes 2014	Water scarcity	Numbers of people (millions) exposed to increased water resources stress	RCP2.6	2050			379–2,997	473–3,434	626–4,088	508–3,481	418–3,033	
Arnell and Lloyd-Hughes 2014	Water scarcity	Numbers of people (millions) exposed to increased water resources stress	RCP4.5	2050			810–2845	881–3,239	1,037–3,975	884–3,444	854–2,879	
Arnell and Lloyd-Hughes 2014	Water scarcity	Numbers of people (millions) exposed to increased water resources stress	RCP6	2050			759–2,668	807–3,054	924–3,564	809–3,227	803–2,682	
Arnell and Lloyd-Hughes 2014	Water scarcity	Numbers of people (millions) exposed to increased water resources stress	RCP8.5	2050			802–2,947	919–3,416	1,006–4,201	950–3,519	854–2,981	
Hanasaki et al. 2013	Water scarcity	Population living in grid cells with CAD < 0.5	RCP8.5	2041–2070					4,188–4,434 (baseline is ~2,000; all regions increase)			Global. Paper includes maps and graphs with regional information
Hanasaki et al. 2013	Water scarcity	Population living in grid cells with CAD < 0.5 (millions)	RCP6.0	2041–2070			2,853–3,043 (baseline is ~2,000; all regions increase)					Global. Paper includes maps and graphs with regional information
UNCCD, 2017	Mean species abundance, aridity; biodiversity, land degradation, water scarcity	Population living in drylands						43% increase				

Table SM7.3 | Literature considered in the expert judgement of risk transitions for Figure 7.3.

Reference	Risk	Variable	Climate scenario	SSP	Timeframe	Non-climatic hazard	Bioenergy area	Impacts	Notes
Humpenöder et al. 2017	Trade-offs with SDGs	Sustainability indicators: SDG 2; 7; 13; 14; 15	No climate change (consistent with strong mitigation)	SSP1	2100 compared to baseline without bioenergy	Bioenergy deployment	636Mha	Only slight impact on sustainability indicators i.e. no trade-offs due to lower food demand in SSP1 compared to baseline	
Humpenöder et al. 2017	Trade-offs with SDGs	Sustainability indicators: SDG 2; 7; 13; 14; 15	No climate change (consistent with strong mitigation)	SSP2	2100 compared to baseline without bioenergy	Bioenergy deployment	636Mha	Pronounced decrease in all sustainability indicators (i.e. increase in adverse side-effects) compared to case without bioenergy	
Humpenöder et al. 2017	Trade-offs with SDGs	Sustainability indicators: SDG 2; 7; 13; 14; 15	No climate change (consistent with strong mitigation)	SSP5	2100 compared to baseline without bioenergy	Bioenergy deployment	636Mha	Pronounced decrease in all sustainability indicators (i.e. increase in adverse side-effects) even more severe than in SSP2	

