Chapter 12: Central and South America
Supplementary Material

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### SM12.1 Characterization of Subregions

<table>
<thead>
<tr>
<th>Sub-region</th>
<th>Countries and territories included</th>
<th>Climate</th>
<th>Geography and biodiversity</th>
<th>Economy</th>
<th>Demography (urban/rural population distribution)</th>
<th>Human development/ inequality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central America (CA)</td>
<td>Guatemala, Belize, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama</td>
<td>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).</td>
<td>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).</td>
<td>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).</td>
<td>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).</td>
<td>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).</td>
</tr>
<tr>
<td>Northwest South America (NWS)</td>
<td>Colombia, Ecuador, and Peru</td>
<td>El Niño Southern Oscillation (ENSO) is the dominant</td>
<td>The sub-region encompasses the coastal lowlands, the</td>
<td>The economy is largely dependent on exports of metals, oil,</td>
<td>NWS includes the capital cities of Bogota, Quito and</td>
<td>The sub-region shows high poverty (22% Ecuador and Peru,</td>
</tr>
</tbody>
</table>
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). The region is the centre of domestication of cocoa, potatoes, coca, camelids, among other useful products. Frequent volcanic eruptions and earthquakes are natural threats.

| 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, 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 Medellín, 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). |
### French Guiana, 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. 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 Belém 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).
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).

<p>| 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, |</p>
<table>
<thead>
<tr>
<th>Northeast South America (NES)</th>
<th>Brazil</th>
</tr>
</thead>
</table>

**NES**’s socio-ecological systems are strongly controlled by rainfall seasonality, with an extended dry period and recurrent severe drought events (Marengo et al., 2015). 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 vegetation.

- **Bolivia and part of the Peruvian Amazon.** The natural vegetation varies from dense tropical humid forest, to floodlands, 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).
- **Northeast South America (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). 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 vegetation.
- **NES**’s socio-ecological systems are strongly controlled by rainfall seasonality, with an extended dry period and recurrent severe drought events (Marengo et al., 2015). 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 vegetation.
- **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 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$^2$.
- **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).**
### Southeast South America (SES)

<table>
<thead>
<tr>
<th>Country</th>
<th>Region Description</th>
<th>Climate Conditions</th>
<th>Biodiversity</th>
<th>Agriculture and Livestock Production</th>
<th>Renewable Electricity</th>
<th>GDP Growth</th>
<th>Inequalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolivia, Paraguay, Brazil, Uruguay and Argentina</td>
<td>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).</td>
<td>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</td>
<td>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</td>
<td>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 (<a href="https://ourworldindata.org/urbanization">https://ourworldindata.org/urbanization</a>). SES has some of the most populous cities in South America, such as São Paulo and Rio de Janeiro in</td>
<td>The region has experienced a growth in GDP. In particular, Paraguay and Bolivia grew at a GDP growth rate around 4.2% (<a href="https://www.worldometers.info/gdp/gdp-by-country/">https://www.worldometers.info/gdp/gdp-by-country/</a>), but inequalities are still important (Inequality-adjusted HDI around 0.54)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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).

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). 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 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 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 fuel energy use. 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.
<table>
<thead>
<tr>
<th>South America (SSA)</th>
<th>Chile and Argentina</th>
<th>Latitudinal gradient and topographic conditions.</th>
<th>Fuel energy consumption.</th>
<th>Process in the last decade.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>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).</td>
<td>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.</td>
<td>Patagonia is a sparsely populated region of about 3 million people in 1,043,076 km² that determines a density of 3-inhabitant km⁻² with a low proportion of inhabitants in rural zones.</td>
</tr>
</tbody>
</table>

Table Notes:

1French Guiana is an overseas department of France.

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**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.](image-url)
Table SM12.2: Vulnerability levels for Cities in CSA based on CAF (2014).

<table>
<thead>
<tr>
<th>Vulnerability level</th>
<th>NES</th>
<th>NSA</th>
<th>NWS</th>
<th>SAM</th>
<th>CA</th>
<th>SES</th>
<th>SSA</th>
<th>SWS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number cities assessed</td>
<td>million people living in cities assessed</td>
<td>Number cities assessed</td>
<td>million people living in cities assessed</td>
<td>Number cities assessed</td>
<td>million people living in cities assessed</td>
<td>Number cities assessed</td>
<td>million people living in cities assessed</td>
</tr>
<tr>
<td>Very high</td>
<td>4</td>
<td>5.08</td>
<td>24</td>
<td>8.15</td>
<td>32</td>
<td>26.09</td>
<td>6</td>
<td>1.85</td>
</tr>
<tr>
<td>High</td>
<td>14</td>
<td>23.18</td>
<td>24</td>
<td>7.52</td>
<td>29</td>
<td>6.34</td>
<td>8</td>
<td>3.43</td>
</tr>
<tr>
<td>Moderate</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>0.08</td>
<td>7</td>
<td>9.74</td>
</tr>
<tr>
<td>Low</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>18</td>
<td>28.26</td>
<td>51</td>
<td>15.75</td>
<td>68</td>
<td>42.17</td>
<td>14</td>
<td>5.28</td>
</tr>
</tbody>
</table>

