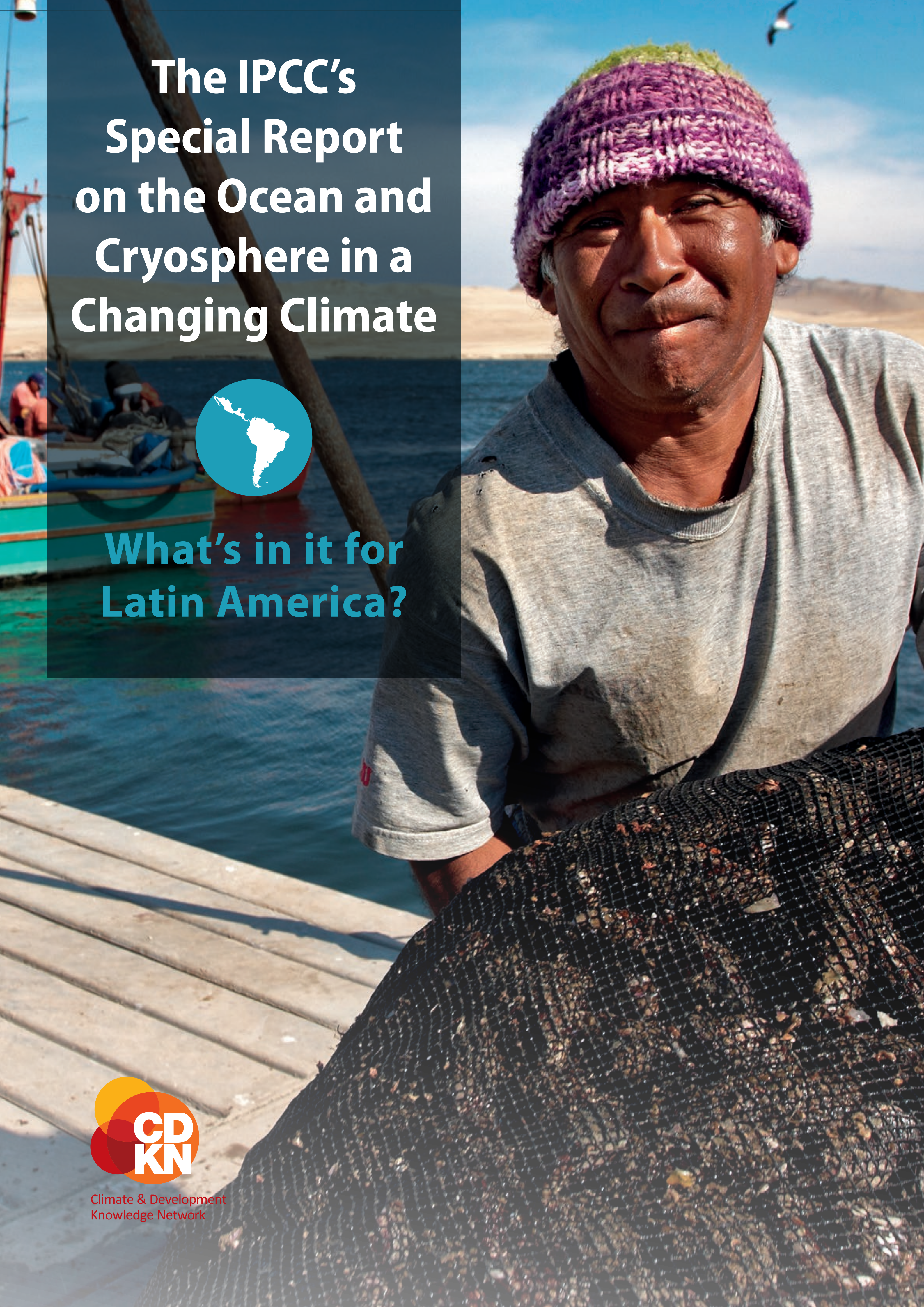
The IPCC's Special Report on the Ocean and Cryosphere in a Changing Climate

What's in it for Latin America?



Climate & Development Knowledge Network

Image: © SPDA | Peru high mountains.

Cover image: © SPDA | Peruvian fisherman.

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Key messages

1 Climate change driven by human activity is changing the temperature and chemistry of the oceans	2 These changes harm marine life and people who depend on it	3 Sea level rise and other climate hazards increasingly affect Latin America
4 Latin America's high mountain frozen lands are melting, with implications for society	5 The best way to limit changes in the oceans and cryosphere is to mitigate climate change	6 Early action reduces climate risks and costs less than dealing with future damages
7 Future-proofing coastal development will be essential	8 Environmental governance and management must join up across scales and address social issues	9 Communication, education and capacity building are critical

CRYOSPHERE: The word 'cryosphere' – from the Greek kryos, meaning cold or ice – describes the frozen components of the Earth system, including snow, glaciers, ice sheets and ice shelves, icebergs and sea ice, ice on lakes and rivers as well as permafrost and seasonally frozen ground.[1]

About this report

The Intergovernmental Panel on Climate Change (IPCC) published its *Special Report on the Ocean and Cryosphere in a Changing Climate* in 2019 (www.ipcc.ch/srocc). The Special Report was a response to proposals from governments and observer organisations to the IPCC.

For its preparation, more than 100 scientists from more than 30 countries assessed "the latest scientific knowledge about the physical science basis and impacts of climate change on ocean, coastal, polar and mountain ecosystems, and the human communities that depend on them."[2] Communities' vulnerabilities and adaptation capacities and societies' options for achieving climate-resilient development pathways were also assessed. The Special Report's findings are of great importance to Latin America and the world.

This publication offers a guide to the IPCC's *Special Report on the Ocean and Cryosphere* prepared for decision-makers in Latin America by the Climate and Development Knowledge Network (CDKN), Overseas Development Institute (ODI), Fundación Futuro Latinoamericano and SouthSouthNorth (SSN). This is not an official IPCC publication.

The IPCC's own *Summary for Policy Makers* focuses principally on global issues and trends. This report distils the richest material available on Latin America from the more than 700 pages of the Special Report. In a few places, we have included supplementary material from recently published research that extends and explains the points made in the IPCC's Special Report. We have clearly labelled this supplementary material 'Beyond the IPCC'. This guide responds to widespread demand among CDKN's Latin America partner networks for region-specific information.

Please visit **www.cdkn.org/oceanreport** for slides, images and infographics you can use in association with this guide.

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Image: © Shutterstock | Woman preparing freshly caught fish for market, Ecuador.

1 Climate change driven by human activity is changing the temperature and chemistry of the oceans

Global warming is driving changes in the oceans today. Average global temperatures are already 1°C higher than pre-industrial times and could reach 1.6°C – 4.3°C by 2100 (under the scenarios used by the IPCC in this assessment) depending on how deeply global society cuts greenhouse gas emissions.[3]

A warmer ocean

The world's oceans are taking the heat from climate change. Until now, the oceans have taken up more than 90% of the excess heat in the climate system.[4]

Marine heatwaves have doubled in frequency since 1982 and are increasing in intensity. They are predicted to become longer, more frequent, more far-reaching and more intense.

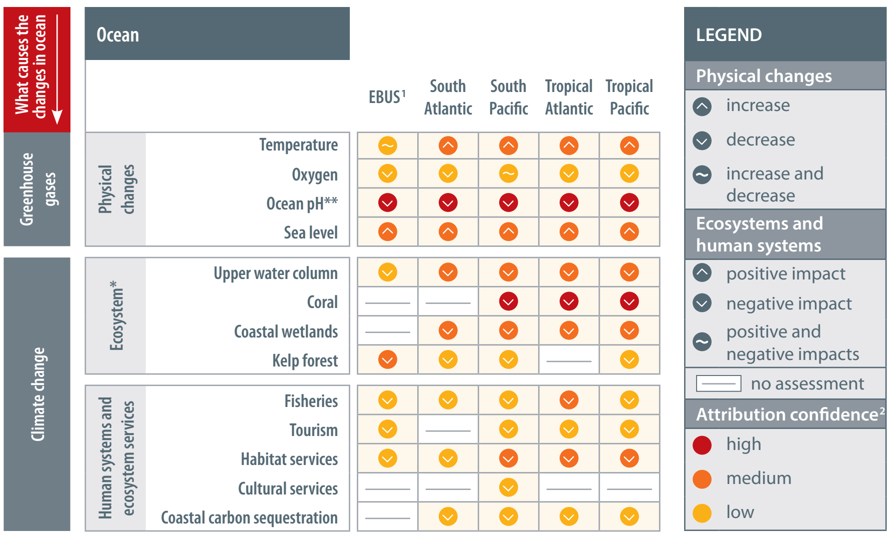
A more acidic ocean

The ocean has taken up between 20% to 30% of human-induced carbon dioxide emissions since the 1980s. This is making the oceans more acidic. The oceans are expected to take up more carbon from the atmosphere between now and 2100. This will increase ocean acidification.

A less productive ocean

Warming has particularly affected the surface layer of the oceans. Now, there is less mixing among layers of ocean water. This means less exchange of oxygen and nutrients among layers, and in turn, less productive biological systems. (See 'productivity' in Glossary.) In the upper layer of the open ocean, the amount of dissolved oxygen in the water decreased between 1970 and 2010.[5]

Figure 1: How changes in the atmosphere and climate have affected the oceans[6]



¹ Eastern Boundary Upwelling Systems (Benguela Current, Canary Current, California Current, and Humboldt Current)

² Attribution confidence means: how much confidence scientists have that this change can be attributed to human-driven climate change.

* Rocky Shores, deep sea, polar benthos, sea-ice-associated ecosystems, sea-ice extent and transportation/shipping were also assessed by the IPCC, but not for the Oceans listed above, around the coasts of Latin America. See the IPCC's *Summary for Policy Makers* for more details

** Decreasing pH means getting more acidic.

2 These changes harm marine life and people who depend on it

A warmer, more acidic ocean, with less oxygen and changes in available nutrients, is already affecting the distribution and abundance of marine life, in coastal areas, in the open ocean and on the sea floor.[7] The average temperature of the Earth's surface (land and ocean combined) is already 1°C higher than in pre-industrial times (see Figure 2, below). Every additional degree of average global warming will affect coastal and ocean ecosystems, with profound implications for human societies and people's wellbeing.

Warming is destroying coral reefs and threatening other fragile ecosystems

Warming ocean waters and a more acidic ocean are destroying coral reefs, sea shells and other immobile species with calcium-based shells, such as mussels and barnacles.[8] Marine heat waves have caused massive coral bleaching events, where corals are killed by heat. It can take 15 years for coral reef ecosystems to recover, if they recover at all.[9]

It is expected that, even at global warming of 1.5°C, the species composition and diversity of today's shallow coral reefs will change. Coral reefs' declining health will greatly reduce their contribution to human society, including to food, coastal protection and tourism industries.[10]

Seagrass meadows and kelp forests are also at very high risk, even at 1.5°C of mean global warming; they, too, are highly sensitive to ocean warming and acidification.