Reference	Risk	Variable	Climate scenario	SSP	Timeframe	Non-climatic hazard	Bioenergy area	Impacts	Notes
Heck et al. 2018	Planetary boundaries transgression	Planetary Boundaries (PBs): biosphere integrity; land-system change; biogeochemical flows; freshwater use	RCP2.6	SSP1	2050 compared to baseline without bioenergy	Bioenergy deployment	870Mha	Upper limit of most PBs is transgressed implying high risk of irreversible shifts	
Heck et al. 2018	Planetary boundaries transgression	Planetary Boundaries (PBs): biosphere integrity; land-system change; biogeochemical flows; freshwater use	RCP2.6	SSP2	2050 compared to baseline without bioenergy	Bioenergy deployment	778Mha	Upper limit of most PBs is transgressed implying high risk of irreversible shifts	
Boysen et al. 2017	Food production	Kcal cap^{-1} day^{-1} production loss (%); N application (Mt yr^{-1})	4.5°C trajectory	NA	2100	Bioenergy deployment	1,078Mha	–43%; 96 Mt yr^{-1}	
Boysen et al. 2017	Food production	Kcal cap^{-1} day^{-1} production loss (%); N application (Mt yr^{-1})	4.5°C trajectory	NA	2100	Bioenergy deployment	2,176Mha	–73%; 151 Mt yr^{-1}	
Boysen et al. 2017	Food production	Kcal cap^{-1} day^{-1} production loss (%); N application (Mt yr^{-1})	4.5°C trajectory	NA	2100	Bioenergy deployment	4,267Mha	–100%; 196 Mt yr^{-1}	
Hasegawa et al. 2018	Population at risk of hunger	Population at risk of hunger (million)	RCP2.6	SSP1	2050 compared to baseline	Mitigation policies (including bioenergy)	262Mha (106–490) (provided by authors)	Approx. +25 million	
Hasegawa et al. 2018	Population at risk of hunger	Population at risk of hunger (million)	RCP2.6	SSP2	2050 compared to baseline?	Mitigation policies (including bioenergy)	752Mha (175–1,904) (provided by authors)	Approx. +78 million (0–170)	
Hasegawa et al. 2018	Population at risk of hunger	Population at risk of hunger (million)	RCP2.6	SSP3	2050 compared to baseline?	Mitigation policies (including bioenergy)	813Mha (171–1,983) (provided by authors)	Approx. +120 million	
Fujimori et al. 2018	Population at risk of hunger	Population at risk of hunger (million)	RCP2.6	SSP1	2050 compared to baseline	Mitigation policies (including bioenergy)	90Mha	Approx. +20 million	
Fujimori et al. 2018	Population at risk of hunger	Population at risk of hunger (million)	RCP2.6	SSP2	2050 compared to baseline	Mitigation policies (including bioenergy)	170Mha	Approx. +100 million	
Fujimori et al. 2018	Population at risk of hunger	Population at risk of hunger (million)	RCP2.6	SSP3	2050 compared to baseline	Mitigation policies (including bioenergy)	220Mha	Approx. +260 million	
Obersteiner et al. 2016	Agricultural water use	Km^3		SSP1	2030	Bioenergy	210Mha	Approx. +13km^3	
Obersteiner et al. 2016	Agricultural water use	Km^3		SSP2	2030	Bioenergy	210Mha	Approx. +12km^3	
Obersteiner et al. 2016	Agricultural water use	Km^3		SSP3	2030	Bioenergy	210Mha	Approx. +11km^3	
Hejazi et al. 2014	Bioenergy water withdrawal	Km^3		SSP3	2050	Bioenergy	150Mha	Approx. +300km^3	Paper uses a pre-cursor to the SSP3, with a similar population and storyline
Hasegawa et al. 2015	Population at risk of hunger	Population	RCP2.6	SSP2	2050	Bioenergy	280Mha	Approx. +2 million	
Fujimori et al. 2019	Population at risk of hunger	Population	No climate; but assessed in SM as small effect	SSP2	2050	Bioenergy	38–395Mha	Approx. 25–160 million	Difference between 1.5°C scenario and Baseline for both bioenergy and impact. Total population at risk of hunger is ~300 to >500 million; total increase in population at risk of hunger is 50 to 320 M. Authors state that roughly half is attributed to bioenergy; those numbers are included here
Fujimori et al. 2019	Population at risk of hunger	Population	No climate; but assessed in SM as small effect	SSP2	2050	Bioenergy	43–225Mha	Approx. 20–145 million	Difference between 2°C scenario and Baseline for both bioenergy and impact. Total population at risk of hunger is ~290 to ~500 million; total increase in population at risk of hunger is 40 to 290 M. Authors state that roughly half is attributed to bioenergy; those numbers are included here

Table SM7.4 | Risks thresholds for different components of desertification, land degradation and food security as a function of global mean surface temperature change relative to pre-industrial times. The confidence levels are defined according to the IPCC guidance note on consistent treatment of uncertainties (Mastrandrea et al., 2010). These data are used in Figure 7.1.

Component	Risk Transition	Global mean surface temperature change above pre-industrial levels °C		Confidence
Low Latitude Crop Yield	Undetectable to Moderate	Min	0.5	High
		Max	0.7	
	Moderate to High	Min	1.2	Medium
		Max	2.2	
	High to Very High	Min	3.0	Medium
		Max	4.0	
Food Supply Stability	Undetectable to Moderate	Min	0.75	High
		Max	0.85	
	Moderate to High	Min	0.9	Medium
		Max	1.4	
	High to Very High	Min	1.5	Medium
		Max	2.5	
Permafrost Degradation	Undetectable to Moderate	Min	0.3	High
		Max	0.7	
	Moderate to High	Min	1.1	High
		Max	1.5	
	High to Very High	Min	1.8	Medium
		Max	2.3	
Vegetation Loss	Undetectable to Moderate	Min	0.7	High
		Max	1.0	
	Moderate to High	Min	1.6	Medium
		Max	2.6	
	High to Very High	Min	2.6	Medium
		Max	4.0	
Coastal Degradation	Undetectable to Moderate	Min	0.8	High
		Max	1.05	
	Moderate to High	Min	1.1	High
		Max	1.6	
	High to Very High	Min	1.8	High
		Max	2.7	
Soil Erosion	Undetectable to Moderate	Min	0.8	Medium
		Max	1.2	
	Moderate to High	Min	2.0	Low
		Max	3.5	
	High to Very High	Min	4.0	Low
		Max	6.0	
Fire	Undetectable to Moderate	Min	0.7	High
		Max	1.0	
	Moderate to High	Min	1.3	Medium
		Max	1.7	
	High to Very High	Min	2.5	Medium
		Max	3.0	

Component	Risk Transition	Global mean surface temperature change above pre-industrial levels °C		Confidence
Water Scarcity in Drylands	Undetectable to Moderate	Min	0.7	High
		Max	1.0	
	Moderate to High	Min	1.5	Medium
		Max	2.5	
	High to Very High	Min	2.5	Medium
		Max	3.5	
Food Access	Undetectable to Moderate	Min	0.8	Medium
		Max	1.1	
	Moderate to High	Min	1.4	Low
		Max	2.4	
	High to Very High	Min	2.4	Low
		Max	3.4	
Food Nutrition	Undetectable to Moderate	Min	1.1	Low
		Max	1.7	
	Moderate to High	Min	1.9	Low
		Max	2.2	
	High to Very High	Min	2.3	Low
		Max	3.3	

