Chapter 12: Central and South America
Supplementary Material

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SM12.1 Characterization of Subregions

Table SM12.1: Characterization of subregions.

Sub-region	Countries and territories included	Climate	Geography and biodiversity	Economy	Demography (urban/rural population distribution)	Human development/ inequality
Central America (CA)	Guatemala, Belize, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama	The humid and rainy climate of CA results from high temperatures and its location between the Pacific Ocean and the Caribbean Sea in the Atlantic, providing abundant rainfall throughout most of the territory (higher than 5 m yr^{-1} in some areas). The rain shadow effect by the mountains enables a tropical dry forest (precipitation as low as 400 mm yr^{-1} and 7-month dry seasons in some areas) on the Pacific side of CA from Guatemala to northern Costa Rica locally known as the "dry corridor" (van der Zee et al., 2012).	The Sierra Madre mountain range and the chain of volcanoes generate a topography that crosses the entire isthmus resulting in a wide range of microclimates. This, in turn, enables a very high biodiversity (both Guatemala and Costa Rica have been declared mega diverse countries) estimated to have 12% of the planet's biodiversity in 2% of its territory (Programa Estado de la Nación - Estado de la Región, 2016).	The region, except Panama and Costa Rica, has low socio-economic indicators, particularly in the rural areas. In 2014, 59% of the population had at least one basic needs unsatisfied (Programa Estado de la Nación - Estado de la Región, 2016). The economy relies heavily (2/3 of the GDP) on the service sector (e.g., commerce, financial intermediaries) export cash crops (e.g., sugar, coffee, and bananas), and subsistence small farming. Remittances represent 10–20 percent of the GDP of Guatemala, Honduras and El Salvador (NU CEPAL, 2018).	The population is 47 million people, with Guatemala having the largest population (1/3 of Central America) and metropolitan area, Guatemala City, with around 3 million people. Urban population is 45-60% in Belize, Guatemala, Honduras and Nicaragua; and 72%-80% in El Salvador, Panamá and Costa Rica. Population density ranges from 37 persons km^{-2} in Belize to 302 persons km^{-2} in El Salvador. (Programa Estado de la Nación - Estado de la Región, 2016; ECLAC, 2019).	Costa Rica and Panama's high development index, largest GDP per capita and lowest poverty rates in the region are due to an industry- and commerce-based economy. Still, poverty in CA is higher than in SA, particularly in Guatemala and Honduras with high inequality and overall poverty rates approaching 60% and reaching 79% in rural areas and among Indigenous Peoples (NU CEPAL, 2018; ECLAC, 2019).
Northwest South America (NWS)	Colombia, Ecuador, and Peru	El Niño Southern Oscillation (ENSO) is the dominant	The sub-region encompasses the coastal lowlands, the	The economy is largely dependent on exports of metals, oil,	NWS includes the capital cities of Bogota, Quito and	The sub-region shows high poverty (22% Ecuador and Peru,

		phenomenon affecting weather conditions particularly along the Pacific Coast of NWS with effects of heavy rains, storms, floods, landslides, heat and cold waves and extreme sea level (Ashok et al., 2007) The eastern flank of the tropical Andes is the wettest region in the Amazonia. One of the rainiest places on Earth is situated alongside the Pacific coast of NWS, witnessing mean annual precipitation rates reaching 13,000 mm. The Chocó low-level-jet is a singular southwesterly circulation feature acting over the easternmost tropical Pacific and is enhanced by atmosphere-ocean-land surface interactions over the Pacific coast (Espinoza et al., 2020) .	Andes and the upper Amazon basin from the Colombian Caribbean to southern Peru. The tropical location, the altitudinal gradient and the cold and warm ocean currents converging at the Equator, contribute to a high biological, agricultural, and climatic diversity, including three biodiversity hotspots: Tropical Andes, Western Amazonia and Tumbes-Choco-Magdalena (Myers et al., 2000; Mittermeier et al., 2011). The region is the centre of domestication of cocoa, potatoes, coca, camelids, among other useful products. Frequent volcanic eruptions and earthquakes are natural threats.	coal, gas, fisheries, shrimp, banana, cocoa, coffee, flower crops, cattle, forest products, among others, and illicit crops such as coca and poppy, although their contribution to economy is hard to quantify (Vallejo, 2015; The World Bank, 2019). Remittances from migrants abroad and tourism are important for the economy. There are millions of small farmers and fishermen that provide food for local markets. Industry is more developed and large in Colombia and Peru. A growing hydropower, and oil, are the main sources of energy.	Lima, and big cities like Medellin, Cali and Guayaquil. The sub-region has a rampant urbanization, up to 70% in Ecuador and >80% in Peru and Colombia by 2021 (CELADE, 2019). Of the more than 5 million Indigenous Peoples, the Quechua is the largest group (Sichra, 2009).	27% Colombia in 2017) and inequality (Gini 0.44 Ecuador, 0.45 Peru, 0.51 Colombia in 2014) indicators (ECLAC, 2019).
North South America (NSA)	Colombia, Venezuela, Guyana, Suriname,	According to Köppen-Geiger's global climate map,	The sub-region extends north-south from the Caribbean	Agriculture (mainly cattle for beef and soy) and mining (oil,	Brazil and Venezuela are the most populated countries of	Brazil presents the highest Gini inequality coefficient

	French Guiana[1], and Brazil	the subregion is characterized by a tropical climate with three subtypes: Af (Tropical rainforest), Am (Tropical monsoon) and Aw (Tropical savannah) (Kottek et al., 2006; Peel et al., 2007; Beck et al., 2018; Cui et al., 2021). The annual precipitation cycle is bimodal and Its spatio-temporal variability is governed by the meridional migration of the intertropical convergence zone (Almazroui et al., 2021). However, local low-level jet structures controlled by thermal gradients and orography are key elements for regional atmospheric moisture transfer and for the definition of local precipitation patterns (Poveda et al., 2006; Durán-Quesada et al., 2012; Sierra et al., 2015; Hoyos et al., 2019). The main source of moisture for the NSA is the Atlantic Ocean. Its seasonal pattern is	and Atlantic coasts to Northern Amazonia; encompassing part of the Andes the Brazilian and Guyana Shields, and wide areas of floodplains along the major rivers (Amazon, Orinoco and Rio Negro) (IPBES, 2018). The sub-region harbours high biodiversity with high degree of endemism, including the Venezuelan tropical Andes, a recognized biodiversity hotspot (Brooks et al., 2006; da C Jesus et al., 2009; Hoorn et al., 2010; Zador et al., 2015; Barlow et al., 2018).	bauxite and gold) are the main economic activities in NSA. However, wholesale and retail trade, tourism, hydropower energy production, communication, among others also contribute with the GDP of the sub-region.	the sub-region. Brazil's demographic density within NSA is very low (less than 1 person km^{-2}) in forested areas, in contrast to large and dense urban centres such as Manaus and Belem with 2-3 million inhabitants (IBGE, 2016; Tritsch and Le Tourneau, 2016). The highly deforested areas have lost 20 to 24% of its population in the period from 2000 to 2010 (Tritsch and Le Tourneau, 2016), inflating the urban centres in the region. There is an important percentage of Indigenous Peoples mostly settled in the forest (Minea, 2017).	(0.54), followed by Suriname (0.528), Venezuela (0.434) and Guyana (0.432). (UNDP, 2010; Hellebrandt and Mauro, 2015).

		determined by the dynamics of easterly winds flowing over this Ocean, which, when interacting with the Andes orographic barrier, give rise to the South American low-level jet that transports water vapour and contributes to the atmospheric humidity of the Amazon (Durán-Quesada et al., 2012; Sierra et al., 2015; Bovolo et al., 2018).The interannual variability of precipitation and hydroclimatic extremes in the subregion are also governed by the El Niño Southern Oscillation (ENSO) phenomenon. The main hydroclimatic effects include drier atmospheric phases during the El Niño stage and wetter ones during the La Niña stage (Durán-Quesada et al., 2012; Hoyos et al., 2019).				
South America Monsoon (SAM)	Peru, Brazil and Bolivia	The sub-region is characterized by tropical climate - with	Most of the area lies in Brazilian territory, including areas in	The area in Bolivia and Brazil faces, particularly in the last	The region is home for more than 50 million people and	The region faces large inequalities in socio-economic conditions,

		mean annual temperature above 18 ºC and mean annual precipitation of 2.2 m, with high spatial variation. Marked precipitation seasonality and short, or absent, dry season, is observed. Changes in surface cover (from native vegetation to pasture and crops) lead to changes in sensible heat fluxes, evapotranspiration and surface temperature, leading to temperature increase higher than the global average, up to 5ºC (Dias et al., 2015; Panday et al., 2015; Silvério et al., 2015; Spera et al., 2016; Coe et al., 2017).	Bolivia and part of the Peruvian Amazon. The natural vegetation varies from dense tropical humid forest, to flood lands, grasslands and savannahs. In Brazil, the most important biome within this area is the Cerrado (~2 million km^2) and Pantanal (~150,000 km^2). Both are highly diverse systems, with Cerrado being a hotspot of biodiversity; Pantanal, the largest flooded ecosystem in the globe, also covers part of Bolivia.	20 years, intense rates of deforestation and consequent increase in production of agricultural commodities (soy, corn, sugar cane, meat and wood products). The region is an important food supplier to the European and Asian markets (Strassburg et al., 2014; Henders et al., 2015).	home to multiple Indigenous Peoples in Bolivia and in the Peruvian and Brazilian Amazon. In Brazil, the population in the area is about 13 million people, with 80% living in cities. In 13% of the area, the population density is close to 18 person's km^{-2}, but in 87% of the area, the density goes from 2 to 5 person's km^{-2}.	especially in the areas of agriculture frontier (Strassburg et al., 2014; Moutinho et al., 2016; Martinelli et al., 2017). There is widespread deforestation in the region in the so-called "Arc of Deforestation" (Brondízio et al., 2016).
Northeast South America (NES)	Brazil	NES's socio-ecological systems are strongly controlled by rainfall seasonality, with an extended dry period and recurrent severe drought events (Marengo et al.,	It is a predominantly semi-arid region covered by seasonally dry tropical forest and woodlands (known as Caatinga) in its hinterland, with some localized, discontinuous strips of humid tropical	The region's formal economy is based mostly on public services (e.g., pensions and government expenditures), followed by a modest contribution of agriculture, which is	NES is home to about 60 million people, most living in urban areas and with high poverty levels (estimate for 2019 from the Brazilian Institute of Geography and Statistics (IBGE),	Despite significant improvements in the last decade, it is still the region with the lowest human development index in Brazil (Vieira et al., 2015; Silva et al., 2017).

		2017b; Silva et al., 2017).	forest at the coast (known as Atlantic Forest) (Silva et al., 2017). Being an arid region, it is expected to have low biodiversity levels, but it is a particularly understudied region. Recent surveys are showing that it is more biologically diverse than previously thought (Silva et al., 2017). The Caatinga has already lost most of its original vegetation cover and what remains is poorly protected (CNUC and MMA, 2020; Souza et al., 2020).	mostly for subsistence, and the industry, scattered mostly in major urban centres along the coast (Silva et al., 2017).	https://cidades.ibge.gov.br/) (Silva et al., 2017).	
Southeast South America (SES)	Bolivia, Paraguay, Brazil, Uruguay and Argentina	In this densely populated, highly productive sub-region, climatic conditions are strongly tied to ENSO, whose influence is moderated by local air-sea thermodynamics in the South Atlantic (WGI AR6 Atlas).	The Brazilian Atlantic Forest, in northern SES, is one of the World's biodiversity hotspots (Myers et al., 2000). Biological diversity in SES decreases towards the south, with moderate levels in the Chaco and low diversity in Patagonia (Pimm et al., 2014). The La Plata basin is a rich	Agriculture and livestock production constitutes a large sector of SES economy, with large, export-oriented, capital-intensive farms coexisting with small, labour-intensive, subsistence farms (OECD and FAO, 2019). Most of SES region's renewable electricity	More than 90% of the population live in urban areas, mostly in coastal areas. Only Paraguay and Bolivia still have about 30 to 40% rural population (https://ourworldindata.org/urbanization). SES has some of the most populous cities in South America, such as São Paulo and Rio de Janeiro in	The region has experienced a growth in GDP. In particular, Paraguay and Bolivia grew at a GDP growth rate around 4.2% (https://www.worldometers.info/gdp/gdp-by-country/), but inequalities are still important (Inequality-adjusted HDI around 0.54)

		Other main atmospheric circulation features are driven by both sub-tropical Atlantic and Pacific anticyclones, the "Chaco" continental orographic–dynamic–thermal low, the easterlies naturally deflected by the Andes orography towards the south-east and south into subtropical latitudes producing a north–south low-level jet. (Collazo et al., 2019).	hydrology region that supplies water to the plains biome of South America, the most important grazing and cropland areas in the continent. The Guarani Aquifer, located beneath the surface of Argentina, Brazil, Paraguay and Uruguay, is the second largest known aquifer system in the world (Foster et al., 2006).	comes from hydrological power (Irena Agency, 2016). There is a north-south gradient in economic development, from São Paulo State in Brazil, arguably the largest economic and industrial hub in South America, to Chaco and Patagonia in the south, recognized as wilderness areas (Mittermeier et al., 2003).	Brazil and Buenos Aires in Argentina (UNDESA, 2019).	(http://hdr.undp.org/en/countries). Less than 10% of the working force is employed in the rural sector. The needs of the urban poor are largely neglected increasing their vulnerability to changes in economic conditions and natural hazards (Almansi et al., 2010; Hardoy and Almansi, 2011).
Southwest South America (SWS)	Peru, Chile, Bolivia and Argentina	This subtropical area presents a variety of sub-climates: arid, semiarid, Mediterranean and temperate. The climate and sub-climates present are influenced by the Pacific Ocean and the Andes. Water sources are mainly linked to the storage capacity of the mountain areas. The variety of climates is also reflected by the variety of ecosystems in the area, which are determined by	The region includes the hyper arid area of the Atacama Desert with a precipitation of less than 2 mm yr^{-1} (Ritter et al., 2019); the semiarid area with sclerophyllous ecosystems; the Mediterranean zone where large areas are allocated for agriculture; and the oceanic temperate area characterized by forest plantations and native forests.	The economy in the area is diverse in terms of productive sectors. While fisheries are present in all the sub areas; mining production is predominant in the hyper arid area; in the semiarid area presents mining and agriculture, and in the Mediterranean area, agriculture is the main economic activity. All activities are linked to natural resources. In this area, countries present an important proportion of fossil	Population in Peru is around 31 million, with more than half under 30 years of age. Peru is today a mostly urban country, with a great proportion of Indigenous Peoples living in urban areas, especially in the south of the country. Population in Chile is about 19 million, and the metropolitan area concentrates over 40%. Around 12% live in rural areas. The country experienced an intense immigration	Chile and Peru presented an important economic growth in the last decades, but inequity persists. Population living under the poverty line in Peru is 22.7% and in Chile is 14.4%. While there are interesting advances in poverty reduction in the area, the general socio-economic condition of households is vulnerable to external shocks.

		latitudinal gradient and topographic conditions.		fuel energy consumption.	process in the last decade.	
South America (SSA)	Chile and Argentina	The climate is mostly cool and dry, dominated by air masses coming from the Pacific Ocean. The region is located between the semi-permanent anticyclones of the Pacific and the Atlantic oceans. Most of the central portion of Patagonia receives less than 200 mm yr^{-1}, but with the highest precipitation in the western side of the Andes (5000–10,000 mm yr^{-1}) (Garreaud et al., 2013).	The sub-region corresponds to the Patagonia, including Andes Mountains, deserts, pampas, and grasslands to the east. It is a unique region with the presence of impressive ice fields and glaciers. The region has some of the most extensive wilderness areas on the planet. Natural grasslands comprise almost 30% of the Americas (White et al., 2000). Overgrazing for over 400 years has degraded the soils and reduced productivity (Piñeiro et al., 2006).	The main economic activities have been mining (coal, gold, silver), livestock (sheep), agriculture (crops and fruit near the Andes and valleys), and oil and gas. Traditionally, the region has exploited its hydroelectric potential by building big hydroelectric dams (Silva, 2016). Wind is a significant renewable energy source that is increasing.	Patagonia is a sparsely populated region of about 3 million people in 1,043,076 km^2 that determines a density of 3-inhabitant km^{-2} with a low proportion of inhabitants in rural zones.	The Human Development Index (HDI) of the Patagonia region in Argentina classifies the area as “very high” (HDI= 0.861) and with a Gini index of 0.379.

Table Notes:
[1]French Guiana is an overseas department of France.

SM12.2 Methodology for Figure 12.7: Vulnerability Index

SM12.2.1 Sectors Definition

Food systems: Includes the vulnerability of all components of agri-food systems to climate change, from the vulnerability of primary production to marketing systems taking into account the interactions between socio-economic, institutional and environmental systems.

Cities and infrastructure: This sector includes aspects such as population density, urban concentration, quality of infrastructure related to trade and transport, and the capacity of cities to provide services in the climate change context.

Population in poverty and their livelihoods: Refers to predisposition of the population living in poverty and their livelihoods to be negatively affected by climate change. It takes into account aspects such as income levels, equity, population density, GDP or GDP per capita, production levels, among other indicators that account for their adaptive capacities, as well as the exposure and sensitivity of their livelihoods to be affected by climate change

Water: Refers to predisposition of a system that provides water to be negatively affected by climate change. It takes into account indicators such as changes in annual runoff, groundwater recharge rate, water demand, population density, capacity to supply water, annual precipitation, temperature changes and others.

Health: Takes into account indicators such as change of length of transmission season of vector-borne diseases, change of deaths from climate change induced diseases, access to improved sanitation facilities and size and population density

Terrestrial and freshwater ecosystems: Refers to the predisposition of terrestrial, freshwater ecosystems, biodiversity, including ecosystem services, to be negatively affected by climate change. It takes into account indicators such as changes in species richness, changes in vegetation cover, changes in temperature and precipitation regimes, surface and number of protected areas and others.