Species are on the move

Marine species are on the move, as a result of climate change. This means that in any one place, the abundance and mix of species is changing. In turn, this means the interactions among different species (e.g. between predators and prey) is also changing.[11] For example, warming and decreases in oxygen content are projected to affect fishes' growth, leading them to have smaller bodies (the greater the climate change, the greater the effect will be). An expected decrease in larger-bodied fishes in the oceans could reduce predation and so increase the dominance of smaller-bodied fishes in the epipelagic zone (the top 200 metres of ocean water). Furthermore, fishes exposed to ocean acidification levels expected under the highest global warming scenario have impaired sensory abilities and altered behaviour: they are less able to see, hear, and avoid predators.[12]

Fish stocks are and will be affected

The distribution of fish populations is shifting.[13] These changes in the natural environment will have particular impacts on local people that depend on fish stocks for their livelihoods and for their own food supplies.[14]

Ocean warming will also cause the biomass of marine animals to decrease across the world's oceans as a whole this century. The size of maximum potential fish catches will decrease, although this will vary by region.[15]

It is thought that future ocean warming will have a particularly strong impact, by decreasing the fish catches of tropical oceans (three times greater decreases than the global average under the highest warming scenario). Commercially-important tuna species such as albacore, Atlantic and southern bluefin tuna are predicted to shift towards the poles (e.g. South Pole) and decrease in abundance in tropical waters. Some tropical species such as skipjack tuna are expected to remain abundant, but with changes in their distribution across tropical waters by the middle of the 21st century.

Overall, scientific models show that the greater greenhouse gas emissions and global warming are, the greater the impact on fish stocks and their distribution will be.[16] However, it is difficult to predict catch sizes with much certainty as the management of fisheries will have such a great influence, too; a critical area that falls under governance matters. (See Section 9 of this volume.)

"Fisheries catches and their composition in many regions are already impacted by the effects of warming and changing primary production on [the] growth, reproduction and survival of fish stocks (high confidence)."[17]

Box 1: The IPCC's confidence levels

This matrix helps explain what the IPCC means by high, medium or low confidence.[18]

High confidence means that there is a high level of agreement and evidence in the literature to support the categorisation as high, medium or low.

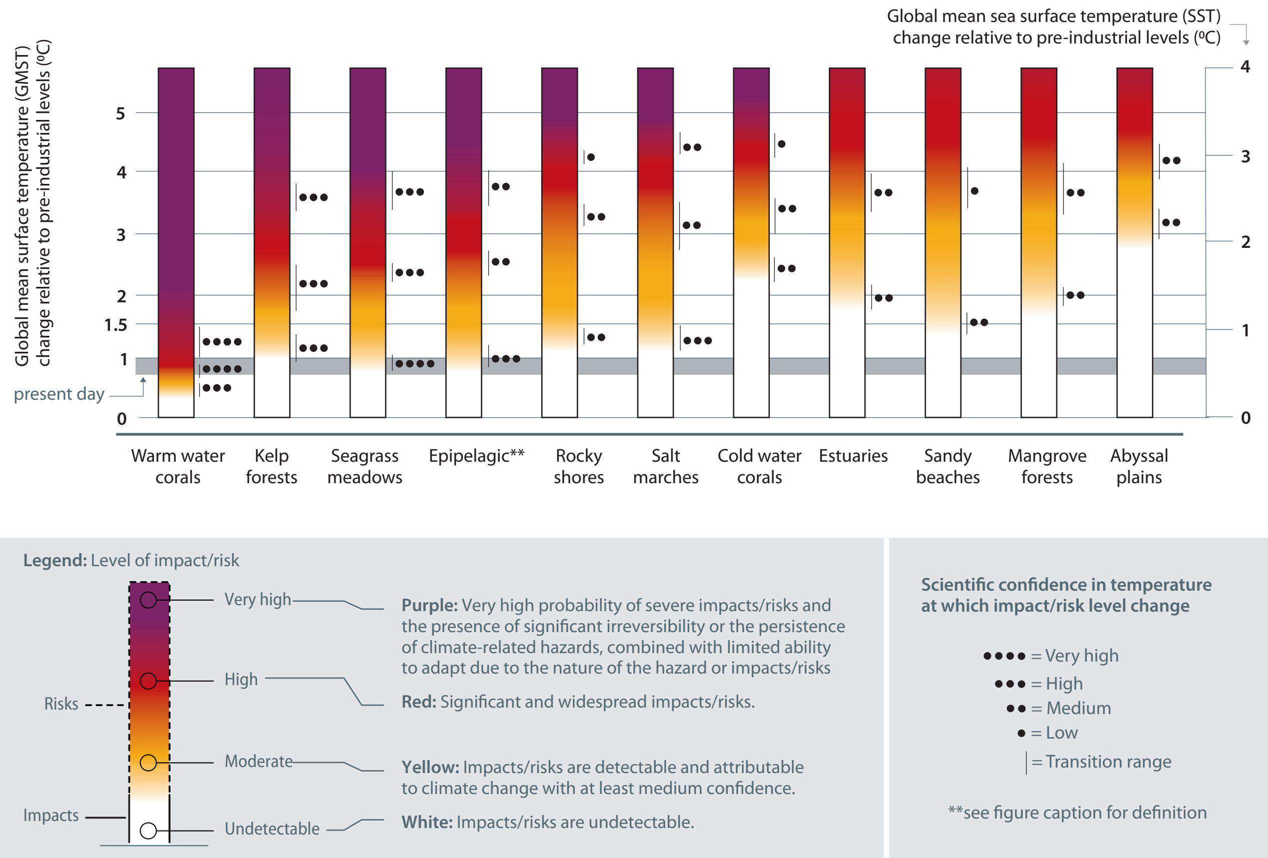
Low confidence denotes that the categorisation is basedon only a few studies. Medium confidence reflects medium evidence and agreement.[19] Confidence increases towards the top-right corner as suggested by the increasing strength of shading.

Agreement			
	High agreement Limited evidence	***High agreement Medium evidence***	***High agreement Robust evidence***
	Medium agreement Limited evidence	***Medium agreement Medium evidence***	***Medium agreement Robust evidence***
	Low agreement Limited evidence	***Low agreement Medium evidence***	***Low agreement Robust evidence***

Evidence (type, amount, quality, consistency)

Confidence Scale: higher – lower

Figure 2: Every degree of global warming will harm coastal ecosystems further[20]



The Humboldt Current in the Eastern Pacific is changing

The Humboldt Current is an ocean upwelling system that brings cold, nutrient-rich waters from the deep water to the surface in the Eastern Pacific, affecting the coasts of Chile, Peru and Ecuador.

Like other 'Eastern Boundary Upwelling Systems' of this type around the world, the Humboldt Current is a very rich ocean ecosystem. The nutrients support large stocks of fish and other marine organisms.[21]

The total economic value of the goods and services provided by the Humboldt Current is estimated to be US$19.45 billion per year. Therefore, although their area is small compared to other ocean ecosystems, climate change impacts on upwelling systems like the Humboldt Current will have disproportionately large consequences for human society.[22]

In the last few decades, the Humboldt Current has become more acidic and deoxygenated, although thus far it has been difficult to attribute these changes confidently to human-driven climate change.

Scientific models predict that the Humboldt Current will become further de-oxygenated and more acidic by 2100, affecting the health of marine wildlife that depend on its waters.[23] The human-influenced climate changes and their impacts on the Humboldt Current are expected to emerge in the latter half of this century.[24]

These changes will put at risk the ecosystem benefits that these ocean upwelling systems provide to human societies living near them, such as fisheries and aquaculture.[25]

Image: © Flickr, Lorena Betta | Fish processing, Peru.

3 Sea level rise and other climate hazards increasingly affect Latin America

Sea levels are rising at a faster rate

Globally, sea level is now rising at a rate of 3.6 mm per year. That is twice as fast as it rose in the 20th century.[26] The acceleration in the rate of sea level rise in recent decades is a global phenomenon, driven by increasing rates of ice loss from the Greenland and Antarctic ice sheets.[27]

The continued melting of glaciers and thermal expansion of the oceans worldwide have also contributed, since water expands in volume as it warms. [28]

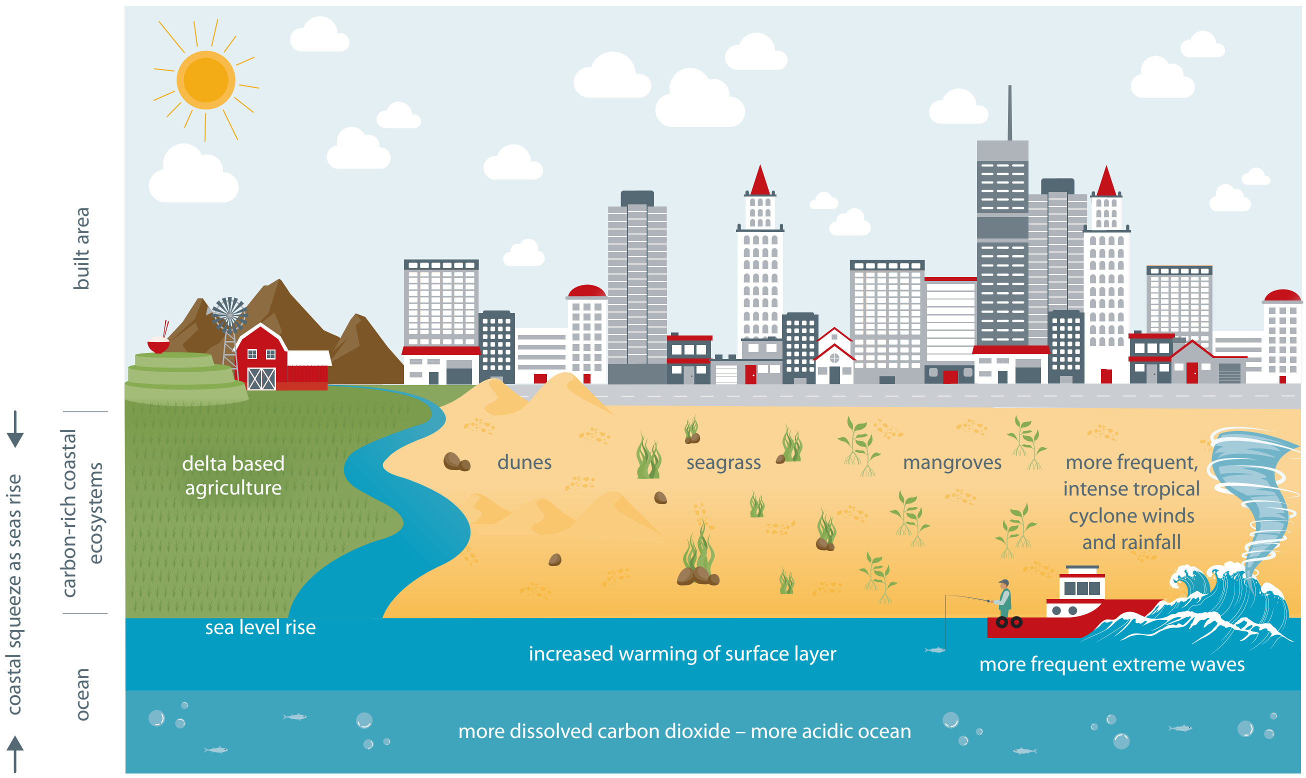
Sea levels continue to rise at an increasing rate. [29] Sea level rise could reach around 29 – 59 cm by 2100 even if greenhouse gas emissions are sharply reduced and global strongly warming is limited to well below 2°C. Sea levels will rise even more, by 61 – 110 cm on average worldwide, under a high emissions scenario.[30]

Sea level rise is creating a 'coastal squeeze' on important coastal ecosystems which are fertile and biologically productive and underpin the livelihoods of millions of Latin Americans. These include mangrove forests, seagrasses, coastal wetlands, delta-based agriculture and dune ecosystems. Coastal squeeze describes what happens when the built environment (e.g. settlements and infrastructure) provide a hard barrier for ecosystems on one side, and rising seas provide a barrier on the other. See Figure 3 below.[31]

There will be more frequent extreme sea level events, too. These occur, for example, during high tides and intense storms.[32]

In low-lying coastal zones, 680 million people worldwide are now at risk from rising oceans, a figure which will reach a billion people by 2050.[33] Sea level rise could displace people. Some evidence of human displacement linked to sea level rise is discussed in Box 2.

