Puerto Rico's State of the Climate

Assessing Puerto Rico's Social-Ecological Vulnerabilities in a Changing Climate

2010-2013

EXECUTIVE SUMMARY—ENGLISH VERSION

THE PUERTO RICO CLIMATE CHANGE COUNCIL

Temperatures are increasing, precipitation patterns are changing, extreme events are occurring more frequently, oceans are more acidic, and sea level is rising. These climatic changes are projected to occur at much faster than natural rates. Some types of extreme weather and climate events have already increased in frequency and intensity and these changes are projected to continue.

Climate changes are already affecting some aspects of society, the economy and natural ecosystems of Puerto Rico and these effects are expected to increase. Not all of these changes will be gradual. When certain tipping points are crossed, impacts can increase dramatically. Past climate is no longer a reliable guide to the future. This affects planning for public and private infrastructure, tourism and industry, water resources, energy and all other social and economic systems.

In response to these changes, the Puerto Rico Climate Change Council (PRCCC) was convened in November 2010 to assess Puerto Rico's vulnerabilities and recommend strategies to respond to changes. The PRCCC is comprised of four working groups: (WG1) Geophysical and Chemical Scientific Knowledge; (WG2) Ecology and Biodiversity; (WG3) Society and Economy; and (WG4) Communicating Climate Change and Coastal Hazards. Based on the results of PRCCC's WG1, WG2 and WG3 as well as the results of coastal hazards risk assessment workshops conducted with thirty of the forty-four coastal municipalities, the PRCCC concludes that Puerto Rico's climate is changing and coastal communities of Puerto Rico, critical infrastructure, wildlife and ecosystems are all vulnerable to various impacts associated with changes in global, regional, and island weather and oceanographic conditions.

The Climate is Always Changing

When the term "climate change" is heard it is often assumed that the changes we are seeing are a new phenomenon and that the change itself is the reason behind the concerns the international scientific community has expressed. This is a misperception. The earth's climate has always changed and will continue to change. The concern lies with the rate of change, how fast we are seeing changes as compared to how fast they occurred in the past, and whether humans and nature will adapt to appropriately to the changes. Furthermore, the cause of this climatic change is linked to human actions; the burning of fossil fuels for energy which releases heat-trapping gasses into the atmosphere. These emissions have led to a rapid warming of the earth's climate.

DRNA · NOAA · Coastal Zone Management Program · Forest Service U.S. Department of Agriculture · USGS science for a changing world · United States Environmental Protection Agency · U.S. Fish & Wildlife Service · US Army Corps of Engineers

Sea Grant University of Puerto Rico · Departamento de Desarrollo Económico y Comercio · Compañía de Turismo Puerto Rico · Gobierno de Puerto Rico · Caribbean Coastal Ocean Observing System CariCOOS.org Waves | Wind | Currents | Ocean Color · Agencia Estatal para el Manejo de Emergencias y Administración de Desastres Puerto Rico

Bahía de Jobos Un estuario diferente... · Programa del Estuario de la Bahía de San Juan · NOAA's Office of Ocean and Coastal Resource Management · International Institute of Tropical Forestry · NOAA Coastal Services Center Linking People, Information, and Technology

la Regata El Periódico Náutico de Puerto Rico · CATEC · CFMC · GEO Ambiente · Programa de Arrecifes de Coral de Puerto Rico DRNA

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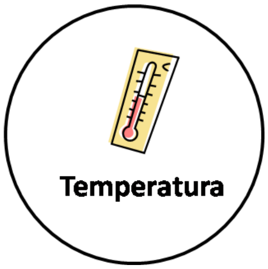
ridge to reefs · Fideicomiso de Conservación de Puerto Rico · GAIA Grupos Ambientales Interdisciplinarios Aliados · CCRI

Observed Trends and Future Projections



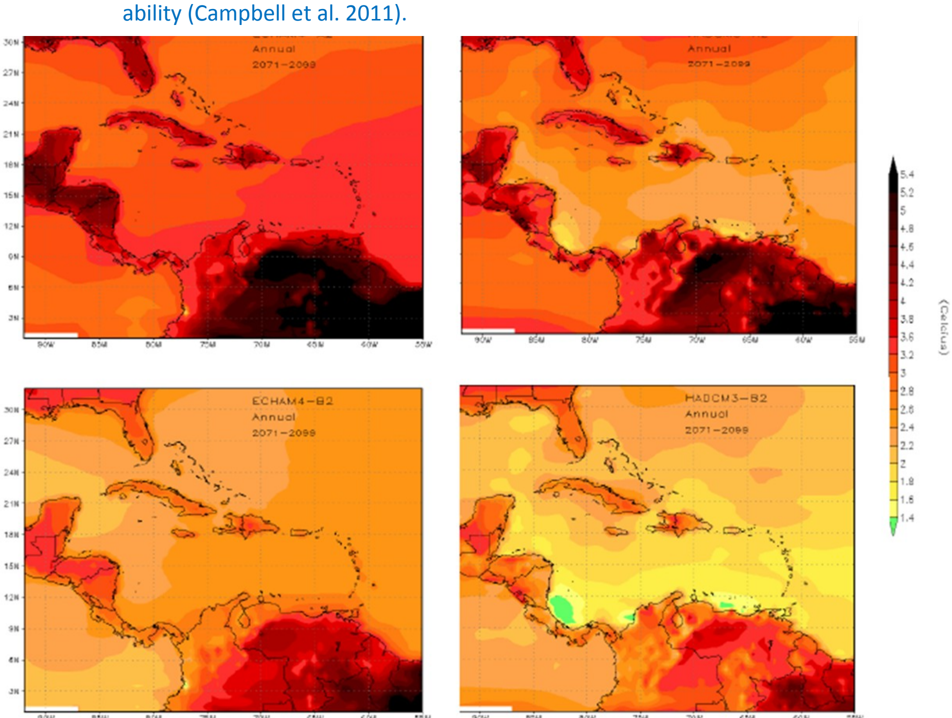
Observed global surface temperatura trends