2 Tables Notes
3 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
4
5

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


<table>
<thead>
<tr>
<th>Coral Reefs</th>
<th>Climate change projected Impacts by CSA subregions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA and NWS (2003 – 2015) (OW)</td>
<td>CA and NWS by 2040 – 2043</td>
</tr>
<tr>
<td>• Lower abundance, coral cover and coral density</td>
<td>• Increasing locations with coral bleaching (7.95% y⁻¹) (RCP 8.5)</td>
</tr>
<tr>
<td>• Lower coral diversity and richness</td>
<td>CA by 2050 – 2080</td>
</tr>
<tr>
<td>• Changes in the coral community structure</td>
<td>• Increasing hot spot locations for future bleaching</td>
</tr>
<tr>
<td>• Decline in skeletal extension rates for nearshore corals</td>
<td>CA, NSA and NES by 2100</td>
</tr>
<tr>
<td>CA (2006 – 2010) (OW + CV)</td>
<td>• Distribution range changes (RCP 2.6, 4.5 and 8.5)</td>
</tr>
<tr>
<td>• Increasing locations with coral bleaching</td>
<td>• Reduction and loss of suitable habitat (RCP 2.6, 4.5 and 8.5)</td>
</tr>
<tr>
<td>CA and NSA (1971 – 2010) (OW)</td>
<td>• Loss of suitable areas (between 46-59%) (RCP 4.5 and 8.5)</td>
</tr>
<tr>
<td>• Reduction of reef habitat for reef fish assemblages</td>
<td></td>
</tr>
<tr>
<td>• Changes in the abundance of coral reef community</td>
<td>• Reduction of distribution range of pelagic species with commercial interest (RCP 2.6, 4.5, 6.0 and 8.5)</td>
</tr>
<tr>
<td>• Extreme reduction in coral cover (between 83-89% of mortality)</td>
<td>NSA by 2100 (SLR)</td>
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<tr>
<td>• Massive coral bleaching events</td>
<td>• Moderate erosion of delta’s shoreline</td>
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<tr>
<td>Estuaries</td>
<td>• Migration or loss of mangroves</td>
</tr>
<tr>
<td>NES (1988 – 2010) (P)</td>
<td>• Abrupt shifts in the Warao's traditional environments</td>
</tr>
<tr>
<td>• Increasing area colonized by mangrove vegetation (+10%)</td>
<td>• Potential migrations and abandonment of ancestral territories (Scenario: 0.9 – 1.25 mm yr⁻¹ + land subsidence rate of 4.4 mm yr⁻¹)</td>
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<tr>
<td>SES (1978 – 2012) (OW + SLR + WD + WI + P-ENSO)</td>
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<tr>
<td>• Phenological shifts in phytoplankton blooms</td>
<td>SES by 2050 – 2080</td>
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<tr>
<td>• Reduction of the chlorophyll concentration (1% y⁻¹)</td>
<td>• Reduction of distribution range of pelagic species with commercial interest (RCP 2.6, 4.5, 6.0 and 8.5)</td>
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<tr>
<td>• Changes in plankton community’s composition</td>
<td>NSA by 2100 (SLR)</td>
</tr>
<tr>
<td>• Changes in food web structure</td>
<td>• Moderate erosion of delta’s shoreline</td>
</tr>
<tr>
<td>• Changes in land cover of vegetated wetlands</td>
<td>• Migration or loss of mangroves</td>
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<tr>
<td>• Increasing water turbidity (4% y⁻¹)</td>
<td>• Abrupt shifts in the Warao's traditional environments</td>
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<tr>
<td>SES (1980 – 2017) (OW + WD + WI + P-ENSO + UI + CC)</td>
<td>• Potential migrations and abandonment of ancestral territories (Scenario: 0.9 – 1.25 mm yr⁻¹ + land subsidence rate of 4.4 mm yr⁻¹)</td>
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<tr>
<td>• Increasing water turbidity</td>
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<tr>
<td>• Increased offshore productivity (by 2% between 1997-2017)</td>
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<tr>
<td>• Poleward shift of pelagic species with commercial interest</td>
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<tr>
<td>• Shifts in phytoplankton phenology and community structure</td>
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<tr>
<td>• Increase of cyanobacteria and dinoflagellate presence</td>
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<tr>
<td>• Changes in species abundance (47 species)</td>
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<tr>
<td><strong>Changes of subtropical species distributional range (southward)</strong></td>
<td><strong>Rapid population growth of small pelagic fishes</strong></td>
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<td><strong>Kelps</strong></td>
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<tr>
<td>• Reduced kelp canopy</td>
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<td>SES (1969 – 2017) (OW)</td>
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<tr>
<td>• Reduced kelp coverage (2.6% y(^{-1}))</td>
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<tr>
<td>• Overall kelp loss (52%)</td>
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<td>• Coverage increase of filamentous turfs (24%)</td>
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<td>SWS and SSA by 2050</td>
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<tr>
<td>• South poleward expansion (RCP 2.6 and 8.5)</td>
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<tr>
<td>• Habitat range reduction (50%) (RCP 2.6 and 8.5)</td>
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<tr>
<td>SWS by 2100</td>
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<tr>
<td>• Southward expansion (RCP 2.6 and 8.5)</td>
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<tr>
<td>• Reduction of native distributional range (50%) (RCP 2.6 and 8.5)</td>
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<td><strong>Mangroves</strong></td>
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<tr>
<td>CA (2000 – 2013) (EV)</td>
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<tr>
<td>• Negative short-run effects on economic activity of coastal lowlands</td>
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<tr>
<td>• Permanent loss of economic activity between 5 to 7 months (24%)</td>
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<td>• Permanent setbacks in economic activity after 6 years of the event</td>
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<tr>
<td>• Mangrove retreats</td>
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<td>• Changes in vegetation composition</td>
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<td>• Changes in soil composition</td>
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<tr>
<td>NWS (2002 – 2014) (P-ENSO + P-PDO)</td>
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<tr>
<td>• Higher NDVI (mangrove vegetation) under short drought events</td>
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<tr>
<td>• Lower NDVI (mangrove vegetation) under large drought periods</td>
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<tr>
<td>NSA (1950 – 2010) (WV-NAO)</td>
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<tr>
<td>• Variations in mangrove area</td>
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<tr>
<td>NES (1984 – 2017) (SLR)</td>
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<tr>
<td>• Mangrove land invasion (2.7 km(^2) of inner tidal flats)</td>
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<tr>
<td>• Increasing mangrove mortality</td>
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<tr>
<td>• Decreasing latitudinal trend in migration (between 0.136 to 0.081 km(^2) yr(^{-1}))</td>
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<tr>
<td>CA and NSA by 2100</td>
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<tr>
<td>• Global poleward migration (2 degrees of latitude) (A1b scenario)</td>
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<tr>
<td>• Global decrease of suitable coastal area (A1b scenario)</td>
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<tr>
<td>• Higher loss of mangrove species (A1b scenario)</td>
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<tr>
<td>CA, NSA, and NES by 2100 (SLR + EV)</td>
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<tr>
<td>• Changes in distribution (43%) (Scenario: +1m SLR and +10% storm)</td>
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<tr>
<td>• Loss of mangroves (57%) (Scenario: +1m SLR and +10% storm)</td>
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<tr>
<td>• Economical losses (231% of the GDP at risk) (Scenario: +1m SLR and +10% storm)</td>
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<tr>
<td>NES by 2100 (SLR + P)</td>
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<tr>
<td>• Mangrove landward expansion (2.93 km(^2)) (Scenario: 5 mm yr(^{-1}) and stable rainfall)</td>
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<tr>
<td>• Mangrove landward expansion (1.35 km(^2)) (Scenario: 3 mm yr(^{-1}) and decreased rainfall)</td>
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<tr>
<td>• Lower mangrove migration rates (0.017 km(^2) yr(^{-1})) (Scenario: 5 mm yr(^{-1}) and stable rainfall)</td>
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<tr>
<td>• Lower mangrove migration rates (0.036 km(^2) yr(^{-1})) (Scenario: 3 mm yr(^{-1}) and decreased rainfall)</td>
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<td><strong>Rocky Shores</strong></td>
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<tr>
<td>SES (2010 – 2013) (EV + PP)</td>
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<tr>
<td>• Increasing number of stranding events of marine birds</td>
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<tr>
<td>• Increased penguin reproductive failures</td>
<td></td>
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<tr>
<td>• Increased penguin chick mortality</td>
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<tr>
<td>SWS (2009 – 2018) (OW + EV)</td>
<td></td>
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<tr>
<td>• Increasing number of stranded fauna (sea lion pups)</td>
<td></td>
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<tr>
<td>NWS and SWS by 2100</td>
<td></td>
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<tr>
<td>• Changes in the pelican spatial distribution (RCP 8.5)</td>
<td></td>
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<tr>
<td>• Decrease (20%) in the pelican breeding distribution (RCP 8.5)</td>
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<tr>
<td><strong>Exclusive Economic Zones (EEZ)</strong></td>
<td></td>
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</tbody>
</table>
### 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)