Figure 3: Rising seas and coastal development put a 'squeeze' on coastal ecosystems



“Increases in tropical cyclone winds and rainfall, and increases in extreme waves, combined with relative sea level rise, exacerbate extreme sea level events and coastal hazards (high confidence).”[34]

Box 2: Climate change as one factor in human displacement and migration

Marine flooding is already affecting deltas around Latin America and the world with impacts on communities.[35] Marine flooding can come about from a mixture of human factors, climate variability and the effects of climate change, including more frequent extreme weather events.

Human activity is disturbing delta ecosystems because upstream land-use changes and dams on rivers interfere with natural sediment flows into deltas. Natural subsidence can occur in deltas while mean sea level rises and naturally occurring events such as El Niño bring heavier rainfall and storm swells.

In the San Juan River delta, Colombia, the recurrence of floods in El Niño years meant that several villages (El Choncho, San Juan de la Costa, Caarambira, Togorama) needed to be relocated. [36]

In the coming years, ‘significantly higher risks of human displacement’ may be expected in low-income, low-lying islands and coasts, such as Guatemala.[37]

Meanwhile, migration from high mountain areas of South America, documented in the IPCC Special Report, is associated with changes in the cryosphere environment. Wage labour migration is a centuries-old practice in the Andean region.

Climate change and migration in the region tend to be linked by stress on livelihoods: climate change impacts agricultural productivity, which affects livelihoods, which drives people to move for the short-term, the long-term, or permanently, and domestically or even internationally, in search of better lives.

A study from the central Peruvian Andes shows that people from villages with the highest dependence on glacier meltwater ‘travel further and stay away longer than the villages where glacier meltwater forms a smaller portion of stream flow’.[38] A study from the Peruvian Andes also shows that there are generational differences in migration. In this case, younger adults are selling off their animals and moving away to larger cities, while people over 50 are more likely to stay. The loss of young adults is reducing the ability of households to carry out more demanding work.[39]

The IPCC concludes that there is increasing evidence that ‘people are rarely moving exclusively due to changes in ocean- and cryosphere-based conditions, and that migration as a result of disasters and increasing hazards strongly interact with other drivers, especially economic and political motivations (high confidence)’.[40]

Extreme weather events are becoming more frequent

Sea level rise is one of many climate-related hazards to affect the coasts of Latin America and other coasts worldwide. Extreme weather events such as cyclones, flooding and marine heatwaves all have an impact on coastal communities and will do in the future.

On average, tropical cyclones will become more intense, wetter, and more frequent (note that this applies to tropical areas, not globally) and they will be associated with higher extreme sea levels. Wave heights in the tropical eastern Pacific will increase under mid- and high-level scenarios for global warming.[41]

El Niño and La Niña events are part of natural climate variability. El Niño events bring ‘pronounced’ rainfall to the normally dry equatorial areas of the eastern Pacific, such as Ecuador, Peru and Colombia. La Niña brings below-average rainfall to coastal Peru and Chile but more rainfall to the central Andes.

The IPCC finds with ‘medium confidence’ that the strongest El Niño and La Niña events since pre-industrial times have occurred in the past 50 years.[42] What is more, extreme El Niño and La Niña events are likely to occur more often with global warming, even with relatively low levels of warming.[43]

Warming, sea level rise, and enhanced loads of nutrients and sediments in deltas have contributed to salinisation and deoxygenation in estuaries (high confidence).[44]

Cascading impacts and compound risks

Extreme weather events are hazards that can create cascading impacts on people and the environment. When these are combined with non-climatic issues (such as social inequality or other aspects of unsustainable development), they can affect people's exposure and vulnerability and create compound risks.[45]

More generally, too, climate change (including slow-onset changes) adds pressure to the fragile ecosystems that have already been depleted by unsustainable development.

Coastal ecosystems such as sea grasses and mangroves are affected by ocean warming including acidification, loss of oxygen, salinity intrusion and sea level rise.

These climate-related hazards combine with unsustainable human activities such as polluting, reef and sand mining, habitat degradation and groundwater extraction to further degrade ecosystems and create negative local impacts.[46]

The following are examples of how climate change impacts can combine with unsustainable development to harm people and the environment:

- Algal blooms are now increasing in estuaries worldwide, including in Latin America. This is partly driven by direct environmental pollution, such as nutrient runoff from farms and pollution by factories. It is also compounded by climate change, because increased temperatures stimulate bacterial respiration.[47] People are most vulnerable to harmful algal blooms where there is poor monitoring and weak early warning systems.[48]
- In the oceans, warming and oxygen loss (driven by climate change) are changing the abundance and distribution of fish and other marine species. This compounds the problem of overfishing that already affects many fish stocks.
- Meanwhile, climate change increases the way that sea organisms bioaccumulate dangerous substances such as persistent organic pollutants and mercury. The risks of negative impacts are increasing, both for marine ecosystems and for people who eat a lot of seafood. Seafood is becoming less safe.[49]

Box 3: When does climate change play a role in disaster?[50]

The extreme event: Southern Amazon (2010)

Widespread drought in the Amazon led to the lowest river levels of major Amazon tributaries on record.

Attribution to human-made climate change: A study based on climate models of the severe southern Amazonian drought indicates that human influences on the climate as well as natural sea surface temperature variability increased the probability of the event.

Impacts and costs: The 2010 drought reduced the amount of carbon that the Amazonian forest lands absorbed from the climate (known as the 'carbon uptake') compared to long-term averages.

The extreme event: Peru rainfall (2017)

Peru suffered an extremely wet rainy season in 2017.

Attribution to human-made climate change: Human influence on the climate is estimated to make such events 1.5 times more likely to occur now than in the past.

Impacts and costs: Widespread flooding and landslides affected 1.7 million people, with a death toll of 177 and estimated economic damages of US$3.1 billion.

The extreme event: Uruguay rainfall (2017)

Uruguay suffered from very heavy April-May rainfall in this year.

Attribution to human-made climate change: The risk of extreme rainfall in the Uruguay River basin increased two-fold as a result of human influences on the climate.

Impacts and costs: This event triggered widespread flooding over the banks of the Uruguay River, causing economic losses of US$102 million and the displacement of 3,500 people.

The extreme event: coastal Peru ocean warming (2017)

There was strong, shallow water warming of up to 10°C off the northern coast of Peru.

Attribution to human-made climate change: It is unknown whether global warming increased the probability of this event, or whether it was due to natural climate variability.

Impacts and costs: The event caused heavy rainfall and flooding. It affected anchovies by decreasing their fat content and driving early spawning as a reproductive strategy.

The extreme event: southwestern Atlantic Ocean warming (2017)

From February to March 2017, sea surface temperatures were 1.7°C higher than the previous maximum between latitudes 32°S and 38°S.

Attribution to human-made climate change: High air temperature and low wind speed led to a marine heatwave. However, it is unknown whether global warming increased the probability of this happening.

Impacts and costs: There were mass fish mortalities.

Beyond the IPCC: Women and men are differently affected by climate-related hazards on Latin America's coasts: Decision-making processes should reflect this[51]

An initiative for more climate-resilient development in coastal Mexico highlighted that (i) women are differently impacted by climate change than men; and (ii) discriminatory decision-making processes and cultural mores undermine women's ability to build their resilience. Governance processes and disaster management needs to account for this.

Coyuca de Benitez on Mexico's Pacific coast has suffered repeated tropical storms and tidal surges in the past decade. The coastal urban system, situated along a 16 km-long lagoon in Guerrero State, combines urban sprawl with traditional fishing and farming activities. Incorporating 14 settlements, it is home to 30,000 people. In 2013, Cyclones Ingrid and Manuel damaged 70% of the Coyuca de Benitez area, including 2,500 houses and critical infrastructure. In 2015, a sea surge affected hundreds of people, and then in 2017, Hurricane Max caused further damage to homes and businesses.

These extremes of weather are happening more often than in preceding decades. A picture of Coyuca in 'climate crisis' was detailed through painstaking investigation by the Climate Resilient Coyuca project – an initiative of the Climate Resilient Cities in Latin America programme.

The research found:

Women are the first defenders for climate-related disasters

Society in this part of Guerrero State is starkly divided along gender lines. Women are the primary caregivers, with almost sole responsibility for the welfare and wellbeing of elderly and disabled relatives, children and infants. To guard against storm-related injuries, women lead in securing others' safety. They provide food, find drinking water and care for community members who fall sick from water-borne diarrhoeal diseases.

However, women have little access to education and the formal labour market and thus to the healthcare provision associated with formal employment. Women therefore end up providing a safety net to others in their families and communities, but receive insufficient support themselves as carers.

Limited local governance to date

People's self-help efforts go a long way toward keeping families afloat and providing coping mechanisms. The researchers found that these efforts could be strengthened if local government stepped up to provide disaster relief and climate-smart urban planning.

What is more, many of the land use planning and infrastructure investment decisions of local government have made the population even more vulnerable to climate changes such as sea level rise, cyclones and intense rain. For instance, roads and bridges are constructed using materials that increase storm water runoff and the accumulation of water, or infrastructure is built too close to an eroding coastline.

Image: © Coyuca Resiliente al Clima | Community members of the Coyuca lagoon area discuss climate resilience.

Local decision-making processes, concerning both long-term urban planning and shorter-term emergency responses, have been opaque and almost entirely male dominated.

Coyuca's first local adaptation strategy

The 'Climate Resilient Coyuca' initiative created a local platform which pinpointed the diverse climate-related impacts and needs of all groups of citizens. It developed solutions that could benefit all local people.

This gender-balanced multi-stakeholder platform contributed to and guided several activities:

(a) A climate vulnerability and risk assessment identified women's unequal burdens in clean-up and caregiving roles before, during and after extreme weather events.

(b) Assessments were made of local government performance, identifying severe gaps in local government's ability to meet public service needs.

(c) A 'Gender-Sensitive and Participatory Climate Change Adaptation Strategy' was formulated that commits local government, communities and academia to working together in order to:
- compile further knowledge on climate-smart urban development in the Coyuca Lagoon Urban Area;
- encourage collective public action for climate resilience; and
- communicate climate change, gender inequities and urban development processes broadly among public officials and the local population.

Image: © SPDA | Peru.

4 Latin America's high mountain frozen lands are melting – with implications for society

Frozen lands (the cryosphere) are melting as a result of climate change – with implications for the Andean region.

River runoff is changing

Changes in the cryosphere have far-reaching local and regional impacts across river basins and watersheds.