The past three decades have been Earth's warmest since reliable surface temperature records began to be kept in 1850, with a global average increase of about 1^0 C (1.8^0 F) over that period. In Puerto Rico our annual average temperature rose the same amount about between 1900 and 2010. According to the Intergovernmental Panel on Climate Change (IPCC), global average temperatures have risen by 0.6^0 C ($1.1\ ^0$ F) since 1970 and can be expected to rise another $1.4\ ^0$ C ($1.8 – 7.2\ ^0$ F) by the end of the 21st Century, depending on future societal practices and the amount of greenhouse gas emissions released into the atmosphere. This temperature increase was recently affirmed by the *Berkeley Earth Surface Temperature* analysis. Using the largest data set available to date the Berkeley team found that over the past 250 years the earth experienced a rise of approximately $1.5\ ^0$ C and about $0.9\ ^0$ C in the past 50 years.

Observed and Projected Changes in Surface Temperatures for Puerto Rico

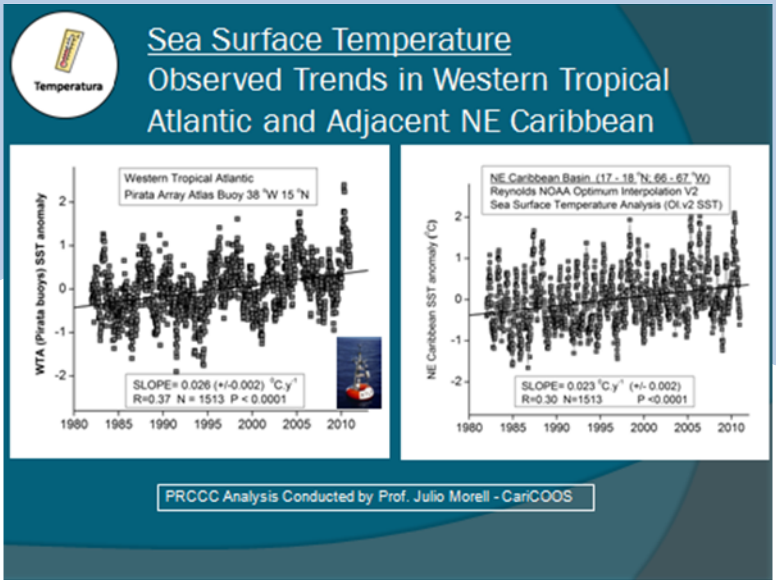
Over the 20th century, average annual air temperatures in the Caribbean islands have increased by more than 0.6°C or 1.0°F. In Puerto Rico, station analyses show significant increases in annual and monthly average temperatures and a rise of 0.012°C/yr to 0.014°C/yr (0.022 to 0.025°F/yr) was observed from 1900 to present. Therefore, Puerto Rico does follow the larger-scale trend in warming, although some locations on the island are warming faster than others.

Figure 1 Mona Climate Studies Group found that irrespective of scenario the Caribbean was expected to warm (warming between 1°C and 5°C) with greater warming under A2 (high emissions) scenario. The warming was consistent with projections for other parts of the globe and far exceeds natural variability (Campbell et al. 2011).



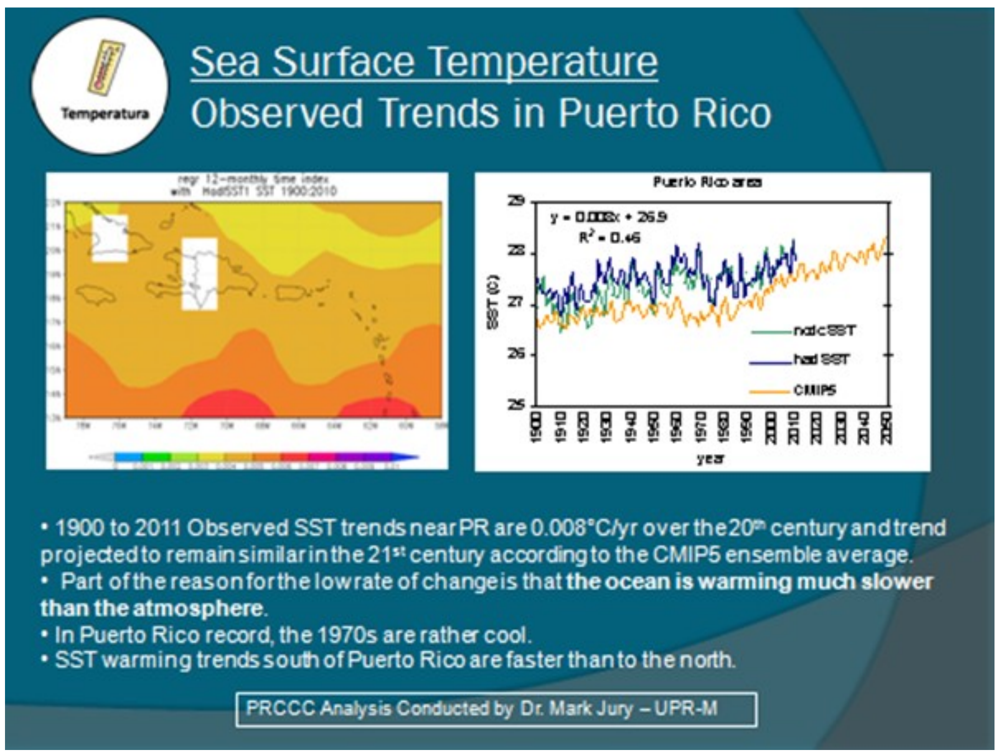
Urban heat islands exist in Puerto Rico where temperatures are higher in developed areas than in rural, vegetated areas. For instance, San Juan's observed temperature trend is higher than the rest of the island at 0.022°C/yr (0.04°F/yr) since 1900. If this trend continues, San Juan's average annual temperature will have increased to 27°C (80.6°F) in 2050 (as compared to 25.5°C o 77.9°F in 1950). There is consensus on continued warming into the future amongst all climate modeling studies. Over the coming century, projected temperature increases for the Caribbean are projected to be slightly below the global average of 2.5 - 4°C (4.5 – 7.2°F) by 2100, but slightly above the tropical average. Projected temperature increases are expected to be significant by late century at all locations. Projections for the Caribbean show a greater than 1.5°C rise in annual temperature by 2100, with greatest warming over Cuba, Jamaica, Hispaniola, Central America and northern South America, where the increase is greater than 2°C across all seasons. Projections for Puerto Rico show as Little as 0.02°C/year warming through 2050, in other words at least 0.8 °C (1.44°F) by mid-century, and as much as 2-5°C (3.6-9°F) by the year 2100.