### SWS 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)

### SES and NES 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

<table>
<thead>
<tr>
<th>SES (1978 – 2012) (OW + SLR + WD + WI + P-ENSO)</th>
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<tbody>
<tr>
<td>Loss of saltmarshes area dominated by <em>Spartina alterniflora</em> (33%)</td>
</tr>
<tr>
<td>Increasing turbidity</td>
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<tr>
<td>Increasing release of organic matter and nutrients from sediments into the water column</td>
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<tr>
<td>Alteration of soil salinity,</td>
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<tr>
<td>Changes in plant growth</td>
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<tr>
<td>Changes in food quality</td>
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<tr>
<td>Changes in herbivorous abundance</td>
</tr>
</tbody>
</table>

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*
<table>
<thead>
<tr>
<th>Sandy Beaches</th>
<th>NES by 2100</th>
</tr>
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<tbody>
<tr>
<td>CA (2010 - 2015) (EV)</td>
<td>Decreasing (from 75.2% to 65.1%) of turtle hatching success events (RCP 4.5 and 8.5)</td>
</tr>
<tr>
<td>NES (2005 - 2016) (OW + SR + EV + W VH)</td>
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<tr>
<td>SES (1980 – 2017) (OW + WD + WI + P-ENSO +UI + CC + EV)</td>
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<tr>
<td>SES (1984 – 2007) (OW)</td>
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</tbody>
</table>

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.**

<table>
<thead>
<tr>
<th>Ocean and Coastal Ecosystems</th>
<th>Observed and Projected Impacts (see Table 12.A3)</th>
<th>Sensitivity to climate and non-climate drivers (see Figure 12.8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>van Hooidonk et al. (2015)</td>
<td>Bove et al. (2019)</td>
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<td></td>
<td>Baumann et al. (2016)</td>
<td>Bove et al. (2020)</td>
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<td></td>
<td>Baumann et al. (2019)</td>
<td>Kelmo et al. (2014)</td>
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<td></td>
<td>de Moraes et al. (2019)</td>
<td>Hill et al. (2019)</td>
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<td></td>
<td>Duarte et al. (2020)</td>
<td>Barbosa et al. (2019)</td>
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<td></td>
<td>Li and Reidenbach (2014)</td>
<td>Evangelista et al. (2016)</td>
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<td>Marques et al. (2019b)</td>
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<td>Altieri et al., 2017</td>
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<td>Seemann et al. (2014)</td>
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<tr>
<td>Estuaries</td>
<td>Guinder et al., 2013</td>
<td>Halac et al. (2014)</td>
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<td>Mangroves</td>
<td>Kelps</td>
<td>Exclusive Economic Zones (EEZs)</td>
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<td>Fiori et al., 2016</td>
<td>Galeano et al. (2017)</td>
<td>Marrari et al. (2017)</td>
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<td>Brendel et al. (2017)</td>
<td>del Valle et al. (2020)</td>
<td>Verba et al. (2020)</td>
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<td>Marrari et al. (2017)</td>
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<td>Silva et al. (2019a)</td>
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<td>Ruaro et al. (2019)</td>
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<td>Saupe et al. (2014)</td>
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<td>Franco et al. (2020)</td>
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<td>Haraguchi et al. (2015)</td>
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<td>Abreu et al. (2017)</td>
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<td>Haimovici and Cardoso (2017)</td>
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<td>Odebrecht et al. (2017)</td>
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<td>Teixeira-Amaral et al. (2017)</td>
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<td>Gonçalves-Araújo et al. (2018)</td>
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<td>Martelo et al. (2019)</td>
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<td>Araújo et al. (2018)</td>
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<td>Vegas-Vilarribia et al. (2015)</td>
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<td>Pinto Godoy and de Lacerda (2014)</td>
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<td>Gedan et al. (2017)</td>
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<td>Taille et al. (2020)</td>
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<td>Ollier et al. (2017)</td>
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<td>Heber et al. (2017)</td>
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<td>Otero et al. (2020)</td>
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<td>Reef et al. (2016)</td>
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<td>de Ramos et al. (2019)</td>
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<td>Koerich et al. (2020)</td>
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<td>Madeira et al. (2019)</td>
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<td>da Silva-Pinto et al. (2020)</td>
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**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)
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)
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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)
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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
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Health
Labor productivity
Dally et al. (2018)
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Sheffield et al. (2013)

Morbidity
Zambrano et al. (2012)
Hutter et al. (2018)
Chaves and Pascual (2006)
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Mortality
UNISDR and CEPREDENAC (2014)
Bárcena et al. (2020)
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Poverty, livelihoods and sustainable development
Territory
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Bárcena et al. (2020)

Income
ECLAC et al. (2015)
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Human dimensions
Migration
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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

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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)
Harseh 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)
Buylaert 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)
(Skarbo and VanderMolen, 2016)
(Schauwecker et al., 2017)
(Vuille et al., 2018)
(Tovar et al., 2013)
(Ramírez-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 infrastructure
(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)
(Doñ-González et al., 2018)
(Lippi et al., 2019)
(Laporta et al., 2015)
(Fletcher et al., 2020)
(Rodríguez-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)
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)
(Anges 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)
SM12.4.1.4 South America Monsoon SAM

Terrestrial Forest / Grasslands Savanna
(Paralovo et al., 2019)
(Ellwanger et al., 2020)

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

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)
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)
(Ohzai 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)
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<th>Water supply, Rainwater drainage and Sewer infrastructure</th>
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<td>(Marengo et al., 2020c)</td>
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<td>(Mettler-Grove, 2020)</td>
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<td>3</td>
<td>(Morales-Yokobori, 2021)</td>
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<td>(Nagy et al., 2019 impacts and adaptation in Central and South America)</td>
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<td>5</td>
<td>(Oyedotun and Ally, 2021)</td>
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<td>(Saito et al., 2019 floods)</td>
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**Health**

**Morbidity**

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<td>(Barros and Lombardo, 2016)</td>
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<td>(Lima and Magaña Rueda, 2018)</td>
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<td>(Geirinhas et al., 2018)</td>
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<td>(Mishra et al., 2015)</td>
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<td>(Rasmussen et al., 2014)</td>
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<td>(Sarricolea and Meseguer-Ruíz, 2019)</td>
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<td>17</td>
<td>(Singh et al., 2020)</td>
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<td>(Son et al., 2016)</td>
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<td>(Vemado and Pereira Filho, 2016)</td>
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<td>(Wong et al., 2013)</td>
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<td>(Wu et al., 2019)</td>
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**Mortality**