Changes underway in glacier-fed rivers cannot be reversed. In regions with little glacier cover such as the tropical Andes, most glaciers have already passed their 'peak levels' of average annual runoff and summer runoff, and runoff can now be expected to decline.[52] Small glaciers such as those found in the Andes are projected to lose 80% of their current ice mass by 2100 under high emission scenarios. Permafrost degradation and decline will also continue in the 21st century.[53]

As mountain glaciers retreat, the amount and timing of water runoff into rivers is changing. These changes in water flows could have implications for hydropower and agriculture in the tropical Andes.[54] The melting of glaciers and permafrost is expected to release heavy metals, especially mercury, which reduces the quality of water for freshwater organisms as well as for household and farming use.[55]

An environment and way of life is threatened

As ice and snow retreat, high mountain ecosystems change, too. Both plant and animal species are moving from lower altitudes to higher up the mountains, and in some cases will run out of habitat with a suitable climate in which to survive.[56]

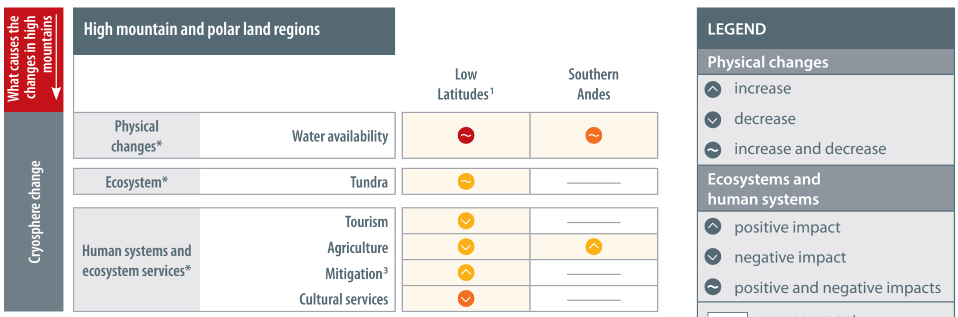
The loss of ice and snow in high mountain regions changes the aesthetic and the cultural value of these areas to society, e.g. in the tropical Andes. There are also implications for tourism and recreation.

Hazards in high mountain areas are increasing

People and infrastructure are becoming more exposed to natural hazards such as landslides as a result of changes in the frozen, high mountain lands.[57] In the Andes, some disasters are attributed to changes in the cryosphere.[58]

In the coming decades, the retreat of mountain glaciers are projected to make slopes less stable and the number of glacier lakes is expected to increase. There will be glacial lake outburst floods, landslides and snow avalanches in new locations and different seasons.[59]

Figure 4: How changes in the atmosphere and the climate have affected the cryosphere[60]



¹ Includes Tropical Andes.
² Attribution confidence means: how much confidence scientists have that this change can be attributed to human-driven climate change.
³ Mitigation refers to an increase or decrease in net mitigation, not to beneficial/adverse value.
* Flood, landslide, avalanche, ground subsidence, forest, lakes/ponds and infrastructure are physical changes in the environment, human systems and ecosystems which the IPCC assessed for impacts of climate change, but not for the cryosphere in the low latitudes (tropical Andes) and Southern Andes. See the IPCC's *Summary for Policy Makers* for more detail.

Box 4: Challenges to farmers and local people as the cryosphere shrinks: the Cordillera Blanca, Peru[61]

Peru's Cordillera Blanca region contains most of the glaciers in the tropics. As local residents are well aware, the size of the glaciers has been shrinking significantly in recent decades. In fact, since the 1940s, hazards related to the melting glaciers have killed thousands of people. Both the rural people living nearby and also urban residents downstream are concerned about, and remain under threat of, landslides and glacier lake outburst floods.

The shrinking glaciers have also led to reduced river runoff in the associated river basins, especially during the dry season. Social and economic factors make people more vulnerable to these hazards and to the effects of reduced runoff and higher temperatures.

Poverty, limited political influence and resources, low levels of (and access to) education and healthcare, and weak government institutions all increase people's vulnerability.

Water security is influenced both by the availability of freshwater and its distribution (IPCC; also, see pages 15–16 below).

Demand for water comes not only from local residents but also from farmers, some of whom are growing to sell on global markets (hydroelectric users and others). All these needs must be managed through water laws and policies and their implementation.

The government has taken measures, meanwhile, to manage flood, landslide and other risks related to the changing Cordillera Blanca. Lake 513 was lowered by 20 metres in the early 1990s to prevent an outburst flood. There was a destructive flood anyway, in 2010, although it was smaller than it would have been without the mitigation work. An early warning system was then installed to alert residents to future threats, but was destroyed as a result of political, social and cultural conflicts.

Early warning systems have also been installed for Lake Palcacocha and for Penu; the latter early warning system has demonstrably reduced risks.

Figure 5: A simplified picture of how runoff changes in a river basin when a glacier melts[62]

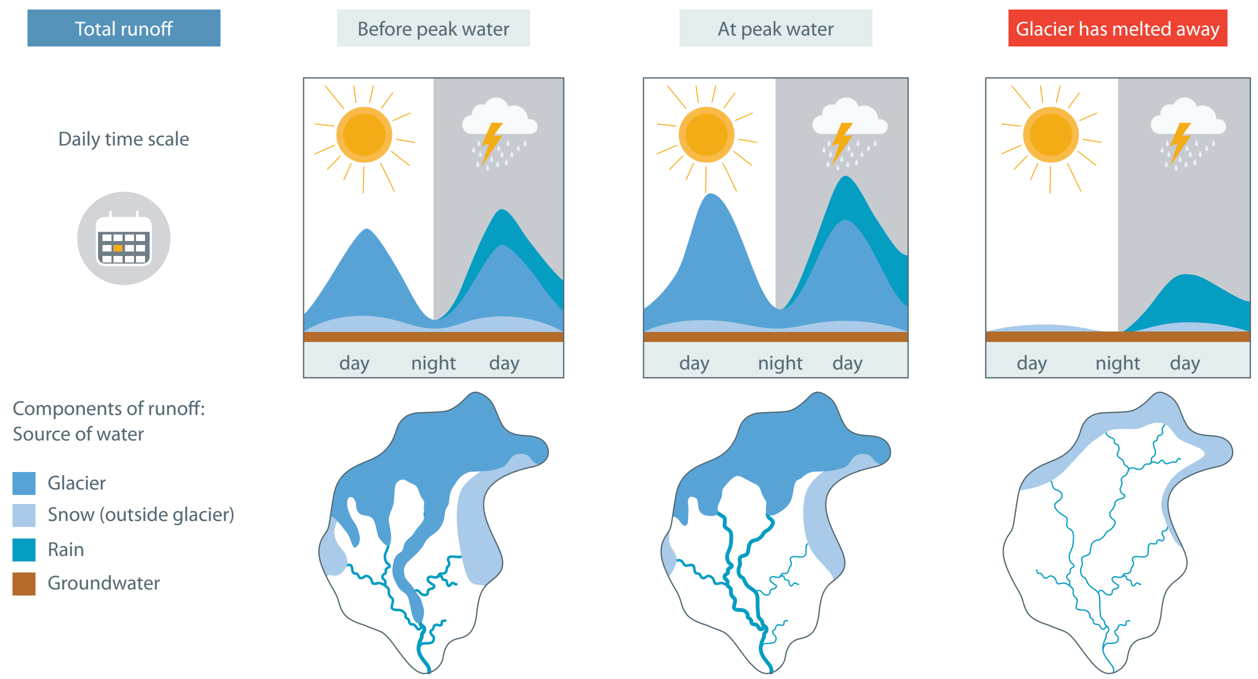


Image: © SPDA | Ecuador.

Beyond the IPCC: A local view on Peru's shrinking glaciers and its impacts[63]

Image: © SPDA | Peru's high mountains.

Despite the evidence of melting glaciers and permafrost in Peru's high mountains and its impacts on society, there remains a significant lack of action to manage the risks at village, district and regional levels. The Glaciers+ Project (2011 – 19) was a climate change adaptation, risk management and water resources management project which investigated these issues and worked with local and national actors to improve resilience and disaster risk reduction in Peru's three main mountain ranges. The project was implemented by CARE Peru and the University of Zurich.

The project found that the following hurdles must be overcome to enable effective disaster risk reduction and climate adaptation action in Peru's mountainous regions:

Poverty

Poverty means that the most vulnerable communities in Peru's mountain regions view climate change adaptation as something which pertains to the distant future. Thus, adaptation measures need to demonstrate a clear improvement not only for the ecosystem or natural resources, but also for more immediate cash flow and financial opportunities for families.

Misinformation about risks

Misinformation on risks is another important issue. Droughts, floods and landslides have become more recurrent. However, mountain residents think, wrongly, that catastrophic disasters related to glacial lake outburst floods (GLOF) are very unlikely to reoccur. Communication is critical and requires cooperation among scientists, technicians, the media and authorities.

However, knowledge of the rate of glacier retreat, the increasing water volume in lakes and GLOF simulations are not enough to ensure that people take action. Many communities living close to the glaciers are situated where floods have already occurred. Therefore, early warning systems or sophisticated technologies provide the best option for risk reduction. Joint efforts of an institutional, local and scientific nature are required to achieve this.

Lack of local knowledge about the climate science

There is still a low level of knowledge of and appreciation for national and international scientific authority among stakeholders who are affected by the rapid environmental changes. In rural areas, local and regional governments know very little or near to nothing about organisations such as the IPCC.

It is important that Latin American and local scientists are heard so that people feel represented. This increases the perceived legitimacy and value of reports. When the scientific information is linked to a person's daily life, such as water supply or the possibility of illness and disease, then the science is recognised as valuable because it relates directly to people's lived realities. If geared this way, the science is considered as important as economic and policy information.

Lack of trust in the public and private sectors

Another key element is a lack of trust in the state and private sectors. Peru has a long history of corruption and bad practices stemming from misinformation about the conditions and social dynamics in the mountain regions, of inefficient communication and of insufficiently participatory processes.

As a result of this, numerous mechanisms and good practices have been developed, from capacity building to empowering local leaders, in order to create the conditions for good environmental governance. These measures are much needed to respond to climate challenges.

Communication processes are crucial. Communication will ensure that public officials, researchers, civil society and businesses understand each other and open spaces for dialogue, planning and intervention on climate change adaptation.

Next steps

It is evident that the IPCC's call for immediate action in its *Special Report on the Ocean and Cryosphere* fits with the need for action in vulnerable communities due to glacier retreat. Both scientists and the population are speaking the same language and demanding the same thing: urgent action. What lies ahead is the task of influencing the political environment and media in order to compel authorities to take decisions. Peru has a good opportunity to do this through the development of its National Policy on Glaciers and Mountainous Ecosystems, which is currently in process.

Beyond the IPCC: Lima, Peru: A capital city at risk from melting glaciers[64]

Lima, a city of 10 million inhabitants, receives only 10mm of rain annually. It is known as the second most habitable desert city on the planet (after Cairo, Egypt). Seventy five percent of its water supply comes from the Lurín, Chillón and Rímac Rivers, which are entirely dependent on the rapidly disappearing glaciers of the high Andean regions adjacent to the capital. The city is set to experience a growing water crisis that requires urgent adaptation measures in order to deal with this challenge.