SM12.2.2 Methodology

In order to evaluate the levels of vulnerability by sub-region and sector we conducted a literature search using the years between 2012 and 2020 in various academic search engines (Google scholar, Scopus, Science direct, and the webpages of relevant journals such as Nature, Science, Climate Science, Global change biology). Studies based on the vulnerability definition of AR4 that include exposure as a component of vulnerability were considered within the analysis as they were the majority available in the literature. Some studies using AR5 definition (which excludes exposure from vulnerability) were also considered. Studies that met the following criteria were selected for analysis: a) databases with climate change vulnerability indexes by country and sector; b) research papers that implements climate change vulnerability indexes by sector at the local, national, regional or global level; c) studies that define some level of vulnerability to climate change based on reviews, projections, and expert judgment of the authors and consequently assigned some degree of vulnerability for a given sector at different scales.

In order to combine different results and manage common vulnerability levels within the figure; we defined four levels of vulnerability ("Low", "Moderate", "High", "Very high") according to risk levels defined in AR5. These vulnerability levels were used to standardise the different indices. In the cases where the vulnerability indices were represented on maps and whenever possible, the figures in the different publications were georeferenced using the QGIS software. They were then combined with the layer of IPCC climatic regions in order to analyse the dominant level of vulnerability within each sub-region. This separation was made on the basis of expert judgement on the approximate areas occupied by each level of vulnerability within each sub-region. Given the scarce amount of literature that studies vulnerability levels, this analysis method allowed for the inclusion of valuable and relevant information in the development of the figure. In the studies where vulnerability was analysed without the implementation of indexes, the authors of these studies used a qualitative classification of vulnerability and this expert judgement was considered in order to establish the degree of vulnerability. This type of information is very relevant since it allows for comparison with data from other index-based studies.

The information standardised in this way was systematized in a database that includes vulnerability levels by sector at sub-region, country or locality scale. For cities, georeferenced locations were taken from a public ArcGIS database (https://hub.arcgis.com/datasets/magis::world-cities?geometry=-118.564%2C-29.382%2C118.564%2C29.382&layer=0). This information thus generated was merged with the IPCC map of climatic regions to determine the number of cities and population by sub-region in relation to their degree of vulnerability to climate change (Table SM12.2).

The information from the literature, and consequently the information included in the database, was generated at different scales. The attribution of the level of vulnerability by sector and sub-region using this information was carried out by expert judgement considering two criteria: 1) Number of cases in which a level of vulnerability is repeated in a sub-region and sector; 2) proportion of the area of the sub-region with each particular vulnerability level.

Confidence was attributed considering the agreement level and evidence quality, as established in the IPCC guidelines. Figure SM12.1 shows a summary of confidence level by sector and subregion of the climate change vulnerability assessment for CSA.

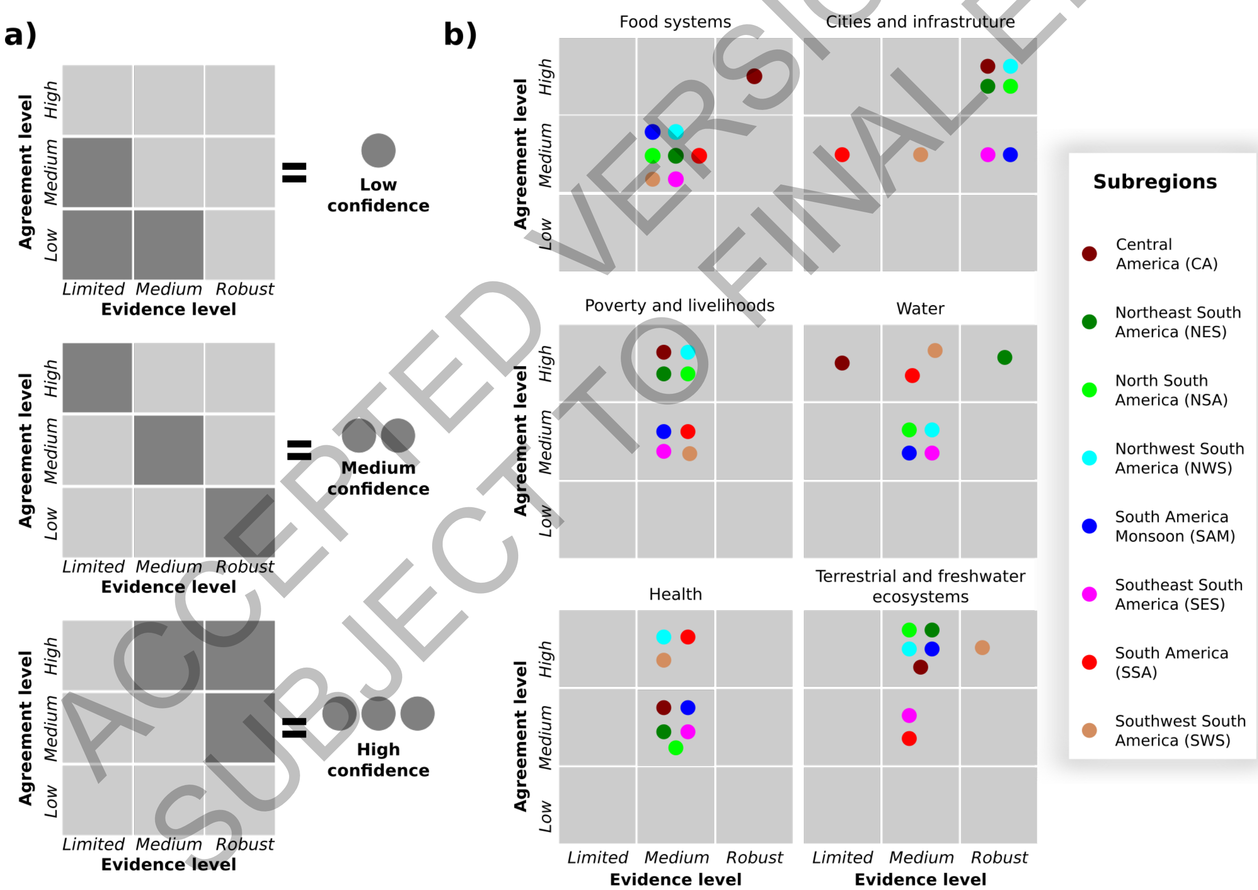

Figure SM12.1: Summary of confidence levels attributed by subregions and sectors. a) represents the criteria established to attribute confidence levels for the vulnerability figure; b) indicates the confidence levels attributed by sector and sub-region.

Table SM12.2: Vulnerability levels for Cities in CSA based on CAF (2014).

	IPCC SUB-REGIONS															
	NES		NSA		NWS		SAM		CA		SES		SSA		SWS	
Vulnerability level	Number cities assessed	million people living in cities assessed	Number cities assessed	million people living in cities assessed	Number cities assessed	million people living in cities assessed	Number cities assessed	million people living in cities assessed	Number cities assessed	million people living in cities assessed	Number cities assessed	million people living in cities assessed	Number cities assessed	million people living in cities assessed	Number cities assessed	million people living in cities assessed
Very high	4	5.08	24	8.15	32	26.09	6	1.85	68	10.52	14	5.38	-	-	-	-
High	14	23.18	24	7.52	29	6.34	8	3.43	17	2.43	39	44.16	2	0.09	4	1.93
Moderate	-	-	3	0.08	7	9.74	-	-	2	0.02	14	19.44	2	0.20	5	7.32
Low	-	-	-	-	-	-	-	-	-	-	-	-	1	0.06	4	0.82
TOTAL	18	28.26	51	15.75	68	42.17	14	5.28	87	12.97	67	68.98	5	0.35	13	10.07

Tables Notes
Cities population data comes from https://hub.arcgis.com/datasets/magis::world-cities?geometry=-118.564%2C-29.382%2C118.564%2C29.382&layer=0

SM12.3 Observed and Projected Ompacts on Oceans, Coastal Ecosystems, and Exclusive Economic Zones by Central and South America Subregions.

Table SM12.3: Climate change hazards: OW: Ocean warming | HW: Heatwaves | SLR: Sea level rise | P-ENSO: Precipitation changes modulate by ENSO | P-PDO: Precipitation changes modulated by Pacific Decadal Oscillation (PDO) | UI: Upwelling intensification | WI: Wind intensity changes | CV: Current velocity | P: Precipitation changes | WD: Wind direction changes | WI: Wind intensity changes | CC: Ocean current changes (intensification + displacement) | EV: Extreme events | WV-NAO: Increasing wave heights modulated by changes in North Atlantic Oscillation (NAO) | PP: Primary productivity changes | WVH: Increasing weight height | EV-ENSO: Extreme events related to ENSO

Observed Impacts* by CSA subregions attributed to climate change hazards	**Climate change projected Impacts** by CSA subregions**
Coral Reefs	
CA and NWS (2003 – 2015) (OW) • Lower abundance, coral cover and coral density • Lower coral diversity and richness • Changes in the coral community structure • Decline in skeletal extension rates for nearshore corals CA (2006 – 2010) (OW + CV) • Increasing locations with coral bleaching CA and NSA (1971 – 2010) (OW) • Reduction of reef habitat for reef fish assemblages NES (2002 – 2017) (OW + CV + HW) • Changes in the abundance of coral reef community • Extreme reduction in coral cover (between 83-89% of mortality) • Massive coral bleaching events	CA and NWS by 2040 – 2043 • Increasing locations with coral bleaching (7.95% y^{-1}) (RCP 8.5) CA by 2050 – 2080 • Increasing hot spot locations for future bleaching CA, NSA and NES by 2100 • Distribution range changes (RCP 2.6, 4.5 and 8.5) • Reduction and loss of suitable habitat (RCP 2.6, 4.5 and 8.5) • Loss of suitable areas (between 46-59%) (RCP 4.5 and 8.5)
Estuaries	
NES (1988 – 2010) (P) • Increasing area colonized by mangrove vegetation (+10%) SES (1978 – 2012) (OW + SLR + WD + WI + P-ENSO) • Phenological shifts in phytoplankton blooms • Reduction of the chlorophyll concentration (1% y^{-1}) • Changes in plankton community's composition • Changes in food web structure • Changes in land cover of vegetated wetlands • Increasing water turbidity (4% y^{-1}) SES (1980 – 2017) (OW + WD + WI + P-ENSO + UI + CC) • Increasing water turbidity • Increased offshore productivity (by 2% between 1997-2017) • Poleward shift of pelagic species with commercial interest • Shifts in phytoplankton phenology and community structure • Increase of cyanobacteria and dinoflagellate presence SES (1983 – 2015) (OW) • Changes in species abundance (47 species)	SES by 2050 – 2080 • Reduction of distribution range of pelagic species with commercial interest (RCP2.6, 4.5, 6.0 and 8.5) NSA by 2100 (SLR) • Moderate erosion of delta's shoreline • Migration or loss of mangroves • Abrupt shifts in the Warao's traditional environments • Potential migrations and abandonment of ancestral territories (Scenario: 0.9 – 1.25 mm yr^{-1} + land subsidence rate of 4.4 mm yr^{-1})

• Changes of subtropical species distributional range (southward) • Rapid population growth of small pelagic fishes	
Kelps	
SSA (1998 – 2019) (OW + EV-ENSO) • Reduced kelp canopy SES (1969 – 2017) (OW) • Reduced kelp coverage (2.6% y^{-1}) • Overall kelp loss (52%) • Coverage increase of filamentous turfs (24%)	SWS and SSA by 2050 • South poleward expansion (RCP 2.6 and 8.5) • Habitat range reduction (50%) (RCP 2.6 and 8.5) SWS by 2100 • Southward expansion (RCP 2.6 and 8.5) • Reduction of native distributional range (50%) (RCP 2.6 and 8.5)
Mangroves	
CA (2000 – 2013) (EV) • Negative short-run effects on economic activity of coastal lowlands • Permanent loss of economic activity between 5 to 7 months (24%) • Permanent setbacks in economic activity after 6 years of the event NWS (1996 – 2004) (EV) • Mangrove retreats • Changes in vegetation composition • Changes in soil composition NWS (2002 – 2014) (P-ENSO + P-PDO) • Higher NDVI (mangrove vegetation) under short drought events • Lover NDVI (mangrove vegetation) under large drought periods NSA (1950 – 2010) (WV-NAO) • Variations in mangrove area NES (1984 – 2017) (SLR) • Mangrove land invasion (2.7 km^2 of inner tidal flats) • Increasing mangrove mortality • Decreasing latitudinal trend in migration (between 0.136 to 0.081 km^2 yr^{-1})	CA and NSA by 2100 • Global poleward migration (2 degrees of latitude) (A1b scenario) • Global decrease of suitable coastal area (A1b scenario) • Higher loss of mangrove species (A1b scenario) CA, NSA, and NES by 2100 (SLR + EV) • Changes in distribution (43%) (Scenario: +1m SLR and +10% storm) • Loss of mangroves (57%) (Scenario: +1m SLR and +10% storm) • Economical losses (231% of the GDP at risk) (Scenario: +1m SLR and +10% storm) NES by 2100 (SLR + P) • Mangrove landward expansion (2.93 km^2) (Scenario: 5 mm yr^{-1} and stable rainfall) • Mangrove landward expansion (1.35 km^2) (Scenario: 3 mm yr^{-1} and decreased rainfall) • Lower mangrove migration rates (0.017 km2 yr^{-1}) (Scenario: 5 mm yr^{-1} and stable rainfall) • Lower mangrove migration rates (0.036 km2 yr^{-1}) (Scenario: 3 mm yr^{-1} and decreased rainfall)
Rocky Shores	
SES (2010 – 2013) (EV + PP) • Increasing number of stranding events of marine birds SSA (1983 – 2010) (OW + EV) • Increased penguin reproductive failures • Increased penguin chick mortality SWS (2009 – 2018) (OW + EV) • Increasing number of stranded fauna (sea lion pups)	NWS and SWS by 2100 • Changes in the pelican spatial distribution (RCP 8.5) • Decrease (20%) in the pelican breeding distribution (RCP 8.5)
Exclusive Economic Zones (EEZ)	

CSA (1997 –2017) (OW) • Chlorophyll concentrations increase (78.23%) for Patagonia Large Marine Ecosystem • Chlorophyll concentrations increase (43.03%) for Humboldt Large Marine Ecosystem • Chlorophyll concentrations increase (26.35%) for South Brazil Large Marine Ecosystem • Chlorophyll concentrations increase (13.35%) for Pacific Coastal Central America Large Marine Ecosystem NSA, NES and SES (1973 – 2015) (OW) • Decline in fishery resource growth rates (26%) NES and SES (1950 – 2010) (OW) • Collapse of tropical and subtropical exploited species SES (1973 – 2017) (OW) • Shift from cool-water to warm-water species in Uruguayan landings	NSA by 2050 • Shrimp fishery economical losses (RCP 4.5) • Collapse of the shrimp stock (exacerbated by worldwide mangrove declines) (RCP 4.5) SWS by 2065 • Negative changes in the habitat suitability and abundance for anchovy (RCP 2.6, 4.5, 6.0, and 8.5) • Slight decline in swordfish capture (6%) (A2 scenario) • Slight decline on common sardine (7%) (CPUE) (A2 scenario) NWS by 2080 • Changes in seerfish distribution (RCP 8.5) CA by 2071-2100 • Substantial loss (>20%) of suitable habitat for many economically important gastropod species (RCP 2.6, 4.5, 8.5) NES and SES by 2071 – 2100 • Higher losses of spiny lobsters (suitable habitat) for the coasts of wider Caribbean/Brazil (RCP 4.5) CA, NWS and SWS by 2100 (OW + PP) • Reduction (15%) in the core pelagic habitat of the Eastern Pacific leatherback (turtle) population (A2 scenario) • Potential distributional Eastern Pacific leatherback (turtle) shifts and behavioral changes (A2 scenario) CSA by 2100 • Potential loss of tuna habitat along the Peru's coastal upwelling area (A2 scenario) • Potential loss of tuna habitat along the Pacific coast of Central America (A2 scenario)
Saltmarshes	
SES (1978 – 2012) (OW + SLR + WD + WI + P-ENSO) • Loss of saltmarshes area dominated *by Spartina alterniflora* (33%) • Increasing turbidity • Increasing release of organic matter and nutrients from sediments into the water column • Alteration of soil salinity, • Changes in plant growth • Changes in food quality • Changes in herbivorous abundance CA, NSA, SES, and SSA (1900 – Present) (OW + SLR + WD + WI + P-ENSO) • Changes in range distribution of *Spartina alterniflora* (extension to higher latitudes) • Increasing abundance to southward of *Spartina alterniflora*	

• Poleward expansion of saltmarshes in the Atlantic Patagonia • Lower capacity to stabilize sediment organic matter	
Sandy Beaches	
CA (2010 - 2015) (EV) • Discouraged leatherbacks successful nesting • Changes in leatherbacks' nesting behaviour NES (2005 - 2016) (OW + SR + EV + WVH) • Reduced hatchling production of turtle eggs • Reduce density of macrofaunal SES (1980 – 2017) (OW + WD + WI + P-ENSO +UI + CC + EV) • Changes in composition and zonation of macrobentic communities • Changes in the occurrence and species assemblage of jellyfish blooms • Increasing and more frequent and intense harmful algal blooms (HABs) • Recurrent mass mortality events of clam populations • Growing detrimental impacts on small-scale fisheries • Higher number of shellfishery closure • Changes in crab population abundance • Changes in crab reproductive and recruitment periods SES (1984 – 2007) (OW) • Decreased clam abundance • Prevalence of clam body abnormalities	NES by 2100 • Decreasing (from 75.2% to 65.1%) of turtle hatching success events (RCP 4.5 and 8.5)

Table Notes:
*Data provided in this column refers to long-term studies attributing impacts to climate change hazards. In parenthesis is provided the time range of the studies and the climate change hazard which impact was attributed.
** Data provided in this column refers to studies addressing projected impacts on coastal and ocean ecosystems for CSA subregions. In parentheses, the time-frames of projections and climate change scenarios are provided.
For references, see Section SM12.3.1 (below)

SM12.3.1 References supporting Figure 12.8, Figure 12.9 and Figure 12.10.