SM7.2 Additional embers

Details of two embers (nutrition and coastal degradation) were not included in Chapter 7 due to space limitations. Changes in atmospheric CO_2, will result in reduced nutritional value of crops (iron, protein, zinc, other micronutrients, and increases in mycotoxins), impacting food utilization, with potential risks to health of vulnerable groups such as children and pregnant women (*high confidence, high agreement*). This may create nutrition-related health risks for 600 million people (Zhou et al. 2018). Further details are provided in Chapter 5 of this Report.

Coastal flooding and degradation bring risk of damage to infrastructure and livelihoods. There are very few global studies investigating past changes in coastal degradation (erosion and flooding) and associated risk (Muis et al. 2018; Mentaschi et al. 2018), yet strong evidence exists that anthropogenic climate change is already affecting the main drivers of coastal degradation, including: mean and extreme sea level (IPCC 2013), storm surges (Wahl et al. 2015) and tropical cyclones (Kossin 2018). It is also clear that land-based processes, such as groundwater extraction and land subsidence, may impact coastal degradation {See Chapter 4, including 4.8.5}.

At 1.5°C there is a high risk of destruction of coastal infrastructure and livelihoods (Hoegh-Guldberg et al. 2018) (*high confidence*). There is an associated strong increase in people and assets exposed to mean and extreme sea level rise and to coastal flooding above 1.5°C. Very high risks start to occur above 1.8°C (*high confidence*) (Hanson et al. 2011; Hallegatte et al. 2013; Vousdoukas et al. 2017; Jevrejeva et al. 2018). Impacts of climate change on coasts is further explored in the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.

SM7.3 SSP and Mitigation Burning Embers

Table SM7.5 | Risks thresholds associated to desertification, land degradation and food security as a function of Global mean surface temperature change relative to pre-industrial levels and socio-economic development. Risks associated to desertification include, population exposed and vulnerable to water scarcity and changes in irrigation supply and demand. Risks related to land degradation include vegetation loss, population exposed to fire and floods, costs of floods, extent of deforestation, and ecosystem services including the ability of land to sequester carbon. Risks to food security include population at risk of hunger, food price increases, disability adjusted life years. The risks are assessed for two contrasted socio-economic futures (SSP1 and SSP3) under unmitigated climate change up to 3°C. These data are used in Figure 7.2.

Component	Risk Transition	Global mean surface temperature change above pre-industrial levels °C		Confidence
Land Degradation (SSP1)	Undetectable to Moderate	Min	0.7	High
		Max	1.0	
	Moderate to High	Min	1.8	Low
		Max	2.8	
	High to Very High	Min		Does not reach this threshold
		Max		
Land Degradation (SSP3)	Undetectable to Moderate	Min	0.7	High
		Max	1.0	
	Moderate to High	Min	1.4	Medium
		Max	2.0	
	High to Very High	Min	2.2	Medium
		Max	2.8	
Food Security (SSP1)	Undetectable to Moderate	Min	0.5	Medium
		Max	1.0	
	Moderate to High	Min	2.5	Medium
		Max	3.5	
	High to Very High	Min		Does not reach this threshold
		Max		
Food Security (SSP3)	Undetectable to Moderate	Min	0.5	Medium
		Max	1.0	
	Moderate to High	Min	1.3	Medium
		Max	1.7	
	High to Very High	Min	2	Medium
		Max	2.7	
Desertification (SSP1)	Undetectable to Moderate	Min	0.7	High
		Max	1.0	
	Moderate to High	Min		Does not reach this threshold
		Max		
	High to Very High	Min		Does not reach this threshold
		Max		
Desertification (SSP3)	Undetectable to Moderate	Min	0.7	High
		Max	1.0	
	Moderate to High	Min	1.2	Medium
		Max	1.5	
	High to Very High	Min	1.5	Medium
		Max	2.8	

Table SM7.6 | Risk thresholds associated with 2nd generation bioenergy crop deployment (in 2050) as a land-based mitigation strategy under two SSPs (SSP1 and SSP3). The assessment is based on literature investigating the consequences of bioenergy expansion for food security, ecosystem loss and water scarcity, these indicators being aggregated as a single risk metric. These data are used in Figure 7.3.

Component	Risk Transition	Land area used for bioenergy crop (Mkm^2)		Confidence
Risk due to bioenergy deployment (SSP1)	Undetectable to Moderate	Min	1	Medium
		Max	4	
	Moderate to High	Min	6	Low
		Max	8.7	
	High to Very High	Min	8.8	Medium
		Max	20	
Risk due to bioenergy deployment (SSP3)	Undetectable to Moderate	Min	0.5	Medium
		Max	1.5	
	Moderate to High	Min	1.5	Low
		Max	3	
	High to Very High	Min	4	Medium
		Max	8	

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