Analysis by the Pontifical Catholic University of Peru shows that the city of Lima must take multiple adaptation measures to avert a water crisis. These include:

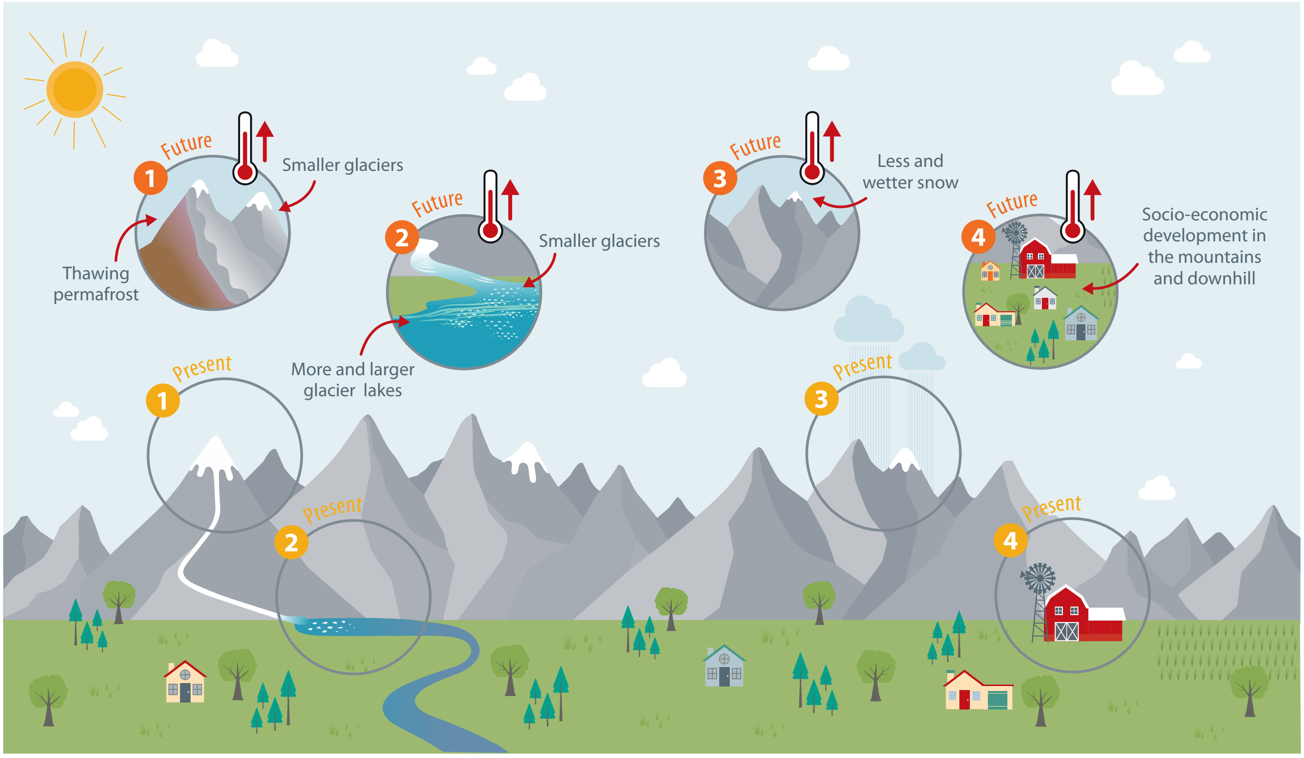
- Addressing inequalities in water access and use: Lima has high levels of inequality, and this includes the access to and daily use of water in different areas. More than a million people in Lima are dependent on delivery of water in private trucks for their water supply. According to Oxfam, they pay ten times more per litre than those who have fixed 24-hour water connections.
- Changes in water and sanitation governance: the city would benefit from policies, programmes and specific actions to promote more efficient water use as well as more equitable access. This could include: raising public awareness of the need to reduce water use and encouraging the use of more efficient fittings for toilets, taps and showers; a tariff based on water usage to discourage excessive consumption; maintenance of water infrastructure (preventing leaks) and treatment and recycling of grey water; and improved control of water usage (both legal and illegal) in the mining sector, to prevent wasting and contaminating the water source.

Image: © SPDA | Peru.

Finally, it is proposed that water management programmes and actions should be multi-sectoral and multi-scaled, which would require restructuring and inter-institutional collaboration. This would improve the participation of sub-national governments and enable greater control where currently they have very limited capacity. It would also provide an essential systemic framework that would make it possible to view the problem more holistically by assessing the total water catchment, and the repercussions on the entire system of actions taken in specific areas.

Image: © SPDA | Peru.

Figure 6: Anticipated changes in high mountain hazards as the climate changes[65]



1 Unstable slopes and landscapes

- ▲ More landslides from rock walls and slopes
- ▼ Local reduction in some hazard types, e.g., less ice falls as glaciers retreat
- ▼ Improved infrastructure against landslides

2 Snow avalanches

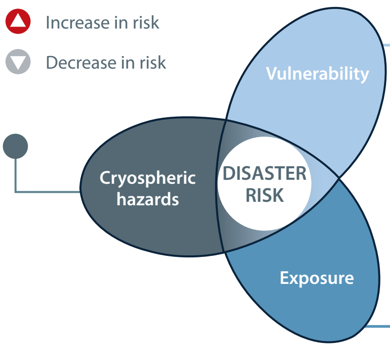
- ▲ More avalanches involving wet snow
- ▼ Less and smaller snow avalanches where snow cover declines
- ▼ Improved measures against snow avalanches

3 Floods

- ▲ More and larger glacier lakes
- ▲ More floods from impacts by avalanches and landslides
- ▲ More rain-on-snow floods at higher elevations
- ▼ Less rain-on-snow floods at lower elevations
- ▼ More preventative measures at/near glacier lakes

Risk framework

- ▲ Increase in risk
- ▼ Decrease in risk



4 Social and infrastructure systems

- ▲ Social inequality and marginalised communities
- ▲ Institutional remoteness
- ▲ Inadequate or inaccessable information
- ▲ Higher populations
- ▲ More mountains tourism
- ▲ Hydropower expansion up-valley
- ▲ More infrastructure in mountain and downhill areas
- ▲ New locations become exposed
- ▼ Improved hazard zonation, education and awareness
- ▼ Improved early warning and emergency response systems

5 The best way to limit changes in the oceans and cryosphere is to mitigate climate change

Human society must reduce greenhouse gas emissions urgently in order to limit the damage from global warming to the Earth's oceans and frozen lands (the cryosphere).[66]

Glaciers are due to keep melting, permafrost will thaw, and snow cover and the extent of Arctic Sea ice will all decline between now and 2050 as a result of large-scale changes in Earth's systems that are already underway. This is inevitable.

However, choices we make today about the emissions pathway of the future will make a difference to global warming and how the oceans and cryosphere respond during the second half of the 21st century. This, in turn, are expected to make a big difference to people's lives and other species on Earth.[67]

Under a high emissions scenario, the Greenland and Antarctic ice sheets will melt at an even faster rate than today and the effects would be felt the world over.[68]

Limiting global warming would help communities downstream of frozen mountain regions to adapt to changes in water supplies and would limit risks related to mountain hazards.[69]

Ocean warming, acidification, oxygen decline, and marine heatwaves are all predicted into the late 21st century. However, their rate of change and intensity will be less under a low emissions scenario.[70]

"Reducing greenhouse gas emissions is the main action to limit global warming to acceptable levels and reduce the occurrence of extreme events and abrupt changes."[71]

Image: © SPDA | Peru.

Figure 7: Mitigation together with adaptation reduces the risks[72]

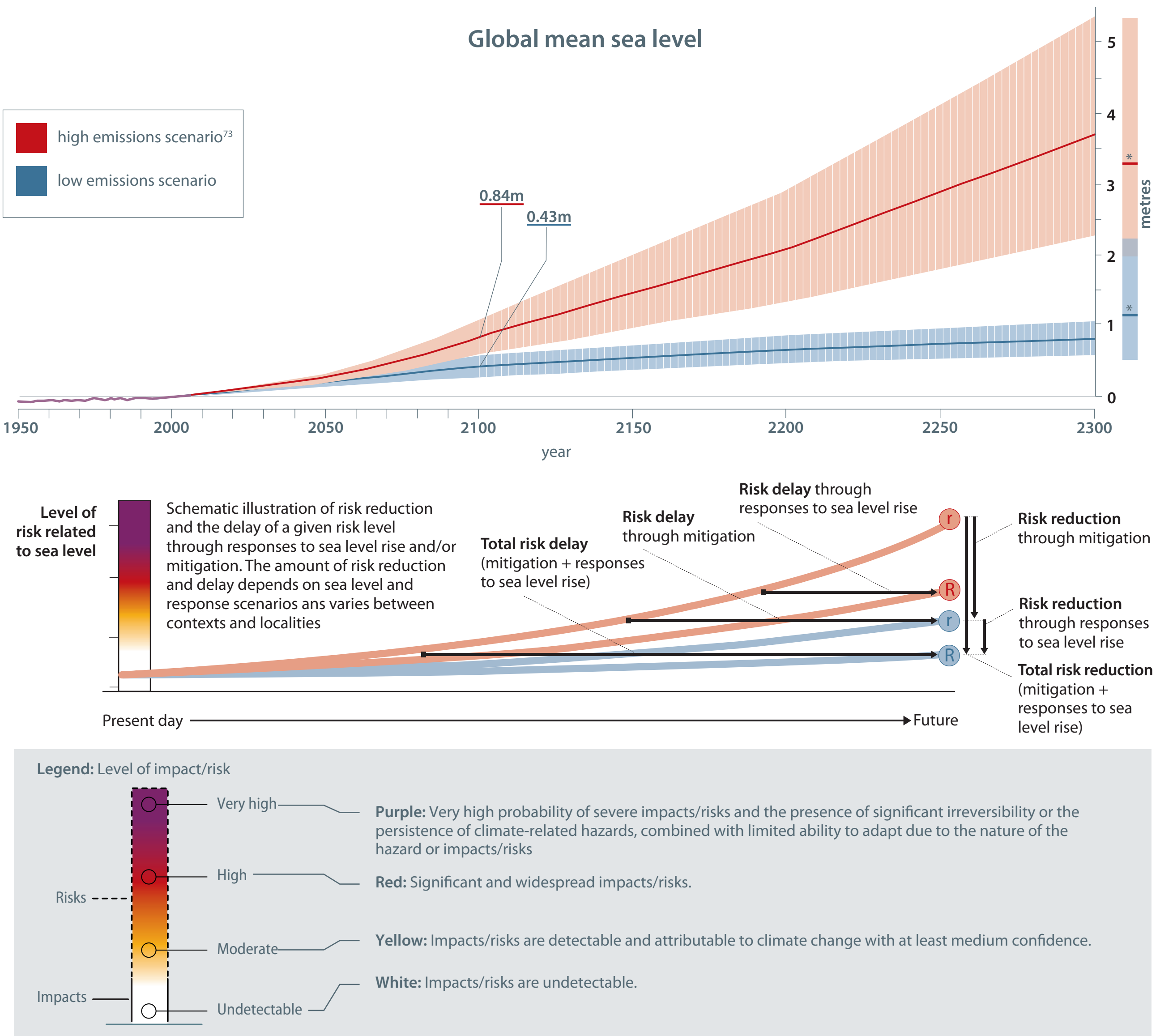


Image: © SPDA | Bolivia.

6 Early action reduces climate risks and costs less than dealing with future damages

Societies, institutions and individuals can all invest in reducing the risks of damage from extreme weather events – and so reducing the likelihood that an event such as a cyclone or flood will turn into a 'disaster'.

The economics of investing in disaster risk reduction – how much disaster loss can be averted for each dollar invested in up-front preparation – varies depending on the circumstances.[74] There is medium evidence about the benefits of investing in disaster risk reduction; figures range from:

- A global estimate is that for every dollar invested in disaster risk reduction, US$2–4 is saved in disaster recovery costs.
- For every euro invested in flood early warning systems in Europe, 400 euros are saved in disaster recovery costs.
- For every 1% increase in flood management funding in the United States, there is a 2% decrease in flood damages.