Ocean and Coastal Ecosystems	Observed and Projected Impacts (see Table 12.A3)	Sensitivity to climate and non-climate drivers (see Figure 12.8)
Coral Reefs	Durante et al. (2018) van Hooidonk et al. (2015) Baumann et al. (2016) Baumann et al. (2019) Arnan et al. (2018) de Moraes et al. (2019) de Oliveira Soares et al. (2019) Duarte et al. (2020) Li and Reidenbach (2014) Maharaj et al. (2018)	Horvath et al. (2016) Bove et al. (2019) Bove et al. (2020) Kelmo et al. (2014) Sarmento et al. (2015) Hill et al. (2019) Mazzuco et al. (2019) Barbosa et al. (2019) Evangelista et al. (2016) Magris et al. (2018) Marques et al. (2019b) Altieri et al., 2017) Seemann et al. (2014)
Estuaries	Guinder et al., 2013)	Halac et al. (2014)

	Pratolongo et al., 2013) Barros et al., 2015) Fiori et al., 2016) Guinder et al. (2017) Brendel et al. (2017) López Abbate et al. (2017) López-Abbate et al. (2019) Machado et al. (2013) Sathicq et al. (2015) Vögler et al. (2015) Marrari et al. (2017) Calliari et al. (2018) Ruaro et al. (2019) Franco et al. (2020) Haraguchi et al. (2015) Abreu et al. (2017) Haimovici and Cardoso (2017) Odebrecht et al. (2017) Teixeira-Amaral et al. (2017) Gonçalves-Araujo et al. (2018) Martelo et al. (2019) Araújo et al. (2018) Vegas-Vilarrúbia et al. (2015) Pinto Godoy and de Lacerda (2014)	Moreau et al. (2014) Villafañe et al. (2015) Gomes and Bernardino (2020) Mardones et al. (2017) Trainer et al. (2020) Navarro et al. (2016) Duarte et al. (2018) Grenier et al. (2020) Navarro et al. (2020) Paul and Calliari (2019)
Mangroves	Bernal et al. (2016) Cohen et al. (2018) Galeano et al. (2017) Walcker et al. (2015) del Valle et al. (2020) Hochard et al. (2019) Barbier and Hochard (2018) Lopes et al. (2018) Record et al. (2013) Blankespoor et al. (2017)	Gedan et al. (2017) Strefezza et al. (2019) Servino et al. (2018) Taillie et al. (2020) Osland et al. (2017) Feher et al. (2017) Liles et al. (2019) Otero et al. (2020) Reef et al. (2016) Bulluck et al. (2019) Pérez et al. (2017)
Kelps	Friedlander et al. (2020) Gorman et al. (2020) Laeseke et al. (2020) Murcia et al. (2020)	de Ramos et al. (2019) Koerich et al. (2020) Mazzuco et al. (2019) Muñoz et al. (2018) Scherner et al. (2013) Hollarsmith et al. (2020) González et al. (2018) Carreja et al. (2016) Kelmo et al. (2014) Sarmento et al. (2015) Madeira et al. (2019) da Silva-Pinto et al. (2020) Ragagnin et al. (2018) Leiva et al. (2018) Seemann et al. (2014)
Exclusive Economic Zones (EEZs)	Willis-Norton et al. (2015) Bjorndal et al. (2017) Marrari et al. (2017) Boavida-Portugal et al. (2018) Verba et al. (2020) Eduardo et al. (2020) Herrera Montiel et al. (2019) Gianelli et al. (2019) Silva et al. (2015) Silva et al. (2016a) Silva et al. (2019a) Lezama-Ochoa et al. (2016) Saupe et al. (2014)	Ramajo et al. (2016) Lagos et al. (2016) Lardies et al. (2017) Navarro et al. (2016) Duarte et al. (2018) Manríquez et al. (2019) Ramajo et al. (2019) Mellado et al. (2019) Grenier et al. (2020) Navarro et al. (2020) Ramajo et al. (2020) González et al. (2018) Riascos et al. (2017)

	Bertrand et al. (2020) Lopes et al. (2018)	Valiñas et al. (2014) Carneiro et al. (2020)
Rocky shores	Boersma and Rebstock (2014) Tavares et al. (2016) Sepúlveda et al. (2020) Cursach et al. (2019)	Tavares et al. (2016) Cursach et al. (2019)
Saltmarshes	Canepuccia et al. (2010) Pratolongo et al. (2013) Negrin et al. (2016) Fiori et al. (2016) López-Abbate et al. (2019) Ruiz-Etcheverry and Saraceno (2020) Barros et al. (2015) Bortolus et al. (2015) Lomovasky et al. (2014) Mueller et al. (2018) Schuerch et al. (2018)	Gomes and Bernardino (2020)
Sandy beaches	Brendel et al. (2017) Carcedo et al. (2017) Carcedo et al. (2019) Celentano and Defeo (2016) Fanini et al. (2020) Franco et al. (2020) Gianelli et al. (2019) Lercari et al. (2018) Manta et al. (2017) McLachlan and Defeo (2018) Orlando et al. (2019) Scapini et al. (2019) Vousdoukas et al. (2020) Machado et al. (2016) Montero et al. (2018) Machado et al. (2019) Ortega et al. (2016) Palomino-González et al. (2020) Castaño-Isaza et al. (2015)	Vafeiadou et al. (2018) Castaño-Isaza et al. (2015) Liles et al. (2019)

SM12.4 Observed and Projected Impacts by Sub-region

SM12.4.1 References to Figure 12.9 Observed and projected impacts by sub-region

SM12.4.1.1 Central America CA

Terrestrial and freshwater ecosystems

Tropical forest

Castro et al. (2018)
Feeley et al. (2013)
Lyra et al. (2017)
Stan et al. (2020)
Pons et al. (2018)

Lakes, rivers and wetlands

CEPAL and CAC-SICA (2020)
CEPAL (2010)

Mountains

Imbach et al. (2017)
ECLAC et al. (2015)
FAO (2016b)

Bouroncle et al. (2017)
Hannah et al. (2017)

Oceans and coastal areas
See section SM12.3

Water
Streamflows
CEPAL and CAC-SICA (2020)
Anderson et al. (2019)
CEPAL (2010)

Food, fibre, and other ecosystem products
Annual crop systems
Imbach et al. (2017)
ECLAC et al. (2015)
FAO (2016b)
Bouroncle et al. (2017)
Donatti et al. (2019)
Castellanos et al. (2018)
Läderach et al. (2017)
Bacon et al. (2017)
Harvey et al. (2018)
Calvo-Solano et al. (2018)
Byers et al. (2018)
Depsky and Pons (2021)
Imbach et al. (2018)

Livestock and pasture
Calvo-Solano et al. (2018)

Permanent crops (Fruits production)
CEPAL and CAC-SICA (2020)
Imbach et al. (2017)
FAO (2016b)
CEPAL et al. (2018)
Läderach et al. (2013)
Läderach et al. (2017)
Bacon et al. (2017)
Harvey et al. (2018)
Byers et al. (2018)
Depsky and Pons (2021)

Forestry and wood production
Castro et al. (2018)
Feeley et al. (2013)
Lyra et al. (2017)
Stan et al. (2020)
Byers et al. (2018)
Lyra et al. (2017)
Gotlieb and García Girón (2020)

Cities and infrastructure
Urban land and Built environment
Bárcena et al. (2020)
Reyer et al. (2017)
Ishizawa and Miranda (2016)

Land use
UNISDR and CEPREDENAC (2014)
Bárcena et al. (2020)

Housing stock
Bárcena et al. (2020)
Reyer et al. (2017)
Ishizawa and Miranda (2016)

Water supply, Rainwater drainage and Sewer infrastructure
CEPAL and CAC-SICA (2020)
CEPAL (2010)
Storlazzi et al. (2018)

Mobility and transport systems
Bárcena et al. (2020)
Reyer et al. (2017)
Ishizawa and Miranda (2016)

Health
Labor productivity
Dally et al. (2018)
Johnson et al. (2019)
Sheffield et al. (2013)

Morbidity
Zambrano et al. (2012)
Hutter et al. (2018)
Chaves and Pascual (2006)
Hurtado et al. (2018)

Mortality
UNISDR and CEPREDENAC (2014)
Bárcena et al. (2020)
Ishizawa and Miranda (2016)

Poverty, livelihoods and sustainable development
Territory
UNISDR and CEPREDENAC (2014)
Bárcena et al. (2020)

Income
ECLAC et al. (2015)
Walshe and Argumedo (2016)
CEPAL et al. (2018)

Human dimensions
Migration
Baez et al. (2017)
Aguilar et al. (2019)
Ruano and Milan (2014)

Indigenous knowledge and local knowledge
NU CEPAL (2018)
Batzín (2019)

SM12.4.1.2 Northwest South America NWS

Terrestrial and freshwater ecosystems and their services
Armenteras et al. (2020)
Oliveras et al. (2014)
Oliveras et al. (2018)
Hoyos et al. (2013)
Vuille et al. (2015)
Urrutia and Vuille (2009)
Aguilar-Lome et al. (2019)
Pabón-Caicedo et al. (2020)
Ranasinghe et al. (2021)
Reinthaler et al. (2019a)
Mark et al. (2017)
Basantes-Serrano et al. (2016)
Rabatel et al. (2018)
Seehaus et al. (2019)
Vuille et al. (2018)
Thompson et al. (2017)
Masiokas et al. (2020)
Schauwecker et al. (2017)
Cuesta et al. (2019)
Dangles et al. (2017)
Bury et al. (2013)
Polk et al. (2017)
Moret et al. (2016)
Cuesta et al. (2019)
Cauvy-Fraunié and Dangles (2019)
Fadrique et al. (2018)
Zimmer et al. (2018)
Cuesta et al. (2017)
Aguirre et al. (2017)
Seimon et al. (2017)
Duque et al. (2015)
Morueta-Holme et al. (2015)
Crespo-Pérez et al. (2015)
Moret et al. (2020)
Rosero et al., (2021)
Tito et al. (2018)
Cuesta et al. (2020)
Rehm and Feeley (2015b)
Harsch et al. (2009)
Lutz et al. (2013)
Rehm and Feeley (2015a)
Feeley et al. (2011)
Fadrique et al. (2018)
Duque et al. (2015)
Duque et al. (2021)
Álvarez-Dávila et al. (2017)
McDowell et al. (2020)

Ocean and Coastal Ecosystems
See section SM12.3

Water
Jiménez Cisneros et al. (2014)
Cerrón et al. (2019)

Pabón-Caicedo et al. (2020)
Orlove et al. (2019)
Bradley et al. (2006)
Bury et al. (2013)
Buytaert et al. (2017)
Carey et al. (2017)
Michelutti et al. (2015)
Carrivick and Tweed (2016)
Emmer (2017)
Milner et al. (2017)
Reyer et al. (2017)
Vuille et al. (2018)
Cuesta et al. (2019)
Drenkhan et al. (2019)
Hock et al. (2019)
Polk et al. (2017)
Young et al. (2017)
Kronenberg et al. (2016)
Motschmann et al. (2020)
Baraer et al. (2012)
Vuille et al. (2018)
Molina et al. (2020)
Somers et al. (2019)
Mark et al. (2017)
Colonia et al. (2017)
Drenkhan et al. (2019)
Hock et al. (2019)
Chevallier et al. (2011)
Soruco et al. (2015)
Mark et al. (2017)

Food, fibre and other ecosystem products
Postigo (2014)
Bergmann et al. (2021)
Bayer et al. (2014)
(Tapasco et al., 2015)
(Aragón et al., 2021)
(Coayla and Culqui, 2020)
(Lambert and Eise, 2020)
(Duchicela et al., 2019)

Case Study 2.6.5.4
(Morueta-Holme et al., 2015)
(Skarbø and VanderMolen, 2016)
(Schauwecker et al., 2017)
(Vuille et al., 2018)
(Tovar et al., 2013)
(Ramirez-Villegas et al., 2014)
(Ovalle-Rivera et al., 2015)
(Cernusak et al., 2013)
(van der Sleen et al., 2015)
(Lowe et al., 2017)
(Ponce, 2020)
(Altea, 2020)
(Heikkinen, 2017)

Cities and infraestructure

(Briones-Estébanez and Ebecken, 2017)
(Miranda Sara and Baud, 2014)
(Cuvi, 2015)
(Miranda Sara et al., 2016)
(Emmer, 2017)
(Emmer et al., 2016)
(Bertrand et al., 2020)
(French and Mechler, 2017)
(Takahashi and Martínez, 2019)
(Christidis et al., 2019)
(Coayla and Culqui, 2020)
(Martínez et al., 2017)
(Rosales-Rueda, 2018)
(Isla, 2018)
(Morera et al., 2017)
(Salazar et al., 2018)
(Puente-Sotomayor et al., 2021)
(Chevallier et al., 2011)
(Soruco et al., 2015)
(Mark et al., 2017)

Health
(Stewart-Ibarra and Lowe, 2013)
(Sippy et al., 2019)
(Petrova et al., 2020)
(Lowe et al., 2017)
(Portilla Cabrera and Selvaraj, 2020)
(Lippi et al., 2019)
(Sánchez et al., 2017)
(Quintero-Herrera et al., 2015)
(Arias-Monsalve and Builes-Jaramillo, 2019)
Section 7.2.2.1; Section 7.3.1.3
(Mattar et al., 2013)
(Colón-González et al., 2018)
(Lippi et al., 2019)
(Laporta et al., 2015)
(Fletcher et al., 2020)
(Rodriguez-Morales et al., 2019)
(Garcia-Solorzano et al., 2019)

Poverty, livelihoods, and sustainable development
(Postigo, 2014)
(Bergmann et al., 2021)
(Bayer et al., 2014)
(Tapasco et al., 2015)
(Oliver-Smith, 2014)
(Duchicela et al., 2019)
Case Study 2.6.5.4

Human dimension
(Løken, 2019)
(Bergmann et al., 2021)
(Ariza-Montobbio and Cuvi, 2020)
(Gutierrez et al., 2020)
(Nagy et al., 2018)
(Cáceres-Arteaga et al., 2020)
(Gurgiser et al., 2016)

(Herrador-Valencia and Paredes, 2016)
(Paerregaard, 2018)
(Scoville-Simonds, 2018)
(Rasmussen, 2016)
Global Internal Displacement Database, https://www.internal-displacement.org/database/displacement-data
(Gray and Bilsborrow, 2013)
(Zimmerer, 2014)

SM12.4.1.3 Northern South America NSA

Terrestrial and freshwater ecosystems

Tropical Forests

(Doughty et al., 2015)
(Feldpausch et al., 2016)
(Anderson et al., 2018)
(Brienen et al., 2015)
(Rammig, 2020)
(Sullivan et al., 2020)
(Anadón et al., 2014)
(Olivares et al., 2015)
(Sampaio et al., 2019)
(Nobre et al., 2016b)

Grassland and savanna

(Sankaran, 2019)
(Eloy et al., 2019)
(Mistry et al., 2016)
(Moncrieff et al., 2016)
(Couto-Santos et al., 2014)

Mountains

(Chacón-Moreno et al., 2021)
(Leroy, 2019)
(Arzac et al., 2019)
(Helmer et al., 2019)
(Llambí and Rada, 2019)
(Mavárez et al., 2019)
(Garavito et al., 2015)

Water

Streamflow and rivers

(Heerspink et al., 2020)
(Brêda et al., 2020)
(Farinosi et al., 2019)
(Guimberteau et al., 2017)
(Ribeiro Neto et al., 2016)
(Sorribas et al., 2016)

Food, fibre and other ecosystems products

Annual crop systems

(Tomby and Zhang, 2018)
(Tomby and Zhang, 2019)
(Cochran et al., 2016)
(Pinho et al., 2015)
(Riad and Donk, 2017)
(Contreras Mojica et al., 2018)

Permanent crops (Fruits production)
(Bebber, 2019)
(Ortega Andrade et al., 2017)

Forestry and wood production
(Torremorell et al., 2021)
(Pacheco et al., 2014)
(Silva Junior et al., 2020)
(Doughty et al., 2015)
(Feldpausch et al., 2016)
(Anderson et al., 2018)
(Brienen et al., 2015)
(Rammig, 2020)
(Sullivan et al., 2020)
(Anadón et al., 2014)
(Olivares et al., 2015)
(Sampaio et al., 2019)

Fishery and aquaculture
(Camacho Guerreiro et al., 2016)
(Pinho et al., 2015)
(Marengo et al., 2013)
(Marengo and Espinoza, 2016)

Cities and infrastructure
Urban land and built environment; land use; housing stock, water supply; rainwater drainage and server infrastructure; energy; mobility and transport systems

(Marengo et al., 2013)
(Carrera et al., 2018)
(Gheuens et al., 2019)
(Miralles-Wilhelm et al., 2019)
(Mahlknecht et al., 2020)
(Almeida Prado et al., 2016)
(Angeles et al., 2018)
(Arias et al., 2020)
(Bezerra et al., 2021)
(Donk et al., 2014)
(Donk et al., 2018)
(Donk et al., 2019)
(Farinosi et al., 2019)
(Invidiata and Ghisi, 2016)
(Mendes et al., 2017)
(Viviescas et al., 2019)
(CAF, 2014)
(Parry et al., 2018)

Health
Morbidity
(Confalonieri et al., 2014b)
(Pan et al., 2014)
(Filho et al., 2016)
(Nava et al., 2017)
(WHO and UNFCCC, 2020)
(Laguna et al., 2017)
(Aragão et al., 2018)
(de Oliveira Alves et al., 2017)

(Paralovo et al., 2019)
(Ellwanger et al., 2020)