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

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<td>Terrestrial and freshwater ecosystems and their services</td>
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<td>(Camarero and Fajardo, 2017)</td>
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<td>(Díaz-Hormazábal and González, 2016)</td>
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<td>Ocean and Coastal Ecosystems, and their services</td>
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<td>(Sepúlveda et al., 2020)</td>
<td>(Friedlander et al., 2020)</td>
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<td></td>
<td>(Cursach et al., 2019)</td>
<td>(Laeseke et al., 2020)</td>
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<td></td>
<td>• Sandy beaches</td>
<td>(Murcia et al., 2020)</td>
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<td></td>
<td>(Martínez et al., 2018)</td>
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<td></td>
<td>(Ministerio de Medio Ambiente de Chile, 2019)</td>
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<td></td>
<td>(Winckler et al., 2017)</td>
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<tr>
<td></td>
<td>• Upwelling systems and EEZs</td>
<td>• Upwelling systems and EEZs</td>
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<td></td>
<td>(Schneider et al., 2017)</td>
<td>(IPCC, 2019b)</td>
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<td></td>
<td>(Aguirre et al., 2018)</td>
<td>(Silva et al., 2015)</td>
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<td>(Anabalón et al., 2016)</td>
<td>(Silva et al., 2019a)</td>
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<td>(Jacob et al., 2018)</td>
<td>(Silva et al., 2016a)</td>
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<td></td>
<td>(Ramajo et al., 2020)</td>
<td>(Boavida-Portugal et al., 2018)</td>
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<td></td>
<td>• Kelps</td>
<td>(Bertrand et al., 2020)</td>
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<tr>
<td>Topic</td>
<td>Sources</td>
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<tr>
<td><strong>Water</strong></td>
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<tr>
<td>Streamflow</td>
<td>(Muñoz et al., 2020a) · (Yevenes et al., 2018) · (Ragettli et al., 2016)</td>
<td></td>
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<tr>
<td>Water quality and availability</td>
<td>(Bocchiola et al., 2018) · (Yevenes et al., 2018) · (Araya-Muñoz et al., 2016) · (Sepúlveda et al., 2015) · (Monsalves-Gavilán et al., 2013)</td>
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<tr>
<td><strong>Food, fibre and other ecosystem products</strong></td>
<td></td>
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</tr>
<tr>
<td>Fisheries and aquaculture systems</td>
<td>(IPCC, 2019b) · (León-Muñoz et al., 2018) · (Quiñones et al., 2019) · (Soto et al., 2019) · (Armiho et al., 2020) · (Mellado et al., 2019) · (Bertrand et al., 2020)</td>
<td></td>
</tr>
<tr>
<td>Agricultural systems</td>
<td>(Yevenes et al., 2018) · (Peña-Guerrero et al., 2020) · (Oertel et al., 2020) · (Ray et al., 2015) · (Zambrano et al., 2016) · (Lesjak and Calderoni, 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)</td>
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<tr>
<td><strong>Cities and infrastructure</strong></td>
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<tr>
<td>Mortality and Morbidity</td>
<td>(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)</td>
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<tr>
<td><strong>Health</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mortality and Morbidity</td>
<td>(Tapia-Garay et al., 2018) · (Ayala et al., 2019)</td>
<td></td>
</tr>
</tbody>
</table>
**Human dimension**

- Indigenous knowledge and local knowledge
  - Parraguez-Vergara et al., 2016
  - Meldrum et al., 2018
  - Perreault, 2020

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**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

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

<table>
<thead>
<tr>
<th>Nature of key risk</th>
<th>Geographic region</th>
<th>Consequence that would make the risk severe</th>
<th>Associated changes in hazards</th>
<th>Associated changes in exposure</th>
<th>Associated changes in vulnerability</th>
<th>Confidence in key risk identification and traceability to chapter section</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Risk of food insecurity due to frequent/extreme droughts</td>
<td>Central and South America</td>
<td>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.</td>
<td>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.</td>
<td>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.</td>
<td>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.</td>
<td>Medium confidence (12.3.1 to 12.3.8)</td>
<td>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)</td>
</tr>
<tr>
<td>2. Risk to life and infrastructure due</td>
<td>CA, NWS, NSA, SAM, SES, SWS</td>
<td>Death and severe health effects, disruption of...</td>
<td>More frequent and stronger storms and heavy precipitation</td>
<td>More people exposed to floods and</td>
<td>Vulnerable populations are usually low</td>
<td>Medium confidence (12.3.1 to 12.3.4, 12.3.6, 12.3.7)</td>
<td>Hirabayashi et al. (2013); Kundzewicz et al.</td>
</tr>
<tr>
<td>Event Type</td>
<td>Reasons and Impacts</td>
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</tr>
<tr>
<td>Floods and landslides</td>
<td>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. 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.</td>
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</tr>
</tbody>
</table>

3. Risk of water insecurity | Seasonal water availability change and decline due to Glacier shrinkage and snow cover change, more pronounced dry. Unjust and unequal water consumption. High confidence (12.3.1, 12.3.2, 12.3.4 to 12.3.7) | Buytaert and Breuer (2013); Hidalgo et al. (2013); Emmer et al. (2020); Huggel et al. (2020); Poveda et al. (2020); Hirabayashi et al. (2021); Stuart-Smith et al. (2021) |
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 m³ capita⁻¹ yr⁻¹).

<table>
<thead>
<tr>
<th>4. Risk of severe health effects due to increasing epidemics (in particular vector-borne diseases)</th>
<th>CA, NWS, NSA, SAM, NES, SES, SWS</th>
<th>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</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low sanitation conditions, particularly in low-income neighbourhoods and for Indigenous</td>
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<tr>
<td></td>
<td></td>
<td>High confidence (12.3.1 to 12.3.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Colón-González et al. (2013); Hofmeijer et al. (2013); Caminade et al. (2014); Barcaza et al. (2017); Buytaert et al. (2017); Miranda Sara 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)</td>
</tr>
<tr>
<td>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 <em>Plasmodium falciparum</em> 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 occurrence by 0.4 million km$^2$ in South America for RCP 4.5 in 2080. With 47-99 elevation range expansion.</td>
<td>elevation range expansion.</td>
<td>rates. Increased population exposed to arboviruses due to expansion of <em>Aedes</em> spp., including places of higher altitude and latitude - in Argentina, Guatemala, Ecuador, Brazil, and Bolivia.</td>
</tr>
<tr>
<td>5. Systemic risks of surpassing infrastructure and public service systems</td>
<td>Central and South America</td>
<td>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.</td>
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</tr>
<tr>
<td>6. Risk of large-scale changes and biome shifts in the Amazon</td>
<td>NSA, SAM, NES</td>
<td>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.</td>
</tr>
</tbody>
</table>
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. 

| 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 CO₂, | Continued exposure to increased atmospheric CO₂ 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- 

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)
### 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 intrusion, coastal erosion. | Continuing and high trajectories of sea level rise, with 0.29-0.59 cm under RCP 2.6 and 0.61-1.10 cm under RCP 8.5 by 2100 (relative to 1985-2005) projected. More intense and persistent coastal flooding, saltwater intrusion, coastal erosion. | 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) |
| Guldberg et al. (2017); Hughes et al. (2018); Osorio-Cano et al. (2019); Helmuth et al. (2020) | 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.

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.