Investing in healthy ecosystems to reduce the risks from extreme weather events has yielded measurable monetary benefits:

- Wetlands and floodplains in Vermont, US, reduced damages caused by storms by 54–78% (wetlands) and by 84–95% (floodplains).
- For the whole of the US, wetlands provide US$23.2 billion per year in storm protection services.
- The loss of 1 hectare of wetland is estimated to correspond to an average US$33,000 increase in storm damage from specific storms.

Engineered structures, such as breakwaters, sea walls and dikes, are also expected to reduce risks. For tropical and extratropical cyclones, investing in disaster risk reduction, early warning systems and flood management (both ecosystem-based and engineered) all decrease economic losses from extreme weather events.[75]

For the extreme El Niño/La Niña events that are expected to affect Latin America increasingly, investments in long-term monitoring and improved forecasts are highlighted as important. Robust forecast information can be used to manage risks to human health, agriculture, fisheries, coral reefs, aquaculture, wildfire, drought and flood management.[76]

Slow-onset impacts of climate change such as rising sea level also increase risks for human communities in low-lying coastal areas. Investing in ambitious adaptation action can reduce the risks of these slow-onset events, but the benefits depend on the location.[77] Options for future-proofing coastal development from sea level rise are explored in the following section.

"Investing in preparation and prevention against the impacts from extreme events is very likely less than the cost of impacts and recovery (medium confidence). Coupling insurance mechanisms with risk reduction measures can enhance the cost-effectiveness of adapting to climate change (medium confidence)."[78]

Image: © SPDA | Bolivia.

Beyond the IPCC: The coast of South America: a densely populated area with many social inequalities[79]

In South America, one in four people in the region lives less than 50 km from the coast. An increase in sea levels could have serious consequences for the coastal regions of Latin America.

The city of Buenos Aires and the Conurbano Bonaerense are cases in point, demonstrating communities' vulnerabilities and how the ability to respond to the flood crisis depends to a large extent on people's socioeconomic status.

The coast of the Río de la Plata (including the area of the Conurbano Bonaerense) has about 14 million inhabitants. According to the study *Climate Change in the Río de la Plata*, the main cause of the floods are the *sudestadas* – weather phenomena common to the region that are characterised by strong winds coming from the southeast and very high tides. The sea level rise associated with climate change generates an increase in the level of the estuary that can already be observed; in the last century, the average level of the Río de la Plata in the Puerto de Buenos Aires area increased by 17 centimetres.

One of the areas most exposed to recurrent flooding is the southern coast of Greater Buenos Aires, on the banks of the Matanza-Riachuelo Rivers, where 5.8 million inhabitants live. There, precarious settlements are inhabited by people with a high level of unmet basic needs, without access to housing, services or decent housing conditions. It is the most urbanised and industrialised area of the country.


Image: © SPDA | Bolivia.

The Plan of Urbanisation of Villages and Precarious Settlements at Environmental Risk of the Matanza-Riachuelo Basin provides for the relocation of 17,771 families who are at highest environmental risk, not only because of flooding, but because they are in contact with pollution that has affected water and soil quality for decades. Ten years after the plan was launched, only 20% of beneficiary families have been assisted.

Families like these are extremely vulnerable and unable to cope with flooding that affects the basin and promises to worsen. This is not only due to socioeconomic status, but also to the lack of public policies to adapt to climate change of the various state authorities that administer the basin. As the IPCC report states, the rise in average sea level hits the most vulnerable people.

Image: © SPDA | Peru.

7 Future-proofing coastal development will be essential

Future-proofing coastal development will be an essential part of society's response to sea level rise. Using 'hard' infrastructure like sea walls to protect coastal settlements from sea level rise, storm surges and other climate hazards is popular worldwide. Nature-based solutions or so-called 'green grey' solutions that combine ecosystem approaches and hard infrastructure are growing in popularity.[80]

This table describes a range of measures being taken to protect human settlements and assets from sea level rise. Whether these options can work depends on the local geography and context.

The IPCC has assessed each option for its effectiveness:

Figure 8: Options for responding to sea level rise: both mean levels and extreme sea levels (e.g. storm surges)[81]

Option		Potential effectiveness in terms of reducing sea level rise risks (technical biophysical limits)	Advantages (beyond risk reduction)
1 **Hard protection** refers to the use of engineered infrastructure to protect against coastal flooding, erosion and salt water intrusion. It can include dikes, seawalls, breakwaters, barriers and barrages.		Up to multiple metres of sea level rise ●●●	Predictable levels of safety
2 **Sediment-based protection** refers to what are sometimes called 'soft' protection measures such as nourishing beaches, shores and dunes.*		Effective but depends on sediment availability ●●●	High flexibility
3 **Ecosystem-based adaptation** is about conserving or restoring coastal ecosystems such as coral reefs and wetlands. It is also refered to as 'green infrastructure' and 'nature-based solutions'. These features can absorb wave energy and so reduce the force of waves and provide retention areas for water to pool and/or infiltrate. They can reduce erosion by trapping coastal sediments and trap organic matter.	**Coral conservation**	Effective up to 0.5cm/year of sea level rise. Strongly limited by ocean warming and acidification. Constrained at 1.5°C warming and lost at 2°C at many places ●●●	Opportunity for community involvement
	Coral restoration		
	Wetland conservation (marshes, mangroves)	Effective up to 0.5-1cm/year sea level rise ●● decreased at 2°C ●●●	
	Wetland restoration (marshes, mangroves)		

Confidence in the effectiveness of this measure in responding to sea level rise:

●●●●	Very High
●●●	High
●●	Medium
●	Low

*Often hard protection, sediment-based protection and ecosystem-based adaptation are used in combination, called 'hybrid measures'. For example, a belt of marshland could be established in front of a seawall or a seawall could be created with niches for habitat formation.

1 3 Image: © World Fish | Hybrid measures: a combination of built 'hard' coastal protection combined with ecosystem-based measures.

Figure 9: Different types of responses to coastal risk and sea level rise

	Co-benefits	Drawbacks	Economic efficiency	Governance challenges
	Dikes can be multifunctional, e.g. used for recreation or other land uses	Destruction of habitat through coastal squeeze, flooding and erosion downdrift, lock-in, disastrous consequences if defence infrastructure fails	Highly efficient if the assets behind protection is high, as found in many urban and densely populated coastal areas	Often unaffordable for poorer areas. Conflicts between objectives (e.g. conservation, safety and tourism), conflicts about the distribution of public budgets, lack of finance
	Preservation of beaches for recreation/tourism	Destruction of habitat, where sediment is sourced	High if tourism revenues are high	Conflicts about the distribution of public budgets
	Habitat gain, biodiversity, carbon sequestration, income from tourism, enhanced fishery productivity, improved water quality. Provision of food, medicine, fuel, wood, and cultural benefits	Long-term effectiveness depends on ocean warming, acidification and emission scenarios	Limited evidence on cost-benefit ratios. Depends on population density and the availability of land	Permits for implementation are difficult to obtain. Lack of finance. Lack of enforcement of conservation policies. Ecosystem based adaptation options dismissed due to short-term economic interests and (where relevant, low) availability of land
		Safety levels less predictable, (some alternative) development benefits will not be realised		
		Safety levels less predictable, a lot of land required, barriers for landward expansion of ecosystems have to be removed		

1 Image: © Shutterstock | Sea wall.

3 Image: © World Fish | Planted mangrove plot.

Option		Potential effectiveness in terms of reducing sea level rise risks (technical biophysical limits)	Advantages (beyond risk reduction)
4 **Coastal advance** These measures create new land by building seaward, reducing risks for the land behind it and the newly elevated land. It can include land filling with pumped sand or other fill material, planting vegetation and surrounding low areas with dikes (called polderisation) which requires draining and pumping systems		Up to multiple metres of sea level rise	Predictable levels of safety
5 **Coastal accommodation** is about diverse measures to make coastal zones more habitable and reduce the vulnerability of people and their environment. It includes biological and physical measures such as raising houses on stilts, adopting floating gardens to deal with flooding and erosion, and switching land uses (e.g. from rice farming to shrimp aquaculture) to accommodate salt water intrusion. It also includes institutional measures such as early warning systems and insurance schemes.		Very effective for small sea level rise	Mature technology; sediments deposited during floods can raise elevation
6 **Retreat** reduces risks by moving exposed people, assets and activities out of the hazard zone. Planned relocation is typically initiated by governments and may include financial incentives, whereas displacement occurs when people's movement is involuntary and unforeseen. Migration is a person's voluntary permanent or semi-permanent movement.	**Planned relocation**	Effective if alternative safe localities are available	Sea level risks at origin can be eliminated
	Forced displacement	Addresses only immediate risk at place of origin	Not applicable

4 Image: © REACH | Polder technology to manage water in areas of coastal advance.

5 Image: ©Shutterstock | Aquaculture on the Sonora coast, Mexico.

Co-benefits	Drawbacks	Economic efficiency	Governance challenges
Generates land and land sale revenues that can be used to finance adaptation	Groundwater salinisation, enhanced erosion and loss of coastal ecosystems and habitat	Very high if land prices are high as found in many urban coasts	Often unaffordable for poorer areas. Social conflicts with regards to access and distribution of new land
Maintains landscape connectivity	Does not prevent flooding/ impacts	Very high for early warning systems and building-scale measures	Early warning systems require effective institutional arrangements
Access to improved services (health, education, housing), job opportunities and economic growth	Loss of social cohesion, cultural identity and wellbeing. Depressed services (health, education, housing, job opportunities and economic growth)	Limited evidence	Reconciling the divergent interests arising between relocated people and people in destination location
	Range from loss of life to loss of livelihoods and sovereignty	Not applicable	Raises complex humanitarian questions on livelihoods, human rights and equity

5 Image: © Shutterstock | Traditional stilt houses, Chile.

6 Image: © Red Cross Climate Centre | Woman left displaced after hurricane, Nicaragua.

“The potential climate benefits of blue carbon ecosystems can be a very modest addition to, and not a replacement for, the very rapid reduction of greenhouse gas emissions.”[82]

Blue carbon: An opportunity to integrate adaptation and mitigation action

Protecting and restoring what is called coastal ‘blue carbon’ ecosystems such as mangroves, tidal marshes and seagrass meadows can help mitigate climate change by locking up carbon. At the same time, protecting these ecosystems can provide climate change adaptation benefits and help conserve biodiversity and local livelihoods, by:

- providing storm protection
- improving water quality
- benefiting fisheries.[83]

Globally, these measures would make a modest contribution to halting global warming. But locally and nationally, investing in blue carbon can be an important approach.

The potential and the limits of ecosystem-based approaches

Ecosystem-based approaches to coastal protection include restoring the types of blue carbon ecosystems described above. They can have many benefits for human communities and the health of entire ecosystems. They can reduce local climate risks.

However, they are considered to be most effective in low emissions scenarios where further global warming is largely limited. If global warming is too high, then it is thought that ecosystem-based approaches will hit their limits. Unfortunately, it is hard to judge where those limits will be.[84]

Image: © SPDA | Fisherman, Peru.

8 Ecosystem governance and management must join up across scales and address social issues

An integrated approach

Adapting to changes in the oceans and cryosphere calls for effective governance across scales and boundaries. That is because the changes underway in the oceans and cryosphere have effects that go far beyond administrative boundaries. For example, changes to mountain ecosystems can affect whole river basins.[85]

Extreme events such as floods and landslides, or tropical cyclones, pose less risk to people if climate change adaptation and disaster risk reduction approaches are well integrated. Climate-affected sectors and disaster management agencies need to coordinate well – both in policy-making and on-the-ground delivery.