SM12.4.1.4 South America Monsoon SAM

Terrestrial Forest / Grasslands Savanna
(Warszawski et al., 2013)
(Strassburg et al., 2017)
(Yu et al., 2019)
(Esquivel-Muelbert et al., 2019)
(Malhado et al., 2010)
(Silva Junior et al., 2020)
(Anderson et al., 2018)
(Brando et al., 2014)
(Lapola et al., 2014)
(Hofmann et al., 2021)
(Anjos et al., 2021)
(Garcia et al., 2021)
(Silva et al., 2019c)
(Lázaro et al., 2020)
(Ciemer et al., 2019)
(Aguiar et al., 2016a)
(Boers et al., 2017)
(Marengo et al., 2021b)

Lake Rivers and wetlands + streamflow / Energy
(Marengo and Espinoza, 2016)
(Marengo et al., 2018)
(Bergier et al., 2018)
(de Oliveira et al., 2019b)
(Marengo et al., 2017b)
(Mesquita et al., 2018)
(Marcovitch et al., 2010)
(Mohor et al., 2015)
(Thielen et al., 2020)
(Marengo et al., 2021a)
(Ribeiro Neto et al., 2016)
(Lucena et al., 2018)
(Lázaro et al., 2020)
(Ovando et al., 2016)
(FAO, 2016a)
(Molina-Carpio et al., 2017)
(Heerspink et al., 2020)
(Marengo et al., 2021b)

Health (Morbidity and Mortality)
(de Souza Hacon et al., 2019)
(Sousa et al., 2018)
(Ovando et al., 2016)
(de Oliveira et al., 2020a)

Crop systems / Livestock
(Leite-Filho et al., 2021)
(Ovando et al., 2016)
(Pompeu et al., 2021)
(FAO, 2016a)
(Garcia et al., 2021)

SM12.4.1.5 Northeast South America NES

Terrestrial and freshwater ecosystems and their services

Tropical Forests

(Cavalcante and Duarte, 2019)
(Arnan et al., 2018)
(da Silva et al., 2018)
(de Oliveira et al., 2012)
(Tomasella et al., 2018)
(Silva et al., 2019b)

Lakes, rivers and wetlands

(Silva et al., 2019b)
(Marengo et al., 2017b)

Ocean and Coastal Ecosystems

Estuaries

(Pinto Godoy and de Lacerda, 2014)

Mangroves

(Godoy and Lacerda, 2015)
(Cohen et al., 2018)

Coral reefs

(de Moraes et al., 2019)
(Duarte et al., 2020)
(Krug et al., 2013)
(Leão et al., 2016)
(de Oliveira Soares et al., 2019)
(Magris et al., 2018)

Exclusive Economic Zones (EEZs)

(Gasalla et al., 2017)
(Verba et al., 2020)

Water

Streamflow

(Marengo et al., 2017b)
(Vieira et al., 2015)
(de Jong et al., 2018)

Food, fibre and other ecosystem products

Annual Crop Systems

(Marengo et al., 2017b)
(Ferreira Filho and Moraes, 2015)
(Nabout et al., 2016)
(Gateau-Rey et al., 2018)
(Forcella et al., 2015)
(Ribeiro Neto et al., 2016)
(Mariano et al., 2018)
(Marengo et al., 2020b)
(Tomasella et al., 2018)
(Sousa et al., 2021)
(Martins et al., 2019)

Livestock and pasture

(Marengo et al., 2017b)
(Tomasella et al., 2018)
(Sousa et al., 2021)
(Schulz et al., 2018)

Permanent crops (Fruit production)
(Marengo et al., 2017b)
(Duden et al., 2021)
(Santos et al., 2021)
(Sentelhas and Pereira, 2019)
(de Oliveira et al., 2020b)

Forestry and wood production
(Silva et al., 2020)
(Silva et al., 2019b)
(de Espindola et al., 2021)
(Pereira et al., 2020)
(Pinheiro et al., 2017)
(Schulz et al., 2018)
(Torres et al., 2017)
(Dantas et al., 2020)

Fisheries and aquaculture systems
(Vieira et al., 2015)
(Gasalla et al., 2017)

Cities and infrastructure
Water supply, Rainwater drainage and Sewer infrastructure
(Marengo et al., 2017b)
(Vieira et al., 2015)
(de Souza Hacon et al., 2019)
(Marengo et al., 2019)
(Salvador et al., 2020)
(Sena et al., 2014)
(Ribeiro Neto et al., 2016)

Energy
(de Jong et al., 2018)
(Marengo et al., 2017b)
(Ribeiro Neto et al., 2016)

Health
Labour productivity
(Marengo et al., 2017b)
(Marengo and Bernasconi, 2015)
(Ferreira Filho and Moraes, 2015)

Morbidity
(Marengo and Bernasconi, 2015)
(de Souza Hacon et al., 2019)
(Marengo et al., 2019)
(Salvador et al., 2020)
(Sena et al., 2014)
(Confalonieri et al., 2014a)

Mortality
(Marengo et al., 2017b)

(de Oliveira et al., 2019a)
(de Souza Hacon et al., 2019)
(Confalonieri et al., 2014a)

Poverty, livelihoods, and sustainable development

Livestock mortality

(Marengo et al., 2017b)

Income

(Confalonieri et al., 2014a)

Human dimension

Migration and displacement

(Confalonieri et al., 2014a)

Conflicts

(Araujo et al., 2019)

Indigenous knowledge and local knowledge

(Bragagnolo et al., 2017)

SM12.4.1.6 Southeast South America SES

Terrestrial and freshwater ecosystems

Tropical and temperate forest

(Aguiar et al., 2016b)
(Borges et al., 2019)
(Braz et al., 2019)
(Ferro et al., 2014)
(Hoffmann et al., 2015)
(Loyola et al., 2014)
(Loyola et al., 2012)
(Martins et al., 2015)
(Vale et al., 2018)
(Vale et al., 2021)
(Manes et al., 2021)
(Chillo et al., 2018)
(Alarcón and Cavieres, 2018)

Lakes, rivers and wetlands

(Schivo et al., 2019)
(Ruaro et al., 2019)
(Gasalla et al., 2017)
(Crego et al., 2014)
(Godoy and Lacerda, 2015)

Oceans and coastal areas

See section SM12.3

Water

Aquifers and groundwater

(Zaninelli et al., 2019)
(Martinez et al., 2016)
(Kundzewicz and DÖLl, 2009)
(Guevara-Ochoa et al., 2020)

Streamflow
(Tiezzi et al., 2018)

Water quality
(Flörke et al., 2018)
(Santarosa et al., 2021)
(Torremorell et al., 2021)

Food, fibre, and other ecosystem products
Annual crop systems
(Spennemann et al., 2018)
(Green et al., 2019)
(Ferrero et al., 2018)
(Rolla et al., 2018)
(Nehren et al., 2019)

Livestock and pastures
(Brêda et al., 2020)
(Maia et al., 2018)
(Picasso et al., 2014)
(Cruz et al., 2018)

Permanent crops (Fruit production)
(Tavares et al., 2018)
(Ambrizzi et al., 2019)
(Gomes et al., 2020)

Fisheries and aquaculture systems
(Ruaro et al., 2019)
(Bezerra et al., 2019)
(Rodrigues et al., 2019)
(Araújo et al., 2018)

Cities and infrastructure
Urban land and Built environment
(Barros et al., 2015)
(Cerón et al., 2021)
(D'Onofrio et al., 2008)
(Mettler-Grove, 2020)
(Nagy et al., 2014)
(Nagy et al., 2019)
(Ohz et al., 2020)
(Oyedotun and Ally, 2021)
(Santamaria-Aguilar et al., 2017)
(Souza et al., 2019)
(Zambrano et al., 2017)
(Morales-Yokobori, 2021)

Land use
(D'Onofrio et al., 2008)
(Isla and Schnack, 2009)
(Muehe, 2010)
(Nagy et al., 2014)
(Barros, 2006)
(da Fonseca Aguiar and Cataldi, 2021)
(Debortoli et al., 2017)
(Haque et al., 2019)

(Marengo et al., 2020c)
(Mettler-Grove, 2020)
(Morales-Yokobori, 2021)
(Nagy et al., 2019 impacts and adaptation in Central and South America)
(Oyedotun and Ally, 2021)
(Saito et al., 2019 floods)

Water supply, Rainwater drainage and Sewer infrastructure
(Cunningham et al., 2017)
(Nobre et al., 2016a)
(PBMC, 2014)
(Flörke et al., 2018)
(Marengo et al., 2017b)
(Lima and Magaña Rueda, 2018)
(Marengo et al., 2020a)
(Muehe, 2010)
(Ohz et al., 2020)
(Khalid et al., 2020)
(Silva de Souza et al., 2021)
(de Souza and Ramos da Silva, 2021)
(Quadrado et al., 2021)

Health

Morbidity
(Araujo et al., 2015)
(Barros and Lombardo, 2016)
(Ceccherini et al., 2016)
(de Azevedo et al., 2018)
(de Farias et al., 2021)
(Lima and Magaña Rueda, 2018)
(Diniz et al., 2020)
(Ferreira and Duarte, 2019)
(Geirinhas et al., 2018)
(Lapola et al., 2019)
(Mettler-Grove, 2020)
(Mishra et al., 2015)
(Neiva et al., 2017)
(Peres et al., 2018)
(Rasmussen et al., 2014)
(Sarricolea and Meseguer-Ruiz, 2019)
(Singh et al., 2020)
(Son et al., 2016)
(Ulpiani, 2021)
(Vemado and Pereira Filho, 2016)
(Wong et al., 2013)
(Wu et al., 2019)

Mortality
(Barros et al., 2015)
(Araujo et al., 2015)
(Barros and Lombardo, 2016)
(Geirinhas et al., 2018)
(de Azevedo et al., 2018)
(Son et al., 2016)
(Diniz et al., 2020)

Human dimensions

Migration
(Thiede et al., 2016)
(Abeldaño Zuñiga and Fanta Garrido, 2020)
(Gemenne et al., 2016)

SM12.4.1.7 Southwest South America SWS

Table SM12.4: References to Figure 12.9: Observed and projected impacts for the SWS sub-region.

Sector	References for Observed Impacts	References for Projected Impacts
Terrestrial and freshwater ecosystems and their services	• **Temperate Forests** (Peña et al., 2014) (Urrutia-Jalabert et al., 2015) (Camarero and Fajardo, 2017) (Fontúrbel et al., 2018) (Venegas-González et al., 2018) (Boisier et al., 2016) (Díaz-Hormazábal and González, 2016) (Martinez-Harms et al., 2017) (Urrutia et al., 2018) (Gómez-González et al., 2018) (Bowman et al., 2019) (de la Barrera et al., 2018) (Peña-Guerrero et al., 2020) • **Lakes, rivers and wetlands** (Wilson et al., 2018) (Pizarro et al., 2016) (Iribarren Anacona et al., 2015) (Jacquet et al., 2017) (Reinthaler et al., 2019b) (Meza et al., 2014) (Muñoz et al., 2020a) (Bocchiola et al., 2018); (Yevenes et al., 2018) (Peña-Guerrero et al., 2020) (Oertel et al., 2020) (Ragettli et al., 2016) (Domic et al., 2018) • **Mountains** (Wilson et al., 2018) (Iribarren Anacona et al., 2015) (Jacquet et al., 2017) (Reinthaler et al., 2019b) (Sepúlveda et al., 2015) • **Deserts** (Acosta-Jamett et al., 2016) (Neilson et al., 2017) (Díaz et al., 2019)	• **Temperate Forests** (Gutiérrez et al., 2014) (Correa-Araneda et al., 2020) (Bourke et al., 2018) (Glade et al., 2016) (Jantz et al., 2015) (Mantyka-Pringle et al., 2015) (Warren et al., 2018) (Cuyckens et al., 2015) (Manes et al., 2021) • **Lakes, rivers and wetlands** (Bocchiola et al., 2018) (Vargas et al., 2013)
Ocean and Coastal Ecosystems, and their services	• **Rocky shores** (Sepúlveda et al., 2020) (Cursach et al., 2019) • **Sandy beaches** (Martínez et al., 2018) (Ministerio de Medio Ambiente de Chile, 2019) (Winckler et al., 2017) • **Upwelling systems and EEZs** (Schneider et al., 2017) (Aguirre et al., 2018) (Anabalón et al., 2016) (Jacob et al., 2018) (Ramajo et al., 2020)	• **Kelps** (Friedlander et al., 2020) (Laeseke et al., 2020) (Murcia et al., 2020) • **Rocky shores** (Cursach et al., 2019) (Boavida-Portugal et al., 2018) • **Upwelling systems and EEZs** (IPCC, 2019b) (Silva et al., 2015) (Silva et al., 2019a) (Silva et al., 2016a) (Boavida-Portugal et al., 2018) (Bertrand et al., 2020)

	(IPCC, 2019b) (León-Muñoz et al., 2018) (Quiñones et al., 2019) (Soto et al., 2019) (Armijo et al., 2020) (Mellado et al., 2019) (Bertrand et al., 2020)	
Water	• **Streamflow** (Muñoz et al., 2020a) (Yevenes et al., 2018) (Ragettli et al., 2016) • **Water quality and availability** (Bocchiola et al., 2018) (Yevenes et al., 2018) (Araya-Muñoz et al., 2016) (Sepúlveda et al., 2015) (Monsalves-Gavilán et al., 2013)	• **Streamflow** (Meza et al., 2014) (Ragettli et al., 2016) (Vargas et al., 2013) • **Water quality and availability** (Bocchiola et al., 2018) • **Groundwater** (Meza et al., 2014) (Ragettli et al., 2016) (Vargas et al., 2013)
Food, fibre and other ecosystem products	• **Fisheries and aquaculture systems** (IPCC, 2019b) (León-Muñoz et al., 2018) (Quiñones et al., 2019) (Soto et al., 2019) (Armijo et al., 2020) (García-Reyes et al., 2015) (Duarte et al., 2016) (Navarro et al., 2016) (Lagos et al., 2016) (Lardies et al., 2017) (Ramajo et al., 2019) (Duarte et al., 2018) (Mellado et al., 2019) (Bertrand et al., 2020) • **Agricultural systems** (Yevenes et al., 2018) (Peña-Guerrero et al., 2020) (Oertel et al., 2020) (Ray et al., 2015) (Zambrano et al., 2016) (Lesjak and Calderini, 2017) (Ferrero et al., 2018) (Haddad et al., 2019) (Zúñiga et al., 2021) (Webb et al., 2020) (Novoa et al., 2019) (Fernandez et al., 2020)	• **Fisheries and aquaculture systems** (IPCC, 2019b) (Silva et al., 2015) (Silva et al., 2019a) (Silva et al., 2016a) (Bertrand et al., 2020) • **Agricultural systems** (Melo and Foster, 2021) (Fernandez et al., 2020) (Aggarwal et al., 2019) (Ávila-Valdés et al., 2020) (Beyá-Marshall et al., 2018) (Lobos et al., 2018) (O'Leary et al., 2018) (Reyer et al., 2017) (Silva et al., 2016b) (Toro-Mujica et al., 2017) (Lizana et al., 2017) (Zhang et al., 2015) (Mera et al., 2015) • **Forestry systems** (Melo and Foster, 2021)
Cities and infrastructure	(Martínez et al., 2018) (Ministerio de Medio Ambiente de Chile, 2019) (Winckler et al., 2017) (Araya-Muñoz et al., 2016) (Monsalves-Gavilán et al., 2013) (Moser-Reischl et al., 2019) (Rouault et al., 2019)	
Health	• **Mortality and Morbidity** (Monsalves-Gavilán et al., 2013) (de la Barrera et al., 2018) (Bowman et al., 2019) (Leiva G et al., 2013) (Pino et al., 2015) (Herrera et al., 2016) (Henríquez and Urrea, 2017)	• **Mortality and Morbidity** (Tapia-Garay et al., 2018) (Ayala et al., 2019)

	(Ugarte-Avilés et al., 2017) (González et al., 2019) (Johns et al., 2018) (Matus C and Oyarzún G, 2019) (Sánchez et al., 2019) (Terrazas et al., 2019) (Cakmak et al., 2021)	
Human dimension	• **Indigenous knowledge and local knowledge** (Parraguez-Vergara et al., 2016) (Meldrum et al., 2018) (Perreault, 2020)	

SM12.4.1.8 Southern South America SSA

Terrestrial and freshwater
(Isla et al., 2010)
(Aguayo et al., 2019)
(Suarez et al., 2004).
(Raffaele et al., 2016)
Inostroza et al. 2016

Water
(Foresta et al., 2018)
(Moragues et al., 2019)
(Zemp et al., 2019)
(Meier et al., 2018)

Food, fibers and others
(Joyce et al., 2016)
(Junk et al., 2013)
(Kubisch et al., 2016)
(Crego et al., 2014)
(Rodríguez-Catón et al., 2016)
(Ignazi et al., 2020)

SM12.4.2 Methodology used to assess synthesis of observed and projected impacts (for Figure 12.10)

The synthesis of observed and projected impacts for the Central and South America region (Figure 12.10) is fully based on the detailed assessment as represented in Figure 12.9. The detailed assessment defines several systems or components for each sector. The synthesis assessment only represents the sectors for each sub-region. Both the detailed and the synthesis assessment apply three different levels of impacts: highly, medium and low impacted, with the corresponding level of confidence.
To define the level of impact and confidence for a certain sector and sub-region in the synthesis assessment, all corresponding systems/components are considered.
The criteria taken into account to define level of impact and confidence of a sector are as follows:

- Level of impact of each corresponding system/component;
- Level of confidence of each corresponding system/component;
- Numerical predominance of certain levels of impact and confidence among different systems/components per sector, and average across them;
- Importance of system/component for sector of the respective sub-region;
- Number of assessed systems/components of sector (relative to total number of defined systems/components for respective sector).

The application of these criteria for the synthesis assessment can be illustrated as follows: if there are several systems/components within one sector with different levels of impact and confidence, first a sort of arithmetic average of level of impact and confidence is defined which is then evaluated against the importance of each system/component for the sector and sub-region. If the assessment of a sector is

incomplete, in particular if only one system/component was assessed, then a lowering of the level of confidence is applied, adopting the level of impact indicated for the one system.
This same methodology is applied for both observed and projected impacts.