<table>
<thead>
<tr>
<th>OVERVIEW</th>
<th>GLACIER CHANGE</th>
<th>IMPACTS</th>
<th>ADAPTATION</th>
<th>POLICY AND INVENTORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>Total glacier area</td>
<td>AR: -98% (1952-2019)¹</td>
<td>SOC: loss of cultural identity and cuts for local tourism¹</td>
<td>NDC: 2017 Do not include glaciers, only mention fragile mountain ecosystems</td>
</tr>
<tr>
<td>VE</td>
<td>0.1 km²</td>
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</tbody>
</table>

1. For selected glaciers (mountain range, max. extent, area) Future outlook. Economic losses and unemployment.
<table>
<thead>
<tr>
<th>Country</th>
<th>Glacier</th>
<th>Area</th>
<th>AR</th>
<th>Risk of Extinction</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pico Humboldt (Sierra Nevada de Mérida, 4942 m asl.)</td>
<td>0.1 km²</td>
<td>-99% (1910-2019)</td>
<td>Pico Humboldt, the last remaining glacier, is under imminent risk of extinction</td>
<td></td>
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</tr>
<tr>
<td>CO</td>
<td>Nevada del Ruiz (Cordillera Central, 5321 m asl.)</td>
<td>8 km²</td>
<td>-51% (1986-2017)</td>
<td>Most Colombian glaciers are at risk of extinction in the near-future, only the highest summits will likely remain after 2050</td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>Antisana (Cordillera Real, 5760 m asl.)</td>
<td>16 km², ~0.6 km³</td>
<td>-33% (1979-2007)</td>
<td>Several Ecuadorian glaciers are at risk of extinction in the near-future, only the highest summits (≥5600 m asl.) will likely remain after 2050. Antisana would heavily reduce or disappear by 2100 (projected area loss: -72% for RCP2.6 and -98% for RCP8.5)</td>
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</table>

**NDC:** Explicitly mention glacier shrinkage, mountain ecosystems and links to hydrological risks

**CCL:** Climate Change Framework Law no. 1931 (2018) underway

**GLL:** -

**INV:** 2017 (published in 2018)²

**ECO:** Upward expansion of several plant species at Chimborazo (1986-2013)³ and ground beetle species at Antisana and Carihuairazo (2016-2017)⁴ in deglaciating areas; decreasing meltwater contribution would lead to environmental and taxonomic diversity loss⁵

**NbS/FIN:** First water fund in CSA launched in 2000 for improving Quito’s water quality in a context of high mountain ecosystem deterioration⁶,⁷; NbS: water fund for ecosystem conservation of the glacier-fed Tungurahua Páramo⁸

**NDC:** 2019

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

**ECO:** Upward expansion of several plant species at Chimborazo (1986-2013)³ and ground beetle species at Antisana and Carihuairazo (2016-2017)⁴ in deglaciating areas; decreasing meltwater contribution would lead to environmental and taxonomic diversity loss⁵

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**NDC:** 2019

Explicitly mention glacier shrinkage, mountain ecosystems and links to hydrological risks

**CCL:** -

**GLL:** -

**INV:** 2017 (published in 2018)²
<table>
<thead>
<tr>
<th>PE</th>
<th>AR: -54% (1962-2016)(^9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OT</td>
<td>MB: 0 to -2.0 m w.e. yr(^-1) (2000-2018)(^4)</td>
</tr>
<tr>
<td>NWS-SAM</td>
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</tbody>
</table>

| Cordiller Blanca (6768 m asl.) |
| 449 km\(^2\) |
| AR: -38% (1962-2016)\(^9\) |

| Cordiller Vilcanota (6384 m asl.) |
| 255 km\(^2\) |
| AR: -48% (1962-2016)\(^9\) |

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 Cordiller 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\(^{28}\)

**AWB**: educational route established at Pastoruri glacier for sensitizing visitors to the impacts of climate change and conservation;\(^{35}\)

| 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; construction of 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\(^{34}\)

**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)\(^{19}\)

**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
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<tbody>
<tr>
<td>BO</td>
<td>Zongo</td>
<td>Cordillera Real, 6000 m asl.</td>
<td>35% (1980s-2013)(^{40})</td>
<td>-0.4 to -0.6 m w.e. yr(^{-1}) (2000-2018)(^{4})</td>
<td>-12% (1997-2010)(^{41})</td>
<td>plant succession and increase in plant richness, cover, and abundance in the Cordillera Real (1975-2013)(^{42})</td>
<td>effective adaptation to drought vulnerability (Pucara basin) as a function of national development pathway(^{43})</td>
<td>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})</td>
<td>Educational route established at the vanished Chacaltaya glacier site for sensitizing visitors to the impacts of climate change and conservation(^{1,42}); migration as a result of combined socioeconomic pressure and glacier shrinkage and water shortage (Palecta, La Paz)(^{46}); vanishing glacier site (Chacaltaya) as a new attractive for guided tourism(^{45})</td>
<td>Explicitly mention glacier shrinkage as driver of vulnerability(^{46})</td>
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<td></td>
<td>Zongo</td>
<td></td>
<td>(2) km(^{2}), (8.6) km(^{3})(^{41})</td>
<td>Several Bolivian glaciers are at risk of extinction in the near-future, only higher summits (&gt;5500 m asl.) will likely remain after 2050(^{12,41})</td>
<td>Zongo glacier would heavily reduce by 2100 (projected volume loss: -40% for RCP2.6 and -89% for RCP8.5 (2016-2100)(^{41})</td>
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<tr>
<td>CH</td>
<td>Maipo river basin</td>
<td>(Central Andes, 6570 m asl.)</td>
<td>29% (1955-2016)</td>
<td>-0.1 m w.e. yr(^{-1}) (1955-2016)</td>
<td>peak water reached (Biobio: 2002, Rapel: 2010)(^{3})</td>
<td>reframing of adaptation plans for water access of mountain communities(^{29}); improved integration of local</td>
<td></td>
<td></td>
<td></td>
<td>Briefly mention snow decline and glacier shrinkage as drivers of vulnerability(^{45})</td>
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<td>23,708 km(^{2}) (2015)(^{47})</td>
<td>378 km(^{2})</td>
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</table>
| 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)\(^{17}\) |
|---|---|---|---|
| AR | Monte Tronador (North Patagonia, 3475 m asl.)  
57 km\(^2\) (2017)\(^{52}\)  
DA, WA SES-SSA | 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 (2\(^{nd}\))  
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 2\(^{nd}\) NDC)  
CCL: Law on Minimum Budgets for Adaptation and Mitigation of Climate Change Law No. 27.520 (2019)\(^{55}\)  
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.