Observed Trends and Future Projections (*continued from page 4*)



Caribbean sea surface temperatures (SST) have warmed by 1.5°C over the last century. Three SST analyses were conducted for the PRCCC. The first used the West Tropical Atlantic Prediction and Research Moored Array (PIRATA) station data and found an increase of 0.026 (+/-0.002)°C per year from 1981 to 2010. The second analysis used the optimum interpolation SST analysis product (OI.v2 SST), which is operationally issued weekly for one degree grid for the global ocean, and found an increase of 0.023 degrees (+/- 0.002) °C per year from 1982 to 2011. The third analysis found observed SST trends near Puerto Rico to be 0.008°C/year over the 20th century. Different SSST trends are found depending on the length of time analyzed. If only data for recent decades are considered, then the SST trend is higher. However, all trends show a clear warming.

SST warming trends south of Puerto Rico are faster than to the north and sub-surface temperatures are warming faster than the surface, particularly south of Puerto Rico. The higher rate of warming south of Puerto Rico is related to a significant weakening of trade winds (as they travel over the higher elevations of the central mountain range), evaporation and westward currents. The Caribbean has warmed faster than the Atlantic. This observed warming trend is projected to remain similar in the 21st century according to two studies conducted for the PRCCC. One showing that an increase of 1.17^{0} C (2.1^{0}F) over a 50 year period can be expected. Additionally, SST above the threshold for coral bleaching will be exceeded over a third of the year.



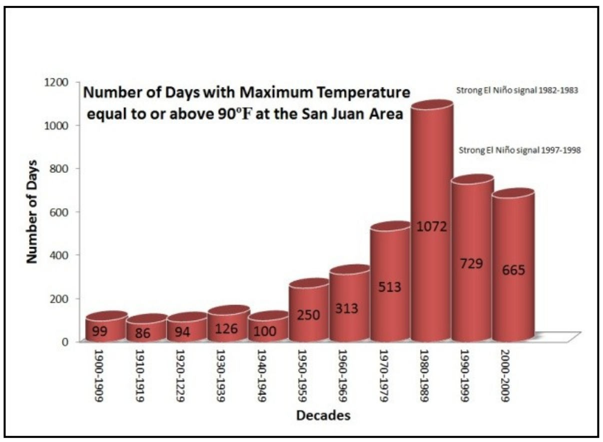
Caribbean sea surface temperatures (SST) have warmed by 1.5°C over the last century. Three SST analyses were conducted for the PRCCC...All three trends show a clear warming...SST above the threshold for coral bleaching will be exceeded over a third of the year.

EXTREME TEMPERATURE EVENTS

Caribbean trends show the extreme intra-annual temperature range was decreasing (becoming more uniform throughout the year) and that the number of very warm days and nights has been increasing dramatically since the late 1950s while the number of very cool days and nights have been decreasing. These trends are consistent in Puerto Rico where we are experiencing a greater frequency of days with maximum temperature equal to or above 90°F (32.2°C) and a lower frequency of days with temperature equal to or below 75°F (23.9°C). And during 2010 and 2011, about 100 days with temperature equal to or above 90°F were ob-served; this is the same number of days observed per decade during 1900 through 1949.

Models project substantial warming in temperature extremes by the end of the 21^{st} century. It is *virtually certain*, according to the IPCC, that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21^{st} century at the global scale.

For Puerto Rico, climate projections for extreme events show a probable increase in extreme heat days and cold events are expected to become exceedingly rare. The projected rate of warming is most rapid in winter (December, January, February).