SM12.5 Key Risks

Table SM12.5: Key risks identified and assessed for the Central and South America region.

Nature of key risk	Geographic region	Consequence that would make the risk severe	Associated changes in hazards	Associated changes in exposure	Associated changes in vulnerability	Confidence in key risk identification and traceability to chapter section	References
1. Risk of food insecurity due to frequent/extreme droughts	Central and South America	Substantial decrease in yield for key crops, disruption of food provision chains, inability to acquire food for large parts of the population, reduced capacity or production of goods (food, fibre, fuel) and increased malnutrition. Reduction in agricultural yield of 38% projected in Central America for 2100.	More frequent and/or longer drought and extreme hot periods. Desertification of semiarid regions. High variability in the yearly rainfall patterns, particularly a severe decrease in rainfall at the onset of the rainy season. Decrease in amount of rainfall overall.	More people exposed to food insecurity due to spatially more extensive drought, high population growth rate (including rural areas) and more population dependent on goods.	Reduced capacity of farmers, especially small-scale, to adapt to changing climatic conditions. Soil degradation. Limited institutional and governance-related capacities, inefficient water management including water storage and irrigation systems. Insufficient governmental support of adaptation measures, financial contributions, infrastructure, technology, insurance, early warning systems, research and innovation.	*Medium confidence* (12.3.1 to 12.3.8)	Marengo et al. (2014); Ponce et al. (2014); Rosenzweig et al. (2014); Sanabria et al. (2014); Greve and Seneviratne (2015); Marengo and Bernasconi (2015); Vieira et al. (2015); Arnell et al. (2016); Kummu et al. (2016); Kuzdas et al. (2016); Hannah et al. (2017); Marengo et al. (2017b); Veldkamp et al. (2017); IPCC (2018b); Tomasella et al. (2018); Parker et al. (2019); Garreaud et al. (2020); Depsky and Pons (2021); Zhong et al. (2021)
2. Risk to life and infrastructure due	CA, NWS, NSA, SAM, SES, SWS	Death and severe health effects, disruption of	More frequent and stronger storms and heavy precipitation	More people exposed to floods and	Vulnerable populations are usually low	*Medium confidence* (12.3.1 to 12.3.4, 12.3.6, 12.3.7)	Hirabayashi et al. (2013); Kundzewicz et al.

to floods and landslides		critical infrastructure and basic service provision systems. Flood frequency projected to increase in almost entire region, with the exception of Central America, southern South America and eastern Brazil. Population affected by river floods in South America projected to increase 50-400% for 1.5°C and 100-400% for 4°C temperature increase.	events. For some regions higher rainfall variabilities combined with higher extreme rainfall. Changing snow conditions and thawing of permafrost. Retreating glaciers resulting in glacier lakes forming and increased glacier lake outburst flood hazard.	landslides due to changing hazards, land-use and increased population, together with occupation of more risk-prone areas. More people in poverty occupying high-risk areas on steep slopes in urban areas or flood plains in urban and rural areas.	income and marginal. Low resilience in infrastructure and critical service systems. Limited government support through insurance, monitoring and early warning systems, as well as poor disaster management after extreme event.		(2014); Barros et al. (2015); Iribarren Anacona et al. (2015); Jongman et al. (2015); Sepúlveda et al. (2015); Arnell et al. (2016); Carrivick and Tweed (2016); Miranda Sara et al. (2016); Alfieri et al. (2017); Cavalcanti et al. (2017); Marengo et al. (2017a); Wang et al. (2017); Betts et al. (2018); Lyra et al. (2018); Rodríguez-Morata et al. (2018); Wilson et al. (2018); Drenkhan et al. (2019); Stennett-Brown et al. (2019); Aristizábal and Sánchez (2020); Emmer et al. (2020); Huggel et al. (2020); Poveda et al. (2020); Hirabayashi et al. (2021); Stuart-Smith et al. (2021)
3. Risk of water insecurity	CA, NWS, SAM, NES, SES, SWS	Seasonal water availability change and decline due to	Glacier shrinkage and snow cover change, more pronounced dry	Increased demand from intensification	Unjust and unequal water consumption and	*High confidence* (12.3.1, 12.3.2, 12.3.4 to 12.3.7)	Buytaert and Breuer (2013); Hidalgo et al.

		glacier shrinkage and snow cover change, precipitation change, more pronounced dry periods and poor or failed water management and governance. A 2.7°C global warming scenario in 2050 projected up to 112 million people exposed to increasing water resources stress in Meso-America, up to 28 million in Brazil, and up to 31 million in the rest of South America. Following the 2080 fragmented world scenario (RCP6.0-SSP3) 40% of the population in Latin America could be exposed to absolute water scarcity (<500 m^3 $capita^{-1}$ yr^{-1})	periods, and precipitation and circulation changes. Low lying glaciers (<5500 m.a.s.l.) in the Tropical Andes at risk of extinction by 2050 under RCP2.6. Under RCP8.5 by 2100 only the highest peaks of the tropical Andes will still have glacier ice, and glaciers in the Southern Andes will shrink to ca. 50% of the current ice mass. Following 2°C projections, regions between 10-30°S may experience a reduction of 20% in precipitation during dry season (50% in central Brazil).	of agriculture, mining, hydropower and urbanisation. Increase in population and water use/demand dependent on high contribution of glacier/snow melt, especially during drought conditions.	distribution, decreasing or failed water management and storage, low governance capacities, dependence on melt water contribution, low water infrastructure efficiency, vulnerable and growing urban areas.		(2013); Rangecroft et al. (2013); Escurra et al. (2014); Barros et al. (2015); Drenkhan et al. (2015); Arnell et al. (2016); Gosling and Arnell (2016); Kummu et al. (2016); Veldkamp et al. (2016); Barcaza et al. (2017); Buytaert et al. (2017); Miranda Sara et al. (2017); Reyer et al. (2017); Betts et al. (2018); IPCC (2018b); Braun et al. (2019); Drenkhan et al. (2019); Gesualdo et al. (2019); Moreno et al. (2020)
4. Risk of severe health effects due to increasing epidemics (in particular vector-borne diseases)	CA, NWS, NSA, SAM, NES, SES, SWS	Higher epidemics of vector-borne diseases malaria, dengue fever, leishmaniasis and zika, together with diarrheal diseases.	Higher max and min temperatures increase the geographical range of vectors, leading to predicted area of climate suitability and	Density of population increased by urbanization, resulting in higher transmission	Low sanitation conditions, particularly in low-income neighbourhoods and for Indigenous	*High confidence* (12.3.1 to 12.3.7)	Colón-González et al. (2013); Hofmeijer et al. (2013); Caminade et al. (2014); Carvalho et al. (2015); Laporta et

		Severe health effects and damage to health systems in countries with low adaptive capacity. Following the RCP8.5 scenario, geographic distribution of the malaria pathogen *Plasmodium falciparum* could cover 35-46% of South America by 2070. Following the RCP4.5 scenario, climate suitability area for vector of leishmaniasis could increase by 12.8% for South America by 2050, and max. elevation for vector could increase from 1545 to 2213 m.a.s.l. for RCP4.5 scenario and to 2265m for RCP8.5 scenario by 2050. Dengue and Zika vector projected to increase land surface area occurence by 0.4 million km^2 in South America for RCP 4.5 in 2080. With 47-99	elevation range expansion.	rates. Increased population exposed to arboviruses due to expansion of *Aedes* spp., including places of higher altitude and latitude - in Argentina, Guatemala, Ecuador, Brazil, and Bolivia.	Peoples. Insufficient coverage of appropriate water provision and sewage systems. Water accumulation in puddles and containers increases breeding sites for mosquitoes. Underfunding of health system services. Poor malaria control status and low structural and economical capacity to cope. Increase in infections can increase the incidence of more severe forms of dengue.		al. (2015); Ali et al. (2017); French and Mechler (2017); Muñoz et al. (2017); Bittencourt et al. (2018); Monaghan et al. (2018); Carbajo et al. (2019); Kraemer et al. (2019); Lippi et al. (2019); Rao et al. (2019); Ryan et al. (2019)

		million additional people at risk for virus transmission from the vector in Latin America in 2080 following RCP 2.6-8.5.					
5. Systemic risks of surpassing infrastructure and public service systems	Central and South America	Breakdown of public service systems, including infrastructure and health services due to cascading impacts of natural hazards and epidemics, affecting large part of the population.	Higher frequency and magnitude of climate hazards (storms, floods, landslides) together with an increase in spatial and temporal distribution of pathogens/vectors for malaria, dengue, zika and leishmaniasis.	More people and infrastructure exposed to climate/weather events. Increase in the population exposed to arboviruses due to expansion of the area of occurrence of competent vectors.	Increasing vulnerability of public service and infrastructure systems. Insufficient disaster management. Little improvement, maintenance and expansion of public health care systems. Low/decreasing system resilience.	*Medium confidence* (12.3.1 to 12.3.8)	Caminade et al. (2014); Laporta et al. (2015); Arnell et al. (2016); Brondízio et al. (2016); Cavalcanti et al. (2017); French and Mechler (2017); Petrova et al. (2019); Simpson et al. (2021)
6. Risk of large-scale changes and biome shifts in the Amazon	NSA, SAM, NES	Transitioning from tropical forest into other biomes such as seasonal forest or savannah through forest degradation and deforestation. Risk of shift from carbon sink to source. Projected tropical forest area reduction due to only climate forcing 15% larger by 2050 for RCP8.5 than for RCP2.6.	More frequent, stronger and persistent dry conditions. Temperature increase and reduction in annual rainfall. Mean decrease in precipitation of up to 20% during July-Nov in the Amazon basin projected for 2070-2099. Following SSP3- 7.0 (unabated emissions) average ONDJFM temperature in Amazonia in 2100 is 3.6-4.8°C above baseline. Some	Reduced availability of natural sources (food, fibre), for local people. Land use and land cover change (e.g., mining, deforestation). Loss of biodiversity and ecosystem services. Health impacts from increased forest fires particularly for	Strong dependence on non-climatic drivers, in particular land-use change, deforestation, forest fire practices. Low or decreased capacity to monitor and control deforestation.	*Medium confidence* (12.3.3 to 12.3.5)	Oliveira et al. (2013); Seiler et al. (2013); Gatti et al. (2014); Brienen et al. (2015); Doughty et al. (2015); Rowland et al. (2015); Arnell et al. (2016); Nobre et al. (2016b); Tucker Lima et al. (2017); Aragão et al. (2018); Chaves et al. (2018); Lapola et al. (2018); Menezes et al. (2018);

		Combined effect of climate change, deforestation and forest fires predict over 60% reduction for 2050 (RCP8.5). Most changes occur over eastern and southern Amazon. Least change in northwest Amazon. Net-present value of socioeconomic damage (primarily from changes in ecosystem services) over a 30y period after Amazon Forest Dieback is estimated to USD 957-3589 billion (compared to Gross Brazilian Amazon Product: USD 150 billion yr^{-1}). The Amazon carbon sink capacity has decreased by 1/3 since 1990.	models show temperatures of 7-12°C above baseline. Following the SSP1-2.6 scenario, temperatures increase until 2040, with some models showing temperatures of 3.6°C above baseline in 2100.	Indigenous Peoples.			Ciemer et al. (2019); Laporta (2019); MacDonald and Mordecai (2019); Sampaio et al. (2019); Brando et al. (2020); Matos et al. (2020); Parsons (2020); Ruiz-Vásquez et al. (2020); Staal et al. (2020); Gatti et al. (2021); Harris et al. (2021); Qin et al. (2021); Silva Junior et al. (2021)
7. Risk to coral reef ecosystems due to coral bleaching	CA, NSA, NES	Degradation and possible death of the Mesoamerican coral reef, the second largest reef in the world. Severe damage to habitat for marine	Ocean sea surface temperature (SST) increase, and lowered seawater pH and carbonate levels as a consequence of increased levels of atmospheric CO_2,	Continued exposure to increased atmospheric CO_2 levels and increased sea surface temperatures	Ecosystem highly sensitive to water temperature and pH fluctuations. High levels of negative human interference with reefs.	*High confidence* (12.3.1, 12.3.3, 12.3.5)	Meissner et al. (2012); Freeman et al. (2013); van Hooidonk et al. (2013); Alevizon and Porter (2015); Heron et al. (2017); Hoegh-

		species, as well as degrading coastal protection and other ecosystem services, decreased food security from fisheries, lack of income from tourism. For RCP 4.5 scenario by year 2050, virtually entire coral reef will experience annual severe bleaching events.	leading to ocean acidification and coral bleaching. For RCP 4.5, by 2050 mean aragonite (a form of calcium carbonate) saturation is below 3 for all latitudes, meaning carbonate accretion on warm-water coral reefs approaches zero. After 2100 SST anomalies exceed 2°C between 20°S and 60°N. In RCP8.5 scenario, aragonite saturation is below 3 at all latitudes by 2040. SST anomalies exceed 2°C between 50°S and 60°N after 2070.	together with destruction from coastal development, fishing practices and tourism.			Guldberg et al. (2017); Hughes et al. (2018); Osorio-Cano et al. (2019); Helmuth et al. (2020)
8. Risks to coastal socio-ecological systems due to sea level rise, storm surges and coastal erosion	CA, NWS, NSA, NES, SES, SWS, SSA	Coastal flooding and erosion causing severe damage to coastal population and infrastructure. Loss of fisheries and aquaculture, reef degradation and other declines in coastal protection due to increased storm surges and waves. Destruction of coastal marshes and mangroves. Salt water	Continuing and high trajectories of sea level rise, with 0.29-0.59 cm under RCP2.6 and 0.61-1.10 cm under RCP8.5 by 2100 (relative to 1985-2005) projected. More intense and persistent coastal flooding, saltwater intrusion, coastal erosion.	Coastal population growth. Increased number of people, infrastructure and services exposed, need of relocation of millions of people.	Poor planning in coastal development and infrastructure, disproportionate vulnerability and limited adaptation options for rural communities and Indigenous Peoples, increasing urbanisation in coastal cities. Vulnerable touristic facilities in coastal regions generating large	*Medium confidence* (12.3.1 to 12.3.3, 12.3.5 to 12.3.8)	Barros et al. (2015); Neumann et al. (2015); Reguero et al. (2015); Arnell et al. (2016); Jevrejeva et al. (2016); Villamizar et al. (2017); Wahl et al. (2017); IPCC (2018b); IPCC (2018a); IPCC (2019a); Oppenheimer et al. (2019); Osorio-Cano et al. (2019); Grez et al. (2020);

		intrusion and land subsidence. More than 4 million people could be exposed to flooding from relative sea-level rise by the end of the century, assuming RCP8.5 (without adaptation). When projecting sea level rise and increased population it is estimated that >9 million people will be exposed by the end of century.			economic losses and unemployment.		Moreno et al. (2020)

SM12.6 Observed and Projected Glacier Changes

Table SM12.6: Synthesis of observed and projected glacier changes, associated impacts, and adaptation and policy efforts across the Andes. Legend: **Country:** VE = Venezuela, CO = Colombia, EC = Ecuador, PE = Peru, BO = Bolivia, CH = Chile, AR = Argentina. **Glacier region:** IT = inner-tropical Andes, OT = outer-tropical Andes, DA = Dry Andes, WA = Wet Andes (DA + WA = Southern Andes). **Glacier change:** AR = area trend, MB = mass balance trend, VO = volume trend. **Impact:** RIR = river runoff, GLD = glacier lake development, WAQ = water quality, ECO = ecosystem, SOC = socio-culture. **Adaptation:** MAP = management and planning, MOS = monitoring system, NbS = nature-based solutions, GRI = grey infrastructure, FIN = financing, AWB: awareness and behaviour. **Policy and Inventory:** CCL = climate change law, GLL = glacier law, INV = last glacier inventory, NDC = year of submission and update or new version of Nationally Determined Contributions.