1. Ramírez et al. (2020)
2. IDEAM (2018)
3. Rabatel et al. (2018)
4. Dussaillant et al. (2019)
5. Huss and Hock (2018)
6. Huggel et al. (2015)
7. Muccione et al. (2016)
8. Turbay et al. (2014)
10. Cuesta et al. (2019)
11. Rabatel et al. (2013)
14. Moret et al. (2020)
15. Cauvy-Fraunié et al. (2015)
16. Bremer et al. (2016)
17. Grima et al. (2016)
18. Palomo et al. (2021)
19. INAIGEM (2018)
20. Schauwecker et al. (2017)
22. Baraer et al. (2012)
23. Santofimia et al. (2017)
24. Guardamino et al. (2019)
25. Seimon et al. (2017)
29. Mills-Novoa et al. (2017)
30. Chang Kee et al. (2018)
31. IMA (2016)
32. Ochoa-Toacaí et al. (2019)
33. Drenkhan et al. (2019)
34. Lasage et al. (2015)
35. Rasmussen (2019)
36. Paerregaard et al. (2016)
37. McDowell et al. (2021)
38. Haebeli et al. (2017)
39. MINAM (2018)
40. Ramírez Rodríguez (2014)
41. Réveillet et al. (2015)
42. Zimmer et al. (2018)
43. Montaña et al. (2016)
44. Rolando et al. (2017)
45. Kaenzig et al. (2016)
46. Brandt et al. (2016)
47. Barcaza et al. (2017)
48. Aldunce et al. (2017)
49. Mazzorana et al. (2019)
50. Clarvis and Allan (2014)
51. Billi et al. (2020)
52. JANIGELA (2018)
53. Ruiz et al. (2017)
54. Warner et al. (2019)
55. GOA (2019)
### Table SM12.7: Detailed supporting information for Table 12.11, the summary for the feasibility assessment of four adaptation measures.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Adaptation indicators</th>
<th>Questions guiding the adaptation indicators</th>
<th>Assessment</th>
<th>Explanation</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro-economic viability</td>
<td></td>
<td>What are the economic costs and trade-offs of the option? (high costs correspond to low feasibility)</td>
<td>B</td>
<td>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.</td>
<td>Casanova-Lugo et al. (2016); Jacobi (2016); Middendorp et al. (2018); Krishnamurthy et al. (2019)</td>
</tr>
<tr>
<td>Macroeconomic viability</td>
<td></td>
<td>Would the option lead to higher productivity?</td>
<td>C</td>
<td>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.</td>
<td>Middendorp et al. (2018); de Sousa et al. (2019); Jezeer et al. (2019); Maas et al. (2020)</td>
</tr>
<tr>
<td>Economic</td>
<td>Socio-economic vulnerability reduction potential</td>
<td>To what extent does the option reduce inequalities?</td>
<td>C</td>
<td>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.</td>
<td>Krishnamurthy et al. (2019); Castañeda-Ccori et al. (2020)</td>
</tr>
<tr>
<td></td>
<td>Employment &amp; productivity enhancement potential</td>
<td>How many people that can be employed or how much can a system’s productivity increase under the option?</td>
<td>C</td>
<td>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.</td>
<td>Montagnini (2017); Kearney et al. (2019)</td>
</tr>
<tr>
<td>Technological</td>
<td>Technical resource availability</td>
<td>Are the technology and associated human, financial, administrative resources needed for an adaptation option available?</td>
<td>B</td>
<td>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.</td>
<td>Krishnamurthy et al. (2019); Jara-Rojas et al. (2020)</td>
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<tr>
<td>Risks mitigation potential</td>
<td>To what degree can the option reduce the likelihood and/or consequences of risks?</td>
<td>C</td>
<td>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.</td>
<td>Montagnini (2017); Jara-Rojas et al. (2020)</td>
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</tr>
<tr>
<td>Political acceptability</td>
<td>Is the option politically acceptable? Does the option reflect stakeholder perceptions about the meaning and purpose of adaptation?</td>
<td>B</td>
<td>Agroforestry practices enhance the potential of Amazon Indigenous Peoples for making global forest governance more nuanced. There is an intention of incentivate adoption.</td>
<td>Waldron et al. (2017); Rosenstock et al. (2019); González and Kröger (2020)</td>
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<tr>
<td>Institutional</td>
<td>Legal, regulatory feasibility</td>
<td>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?</td>
<td>LE</td>
<td>Land tenure security showed positive effect in adoption of agroforestry practices in Argentine.</td>
<td>Tschopp et al. (2020)</td>
</tr>
<tr>
<td>Institutional capacity &amp; Administrative feasibility</td>
<td>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?</td>
<td>A</td>
<td>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.</td>
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<tr>
<td>Transparency &amp; accountability potential</td>
<td>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?</td>
<td>LE</td>
<td>There is a significant gap between national ambition and national ability to measure and report on agroforestry in UNFCC reports.</td>
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</table>

Jacobi (2016); Montagnini (2017); Waldron et al. (2017); Middendorp et al. (2018); Soler et al. (2018); Tschopp et al. (2020) | Rosenstock et al. (2019)
<p>| 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 &amp; 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) |</p>
<table>
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<tr>
<th>Intergenerational equity</th>
<th>Does the option compromise the ability of future generations to meet their own needs in any way?</th>
<th>NA</th>
</tr>
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<tbody>
<tr>
<td>Ecological capacity</td>
<td>Does the option enhance supporting, regulating or provisioning ecosystem services in any way?</td>
<td>C</td>
</tr>
<tr>
<td>Environmental</td>
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<tr>
<td>Adaptive capacity/resilience building potential</td>
<td>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)?</td>
<td>C</td>
</tr>
</tbody>
</table>

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)

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

<table>
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<tr>
<th>Physical feasibility</th>
<th>Is the physical potential for the adaptation option a constraint?</th>
<th>B</th>
<th>Agroforestry systems have a lower negative impact on soil and water resources given the interaction between the different components</th>
<th>Montagnini (2017); Krishnamurthy et al. (2019)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use change enhancement potential</td>
<td>Does the option enhance carbon stocks? (e.g., through forest restoration)</td>
<td>C</td>
<td>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</td>
<td>Abbas et al. (2017); Feliciano et al. (2018)</td>
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<td>Hazard risk reduction potential</td>
<td>Does the option reduce number of people exposed to a hazard?</td>
<td>NA</td>
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</table>