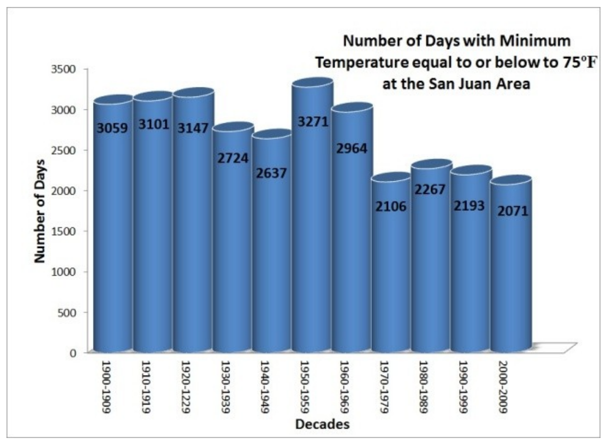


Figure Number of Days with Maximum Temperature equal to or above 90^0F at the San Juan Area (left). Number of Days with Minimum Temperature equal to or below 75^0F (right). Source: NOAA National Weather Service Office, San Juan

Extremes are a natural part of even a stable climate system, but because social-ecological systems have adapted to their historical range of extremes, the majority of events outside this range have primarily negative impacts and therefore it is highly important to assess observed trends and projected changes of these extremes. Globally there is evidence from observations gathered since 1950 of change in some extreme events. Extreme events are rare, which means there are few data available to make assessments regarding changes in their frequency and intensity. The more rare the event the more difficult it is to identify long-term changes. However, the IPCC Special Report on Extremes stated that it is very likely that there has been overall decrease in the number of cold days and nights, and an overall increase in the number of warm days and nights, at the global scale. There have been statistically significant trends in the number of heavy precipitation events in some regions. It is likely that more regions have experienced increases than decreases, although there is strong regional and sub regional variations in these trends.

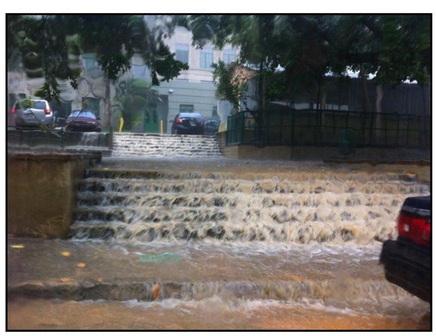
Observed and Projected Changes in Precipitation for Puerto Rico

Observed trends in precipitation for the Caribbean as a whole are unclear from the literature. An analysis for the PRCCC shows that since 1948 the Caribbean Basin has seen decreasing precipitation (-0.01 to -0.05 mm/day/year), with a greater drying trend for the Eastern Caribbean. Specifically for Puerto Rico, one analysis of weather station data from the period of 1948 to 2007 found no clear trends in total annual rainfall for the island as a whole, while another analysis showed decreases in rainfall for the island as a whole, while another analysis showed decreases in rainfall from -0.01 to -0.1 mm/day/year. Regionally within the island, there are indications that the southern region of Puerto Rico has experienced positive trends in annual rainfall while the western and a portion of the northern region showed decreases. Additionally, seasonal trends with observations show negative trends in summer and positive trends in winter.

In order to simulate future climate change, global climate models need to accurately represent observed climate. There is a lot of uncertainty in the magnitude of precipitation changes in the Caribbean, though a majority of global climate models used by the IPCC show future decreases in precipitation are likely. Most IPCC models projected decreases in annual precipitation a few increases, varying from -39 to + 11%, with a median of -12%. The annual mean decrease is projected to be spread across the entire region. December, January, and February in the Greater Antilles are expected to see increased precipitation and June, July, August to see a region-wide decrease. Model projections range from -78 a -10% (with a few models showing +30%) and current evidence suggests drier conditions are more likely than wetter for Puerto Rico, a contrast to the global precipitation signal. Specifically, the PRCCC analysis found that past and future trends are similar, a decrease of rainfall of - 0.0012 to -0.0032 mm/day/year, that are projected to continue through 2050.

Extreme Precipitation Events

Regional downpours, defined as intense precipitation at sub daily (often sub hourly) timescales, are likely to increase in frequency and intensity in a warmer climate due to the greater capacity of warmer air to hold water vapor. Projections concerning extreme events in the sub-tropics remain uncertain, however all report higher risk of increased daily intensity of rainfall. Puerto Rico climate projections for the future show a probable increase in regional downpours, particularly downpour events in May, despite the fact that the observed trends do not show an increase in May downpour events in Puerto Rico. It should be noted that one model shows a projected decrease in heavy rainfall events by the end of the century (2090s).