OVERVIEW **Country** **Total glacier area** **Glacier region** **IPCC Region**	**GLACIER CHANGE** **At country level** **For selected glaciers (mountain range, max. extent, area)** **Future outlook**	**IMPACTS**	**ADAPTATION**	**POLICY AND INVENTORY**
VE 0.1 km²	**AR**: -98% (1952-2019)[1]	**SOC**: loss of cultural identity and cuts for local tourism[1]		**NDC**: 2017 Do not include glaciers, only mention fragile mountain ecosystems

(2019)[1] IT NSA	**Pico Humboldt** (Sierra Nevada de Mérida, 4942 m asl.) 0.1 km^2, **AR**: -99% (1910-2019)[1] Pico Humboldt, the last remaining glacier, is under imminent risk of extinction[1]			**CCL**: Initial framework was set in 2016 **GLL**: - **INV**: 2019 (published in 2020)[1], no official governmental inventory available
CO 37 km^2 (2017)[2] IT NWS	**AR**: -56% (1986-2017)[2] **MB**: -2.5 m w.e. yr^{-1} (1987-2005)[3] -0.4 to -1.0 m w.e. yr^{-1} (2000-2018)[4] **Nevado del Ruiz** (Cordillera Central, 5321 m asl.) 8 km^2[2] **AR**: -51% (1986-2017)[2] Most Colombian glaciers are at risk of extinction in the near-future, only the highest summits will likely remain after 2050[3]	**RIR**: peak water reached (Magdalena: 1981, Conejeras glacier: 2016)[5]	**MAP**: participatory risk management for early warning systems (Cauca basin)[6]; top-down adaptation policymaking prevails while a bottom-up or blended approach could be more effective[7] **NbS**: agroforestry in the glacier-fed Chinchiná River basin to control water levels for coffee cultivation[8]	**NDC**: 2018, 2020 (update) Explicitly mention protection and monitoring of glaciers and mountain ecosystems **CCL**: Climate Change Framework Law no. 1931 (2018) underway **GLL**: - **INV**: 2017 (published in 2018)[2]
EC 44 km^2 (2017)[9] IT NWS	**AR**: -54% (1980s-2017)[9] **MB**: -0.2 to -0.4 m w.e. yr^{-1} (2000-2018)[4] **Antisana (**Cordillera Real, 5760 m asl.) 16 km^2[10], ~0.6 km^3[10] **AR**: -33% (1979-2007)[11] Several Ecuadorian glaciers are at risk of extinction in the near-future, only the highest summits (>5600 m asl.) will likely remain after 2050[10,12] Antisana would heavily reduce or disappear by 2100 (projected area loss: -72% for RCP2.6 and -98% for RCP8.5)[10]	**RIR**: peak water reached (Daule-Vinces: 1980)[5] **GLC**: 10 new glacier lakes (before 2050)[10] **ECO**: upward expansion of several plant species at Chimborazo (1986-2013)[13] and ground beetle species at Antisana and Carihuairazo (2016-2017)[14] in deglaciating areas; decreasing meltwater contribution would lead to environmental and taxonomic diversity loss[15]	**NbS/FIN**: first water fund in CSA launched in 2000 for improving Quito's water quality in a context of high mountain ecosystem deterioration[16,17]; **NbS**: water fund for ecosystem conservation of the glacier-fed Tungurahua Páramo[18]	**NDC**: 2019 Explicitly mention glacier shrinkage, mountain ecosystems and links to hydrological risks **CCL**: - **GLL**: - **INV**: 2017 (published in 2018)[9]

PE 1114 km² (2016)[19] OT NWS-SAM	**AR**: -54% (1962-2016)[19] **MB**: 0 to -2.0 m w.e. yr^{-1} (2000-2018)[4] **Cordillera Blanca** (6768 m asl.) 449 km² **AR**: -38% (1962-2016)[19] **Cordillera Vilcanota** (6384 m asl.) 255 km² **AR:** -48% (1962-2016)[19] Several Peruvian glaciers are at risk of extinction in the near-future, only higher summits (>5500 m asl.) will likely remain after 2050[12,20,21] Glaciers in the Cordillera Blanca would heavily reduce or disappear by 2100 (projected area loss: --58% for RCP2.6 and -99% for RCP8.5)[20]	**RIR**: peak water reached (in 7 deglaciating subcatchments)[5,22] **WAQ**: acid rock drainages and decreasing pH (2014)[23] **GLC**: 71 new glacier lakes likely to develop in Peru until 2100[24] **ECO**: drying of several cushion bogs, amphibian species have colonized deglaciated areas[25] **SOC**: conflict over water resources between competing users;[26] loss of cultural values,[27] e.g., using stones instead of ice blocks at pilgrim procession Qollur Rit'I[28]	**MAP**: reframing of adaptation plans for water access of mountain communities[29] **MOS**: GLOF early warning system at lakes 513 (Cordillera Blanca) and Riticocha (Cordillera Urubamba); lake monitoring at Palcacocha (Huaraz) **NbS**: Phytoremediation approach to mitigate acid rock drainage impacts[30]**;** construction o**f** micro-reservoirs (Pitumarca)[31] and infiltration canals[32] using IK and LK; implementation of ecosystem-based measures and restauration of ancient water management systems in the Nor Yauyos-Cochas Landscape Reserve[18]; pasture and wetland conservation in Chanchayllo[18] **GRI**: large reservoirs as important part of water management but socially contested, more flexible solutions needed (Vilcanota basin)[33]; construction of surface storage dams in the Chorunga River Basin[34] **AWB**: educational route established at Pastoruri glacier for sensitizing visitors to the impacts of climate change and conservation;[35]	**NDC**: 2018, 2020 (update) Explicitly mention glacier shrinkage, links to water resource changes, hydrological risks, disaster risk reduction and other adaptation measures **CCL**: Climate Change Framework Law No. 30754 (2018)[39] First CCL in CSA, explicitly includes glaciers as part of ecosystem-based adaptation **GLL**: Underway (National Policy on Glaciers and Mountain Ecosystems) **INV**: 2016 (published in 2018)[19]

			fostering a water culture for more sustainable use[36]; specific strategies for adapted crop planting based on Indigenous knowledge in the Cordillera Huayhuash[37];new glacier lakes as an increasing attractive for guided tourism[38]; change in irrigation frequency in the Chorunga River basin[34]	
BO 346 km² (2010)[40] OT SAM	**AR**: -~35% (1980s-2013)[40] **MB**: -0.4 to -0.6 m w.e. yr^{-1} (2000-2018)[4] **VO**: -12% (1997-2010)[41] **Zongo** (Cordillera Real, 6000 m asl.) 2 km²[41], 8.6 km³[41] Several Bolivian glaciers are at risk of extinction in the near-future, only higher summits (>5500 m asl.) will likely remain after 2050[12,41] Zongo glacier would heavily reduce by 2100 (projected volume loss: -40% for RCP2.6 and -89% for RCP8.5 (2016-2100)[41]	**ECO**: plant succession and increase in plant richness, cover, and abundance in the Cordillera Real (1975-2013)[42]	**MAP**: effective adaptation to drought vulnerability (Pucara basin) as a function of national development pathway[43] **NbS**: successional agroforestry to restore depleted soils and plantations in the Andean foothills of Alto Beni and Yungas[18]; micro-reservoirs and agroforestry in the puna region[44] **AWB**: Educational route established at the vanished Chacaltaya glacier site for sensitizing visitors to the impacts of climate change and conservation[1,45]; migration as a result of combined socioeconomic pressure and glacier shrinkage and water shortage (Palca, La Paz)[46]**;** vanishing glacier site (Chacaltaya) as a new attractive for guided tourism[45]	**NDC**: 2016 Explicitly mention glacier shrinkage as driver of vulnerability **CCL**: Initial draft The Framework Law of Mother Earth and Holistic Development for Living Well (2012) includes several aspects on climate change adaptation **GLL**: - **INV**: 2010 (published in 2014)[40], currently new INV underway
CH 23,708 km² (2015)[47]	**Maipo river basin** (Central Andes, 6570 m asl.) 378 km² **AR**: -29% (1955-2016) **MB**: -0.1 m w.e. yr^{-1} (1955-2016)	**RIR**: peak water reached (Biobio: 2002, Rapel: 2010)[5]	**MAP**: reframing of adaptation plans for water access of mountain communities[29]; improved integration of local	**NDC**: 2015, 2020 (update) Briefly mention snow decline and glacier shrinkage as drivers of vulnerability

DA, WA SWS-SSA	**VO**: -20% (1955-2016)		communities into adaptation planning[48] **MOS**: observational GLOF warning system at Lake Cachet Dos[49] **NbS**: increasing focus on NbS to avoid negative outcomes from GRI in combination with improved governance (Aconcagua basin)[50]	**CCL**: Underway[51] **GLL**: Underway (since 2005) Explicitly includes glacier monitoring **INV**: 2015 (published in 2017)[47]
AR 8484 km² (2017)[52] DA, WA SES-SSA	**Monte Tronador** (North Patagonia, 3475 m asl.) 57 km² **AR**: -2% (2000-2012) **MB**: -3.1 m w.e. yr^{-1} (2000-2012)[53]	**RIR**: peak water reached (Baker: 2015)[5]	**MAP**: effective adaptation to drought vulnerability (Mendoza basin) as a function of national development pathway[43] **AWB**: the imminent threat of glacier and water loss in the Mendoza region lead to the transformative measure of developing the Glacier Protection Law (see column "Policy and Inventory")[54]	**NDC**: 2016, 2020 (2nd) Explicitly mention glacier shrinkage and snow cover decline, links to the loss of landscape values, tourism and ecosystems and the need for improved resilience and research (mostly in 2nd NDC) **CCL**: Law on Minimum Budgets for Adaptation and Mitigation of Climate Change Law No. 27.520 (2019)[55] **GLL**: Glacier Protection Law No. 26.639 (2010-2019), First GLL in CSA **INV**: 2017 (published in 2018)[52]

SM12.6.1 References used in Figure 11 and Table SM12.6: Synthesis of observed and projected glacier changes, associated impacts, adaptation and policy efforts across the Andes.

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SM12.7 Feasibility Assessment of Adaptation Options

12.7.1 Implementation of Agroforestry Systems in CSA

Table SM12.7: Detailed supporting information for Table 12.11, the summary for the feasibility assessment of four adaptation measures.

Dimension	Adaptation indicators	Questions guiding the adaptation indicators	Assessment	Explanation	References
Economic	**Micro-economic viability**	What are the economic costs and trade-offs of the option? (high costs correspond to low feasibility)	B	Agroforestry provides more diverse and sustainable agricultural production. Other hand, it is recognized that the high initial investment and long wait until trees start to produce creates economic vulnerability. Low prices of products are not sufficient to compensate yield gaps of shaded culture in Ecuador.	Casanova-Lugo et al. (2016); Jacobi (2016); Middendorp et al. (2018); Krishnamurthy et al. (2019)
	Macro-economic viability	Would the option lead to higher productivity?	C	By managing agroforestry systems, farmers could potentially maintain their current production at regional level (e.g., coffee and cocoa plantations) using suitable trees to ameliorate microclimatic conditions.	Middendorp et al. (2018); de Sousa et al. (2019); Jezeer et al. (2019); Maas et al. (2020)
	Socio-economic vulnerability reduction potential	To what extent does the option reduce inequalities?	C	Agroforestry provides several products for a unit of land. Under current conditions, the economic sustainability of farmers seems very difficult to achieve if centered only on a single resource if available surfaces remain restricted. Association is needed, so farmers can negotiate the price of products avoiding intermediaries or companies holding a local monopoly. Agroforestry in dry zones of LAC have significant potential to support livelihood resilience in areas that are traditionally considered to be highly marginalized.	Krishnamurthy et al. (2019); Castañeda-Ccori et al. (2020)
	Employment & productivity enhancement potential	How many people that can be employed or how much can a system's productivity increase under the option?	C	Slash and mulch agroforestry systems provide multiple ecosystem services in Central America than conventional management. But, agroforestry systems depend more on human labour, while conventional agriculture replaces labour with high input technology.	Montagnini (2017); Kearney et al. (2019)

Technological	**Technical resource availability**	Are the technology and associated human, financial, administrative resources needed for an adaptation option available?	B	Technical assistance and training can help in reduce barriers for adoption in Colombia. The contribution of agroforestry systems to sustainability ultimately depends on the management regimes and selection of woody species in drylands of LAC.	Krishnamurthy et al. (2019); Jara-Rojas et al. (2020)
	Risks mitigation potential	To what degree can the option reduce the likelihood and/or consequences of risks?	C	Silvopastoral systems may be included as a policy strategy for the mitigation of consequences of climatic change in Colombia. Agroforestry can reduce risk by income diversification.	Montagnini (2017); Jara-Rojas et al. (2020)
Institutional	**Political acceptability**	Is the option politically acceptable? Does the option reflect stakeholder perceptions about the meaning and purpose of adaptation?	B	Agroforestry practices enhance the potential of Amazon Indigenous Peoples for making global forest governance more nuanced. There is an intention of incentivate adoption.	Waldron et al. (2017); Rosenstock et al. (2019); González and Kröger (2020)
	Legal, regulatory feasibility	Is the option appropriate to jurisdictional context? Is it challenging to implement the legal changes needed for the option? Are there known legal and regulatory barriers?	LE	Land tenure security showed positive effect in adoption of agroforestry practices in Argentine.	Tschopp et al. (2020)

	Institutional capacity & Administrative feasibility	Would current institutions be able to implement the option? Is the option administratively supported? Are human resources to support implementation of adaptation option clearly identified? Are responsibilities delineated for managing implementation of the option?	A	Financial resources are not allocated to agroforestry, government officials do not recognize the socio–economic function of agroforestry in Bolivia. Market schemes (payment for ecosystem services and certifications) are needed to improve economic performance of coffee small-scale farmers in Ecuador. Environmental services provided are not recognized. Issues of coordination among institutions are important to enhance synergies of agroforestry in the region. Collaboration and support of producer organizations might facilitate adoption. Multigoal approaches appears as opportunity for government and institutions.	Jacobi (2016); Montagnini (2017); Waldron et al. (2017); Middendorp et al. (2018); Soler et al. (2018); Tschopp et al. (2020)
	Transparency & accountability potential	Are policy goals and targets for the option explicitly articulated; monitoring and evaluation protocols are set up to track implementation; and transparent reporting mechanisms are in place to synthesize progress and gaps?	LE	There is a significant gap between national ambition and national ability to measure and report on agroforestry in UNFCC reports.	Rosenstock et al. (2019)

Social	**Social co-benefits**	Are there health and education benefits to be had from the option? Does the option minimize negative trade-offs with other development policy goals; identify positive synergies with other policy goals?	C	Managing shade and input in smallholder coffee farms in a way that supports forest butterfly species richness and above-ground carbon storage and produce similar amounts of coffee as more intensified system in Perú. Agroforestry can enhance food security and SDG.	Waldron et al. (2017); Jezeer et al. (2019)
	Socio-cultural acceptability	Is there public resistance to the option? Does the option typically find acceptance within existing socio-cultural norms, utilize diverse knowledge systems including Indigenous knowledge and local knowledge?	A	Threat of fire from uncontrolled slash-and-burn activities is a reason not to plant trees in Bolivia. There exist trade-offs between provision of supporting and regulating services and provisioning and cultural ecosystem services such as yield and profitability. Policymakers should focus on social acceptability of agroforestry.	Jacobi (2016); Mortimer et al. (2018); Soler et al. (2018)
	Social & regional Inclusiveness	Are different social groups and remote regions included in the option? Does the adaptation option adversely affect vulnerable groups or other areas?	B	Adaptive collaborative management processes and participatory land-use planning needed to scale agroforestry adoption. There is a trend that agroforestry focus on the significant supporting role that women play in male-dominated chains.	Gumucio et al. (2018); Buck et al. (2020); Gosling et al. (2020); Maas et al. (2020); Tschopp et al. (2020)

	Intergenerational equity	Does the option compromise the ability of future generations to meet their own needs in any way?	NA		
Environmental	**Ecological capacity**	Does the option enhance supporting, regulating or provisioning ecosystem services in any way?	C	Agroforestry system of land use distinguishes itself from the other systems (crops and afforestation on croplands) through its potential to sequester higher amounts of carbon (in the above- and belowground tree biomass), providing clean water, sustaining higher biodiversity and agricultural production	Casanova-Lugo et al. (2016); Jacobi (2016); Abbas et al. (2017); Brüning et al. (2018); Kearney et al. (2019); Santos et al. (2019)
	Adaptive capacity/resilience building potential	Does the option enhance the ability of systems, institutions, humans to adjust to potential damage, take advantage of opportunities, or respond to consequences? OR Does the option contribute to resilience building (ability to cope with stressors and reorganize to maintain structures and functions, retain capacity to transform)	C	Agroforestry systems reduce or do not increase pest and disease incidence compared with monocultures when good cultural management practices are implemented.	Jezeer et al. (2019); Armengot et al. (2020); Bagny Beilhe et al. (2020); Cerda et al. (2020); Maas et al. (2020)

Geophysical	**Physical feasibility**	Is the physical potential for the adaptation option a constraint?	B	Agroforestry systems have a lower negative impact on soil and water resources given the interaction between the different components	Montagnini (2017); Krishnamurthy et al. (2019)
	Land use change enhancement potential	Does the option enhance carbon stocks? (e.g., through forest restoration)	C	Agroforestry system sequesters higher amounts of carbon (in the above- and belowground tree biomass) compared with crops and afforestation on croplands, and therefore enhance carbon stock over time	Abbas et al. (2017); Feliciano et al. (2018)
	Hazard risk reduction potential	Does the option reduce number of people exposed to a hazard?	NA		

12.7.2 Ecosystem Based Adaptation (EbA) in Terrestrial and Freshwater Ecosystems in CSA

Dimension	**Adaptation indicators**	**Questions guiding the adaptation indicators**	**Assessment**	**Explanation**	**References**
Economic	**Micro-economic viability**	What are the economic costs and trade-offs of the option? (high costs correspond to low feasibility)	B	EbA is a very flexible and diverse adaptation option that embraces a wide range of techniques and political and socioeconomical arrangements. Few papers specifically considered trade-offs between EbA and other activities in CSA, but in general there is no evidence of considerable barriers in this dimension.	Murti and Buyck (2014); Schoolmeester et al. (2016); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)
	Macro-economic viability	Would the option lead to higher productivity?	C	While protecting natural ecosystems, EbA fosters sustainable production, increasing productivity, particularly in the medium and long term. Examples of this can be found in the practices of smallholder farmers in Central America (Guatemala, Honduras, Costa Rica) and in initiatives of adaptive co-management in Ecuador. EbA projects increase the provision of fresh water to local communities in the Chingaza paramo and the city of Bogota.	Murti and Buyck (2014); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Hitoe Mergner (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)

	Socio-economic vulnerability reduction potential	To what extent does the option reduce inequalities?	C	EbA is a strategy that frequently involves bottom-up decision making and local communities' empowerment and participation. As such, it usually contributes to inequality reduction. There are examples of this in all CSA. Nevertheless, studies in Brazil found that EbA strategies that do not reduce poverty, particularly in poor regions, are unlikely to be adaptive in the long term.	Murti and Buyck (2014); Lange et al. (2016); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019)
	Employment & productivity enhancement potential	How many people that can be employed or how much can a system's productivity increase under the option?	C	EbA is a diverse strategy that can be implemented in a variety of ways. When associated with productive activities like food production through seeds, soil and water management, for instance; it increases the output and makes it more sustainable in time. Although few authors assessed the number of people involved in CSA, these practices tend to require more people involved per area unit than more industrialized practices.	Murti and Buyck (2014); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Taffarello et al. (2017); Vela (2017); Ostovar (2019); Richerzhagen et al. (2019)
Technological	**Technical resource availability**	Are the technology and associated human, financial, administrative resources needed for an adaptation option available?	B	In general, EbA does not require technologies that are not available for local communities. It rather depends on Indigenous knowledge and local knowledge. Nevertheless, several authors found limitations in technical assistance and funding for specific key technologies, training and activities for dissemination of practices among communities, communication and reduction in barriers for adoption.	Murti and Buyck (2014); Lange et al. (2016); Schoolmeester et al. (2016); (Harvey et al., 2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); (Hitoe Mergner, 2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)
	Risks mitigation potential	To what degree can the option reduce the likelihood and/or consequences of risks?	C	EbA practices can reduce risk in several ways, from increasing awareness among communities to increasing food diversity and production, together with income diversification. In the Mata Atlantica of Rio de Janeiro State (Brazil) valuing the benefits of nature through EbA, associated with community-based adaptation, can reduce vulnerability by reducing landscape and ecosystem degradation.	Murti and Buyck (2014); Lange et al. (2016); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)