### Economic

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<th>Dimension</th>
<th>Adaptation indicators</th>
<th>Questions guiding the adaptation indicators</th>
<th>Assessment</th>
<th>Explanation</th>
<th>References</th>
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</thead>
<tbody>
<tr>
<td>Micro-economic viability</td>
<td>What are the economic costs and trade-offs of the option? (high costs correspond to low feasibility)</td>
<td>B</td>
<td>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.</td>
<td>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)</td>
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<tr>
<td>Macro-economic viability</td>
<td>Would the option lead to higher productivity?</td>
<td>C</td>
<td>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.</td>
<td>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)</td>
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<tr>
<td>Socio-economic vulnerability reduction potential</td>
<td>To what extent does the option reduce inequalities?</td>
<td>C</td>
<td>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.</td>
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<tr>
<td>Employment &amp; productivity enhancement potential</td>
<td>How many people that can be employed or how much can a system’s productivity increase under the option?</td>
<td>C</td>
<td>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.</td>
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<tr>
<td>Technical resource availability</td>
<td>Are the technology and associated human, financial, administrative resources needed for an adaptation option available?</td>
<td>B</td>
<td>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.</td>
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<tr>
<td>Risks mitigation potential</td>
<td>To what degree can the option reduce the likelihood and/or consequences of risks?</td>
<td>C</td>
<td>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.</td>
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<tr>
<td>Institutional</td>
<td>Political acceptability</td>
<td>Is the option politically acceptable? Does the option reflect stakeholder perceptions about the meaning and purpose of adaptation?</td>
<td>B</td>
<td>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.</td>
<td>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)</td>
</tr>
<tr>
<td>Legal, regulatory feasibility</td>
<td>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?</td>
<td>C</td>
<td>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.</td>
<td>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)</td>
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<tr>
<td>Institutional capacity &amp; Administrative feasibility</td>
<td>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?</td>
<td>B</td>
<td>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.</td>
<td>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)</td>
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<tr>
<td>Transparency &amp; accountability potential</td>
<td>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?</td>
<td>B</td>
<td>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.</td>
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<tr>
<td>Social co-benefits</td>
<td>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?</td>
<td>C</td>
<td>The implementation of EbA strategies in CSA increases community awareness and participation in the decision making process regarding their local resources and ecosystems. EbA can enhance food sovereignty and fosters SDG.</td>
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<tr>
<td>Socio-cultural acceptability</td>
<td>Is there public resistance to the option? Does the option typically find acceptance within existing socio-cultural norms, utilise diverse knowledge</td>
<td>C</td>
<td>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.</td>
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<th>Reference</th>
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<tbody>
<tr>
<td>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)</td>
<td>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)</td>
<td>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)</td>
<td>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)</td>
</tr>
<tr>
<td>Social &amp; regional Inclusiveness</td>
<td>Are different social groups and remote regions included in the option? Does the adaptation option adversely affect vulnerable groups or other areas?</td>
<td>C</td>
<td>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.</td>
</tr>
<tr>
<td>Intergenerational equity</td>
<td>Does the option compromise the ability of future generations to meet their own needs in any way?</td>
<td>C</td>
<td>EbA is defined as an adaptation strategy that fosters protection and restoration of natural ecosystems along with sustainable use of natural resources. Therefore, it does not compromise the ability of future generations to meet their own need.</td>
</tr>
<tr>
<td>Environmental Ecological capacity</td>
<td>Does the option enhance supporting, regulating or provisioning ecosystem services in any way?</td>
<td>C</td>
<td>EbA is defined as an adaptation strategy that fosters protection and restoration of natural ecosystems along with sustainable use of natural resources. Most EbA projects aim at protecting and enhancing ecosystem services.</td>
</tr>
<tr>
<td>Adaptive capacity/resilience building potential</td>
<td>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)?</td>
<td>C</td>
<td>EbA projects increase resilience in CSA by protecting and restoring ecosystem's health and promoting activities in harmony with ecosystems cycles.</td>
</tr>
<tr>
<td>Geophysical</td>
<td>Physical feasibility</td>
<td>Is the physical potential for the adaptation option a constraint?</td>
<td>C</td>
</tr>
</tbody>
</table>

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. (2018); 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

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Adaptation indicators</th>
<th>Questions guiding the adaptation indicators</th>
<th>Assessment</th>
<th>Explanation</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>Micro-economic viability</td>
<td>What are the economic costs and trade-offs of the option? (high costs correspond to low feasibility)</td>
<td>B</td>
<td>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.</td>
<td>Rogers and Tsirkunov (2010); Hallegatte (2012); Toloo et al. (2013); Hallegatte et al. (2017); International Labour Office (2019)</td>
</tr>
</tbody>
</table>
### Macro-economic viability

Would the option lead to higher productivity?

<p>| | | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>C</td>
<td>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.</td>
<td>Hallegatte (2012); Hallegatte et al. (2017); International Labour Office (2019); Muñoz et al. (2020b)</td>
</tr>
</tbody>
</table>

### Socio-economic vulnerability reduction potential

To what extent does the option reduce inequalities?

<p>| | | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>C</td>
<td>Partially yes (poverty alleviation and social protection), particularly for health outcomes that have a greater impact on impoverished populations</td>
<td>Lemos et al. (2002); Lavell (2008); Lavell (2009); Eakin et al. (2015); Escobar et al. (2015); Nagy et al. (2018); Pasetto et al. (2018)</td>
</tr>
</tbody>
</table>

### Employment & productivity enhancement potential

How many people that can be employed or how much can a system’s productivity increase under the option?

<p>| | | |</p>
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<thead>
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</thead>
<tbody>
<tr>
<td>C</td>
<td>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.</td>
<td>International Labour Office (2019)</td>
</tr>
</tbody>
</table>

### Technological

#### Technical resource availability

Are the technology and associated human, financial, administrative resources needed for an adaptation option available?

<p>| | | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>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.</td>
<td>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)</td>
</tr>
</tbody>
</table>

#### Risks mitigation potential

To what degree can the option reduce the likelihood and/or consequences of risks?

<p>| | | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>C</td>
<td>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).</td>
<td>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.</td>
</tr>
<tr>
<td>Institutional capacity &amp; Administrative feasibility</td>
<td>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</td>
<td>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</td>
</tr>
<tr>
<td>Legal, regulatory feasibility</td>
<td>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?</td>
<td>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.</td>
</tr>
<tr>
<td>Political acceptability</td>
<td>Is the option politically acceptable? Does the option reflect stakeholder perceptions about the meaning and purpose of adaptation?</td>
<td>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 practitioners) 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.</td>
</tr>
<tr>
<td><strong>Managing Implementation of the Option?</strong></td>
<td><strong>Responsibilities. Regional institutions may better able to implement health EWSs in areas with limited capacity.</strong></td>
<td></td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Transparency &amp; Accountability Potential</strong></td>
<td><strong>A</strong> 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&amp;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&amp;E capacities. Lowe et al. (2011); Bowman et al. (2016); Lowe et al. (2016); Cardona et al. (2017); Muñoz et al. (2020b)</td>
<td></td>
</tr>
<tr>
<td><strong>Social Co-Benefits</strong></td>
<td><strong>B</strong> 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)</td>
<td></td>
</tr>
<tr>
<td><strong>Socio-Cultural Acceptability</strong></td>
<td><strong>B</strong> 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)</td>
<td></td>
</tr>
<tr>
<td>Social &amp; regional Inclusiveness</td>
<td>Are different social groups and remote regions included in the option? Does the adaptation option adversely affect vulnerable groups or other areas?</td>
<td>B</td>
</tr>
<tr>
<td>Intergeneration al equity</td>
<td>Does the option compromise the ability of future generations to meet their own needs in any way?</td>
<td>C</td>
</tr>
<tr>
<td>Environmental Ecological capacity</td>
<td>Does the option enhance supporting, regulating or provisioning ecosystem services in any way?</td>
<td>LE</td>
</tr>
<tr>
<td>Geophysical</td>
<td>Land use change enhancement potential</td>
<td>Does the option enhance carbon stocks? (e.g., through forest restoration)</td>
</tr>
<tr>
<td>---</td>
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<td>---</td>
</tr>
<tr>
<td>Physical feasibility</td>
<td>Physical feasibility</td>
<td>Is the physical potential for the adaptation option a constraint?</td>
</tr>
<tr>
<td>Adaptive capacity/resilience building potential</td>
<td>Adaptive capacity/resilience building potential</td>
<td>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)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>

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.