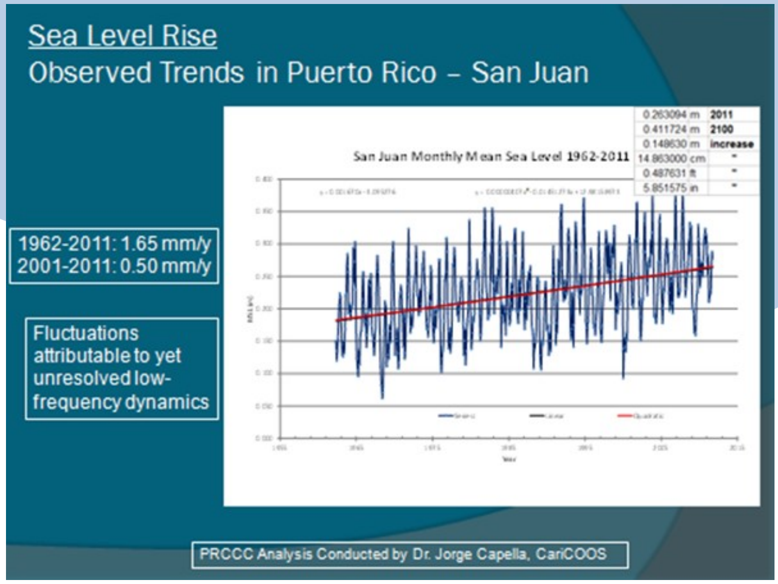


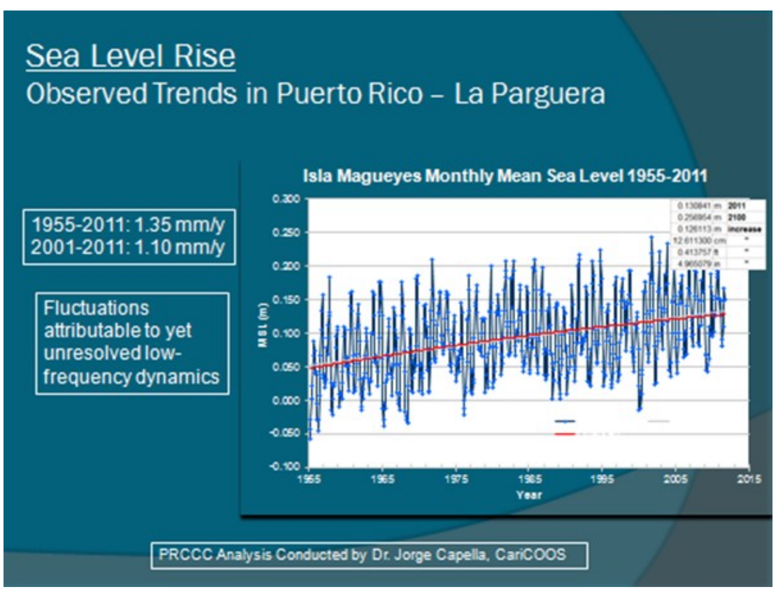
2011 downpour event in Mayaguez, PR: Flooding after only 30 minutes of rain. Photo Credits: Professor Aurelio Mercado, UPR-M. It is *likely* that the frequency of heavy precipitation events like this one will increase in the 21st century

Observed Trends and Future Projections (continued from page 7)

Observed Changes in Sea Level

Both mean conditions and extremes of sea level will change over a range of time scales. Globally speaking, global sea levels have been rising via thermal expansion resulting from warming of the oceans, as well as freshwater input from the melting of a majority of Earth's glaciers and ice sheets. Tide gauge records from Isla Magueyes (south coast of PR) and from San Juan (north coast of PR) contain the longest sea level time series in the U.S. Caribbean. 56.7 years of monthly mean sea level for Isla Magueyes and 49.4 years for San Juan were analyzed. Three analysis were conducted for the PRCCC: (1) Dr. Jorge Capella with UP-R's CariCOOS; (2) UPR Professor Aurelio Mercado; (3) UPR's Dr. Mark Jury. All three studies show sea level rise trends for Puerto Rico. Analyses of Puerto Rico's tide gauges show a rise of at least 1.4 mm/year, which is expected to continue and possibly will accelerate. These accelerations are in accord with satellite data (since 1993) though not to the same magnitude of up to 6mm/year sea level rise as seen from 1970-2009 in the northeast hotspot for sea level rise in the Northeast of the continental United States.





As a result of the already observed sea level rise as well as weak shoreline management practices, coastal erosion is causing a retreat of the coastline of up to one meter per year (1.0 m/yr) in some sectors of Puerto Rico, such as Rincón, according to a USGS report that considered sequences of past aerial photos.

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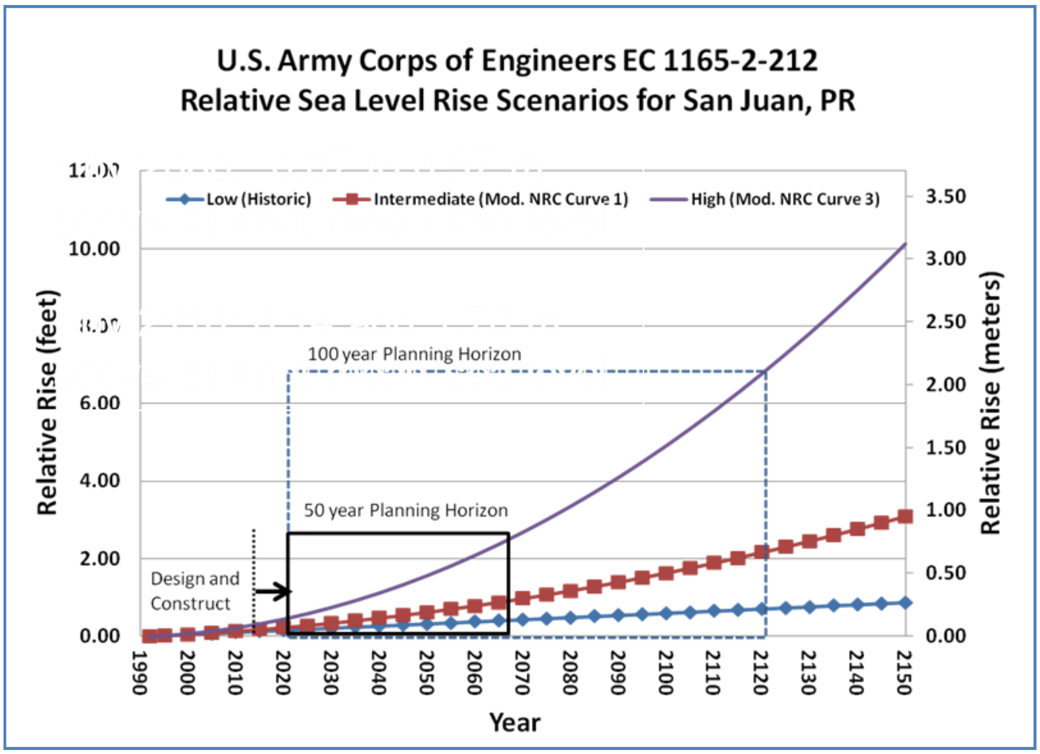
Observed Trends and Future Projections (continued from page 8)