Institutional	**Political acceptability**	Is the option politically acceptable? Does the option reflect stakeholder perceptions about the meaning and purpose of adaptation?	B	EbA is usually recognized as a desirable policy for most stakeholders in CSA, particularly for being a strategy that incorporates environmental and social concerns. Nonetheless, it is not always understood in the same way or under the same priority criteria by all parties involved, generating potential conflicts. It is important that all stakeholders agree on the goals and methods for EbA to be actually effective.	Murti and Buyck (2014); Lange et al. (2016); Oviedo et al. (2016); Schoolmeester et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Hitoe Mergner (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)
	Legal, regulatory feasibility	Is the option appropriate to jurisdictional context? Is it challenging to implement the legal changes needed for the option? Are there known legal and regulatory barriers?	C	In general, the legal framework is not an important barrier for EbA in CSA. Factors like land tenure and rights to resources access, though, can eventually generate barriers that need to be addressed.	Murti and Buyck (2014); Oviedo et al. (2016); Schoolmeester et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Hitoe Mergner (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019)
	Institutional capacity & Administrative feasibility	Would current institutions be able to implement the option? Is the option administratively supported? Are human resources to support implementation of adaptation option clearly identified? Are responsibilities delineated for managing implementation of the option?	B	Current institutions are usually able to implement EbA projects, but lack of coordination among them and clear understanding of goals and strategies is a potential barrier in CSA. Human resources to support EbA are not always clearly identified or do not have their responsibilities clearly delineated.	Murti and Buyck (2014); Lange et al. (2016); Schoolmeester et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Hitoe Mergner (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)

	Transparency & accountability potential	Are policy goals and targets for the option explicitly articulated; monitoring and evaluation protocols are set up to track implementation; and transparent reporting mechanisms are in place to synthesize progress and gaps?	B	Many EbA projects in CSA have not clear goals and targets in terms of climate change adaptation. This makes effective monitoring and articulation in terms of adaptation very difficult. Although the projects can still be effective in this way, they could benefit greatly from improvements on this issue.	Murti and Buyck (2014); Schoolmeester et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Kasecker et al. (2018); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)
Social	**Social co-benefits**	Are there health and education benefits to be had from the option? Does the option minimize negative trade-offs with other development policy goals; identify positive synergies with other policy goals?	C	The implementation of EbA strategies in CSA increases community awareness and participation in the decision making process regarding to their local resources and ecosystems. EbA can enhance food sovereignty and fosters SDG.	Murti and Buyck (2014); Lange et al. (2016); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Vela (2017); Chain-Guadarrama et al. (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)
	Socio-cultural acceptability	Is there public resistance to the option? Does the option typically find acceptance within existing socio-cultural norms, utilise diverse knowledge	C	In CSA, EbA is heavily based in local and Indigenous knowledge, as well as in ecological academic knowledge. For this reason, it is generally culturally accepted in local communities. There is no public opinion resistance to it.	Murti and Buyck (2014); Lange et al. (2016); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Hitoe Mergner (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)

		systems including Indigenous knowledge and local knowledge?			
	Social & regional Inclusiveness	Are different social groups and remote regions included in the option? Does the adaptation option adversely affect vulnerable groups or other areas?	C	EbA strategies are common in remote regions in CSA, although not always recognized as such. EbA tends to benefit vulnerable groups, but care needs to be taken not to ignore aspects as the impact on socioeconomic inequalities when implemented.	Murti and Buyck (2014); Lange et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)
	Intergenerational equity	Does the option compromise the ability of future generations to meet their own needs in any way?	C	EbA is defined as an adaptation strategy that fosters protection and restauration of natural ecosystems along with sustainable used of natural resources. Therefore, it does not compromise the ability of future generations to meet their own need.	Murti and Buyck (2014); Lange et al. (2016); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Hitoe Mergner (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)
Environmenta l	**Ecological capacity**	Does the option enhance supporting, regulating or provisioning ecosystem services in any way?	C	EbA is defined as an adaptation strategy that fosters protection and restauration of natural ecosystems along with sustainable used of natural resources. Most EbA projects aim at protecting and enhancing ecosystem services.	Murti and Buyck (2014); Lange et al. (2016); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Hitoe Mergner (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)

	Adaptive capacity/resilience building potential	Does the option enhance the ability of systems, institutions, humans to adjust to potential damage, take advantage of opportunities, or respond to consequences? OR Does the option contribute to resilience building (ability to cope with stressors and reorganise to maintain structures and functions, retain capacity to transform)	C	EbA projects increase resilience in CSA by protecting and restoring ecosystem's health and promoting activities in harmony with ecosystems cycles.	Murti and Buyck (2014); Lange et al. (2016); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Hitoe Mergner (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)
Geophysical	**Physical feasibility**	Is the physical potential for the adaptation option a constraint?	C	EbA is a very diverse and encompassing adaptation strategy but physical potential is generally not a constraint for this adaptation option in CSA.	Murti and Buyck (2014); Lange et al. (2016); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Hitoe Mergner (2018); Kasecker et al. (2018); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)

	Land use change enhancement potential	Does the option enhance carbon stocks? (e.g., through forest restoration)	C	By protecting and restoring ecosystems health and productivity, EbA usually enhances carbon stocks.	Harvey et al. (2017); Scarano (2017); Chain-Guadarrama et al. (2018); Hitoe Mergner (2018); Kasecker et al. (2018); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020) Murti and Buyck (2014); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Taffarello et al. (2017); Vela (2017); Ostovar (2019)
	Hazard risk reduction potential	Does the option reduce number of people exposed to a hazard?	C	EbA practices can reduce hazard in several ways, from increasing awareness among communities to increasing food diversity and production, together with income diversification. In the Mata Atlantica of Rio de Janeiro State (Brazil) valuing the benefits of nature through EbA, associated with community-based adaptation, can reduce vulnerability by reducing landscape and ecosystem degradation.	Murti and Buyck (2014); Lange et al. (2016); Oviedo et al. (2016); Schoolmeester et al. (2016); Vogt et al. (2016); Harvey et al. (2017); Scarano (2017); Taffarello et al. (2017); Vela (2017); Chain-Guadarrama et al. (2018); Hitoe Mergner (2018); Kasecker et al. (2018); Ostovar (2019); Richerzhagen et al. (2019); Ariza-Montobbio and Cuvi (2020)

12.7.3 Early Warning Systems for Adaptation of Health Systems in CSA

Dimension	**Adaptation indicators**	**Questions guiding the adaptation indicators**	**Assessment**	**Explanation**	**References**
Economic	**Micro-economic viability**	What are the economic costs and trade-offs of the option? (high costs correspond to low feasibility)	B	Although the initial economic investment might be costly, the cost-benefit ratio considering the overall operation of the system and the societal (e.g., health) and economic losses / savings are balanced. Generally, the benefit exceeds the costs, but also important to consider that initial investment cost in setting up the system can be prohibitive.	Rogers and Tsirkunov (2010); Hallegatte (2012); Toloo et al. (2013); Hallegatte et al. (2017); International Labour Office (2019)

	Macro-economic viability	Would the option lead to higher productivity?	C	Yes. The EWS allows the health sector to better use scarce resources and reduces economic losses due to illness by supporting interventions to prevent health problems.	Hallegatte (2012); Hallegatte et al. (2017); International Labour Office (2019); Muñoz et al. (2020b)
	Socio-economic vulnerability reduction potential	To what extent does the option reduce inequalities?	C	Partially yes (poverty alleviation and social protection), particularly for health outcomes that have a greater impact on impoverished populations	Lemos et al. (2002); Lavell (2008); Lavell (2009); Eakin et al. (2015); Escobar et al. (2015); Nagy et al. (2018); Pasetto et al. (2018)
	Employment & productivity enhancement potential	How many people that can be employed or how much can a system's productivity increase under the option?	C	Any system to help prevent workers from getting ill will increase their productivity. The network will also require some minimum new workers, so the health system will have to be expanded.	International Labour Office (2019)
Technological	**Technical resource availability**	Are the technology and associated human, financial, administrative resources needed for an adaptation option available?	A	Mostly no. For many developing countries, human and financial resources are a bottleneck. Many countries are still in the process of building their capacities for the development and implementation of climate services. Regional platforms may provide a solution for technical bottlenecks at national levels.	Aragón-Durand (2014); Janches et al. (2014); Eakin et al. (2015); Viand and Briones (2015); Lowe et al. (2016); Cardona et al. (2017); Lowe et al. (2017); Marchezini et al. (2017); Muñoz et al. (2017); Villamizar et al. (2017); Herrera et al. (2018); Mahon et al. (2018); Nagy et al. (2018); Pasetto et al. (2018); Trotman et al. (2018); Lowe et al. (2020); Muñoz et al. (2020b)
	Risks mitigation potential	To what degree can the option reduce the likelihood and/or consequences of risks?	C	Yes. Early warning systems allow the health system to intervene to reduce the risks of a climate event. However, a large degree of coordination is necessary between relevant local, provincial, and national organisms, from diverse areas, to ensure a holistic risk mitigation that also encompasses health risks (both direct and indirectly).	Ruiz et al. (2006); Aragón-Durand (2014); Eastin et al. (2014); Janches et al. (2014); Watanabe (2015); Lowe et al. (2016); Cardona et al. (2017); Lowe et al. (2017); Marchezini et al. (2017); Aparicio-Effen et al. (2018); Herrera et al. (2018); Nagy et al. (2018); Pasetto et al. (2018); Trotman et al.

					(2018); World Food Programme (2018); International Labour Office (2019); Johansson et al. (2019)
Institutional	**Political acceptability**	Is the option politically acceptable? Does the option reflect stakeholder perceptions about the meaning and purpose of adaptation?	A	EWS are widely accepted, especially by regional authorities. However, in many cases, the needs / perceptions of local authorities and communities are not considered, especially when it comes to top-down strategies. The identification of policy objectives by higher authorities (e.g., political, regulatory or practioners) tends to determine what will be filtered to the lower levels, resulting in mismatched expectations and limited implementation at the community level. Political will is not always there, particularly for climatic risks which are seen not as imminent or urgent as other risks and problems.	Lemos et al. (2002); Lavell (2008); Aragón-Durand (2014); Eakin et al. (2015); Watanabe (2015); Lowe et al. (2017); Villamizar et al. (2017); Aparicio-Effen et al. (2018); Trotman et al. (2018); Lowe et al. (2020); Muñoz et al. (2020b)
	Legal, regulatory feasibility	Is the option appropriate to jurisdictional context? Is it challenging to implement the legal changes needed for the option? Are there known legal and regulatory barriers?	A	Action at a national level is often limited by the lack of a mandate for the health and climate sectors (and other relevant sectors like disaster risk management) to work on climate-health issues. Formal collaboration mechanisms (MOUs) between climate and health sectors are needed to facilitate joint work plans, data sharing agreements, joint spaces of dialogue, etc. At a regional scale, it may be viable to implement an early warning platform for some health outcomes. There is a lack of mandate from existing legal frameworks.	Eakin et al. (2015); Muñoz et al. (2017); Stewart-Ibarra et al. (2019); Lowe et al. (2020); Muñoz et al. (2020b)
	Institutional capacity & Administrative feasibility	Would current institutions be able to implement the option? Is the option administratively supported? Are human resources to support implementation of adaptation option clearly identified? Are responsibilities delineated for	A	Mostly no. Some countries have implemented disaster EWSs and few have implemented EWS for direct health outcomes; however, the countries present very heterogeneous experiences due to institutional and operational weaknesses. National capacities vary widely across the region. Smaller countries with limited capacity often lack the human, financial, and physical resources to implement this option. Even though disaster EWSs present important co-benefits for reducing health problems associated with extreme events, coordination with health systems remains limited. For health EWS, without a clear mandate to work on climate-health issues, the health and climate sectors are unable to delineate and sustain roles and	Lemos et al. (2002); Aragón-Durand (2014); Eakin et al. (2015); Viand and Briones (2015); Watanabe (2015); Cardona et al. (2017); Hallegatte et al. (2017); Lowe et al. (2017); Marchezini et al. (2017); Aparicio-Effen et al. (2018); Herrera et al. (2018); Nagy et al. (2018); Pasetto et al. (2018); Trotman et al. (2018); World Food Programme (2018)

		managing implementation of the option?		responsibilities. Regional institutions may better able to implement health EWSs in areas with limited capacity.	
	Transparency & accountability potential	Are policy goals and targets for the option explicitly articulated; monitoring and evaluation protocols are set up to track implementation; and transparent reporting mechanisms are in place to synthesize progress and gaps?	A	Partially, goals are articulated (e.g., accurately detect and respond to a climate event and/or epidemic prior to the event); however, there is often a lack of systematic M&E and lack of transparency (that is, goals often come from national or other levels, while local goals might not be articulate to other higher policy goals). High heterogeneity observed in the region in terms of corruption and M&E capacities.	Lowe et al. (2011); Bowman et al. (2016); Lowe et al. (2016); Cardona et al. (2017); Muñoz et al. (2020b)
Social	**Social co-benefits**	Are there health and education benefits to be had from the option? Does the option minimize negative trade-offs with other development policy goals; identify positive synergies with other policy goals?	B	Yes, there are co-benefits. However, many countries in the region have not yet implemented, for example, national assessments of climate for health. Few have taken measures to increase the climate resilience of health infrastructure.	Ruiz et al. (2006); Eastin et al. (2014); Escobar et al. (2015); Hallegatte et al. (2017); Lowe et al. (2017); Aparicio-Effen et al. (2018); Herrera et al. (2018); Nagy et al. (2018); Pasetto et al. (2018); Trotman et al. (2018); Lowe et al. (2020)
	Socio-cultural acceptability	Is there public resistance to the option? Does the option typically find acceptance within existing socio-cultural norms, utilise diverse knowledge	B	There is potential for public resistance. The warnings from disaster EWS may or may not be accepted by the public, depending on how they are disseminated and perceptions of credibility of the warning. Few studies assess public acceptability of health EWS, largely because health EWS are less commonly implemented.	Lavell (2008); Aragón-Durand (2014); Eakin et al. (2015); Trotman et al. (2018); Tauzer et al. (2019)

		systems including Indigenous knowledge and local knowledge?		Health EWS rarely utilize diverse knowledge systems including Indigenous knowledge and local knowledge.	
	Social & regional Inclusiveness	Are different social groups and remote regions included in the option? Does the adaptation option adversely affect vulnerable groups or other areas?	B	Diverse groups and remote regions are partially included, as EWS forecasts can be issued often over broad geographic areas; however, the coarse spatial scale of the EWS may mask finer-scale variation in risks faced by vulnerable groups. Few systems, mostly disaster EWS, facilitate the direct participation of vulnerable populations .	Lavell (2009); Eakin et al. (2015); Escobar et al. (2015); del Granado et al. (2016); Villamizar et al. (2017)
	Intergeneration al equity	Does the option compromise the ability of future generations to meet their own needs in any way?	C	If implemented, system will develop a culture of prevention that will be passed on to future generations. Possible positive effect if new generations are educated in risk management through the system	
Environmental	**Ecological capacity**	Does the option enhance supporting, regulating or provisioning ecosystem services in any way?	LE	Yes, but evidence is lacking	Eakin et al. (2015)

	Adaptive capacity/resilience building potential	Does the option enhance the ability of systems, institutions, humans to adjust to potential damage, take advantage of opportunities, or respond to consequences? OR Does the option contribute to resilience building (ability to cope with stressors and reorganise to maintain structures and functions, retain capacity to transform)	C	Yes	Ruiz et al. (2006); Aragón-Durand (2014); Janches et al. (2014); Eakin et al. (2015); Escobar et al. (2015); Watanabe (2015); Lowe et al. (2016); Lowe et al. (2017); Marchezini et al. (2017); Villamizar et al. (2017); Aparicio-Effen et al. (2018); Herrera et al. (2018); Nagy et al. (2018); Pasetto et al. (2018); Trotman et al. (2018); Lowe et al. (2020); Muñoz et al. (2020b)
Geophysical	**Physical feasibility**	Is the physical potential for the adaptation option a constraint?	A	Physical infrastructure is a potential constraint. EWS systems require adequate physical infrastructure for monitoring of hydro-climatic conditions. In some cases, earth observations (satellite data) can substitute in areas with limited coverage when human and computing resources are not available.	Lowe et al. (2013); Escobar et al. (2015); del Granado et al. (2016); Marchezini et al. (2017); Pasetto et al. (2018); Kull et al. (2021)
	Land use change enhancement potential	Does the option enhance carbon stocks? (e.g., through forest restoration)	LE	.	