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)

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)
### 12.7.4 Multi-use of Water Storage Approaches in CSA

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Adaptation indicators</th>
<th>Questions guiding the adaptation indicators</th>
<th>Assessment</th>
<th>Explanation</th>
<th>Evidence (limited, medium, robust)</th>
<th>Agreement (low, medium, high)</th>
<th>Sub-regions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>Micro-economic viability</td>
<td>What are the economic costs and trade-offs of the option?</td>
<td>B</td>
<td>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.</td>
<td>Robust</td>
<td>Medium</td>
<td>NWS NES</td>
<td>Branche (2015); Hunt et al. (2018); Leroy (2019)</td>
</tr>
</tbody>
</table>

References:
- 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)
<table>
<thead>
<tr>
<th>Category</th>
<th>Question</th>
<th>Answer</th>
<th>Confidence</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macro-economic viability</strong></td>
<td>Would the option lead to higher productivity?</td>
<td>C</td>
<td>Robust</td>
<td>NWS NES</td>
</tr>
<tr>
<td></td>
<td>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.</td>
<td></td>
<td></td>
<td>Branche (2015); Hunt et al. (2017); Hunt et al. (2018)</td>
</tr>
<tr>
<td><strong>Socio-economic vulnerability reduction potential</strong></td>
<td>To what extent does the option reduce inequalities?</td>
<td>C</td>
<td>Robust</td>
<td>CA NWS</td>
</tr>
<tr>
<td></td>
<td>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).</td>
<td></td>
<td></td>
<td>Branche (2015); Elgert et al. (2016); Branche (2017); Barriga et al. (2018); Martinez (2018); Drenkhan et al. (2019)</td>
</tr>
<tr>
<td><strong>Employment &amp; productivity enhancement potential</strong></td>
<td>How many people that can be employed or how much can a system’s productivity increase under the option?</td>
<td>NE</td>
<td>Limited</td>
<td>Low</td>
</tr>
<tr>
<td>Technical resource availability</td>
<td>Are the technology and associated human, financial, administrative resources needed for an adaptation option available?</td>
<td>B</td>
<td>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.</td>
<td>Robust</td>
</tr>
<tr>
<td>Risks mitigation potential</td>
<td>To what degree can the option reduce the likelihood and/or consequences of risks?</td>
<td>C</td>
<td>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).</td>
<td>Medium</td>
</tr>
</tbody>
</table>
### Political acceptability

**Question:** Is the option politically acceptable? Does the option reflect stakeholder perceptions about the meaning and purpose of adaptation?

**Answer:** 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.

**Rating:** Robust

**Reference:** Carey et al. (2012); Oré and Geng-Montoya (2014); Barriga et al. (2018); Drenkhan et al. (2019); Schütze et al. (2019)

### Legal, regulatory feasibility

**Question:** 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?

**Answer:** 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 rights 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 minimise environmental impacts.

**Rating:** Medium

**Reference:** Hunt et al. (2017); Marques et al. (2019a)
### Institutional capacity & Administrative feasibility

<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
<th>Robustness</th>
<th>Transparency &amp; Accountability potential</th>
<th>Source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>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?</td>
<td>B</td>
<td>Robust</td>
<td>Limited</td>
<td>Oré and Geng-Montoya (2014); Castex et al. (2015); Barriga et al. (2018); Drenkhan et al. (2019); Marques et al. (2019a)</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Transparency &amp; accountability potential</th>
<th>NE</th>
<th>Limited</th>
<th>Low</th>
<th>Oré and Geng-Montoya (2014); Castex et al. (2015); Barriga et al. (2018); Drenkhan et al. (2019); Marques et al. (2019a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are policy goals and targets for the option explicitly articulated; monitoring and evaluation protocols are set up to track implementation; and</td>
<td>NE</td>
<td>Limited</td>
<td>Low</td>
<td>Oré and Geng-Montoya (2014); Castex et al. (2015); Barriga et al. (2018); Drenkhan et al. (2019); Marques et al. (2019a)</td>
</tr>
<tr>
<td>Social co-benefits</td>
<td>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?</td>
<td>C</td>
<td>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.</td>
<td>Robust</td>
</tr>
<tr>
<td>Socio-cultural acceptability</td>
<td>Is there public resistance to the option? Does the option typically find acceptance within existing socio-cultural norms,</td>
<td>B</td>
<td>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.</td>
<td>Robust</td>
</tr>
<tr>
<td>Social &amp; regional Inclusiveness</td>
<td>Are different social groups and remote regions included in the option? Does the adaptation option adversely affect vulnerable groups or other areas?</td>
<td>B</td>
<td>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).</td>
<td>Robust</td>
</tr>
<tr>
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</tr>
<tr>
<td>Intergenerational equity</td>
<td>Does the option compromise the ability of future generations to meet their own needs in any way?</td>
<td>B</td>
<td>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.</td>
<td>Medium</td>
</tr>
<tr>
<td>Table Heading</td>
<td>Description</td>
<td>Level</td>
<td>Impact</td>
<td>Reference(s)</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
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<td>--------------</td>
</tr>
<tr>
<td>Ecological capacity</td>
<td>Does the option enhance supporting, regulating or provisioning ecosystem services in any way?</td>
<td>C</td>
<td>Medium</td>
<td>NWS, SWS, SSA (Soto-Schönherr and Iroumé, 2016; Buytaert et al. (2017); Ochoa-Tocachi et al. (2019); Ignazi et al. (2020))</td>
</tr>
<tr>
<td>Environmental</td>
<td>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)?</td>
<td>B</td>
<td>Robust</td>
<td>CA, NWS, NES (Lynch (2013); Branche (2015); Haeberli et al. (2017); Hunt et al. (2017); Hunt et al. (2018); Marques et al. (2019a))</td>
</tr>
</tbody>
</table>

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.

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.
<table>
<thead>
<tr>
<th>Physical feasibility</th>
<th>Is the physical potential for the adaptation option a constraint?</th>
<th>C</th>
<th>Across CSA, there is physical-technical feasibility of different options for multipurpose storage and multi-use of water.</th>
<th>Robust</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geophysical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land use change enhancement potential</td>
<td>Does the option enhance carbon stocks? (e.g., through forest restoration)</td>
<td>C</td>
<td>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).</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Hazard risk reduction potential</td>
<td>Does the option reduce number of people exposed to a hazard?</td>
<td>C</td>
<td>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.</td>
<td>Robust</td>
<td>High</td>
</tr>
</tbody>
</table>

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)

Branche (2015); Elgert et al. (2016); Hunt et al. (2017); Hunt et al. (2018); Martinez (2018); Marques et al. (2019a)

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 description 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 Socioeconomic Pathways (SSPs) population projections.

<table>
<thead>
<tr>
<th>Vector-borne Disease</th>
<th>Subregion</th>
<th>Baseline</th>
<th>RCP4.5</th>
<th>RCP8.5</th>
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<tr>
<td></td>
<td></td>
<td>2015</td>
<td>2030</td>
<td>2050</td>
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<tr>
<td>DEN_AE</td>
<td>NES</td>
<td>86,642,905</td>
<td>88,520,106</td>
<td>91,804,588</td>
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<tr>
<td></td>
<td>NSA</td>
<td>38,531,379</td>
<td>40,697,536</td>
<td>45,896,416</td>
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<thead>
<tr>
<th>DEN_A</th>
<th>E</th>
<th>NWS</th>
<th>63,823,409</th>
<th>73,593,771</th>
<th>79,317,494</th>
<th>60,620,222</th>
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<td>56,227,303</td>
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<td>187,682</td>
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<td>83,388,868</td>
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<td>44,782,098</td>
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<td>9,240</td>
<td>2,588</td>
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<td>801,341</td>
<td>1,118,065</td>
<td>6,194,892</td>
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</table>
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