Projected Future Sea Levels for Puerto Rico

The extent of sea level rise is dependent on interactions between the climate system, thermal expansion of ocean water, the breakup of polar ice, melting of glaciers and permafrost and local geological height changes due to tectonic plate movement. The effects of rising sea level will be amplified by the short-term impacts of storm surges. Projected climate change for the second half of this century depends on the level of future heat-trapping emissions. The risk of large sea-level rise already in the 21st century is now estimated to be much greater than the IPCC estimates of 0.18-0.59 meters. The IPCC Special Report on Climate Extremes states that it is *very likely* that mean sea level rise will contribute to upward trends in extreme coastal high water levels in the future. There is *high confidence* that locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to do so in the future due to increasing sea levels, all other contributing factors being equal. Combining climate modeling and paleoclimatic data, total sea-level rise of about 2.0 m by 2100 has been estimated as the maximum that could occur, with a best estimate of about 0.8 meters.



If the observed Puerto Rico sea level rise trend continues linearly, with no acceleration in rate, by 2100 the sea level around Puerto Rico will have risen by at least 0.4 meters. The U.S. Army Corps of Engineers (USACE) conducted an analysis for the PRCCC to project possible future sea level rise for the North and South coasts to 2165. The Figures show a 50 year and 100 year planning horizon for adaptation with sea level rise estimates ranging from 0.07 to 0.57 meters (0.20 to 1.87 feet) above current mean sea level by the year 2060 and between 0.14 and 1.70 meters (0.40 to 5.59 feet) above current mean sea level by the year 2110. Due to the variability and uncertainty in the sys-tem it is important to project sea level rise across a range and plan for all possible future scenarios when possible, rather than just the lower bound conservative estimate.

Based on this information and future projections for sea level rise the PRCCC recommends planning for a rise of 0.5-1.0 meters by 2100.

It is no longer a question of whether the coasts of Puerto Rico and many port cities in the Caribbean will be inundated, but rather it is a question of when and by how much.

Figure: The sea level rise curve for Puerto Rico, provided by the U.S. Army Corps of Engineers for the PRCCC, shows a 50 year and 100 year planning horizon for adaptation with sea level rise estimates ranging from 0.07 to 0.57 meters (0.20 to 1.87 feet) above current mean sea level by the year 2060 and between 0.14 and 1.70 meters (0.40 to 5.59 feet) above current mean sea level by the year 2110

Observed Trends and Future Projections

Observed and Projected Trends for Storms and Hurricanes

Proxy reconstruction of the past 5,000 years of intense hurricane activity in the western North Atlantic suggests that hurricane variability has been strongly modulated by El Niño during this time, and that the past 250 years has been relatively active in the context of the past 5,000 years. Studies suggest that major hurricane activity in the Atlantic was anomalously low in the 1970s and 1980s relative to the past 270 years. According to the U.S. Global Change Research Program, Atlantic tropical storm and hurricane destructive potential as measured by the Power Dissipation Index (which combines storm intensity, duration, and frequency) has increased. This increase is substantial since about 1970, and is likely substantial since the 1950s and 60s, in association with warming Atlantic sea surface temperatures. There have been fluctuations in the number of tropical storms and hurricanes from decade to decade and data uncertainty is larger in the early part of the record compared to the satellite era beginning in 1965. Even taking these factors into account, it is likely that the annual number of tropical storms, hurricanes and major hurricanes in the North Atlantic have increased over the past 100 years, a time in which Atlantic sea surface temperatures also increased. The evidence is not compelling for significant trends beginning in the late 1800s as uncertainty in the data increases as one proceeds back in time. There is also evidence for an increase in extreme wave height characteristics over the past couple of decades in the North Atlantic, associated with more frequent intense hurricanes and in the future there may be an increase in the intensity of winter swells reaching Puerto Rico's coasts.

Current global climate models are rather poor in simulating tropical cyclones, due in part to the coarse spatial resolution of these models, however the IPCC climate simulations suggests that the North Atlantic and Caribbean will experience a decrease in tropical cyclone frequency, but an increase in the frequency of the most intense events. Other models concur. Due to the substantial uncertainties about past and future changes in cyclone activity the scientific debate on this subject is expected to remain very active. The PRCCC recommends increasing preparedness levels for more intense hurricanes. As was found by Working Group 3, delayed decisions may cost human lives, destroy critical infrastructure and damage the economy.

Observed and Projected Trends for Ocean Acidification

Currently, atmospheric carbon dioxide concentration has reached 395 ppm globally and because half of the carbon dioxide released both naturally and by humans is taken up by the oceans, average pH of the oceans has dropped from 8.16 to 8.05 since the year 1800. This change in seawater chemistry is equivalent to an increase of carbon dioxide concentration of about 35% and a decrease in pH of 0.1 units. As a result, there has been a global decrease in surface seawater carbonate saturation states and thus, the rate of calcification in marine calcifying organisms and the precipitation of carbonate minerals like calcite and aragonite are decreasing as well. The Caribbean and Puerto Rico saturate states of carbonate minerals reflects this global trend. For example, the values of aragonite saturate states are declining within the Puerto Rico-Caribbean region at a rate about 3% per decade.