"Transformative governance [that integrates] disaster risk management and climate change adaptation, empowerment of vulnerable groups, and accountability of governmental decisions promotes climate-resilient development pathways (high confidence)."[86]

High mountain governance

The Sendai Framework for Disaster Risk Reduction 2015–2030 provides a framework with targets for countries to address climate and other risks. The Sendai Framework has technical guidelines to address changes in the high mountain frozen lands and the compound risks and cascading impacts on people and the environment.

However, there is limited evidence that countries are using the framework and guidelines to monitor high mountain changes, including the root causes of disasters, and to report on Sendai targets.[87]

The Convention Concerning the Protection of the World Cultural and Natural Heritage is aimed at protecting the world's most significant, irreplaceable places from loss and damage. It also offers countries relevant policy frameworks and strategies for conservation and climate policy.[88]

"Overall, there are promising prospects through international policy frameworks to support governance and adaptation to climate-related changes in the mountain cryosphere while addressing sustainable development."[89]

Ocean governance

At sea, the movement of species means that improved marine protected areas and spatial plans and even entire networks of protected areas will be needed to support species movement.[90] This implies far more ambitious management responses than governments have achieved to date.

Some changes in the ocean are expected to emerge earlier than others, such as the impacts of warming and acidification on tropical coral reefs and fish stocks. This knowledge could help stakeholders to prioritise planning issues and build resilience.[91] New approaches to ocean governance are being trialled but need to be rigorously evaluated. [92]

“The mechanisms for the governance of marine Areas Beyond National Jurisdiction … would benefit from further development.”[93]

Coastal governance

In coastal areas, choosing and putting in place measures to respond to sea level rise presents societies with tough governance challenges and potentially difficult social choices. There are big uncertainties about the degree and impact of sea level rise beyond 2050, and the impacts could fall unequally on different social groups. For example, the economics may favour investing in coastal defences to protect densely populated urban centres with concentrated wealth as opposed to less densely-populated rural areas with more marginalised populations. Investment choices will be highly political and will need to be navigated carefully.

In spite of this, there are methods for developing and analysing options that are designed to deal with future uncertainty. These methods emphasise:

- keeping the ability to be flexible over time
- using criteria to gauge robustness and to establish the usefulness of investments across a range of circumstances
- adjusting decisions periodically as consequences become known
- considering social vulnerability and equity
- creating safe community spaces for public deliberation of options and conflict resolution.[94]

Participatory scenario-building processes, collaborative landscape planning and co-design of ecosystem-based management are all promising, emerging approaches for engaging people on low-lying islands and coasts, enabling them to work together to develop future adaptation scenarios and climate resilience.[95]

“The capacity of governance systems in polar and ocean regions to respond to climate change impacts has strengthened recently but this development is not sufficiently rapid or robust to adequately address the scale of increasing projected risks. (high confidence).”[96]

Image: © SPDA | Fishers, Peru.

9 Communication, education and capacity-building are critical

Human society needs to adapt to profound changes in the world's oceans and cryosphere in the coming decades and take the ambitious action of cutting greenhouse gases to stop catastrophic changes later this century. This will require a vast effort to educate people, and communicate about climate change and build people's capability to act. 'Climate literacy' is needed at all scales.

Education and capacity-building can be context-specific and support local efforts to become more resilient. They can draw on indigenous and local knowledge in ways that resonate with people and encourage understanding and action.[97]

Beyond the IPCC: Communications toolkit helps readers raise awareness

CDKN has created a communications toolkit online at www.cdkn.org/oceanreport which makes some of the key scientific information from the IPCC's Special Report available for free download. This is so that readers can use key infographics and statistics in their own awareness-raising and educational campaigns. Please share the information in this report and online toolkit widely. You can also visit www.cdkn.org/communicating for a practical 'manual' with diverse ideas about communicating and engaging with people on climate action.

Image: © SPDA | Peru.

Conclusion

The IPCC's *Special Report on the Ocean and Cryosphere in a Changing Climate* has revealed how Earth's oceans and frozen and ice-covered lands have been 'taking the heat' of human-induced global warming. The Special Report should transform the way people think and talk about our planet.

It assesses the scientific evidence on changes in our atmosphere and their interaction with oceans and Earth's frozen areas, including snow-covered land, glaciers, ice sheets, sea, lake and river ice, permafrost and seasonally frozen ground.

The Special Report brings to light in a clear, newly-framed way how human-induced climate change is making ice caps and glaciers melt and is warming and changing the chemistry of the oceans. These changes are already well underway, even though most people in the world can scarcely perceive them yet. Over the last few decades, global warming has led to mass loss from ice sheets and glaciers, reductions in snow cover and loss of Arctic sea ice.

Since 1970, the global ocean has taken up more than 90% of the excess heat in the climate. Furthermore, the ocean has become more acidic as a result of increased greenhouse gases in the atmosphere. Melting ice from the Greenland and Antarctic ice sheets is speeding up the rate of sea level rise. On average, global sea levels are now rising two and a half times faster than the rate of sea level rise last century. The sea level will continue to rise under all emission scenarios, but is projected to be less under lower greenhouse gas emission scenarios. Changes in high mountain frozen lands are projected to affect water resources and their many uses by society.

Although still largely invisible, these changes will cause problems in decades to come for the hundreds of millions of people living on exposed coastlines and dependent on safe, regular flows of water from high mountain ecosystems.

Adaptation investments can limit the damage. Significantly, the IPCC's Special Report finds that societies are far better off investing in adaptation solutions now than delaying action and seeking to clean up the damages later. The types of adaptation actions considered by the IPCC on coasts, for example, include: wetland conservation and restoration, hard coastal protection and managed realignment or 'coastal advance' measures, where the sea is allowed to flood certain areas in a managed way. However, it is uncertain when societies will reach the limits at which such adaptation actions are effective.

Some communities in highly exposed mountain environments and particularly fragile coastal environments such as atoll island nations are already living on the edge. They are close to the limits of adaptation in their environments.

As with previous IPCC reports, the biggest takeaway message is that mitigating climate change by cutting global greenhouse gas emissions is by far the best way to limit damage to Earth's marine, coastal and frozen ecosystems and the repercussions for the rest of the planet.

Image: © SPDA | Peru.

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Image: © SPDA | Ecuador.

Glossary[98]

Cascading impacts from extreme weather/climate events occur when an extreme hazard generates a sequence of secondary events in natural and human systems that result in physical, natural, social or economic disruption, whereby the resulting impact is significantly larger than the initial impact. Cascading impacts are complex and multi-dimensional and are associated more with the extent of people's or a system's vulnerability than with the hazard itself.

Climate is usually defined as the average weather over a period of time ranging from months to thousands or millions of years. The relevant quantities are most often temperature, precipitation and wind and the period for averaging them is normally 30 years, as defined by the World Meteorological Organization (WMO). Climate, in a wider sense, is the state of the climate system.

Climate change is a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic (human-made) changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes.

Climate extreme (extreme weather or climate event) is when a variable of weather or climate reaches near the upper (or lower) ends of the range of observed values.

Co-benefits refer to the positive effects that a policy or measure aimed at one objective might have on other objectives, thereby increasing the total benefits for society or the environment. Co-benefits are often subject to uncertainty and depend on local circumstances and implementation practices, among other factors.

Compound weather/climate events are the combination of multiple drivers and/or hazards that contributes to societal and environmental risk.

Compound risks arise from the interaction of hazards, which may be characterised by single extreme events or multiple coincident or sequential events that interact with exposed systems or sectors.

Coral reef is an underwater ecosystem characterised by structure-building stony corals. Warm-water coral reefs occur in shallow seas, mostly in the tropics, with the corals (animals) containing algae (plants) that depend on light and relatively stable temperature conditions. Cold-water coral reefs occur throughout the world, mostly at water depths of 50–500 m. In both kinds of reef, living corals frequently grow on older, dead material, predominantly made of calcium carbonate ($CaCO_3$). Both warm and cold-water coral reefs support high biodiversity of fish and other groups of species, and are considered to be especially vulnerable to climate change.

Cryosphere refers to the components of the Earth at and below the land and ocean surface that are frozen, including snow cover, glaciers, ice sheets, ice shelves, icebergs, sea ice, lake ice, river ice, permafrost and seasonally frozen ground.

Early warning systems (EWS) are the set of technical and institutional capacities to forecast, predict, and communicate timely and meaningful warning information to enable individuals, communities, managed ecosystems, and organisations threatened by a hazard to prepare to act promptly and appropriately to reduce the possibility of harm or loss. Depending on the context, EWS may draw upon scientific and/or indigenous knowledge, and other knowledge types. EWS are also considered for ecological applications, e.g., conservation, where the organisation itself is not threatened by hazard but the ecosystem under conservation is (e.g., coral bleaching alerts), in agriculture (e.g., warnings of heavy rainfall, drought, ground frost, and hailstorms) and in fisheries (e.g., warnings of storm, storm surge, and tsunamis).

Ecosystem is a functional unit consisting of living organisms, their non-living environment and the interactions within and between them. The components included in a given ecosystem and its spatial boundaries depend on the purpose for which the ecosystem is defined: in some cases they are relatively sharp, while in others they are diffuse. Ecosystem boundaries can change over time. Ecosystems are nested within other ecosystems and their scale can range from very small to the entire biosphere. In the current era, most ecosystems either contain people as key organisms, or are influenced by the effects of human activities in their environment.

El Niño-Southern Oscillation (ENSO) The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere-ocean phenomenon, with preferred time scales of two to about seven years, is known as the El Niño-Southern Oscillation (ENSO). It is often measured by the surface pressure anomaly difference between Tahiti and Darwin and/or the sea surface temperatures (SST) in the central and eastern equatorial Pacific. During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the SSTs warm, further weakening the trade winds. This phenomenon has a great impact on the wind, SST and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world, through global teleconnections. The cold phase of ENSO is called La Niña.

Exposure is the presence of: people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Extreme weather event is an event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as an extreme climate event.

Glacier is a perennial mass of ice originating on the land surface by accumulation and compaction of snow and showing evidence of past or present flow. A glacier typically gains mass by accumulating snow, and loses mass in a process called ablation. Land ice masses of continental size (>50,000 km2) are referred to as ice sheets.

Glacial lake outburst flood (GLOF) / Glacier lake outburst is a sudden release of water from a glacier lake, including any of the following types – a glacier-dammed lake, a pro-glacial moraine-dammed lake or water that was stored within, under or on the glacier.

Global warming is an increase in global mean surface temperature (GMST) averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue.

Green infrastructure refers to the interconnected set of natural and constructed ecological systems, green spaces and other landscape features. It includes planted and indigenous trees, wetlands, parks, green open spaces and original grassland and woodlands, as well as possible building and street level design interventions that incorporate vegetation. Green infrastructure provides services and functions in the same way as conventional infrastructure.

Greenhouse gases (GHG) are the gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's ocean and land surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHGs in the Earth's atmosphere. Human-made GHGs include sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs) and perfluorocarbons (PFCs); several of these are also O_3-depleting (and are regulated under the Montreal Protocol).

Hazard is the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

Heat wave is a period of abnormally hot weather.

Human system is any system in which human organisations and institutions play a major role. Often, but not always, the term is synonymous with society or social system. Systems such as agricultural systems, urban systems, political systems, technological systems, and economic systems are all human systems in the sense applied in this report.