	Hazard risk reduction potential	Does the option reduce number of people exposed to a hazard?	C	Yes	Lavell (2008); Aragón-Durand (2014); Eastin et al. (2014); Escobar et al. (2015); Marchezini et al. (2017); Aparicio-Effen et al. (2018); Herrera et al. (2018); Pasetto et al. (2018); Trotman et al. (2018); World Food Programme (2018)

12.7.4 Multi-use of Water Storage Approaches in CSA

Dimension	**Adaptation indicators**	**Questions guiding the adaptation indicators**	**Assessment**	**Explanation**	**Evidence (limited, medium, robust)**	**Agreement (low, medium, high)**	**Sub-regions**	**References**
Economic	**Micro-economic viability**	What are the economic costs and trade-offs of the option?	B	Economic costs would have been a barrier for the regional government and local institutions to construct the Olmos hydropower project in Peru. Only an innovative public-private partnership model allowed for the successful implementation of the large and complex tunnel system and reservoir for water allocation, hydropower production and irrigation. Compared to conventional reservoirs, seasonal pumped-storage infrastructure includes higher overall operation and maintenance costs (e.g., tunnel, pumping infrastructure) but leads to higher revenue and thus income in NE Brazil.	Robust	Medium	NWS NES	Branche (2015); Hunt et al. (2018); Leroy (2019)

	Macro-economic viability	Would the option lead to higher productivity ?	C	The shared use and costs of water allocation and storage for hydropower and agricultural purposes lead to higher productivity and efficiency in Peru. Evidence for seasonal pumped-storage reservoirs suggests a positive cost-revenue balance due to reduced operation costs from evaporation and land use losses. Specific economic activities such as fishing and tourism could benefit from fixed minimum river levels in NE Brazil.	Robust	Medium	NWS NES	Branche (2015); Hunt et al. (2017); Hunt et al. (2018)
	Socio-economic vulnerability reduction potential	To what extent does the option reduce inequalities?	C	Reduction of inequalities of gender in water harvesting projects (Guatemala, Honduras and El Salvador). Multipurpose projects as a coordinated and participatory process involving local stakeholders since the beginning can contribute to more equitable and efficient water use (e.g., in Peru and Costa Rica).	Robust	Medium	CA NWS	Branche (2015); Elgert et al. (2016); Branche (2017); Barriga et al. (2018); Martínez (2018); Drenkhan et al. (2019)
	Employment & productivity enhancement potential	How many people that can be employed or how much can a system's productivity increase under the option?	NE		Limited	Low		

Technological	**Technical resource availability**	Are the technology and associated human, financial, administrative resources needed for an adaptation option available?	B	For water harvesting in Honduras and El Salvador and NE Brazil technologies and human resources are available; financial resources are often brought in by external and/or private actors (e.g., in Costa Rica, Honduras, El Salvador, Brazil and Peru), administrative resources depend on institutional setup. Several cases (e.g., in Peru) highlight that institutions are limited by unclear administrative preconditions to leverage an effective planning and implementation of that option. Human resources often lack specific capacities for both, the technical planning and implementation and the local stakeholder and community coordination. There is high threat of ineffective planning, miscoordination and the generation of conflicts among stakeholders around the implementation of that adaptation option.	Robust	High	CA NWS NES	Carey et al. (2012); Branche (2015); Branche (2017); Martínez (2018); Drenkhan et al. (2019); Marques et al. (2019a)
	Risks mitigation potential	To what degree can the option reduce the likelihood and/or consequences of risks?	C	Seasonal pumped-storage reservoirs include a higher capacity for flood control than conventional reservoirs. Additionally, they contribute to energy security in drought-prone areas or during dry seasons (e.g., drought and water-energy crisis in SE-Brazil 2013-2015). Multipurpose projects provide a cost-effective opportunity to combine flood risk reduction with purposes of water supply and drought management (in Peru).	Medium	Medium	NES NWS	Haeberli et al. (2017); Hunt et al. (2017); Hunt et al. (2018)

Institutional	**Political acceptability**	Is the option politically acceptable? Does the option reflect stakeholder perceptions about the meaning and purpose of adaptation?	A	In Peru, institutions are limited by unclear administrative preconditions to leverage an effective planning and implementation of that option. Human resources often lack specific capacities for both, the technical planning and implementation and the local stakeholder and community coordination. There is high threat of ineffective planning, miscoordination and the generation of conflicts among stakeholders around the implementation of that adaptation option.	Robust	High	NWS	Carey et al. (2012); Oré and Geng-Montoya (2014); Barriga et al. (2018); Drenkhan et al. (2019); Schütze et al. (2019)
	Legal, regulatory feasibility	Is the option appropriate to jurisdictional context? Is it challenging to implement the legal changes needed for the option? Are there known legal and regulatory barriers?	B	Additionally policies would contribute to decentralising the energy sector implementing more seasonal pumped-storage reservoirs in NE Brazil which increase energy security in view of droughts and increasing demand. Multiple and complementary use of water is explicitly established in the Brazilian Water Law (1997) implemented via right grants and monitored by the National Water Agency at basin level (participatory basin committees). During scarcity, priority is given to human consumption. Adopted reservoir and river basin management plan must minimize environmental impacts.	Medium	Medium	NES	Hunt et al. (2017); Marques et al. (2019a)

	Institutional capacity & Administrative feasibility	Would current institutions be able to implement the option? Is the option administratively supported? Are human resources to support implementation of adaptation option clearly identified? Are responsibilities delineated for managing implementation of the option?	B	Examples from Peru (e.g., multipurpose project in Chicón-Urubamba, Cusco) show that current institutions (e.g., Local Municipality) and local communities are adopting a leading role in design and implementation of multi-use of water considering multi-stakeholder perspectives. However, distrust and some exclusion from decision-making can generate important limitations to these processes. Responsibilities are clearly delineated via a Water Law, National Water Agency and local Basin Committees as part of the National Water Resources Management System in Brazil and Peru. Examples from Brazil showcase that in fact only irrigated agriculture and pasture dominate and displace or set other types of use under pressure due to missing administrative-legal capacities and monitoring .	Robust	High	NWS NES SES	Oré and Geng-Montoya (2014); Castex et al. (2015); Barriga et al. (2018); Drenkhan et al. (2019); Marques et al. (2019a)
	Transparency & accountability potential	Are policy goals and targets for the option explicitly articulated; monitoring and evaluation protocols are set up to track implementation; and	NE		Limited	Low		

		transparent reporting mechanisms are in place to synthesize progress and gaps?						
Social	**Social co-benefits**	Are there health and education benefits to be had from the option? Does the option minimize negative trade-offs with other development policy goals; identify positive synergies with other policy goals?	C	Multipurpose projects as a coordinated and participatory process involving local stakeholders since early planning can contribute to more equitable water use and thus attenuate social and water conflicts. However, evidence for NE Brazil suggests that large dam infrastructure for multi-use of water and the consecutive displacement of local communities due to flooding have led to unequitable development in the region favoring some large interest groups.	Robust	Low	CA NWS NES	Carey et al. (2014); Branche (2015); Barriga et al. (2018); Drenkhan et al. (2019); Salinas et al. (2019)
	Socio-cultural acceptability	Is there public resistance to the option? Does the option typically find acceptance within existing socio-cultural norms,	B	Generally, social and environmental acceptance of new reservoirs can be low as these grey infrastructure interventions are associated with considerable social-environmental impacts and are thus contested (e.g., in Peru). However, compared to conventional reservoirs, seasonal pumped-storage infrastructure are 1–2 orders of magnitude smaller leading to reduced impacts in SE-Brazil.	Robust	Medium	NWS NES	Carey et al. (2012); Lynch (2013); Carey et al. (2014); Hunt et al. (2018); Drenkhan et al. (2019)

		utilise diverse knowledge systems including Indigenous knowledge and local knowledge?						
	Social & regional Inclusiveness	Are different social groups and remote regions included in the option? Does the adaptation option adversely affect vulnerable groups or other areas?	B	Evidence for NE Brazil suggests that large dam infrastructure for multi-use of water and the consecutive displacement of local communities due to flooding have led to unequitable development in the region favoring some large interest groups. This has also been described in other countries, such as Peru. However, other studies (e.g., from Costa Rica and Guatemala) indicate successful hydropower planning with local stakeholders and communities which even included the relocation of a village avoiding reducing potential conflict through the establishment of a basin committee and further incentives (Costa Rica).	Robust	Low	CA NWS NES	Branche (2015); Lasage et al. (2015); Elgert et al. (2016); Hunt et al. (2017); Barriga et al. (2018); Boelens et al. (2019); Marques et al. (2019a); Salinas et al. (2019)
	Intergenerational equity	Does the option compromise the ability of future generations to meet their own needs in any way?	B	There is a low level of compromise of ability of future generations for small multipurpose projects and a higher potential for large multipurpose projects, depending on implementation (e.g., in Honduras and El Salvador). In other cases (e.g., Costa Rica), a multipurpose project has been evaluated with high chance for long-term sustainability.	Medium	Medium	CA NWS	Branche (2015); Martínez (2018); Schaub et al. (2019)

Environmental	**Ecological capacity**	Does the option enhance supporting, regulating or provisioning ecosystem services in any way?	C	Water harvesting storage including small pond and infiltration systems provide a large service enhancement potential e.g., in Peru and Chile. For large multipurpose infrastructure it depends on the respective implementation.	Medium	High	NWS SWS SSA	(Soto-Schönherr and Iroumé, 2016); Buytaert et al. (2017); Ochoa-Tocachi et al. (2019); Ignazi et al. (2020)
	Adaptive capacity/resilience building potential	Does the option enhance the ability of systems, institutions, humans to adjust to potential damage, take advantage of opportunitie s, or respond to consequence s? OR Does the option contribute to resilience building (ability to cope with stressors and reorganise to maintain structures and functions, retain capacity to transform)	B	A hydropower project in Costa Rica lead to the inclusion of the lake system Arenales into RAMSAR (Convention on Wetlands) for conservation. Multipurpose projects focusing on integrated flood risk (including early warning systems) and drought management provide co-benefits for increasing resilience and water availability in Peru. However, there are concerns that multi-water-use projects such as Olmos in Peru, evaluated as more efficient and sustainable, are in fact ecologically and socially problematic and increase demand for exacerbating water scarcity levels on the long term. Seasonal pumped-storage reservoirs reduce the stress on riverine ecosystems compared to conventional river dams with high variability of flood extent and environmental conditions (e.g., during drought) in NE Brazil. Integrated river basin management system in NE Brazil considering multiple uses and local stakeholders with an adequate, local strategy guarantees more sustainable use of land, as well as sufficient water	Robust	High	CA NWS NES	Lynch (2013); Branche (2015); Haeberli et al. (2017); Hunt et al. (2017); Hunt et al. (2018); Marques et al. (2019a)

				quantity and quality and, hence, higher resilience in view of increasing drought risk.				
Geophysical	**Physical feasibility**	Is the physical potential for the adaptation option a constraint?	C	Across CSA, there is physical-technical feasibility of different options for multipurpose storage and multi-use of water.	Robust	High	NWS NES SAM SWS SES	Lynch (2013); Meza et al. (2014); Haeberli et al. (2017); Hunt et al. (2017); Hunt et al. (2018); Marques et al. (2019a); Pillco Zolá et al. (2019); Stan and Sanchez-Azofeifa (2019); Qin et al. (2020)
	Land use change enhancement potential	Does the option enhance carbon stocks? (e.g., through forest restoration)	C	Seasonal pumped-storage reservoirs do not per se enhance carbon stocks but they reduce land use area compared to conventional reservoirs and can be included as Clean Development Mechanism (CDM) as part of the UNFCCC's carbon offset scheme (e.g., Olmos project in Peru).	Low	Medium	CA NWS NES	Branche (2015); Elgert et al. (2016); Hunt et al. (2017); Hunt et al. (2018); Martínez (2018); Marques et al. (2019a)
	Hazard risk reduction potential	Does the option reduce number of people exposed to a hazard?	C	Multipurpose projects provide a cost-effective opportunity to combine flood hazard with purposes of water supply and drought management (e.g., in Peru). In NE Brazil, seasonal pumped-storage reservoirs include a higher capacity for flood control than conventional reservoirs.	Robust	High	NWS NES	Haeberli et al. (2017); Hunt et al. (2017); Hunt et al. (2018); Drenkhan et al. (2019)

SM12.8 Supplementary Material to Figure 12.5: Population at Risk for Dengue and Zika Transmission by *Aedes aegypti* and *Aedes albopictus*.

A model-based descriptions of arboviral risk for the Central and South America region was generated, for current and future climate, in terms of the people at risk for temperature dependent transmission, not accounting for control measures. Three time horizons were selected, 2030, 2050, 2080, using RCP4.5 and RCP8.5 projections, for four general circulation models (GCMs), as described in Ryan et al. (2019). Climate model output data for future scenarios were acquired from the research program on Climate Change, Agriculture, and Food Security (CCAFS) web portal (http://ccafs-climate.org/data_spatial_downscaling/), part of the Consultative Group for International Agricultural Research (CGIAR). Model outputs created using the delta downscaling method, from the IPCC AR5 were used, present the mean resulting predicted suitability generated under these models.

For population descriptions, given 'current' climate is a baseline (WorldClim 1.4) from a climate normal period, the 2015 Global Population of the World (GPW) gridded population was used as the baseline population (Doxsey-Whitfield et al., 2015). For the future population projections, the Shared Socioeconomic Pathways (SSPs) projections (O'Neill et al., 2017) were used for the following plausible combinations: RCP4.5 x SSP2 and RCP8.5 x SSP5 (Rogelj et al., 2018). The corresponding projected populations for 2030, 2050, 2080 for each RCPxSSP combination were thus selected.

Following methods in Ryan et al. (2021), the full analysis at a 0.25 degree grid scale was conducted, so as to be consistent between climate and population rasters, but the same methods for estimating the thermal transmission suitability for the two *Aedes sp.* were used as in Ryan et al. (2019).

'Risk' is summarized in terms of the number of people subject to x months of transmission-suitable mean temperature, for dengue (both for *Aedes aegypti* and *Aedes albopictus* transmission, following Ryan et al. (2019) and for Zika transmission by *Ae. aegypti* (following Ryan et al. (2021)) over all sub-regions (n=8). For ease of interpretation, risk was estimated in terms of one or more (1-12) months of suitability.

At baseline climate and population projections, SES has the highest population at risk of one or more months of thermal transmission suitability for dengue transmission by *Aedes aegypti* mosquitoes, and that under all realizations of climate and population scenarios, this risk increase ranges from 22-57%. In contrast, SWS baseline population risk is second lowest at around 2.4 million people; this is projected to increase 204-374%, as changing climate and population distributions coincide. Conversely, NES, with much of the 86.6 million baseline population at risk characterized by up to 12 months of suitability, shows projected ranges of small increases to declining risk (6% - -20%), due to a combination of higher temperatures and population shifts in response to changing climate.

Table SM12.8 The population at risk (PAR) for one or more (1-12) months of transmission suitability by subregion, for the three vector-borne diseases: dengue transmission by *Aedes aegypti* (DEN_AE); dengue transmission by *Aedes albopictus* (DEN_AL); Zika transmission by *Aedes aegypti* (ZIKA) under baseline, 2030, 2050, and 2080 climate time horizons, for 2015 baseline population and the RCP4.5 x SSP2 and RCP8.5 x SSP5 Shared Socioeonomic Pathways (SSPs) population projections.

Vector-borne Disease	Subregion	Population at risk (PAR)						
		Baseline	RCP4.5			RCP8.5		
		2015	2030	2050	2080	2030	2050	2080
DEN_AE	NES	86,642,905	88,520,106	91,804,588	83,388,868	85,325,475	84,145,444	69,577,826
DEN_AE	NSA	38,531,379	40,697,536	45,896,416	45,852,638	38,965,408	41,511,087	37,635,411

DEN_AE	NWS	53,403,871	63,823,409	73,593,771	79,317,494	60,620,222	69,905,342	65,025,416
DEN_AE	SAM	11,783,419	11,876,569	12,904,589	12,849,800	11,104,924	11,015,723	9,648,669
DEN_AE	CA	37,105,009	46,079,995	56,227,303	60,460,588	41,850,730	45,480,438	41,792,097
DEN_AE	SES	120,566,884	177,745,327	188,704,456	178,085,019	171,343,451	172,096,064	146,689,848
DEN_AE	SSA	106,732	122,449	187,682	207,066	159,390	202,661	253,130
DEN_AE	SWS	2,375,431	7,512,986	8,850,700	11,262,181	7,214,624	11,095,852	11,144,813
DEN_AL	NES	86,769,750	88,520,106	91,804,588	83,388,868	85,325,475	84,140,852	59,545,033
DEN_AL	NSA	39,347,043	41,121,514	45,803,170	45,653,455	39,298,900	36,713,417	28,358,980
DEN_AL	NWS	57,694,575	73,177,276	81,871,670	81,575,974	70,075,708	70,006,667	52,903,785
DEN_AL	SAM	11,995,399	12,268,974	13,576,267	13,443,498	11,546,110	11,617,727	9,963,655
DEN_AL	CA	40,584,996	50,442,552	58,804,253	62,720,589	46,227,369	47,733,098	41,562,866
DEN_AL	SES	150,939,847	179,397,129	189,544,821	178,742,310	172,670,294	172,662,144	146,817,554
DEN_AL	SSA	285,942	234,578	256,978	265,752	227,125	277,921	313,584
DEN_AL	SWS	9,386,361	11,946,393	12,859,750	12,868,590	11,711,287	13,619,073	15,244,691
ZIKA	NES	69,425,191	87,516,428	91,546,657	83,303,798	84,449,787	84,075,183	69,577,826
ZIKA	NSA	30,954,018	36,116,766	44,590,076	44,782,098	34,558,531	40,512,590	37,351,429
ZIKA	NWS	34,740,805	55,846,665	63,120,243	64,019,666	53,178,535	56,154,728	54,653,900
ZIKA	SAM	11,043,726	11,166,503	12,394,573	12,101,590	10,696,671	10,597,796	9,040,160
ZIKA	CA	30,574,465	37,676,025	45,882,005	47,667,888	34,082,024	35,914,916	39,155,106
ZIKA	SES	61,915,732	119,656,637	136,470,396	131,918,423	115,333,388	127,279,498	145,263,739
ZIKA	SSA	-	3,069	11,582	9,240	2,588	12,717	69,538
ZIKA	SWS	233,339	829,083	1,006,353	1,176,586	801,341	1,118,065	6,194,892

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