What is difference between global warming and climate change?

Global warming, which is not considered a technical term, refers to the long-term increase in Earth's average temperature. Whereas, *climate change* refers to any long-term change in Earth's climate, or in the climate of a region or a city. This includes warming and also cooling, changes in rainfall averages and downpour events, frequency and intensity of tropical storms and hurricanes, rising or falling sea levels, changes in the pH of our oceans, and other changes.

Climate change is a long-term in the statistics of the weather (including its averages). For example, it could show up as a change in climate normals (expected average values for temperature and precipitation) for a given place and time of year, from one decade to the next.

There are two reasons we would see a long-term increase in Earth's average temperature or a long-term change for a certain climate parameter: Natural variability and human-induced change. Climate change is a normal part of the Earth's natural variability, which is related to interactions among the atmosphere, ocean, and land, as well as changes in the amount of solar radiation reaching the earth. The geologic record including significant evidence for large-scale climate changes in Earth's past. Certain naturally occurring gases, such as carbon dioxide and water vapor, trap heat in the atmosphere causing a greenhouse effect. The greenhouse effect is good for humans and ecosystems as it warms us at a temperature that sustains life on Earth, as opposed to the other planets in our solar system whose greenhouse effect or lack there-of depending on the planet, makes the planets either too cold or too hot to inhabit. Burning of fossil fuels, like coal, oil, and natural gas is adding carbon dioxide to the atmosphere. The current level is the highest in the past 650,000 years. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change concludes that "most of the observed increase in the globally average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

Where can I find more information?

United States Global Change Research Program
www.globalchange.gov

NOAA National Climatic Data Center site on Global Warming:
www.ncdc.noaa.gov/oa/climate/globalwarming.html

Intergovernmental Panel on Climate Change (IPCC) Website
www.ipcc.ch/

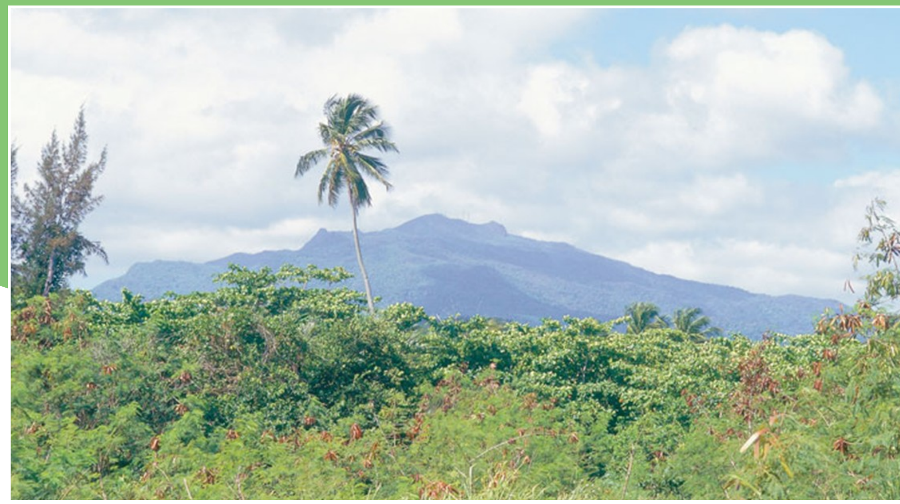
Working Group 2: Ecology and Biodiversity

Puerto Rico is home to some of the world's most impressive natural and manmade wonders, such as 799 miles of coastline with over 300 beaches, vibrant coral reefs, pre-Columbian ceremonial parks and artifacts, the coquí (tiny tree frog endemic to the islands), historic sugar cane and coffee plantations, El Yunque rainforest (the only subtropical rainforest in the U.S. National Forest System), Mona Island that is home to more than 100 endangered species, and 51 natural protected areas that conserve wetlands, dry forests, rainforests, caves and caverns, groundwater, cays and islets, and critical habitats for many species of flora and fauna. All these features are why Puerto Rico has been affectionately given the name *la Isla del Encanto*, the Island of Enchantment. Without healthy ecological systems Puerto Rico would not be able to boast such wonders.

Human activities globally and in Puerto Rico have caused and will continue to cause a loss in biodiversity and natural resources through land-use and land cover change; soil and water pollution and degradation, diversion of water; habitat fragmentation; selective exploitation of species; and the introduction of non-native species. The current rate of biodiversity loss is greater than the natural background rate of extinction. Furthermore, these losses directly impact societies around the world and locally as we are also losing the services the ecosystems and species provide, such as fresh air, clean water, reduction in pollution and contaminant concentrations, drinking water protection, urban heat reduction, natural protection against storm surges and hurricanes, prevention of landslides, recreation and tourism opportunities, cultural and historical preservation, and even mental and spiritual well-being.

Climate change is one of the most critical issues facing biodiversity and natural resource management in the world today. Land and ocean surface temperatures have warmed, the spatial and temporal patterns of precipitation have changed, sea level has risen, and we are experiencing more intense storms. These changes, particularly warmer regional temperatures, have affected the timing of reproduction in animals and plants and/or migration of animals, the length of the growing seasons, species distributions and population sizes, and the frequency of pest and disease outbreaks. Climate change is projected to affect all aspects of biodiversity; however, the projected changes have to take into account the impacts from other past, present, and future human activities. The effects of climate change, in terms of rising sea levels, increasing mean atmospheric and sea surface temperatures and changes in rainfall and weather patterns, are likely to be particularly severe for the ecological systems of the Caribbean islands and small island states.