Ice sheet is an ice body originating on land that covers an area of continental size, generally defined as covering >50,000 km^2, and that has formed over thousands of years through accumulation and compaction of snow.

Loss and Damage, and losses and damages have two general meanings under the IPCC: the term 'Loss and Damage' (capitalised letters) refers to political debate under the United Nations Framework Convention on Climate Change (UNFCCC) following the establishment of the Warsaw Mechanism on Loss and Damage in 2013, which is to 'address loss and damage associated with impacts of climate change, including extreme events and slow onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change.' The expression 'losses and damages' (lowercase letters) has been taken to refer broadly to harm from (observed) impacts and (projected) risks.

Marine heatwave is a period of extreme warm near-sea surface temperature that persists for days to months and can extend up to thousands of kilometres.

Mitigation (of climate change) refers to a human intervention to reduce emissions or enhance the sinks of greenhouse gases (GHG).

Nationally determined contributions (NDCs) is a term used under the United Nations Framework Convention on Climate Change (UNFCCC) whereby a country that has joined the Paris Agreement outlines its plans for reducing its emissions. Some countries' NDCs also address how they will adapt to climate change impacts, and what support they need from, or will provide to, other countries to adopt low-carbon pathways and to build climate resilience. According to Article 4 paragraph 2 of the Paris Agreement, each Party shall prepare, communicate and maintain successive NDCs that it intends to achieve.

Net-zero CO_2 emissions are achieved when anthropogenic CO_2 emissions are balanced by anthropogenic CO_2 removals over a specified period.

Ocean acidification (OA) is a reduction in the pH of the ocean, accompanied by other chemical changes (primarily in the levels of carbonate and bicarbonate ions), over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide (CO_2) from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean.

Ocean deoxygenation is the loss of oxygen in the ocean. It results from ocean warming. It can also be exacerbated by the addition of excess nutrients in the coastal zone.

Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in December 2015 in Paris, France, at the 21st session of the Conference of the Parties (COP) to the UNFCCC. The agreement, adopted by 196 Parties to the UNFCCC, entered into force on 4 November 2016 and as of May 2018 had 195 Signatories and was ratified by 177 Parties. One of the goals of the Paris Agreement is 'Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels', recognising that this would significantly reduce the risks and impacts of climate change. Additionally, the Agreement aims to strengthen the ability of countries to deal with the impacts of climate change. The Paris Agreement is intended to become fully effective in 2020.

Pelagic zone consists of the entire water column of the open ocean. It is subdivided into the 'epipelagic zone' (<200 m, the uppermost part of the ocean that receives enough sunlight to allow photosynthesis), the 'mesopelagic zone' (200–1000 m depth) and the 'bathypelagic zone' (>1000 m depth). The term 'pelagic' can also refer to organisms that live in the pelagic zone.

Permafrost is ground (soil or rock, and included ice and organic material) that remains at or below 0°C for at least two consecutive years. Note that permafrost is defined via temperature rather than ice content and, in some instances, may be ice-free.

Primary production refers to the synthesis of organic compounds by plants and microbes, on land or in the ocean, primarily by photosynthesis using light and carbon dioxide (CO_2) as sources of energy and carbon, respectively. It can also occur through chemosynthesis, using chemical energy, for example, in deep sea vents.

Resilience is the capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation.

Restoration in environmental context involves human interventions to assist the recovery of an ecosystem that has been previously degraded, damaged or destroyed.

Risk is the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services, ecosystems and species. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making. In terms of acting on climate change, there could be risks of actions not achieving the intended objective(s), or having a negative effect on society's other objectives, such as the Sustainable Development Goals (SDGs).[99]

Sea level change (e.g. sea level rise) is a change to the height of sea level, both globally and locally (relative sea level change) at seasonal, annual, or longer time scales due to (1) a change in ocean volume as a result of a change in the mass of water in the ocean (e.g., due to melt of glaciers and ice sheets), (2) changes in ocean volume as a result of changes in ocean water density (e.g., expansion under warmer conditions), (3) changes in the shape of the ocean basins and changes in the Earth's gravitational and rotational fields, and (4) local subsidence or uplift of the land.

Sea surface temperature (SST) is defined as the subsurface bulk temperature in the top few metres of the ocean, measured by ships, buoys, and drifters. Satellite measurements of skin temperature (uppermost layer; a fraction of a millimetre thick) in the infrared or the top centimetre or so in the microwave are also used, but must be adjusted to be compatible with the bulk temperature.

Sendai Framework for Disaster Risk Reduction (2015–2030) outlines seven clear targets and four priorities for action to prevent new, and to reduce existing disaster risks. The voluntary, non-binding agreement recognizes that the State has the primary role to reduce disaster risk but that responsibility should be shared with other stakeholders including local government, the private sector and other stakeholders, with the aim for the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.

Sink refers to any process, activity or mechanism which removes a greenhouse gas (GHG), an aerosol or a precursor of a GHG from the atmosphere (UNFCCC Article 1.8).

Storm surge is the temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.

United Nations Framework Convention on Climate Change (UNFCCC) was adopted in May 1992 and entered into force in March 1994. As of May 2018, it had 197 Parties (196 States and the European Union). The Convention's ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. The provisions of the Convention are pursued and implemented by two treaties: the Kyoto Protocol and the Paris Agreement.

Vulnerability is the predisposition to be negatively affected and it can include being sensitive to harm and unable to cope.[100]

Endnotes

All references are from the IPCC's *Special Report on the Ocean and Cryosphere in a Changing Climate* unless otherwise noted.

1 IPCC Press release, 25 September 2019, 2019/31/PR: 'Choices made now are critical for the future of our ocean and cryosphere'. See www.ipcc.ch/srocc
2 See IPCC *Special Report on Oceans and Cryosphere in a Changing Climate*: Factsheet on www.ipcc.ch/srocc
3 Summary for Policy Makers, Box SPM-1.
4 IPCC Press release, 25 September 2019, 2019/31/PR.
5 Summary for Policy Makers, SPM-10.
6 Derived from Summary for Policy Makers, Figure SPM2.
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8 Summary for Policy Makers, SPM-14.
9 Summary for Policy Makers, SPM-14.
10 Chapter 5, Executive Summary, page 5-8.
11 Summary for Policy Makers, SPM-11.
12 Chapter 5, p5-50.
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20 Summary for Policy Makers, SPM Figure 3d.
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25 Chapter 5, Box 5.3 and Executive Summary, p5-9.
26 IPCC Press release, 25 September 2019.
27 Summary for Policy Makers, A.3.
28 Summary for Policy Makers, A.3.
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30 Summary for Policy Makers, B3.1, pSPM-23.
31 Coastal squeeze diagram: Information from Chapter 5 (see Executive Summary and especially p5-5 and related sections 5.3.2, 5.3.3., 5.4.1., 5.5.1)
32 IPCC Press release, 25 September 2019, 2019/31/PR.
33 Summary for Policy Makers, Start Up Box: The importance of the ocean and the cryosphere for people.
34 Summary for Policy Makers, SPM-10.
35 Cross cutting Box 9, CCB9-6.
36 Cross cutting Box 9, CCB9-6.
37 Cross cutting Box 9, CCB9-8.
38 Chapter 2, pp2-54-2-55.
39 Chapter 2, pp2-54-2-55.
40 Cross cutting Box 9, CCB9-8.
41 Chapter 6, Executive Summary, p6-4.
42 Chapter 6, Executive Summary, p6-4.
43 Chapter 6, Executive Summary, p6-4.
44 Chapter 5, Executive Summary, p5-4.
45 Chapter 6, Executive Summary and also Figure 6.1.
46 Summary for Policy Makers, SPM-13 and SPM-18.
47 Summary for Policy Makers, SPM-18.
48 Chapter 5, Executive Summary, p5-5.
49 Chapter 5, Executive Summary, p5-9.
50 All data in this table from Chapter 6, Figure 6.2 and Table 6.2.
51 Narrative in this box sourced from Climate Resilient Coyuca project and with special thanks to Maria Jose Pacha, more details: https://www.crclatam.net/proyectos/coyuca-resiliente-al-clima.html
52 Summary for Policy Makers, SPM-20.
53 IPCC Press release, 25 September 2019.
54 Summary for Policy Makers, SPM-17.
55 Chapter 2, Executive Summary, p2-5.
56 Summary for Policy Makers, SPM11-12.
57 Summary for Policy Makers, SPM-17.
58 Chapter 2, Section 2.3.2.
59 Summary for Policy Makers, SPM 20.
60 Derived from Summary for Policy Makers, Figure SPM2.
61 Chapter 4, p4-44.
62 From Chapter 2, p2-29 (FAQ2.1, Figure 1)
63 All information and analysis in this box adapted from Price Rios, K. National Glaciers+ Project, www.proyectoglaciares.pe
64 Belén Desmaisón (November 2019). 'How to avoid turning Peru's capital back into a desert.'
65 Based on Chapter 2, Figure 2.7
66 IPCC Press release, 25 September 2019.
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69 IPCC Press release, 25 September
70 Summary for Policy Makers, SPM-21.
71 Chapter 6, p6-61.
72 Data compiled from Summary for Policy Makers figures.
73 The high emission scenario accords with the Representative Concentration Pathway (RCP) 8.5, which the IPCC uses to demonstrate a 'business as usual' emissions scenario without climate mitigation action. The low emission scenario accords with the IPCC's RCP2.6, which is intended to reflect ambitious global action to reduce greenhouse gas emissions to levels in keeping with a 2°C or less average of global warming above pre-industrial levels.
74 Chapter 6, Executive Summary, p6-5.

75 Chapter 6, Executive Summary, p6-5.
76 Chapter 6, Executive Summary, p6-5.
77 Summary for Policy Makers, SPM31.
78 Chapter 6, Executive Summary, p6-5.
79 Narrative in this box sourced from Yanina Paula Nemirovsky, de Fundación Avina y Action LAC; https://cdkn.org/2019/10/opinion-el-aumento-del-mar-no-inunda-a-todos-por-igual/?loclang=es_es (accessed 27 November 2019)
80 Summary for Policy Makers, SPM18-19.
81 All material, this page, from Chapter 4, Box 4-86: Responses to Sea Level Rise.
82 Chapter 5, Executive Summary, p5-10.
83 Summary for Policy Makers, SPM36.
84 Chapter 5, Executive Summary, p5-10.
85 IPCC Press release, 25 September
86 Chapter 6, p6-60.
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88 Chapter 2, p2-57.
89 Chapter 2, p2-57.
90 Summary for Policy Makers, SPM-34.
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92 Chapter 5, Executive Summary, p5-9.
93 Chapter 5, Executive Summary, p5-11.
94 Chapter 4, Executive Summary, p4-6.
95 Cross-Cutting Box 9, CCB9-9.
96 Summary for Policy Makers, SPM-34.
97 Summary for Policy Makers, Section C.
98 All text in this Glossary is reproduced from the IPCC's Glossary for the Special Report on Oceans and Cryosphere in a changing climate, unless otherwise noted. There may be some minor copy editing or shortening of descriptions. Please see https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/SROCC_FD_AnnexI-Glossary_Final.pdf for the full definitive listings.
99 This definition has been shortened and simplified by the authors, from the IPCC's o riginal text.
100 This definition has been shortened and simplified by the authors, from the IPCC's original text.
101 Chapter 6, Box 6, pp6-96 – 6-100.

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