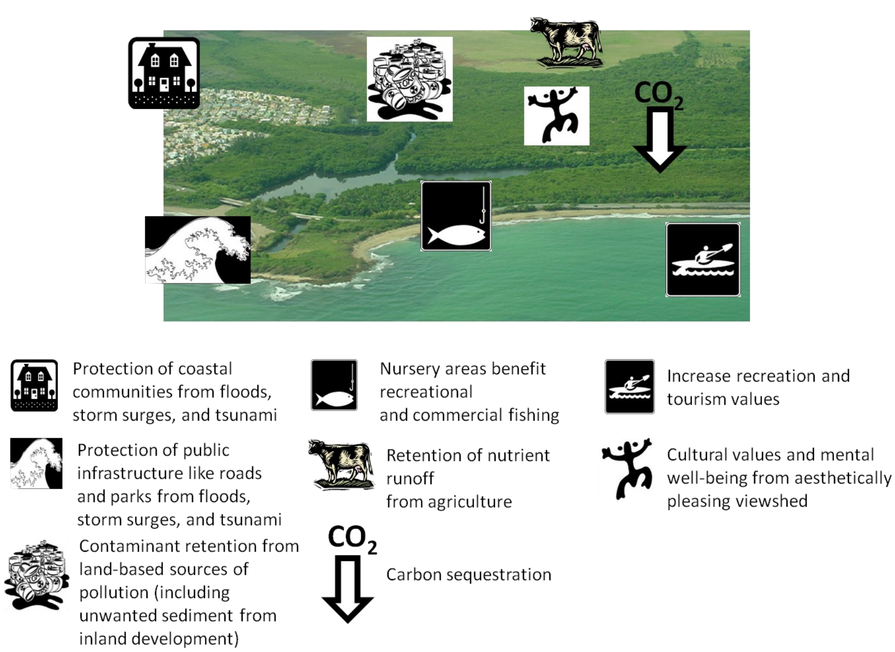
Working Group 2: Ecology and Biodiversity



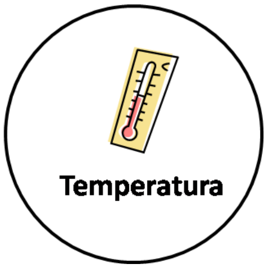
The main effect of climate change on Puerto Rico's ecosystems and species will be synergistic in that already stressed systems will be exposed to additional stressors that push them over their limit of existence, resulting in widespread loss of habitat, unfavorable changes to structure and function, or diminished services to Puerto Rico's society. Some ecosystems and species will acclimate to changing environmental conditions better than others.

While some species may potentially migrate to more favourable conditions in Puerto Rico (e.g., Colorado trees, swamp cyrilla) species already bumping up against the upper limits of their range may not be so fortunate, and could be diminished or lost from Puerto Rico altogether due to the lack of suitable environmental conditions (e.g., dolphinfish, yellowfin tuna). Others may not have the ability to relocate and may become globally extinct, like the Coquí Duende, the Cricket Coqui, and the forest-dwelling Puerto Rican Upland Sphaero. On the other hand, new species or community assemblages could occur in Puerto Rico that may benefit society as they might provide new ecosystem services.

More research is needed on potential future ecosystem states and the ability of future ecosystems to sustain human populations. Healthy ecosystems are our life support system, providing us with essential goods and services that would be extremely expensive or impossible to replace. Ecosystems purify air and water, and provide flood control. They supply us with marketable products and sequester carbon and build soils. They provide recreation, hunting and fishing, and wild places in which to enjoy nature for our spiritual and mental well-being. Puerto Rico's culture is greatly connected to the islands' ecosystems and species, perhaps to a greater extent than many other areas of the world. Human disruption of ecosystems, through climate change and other factors such as habitat destruction and pollution, can reduce ecosystems' ability to provide us with these valuable services.



FORESTS



- Warmer air
- Lower dew point of air masses
- Raised orographic cloud base
- Changes in species composition, forest structure, and ecological function

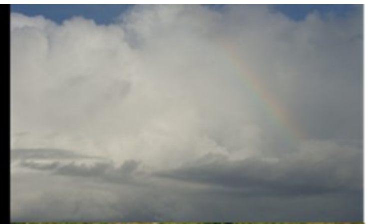
- More intense wind and water
- Increased disturbance
- Alternative regeneration / changes in plant successional direction & biomass
- Novel communities

- Increased seasonality and decreased soil moisture availability
- Altered fruiting and flowering patterns
- Effects on seedling recruitment, germination, survival
- Changes in species composition, forest structure, and ecological function

- Increased risk of saltwater intrusion
- Tolerance levels
- Increased mortality

SHOREBIRDS & SEABIRDS

1. **Increased precipitation** may modify nesting habitat conditions, availability and abundance of food resources, cause nest abandonment, or even death of young and adults.

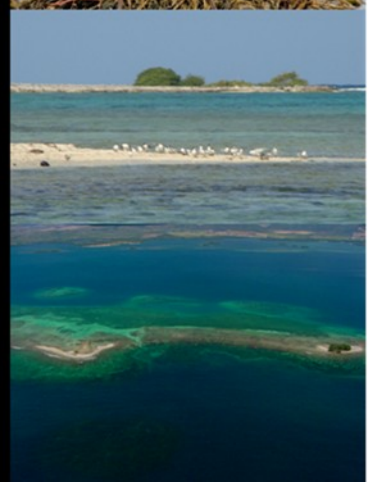


2. **Increased severity of storms** may destruct habitat and result in unsuitable nesting areas in subsequent years, and impaired food acquisition.

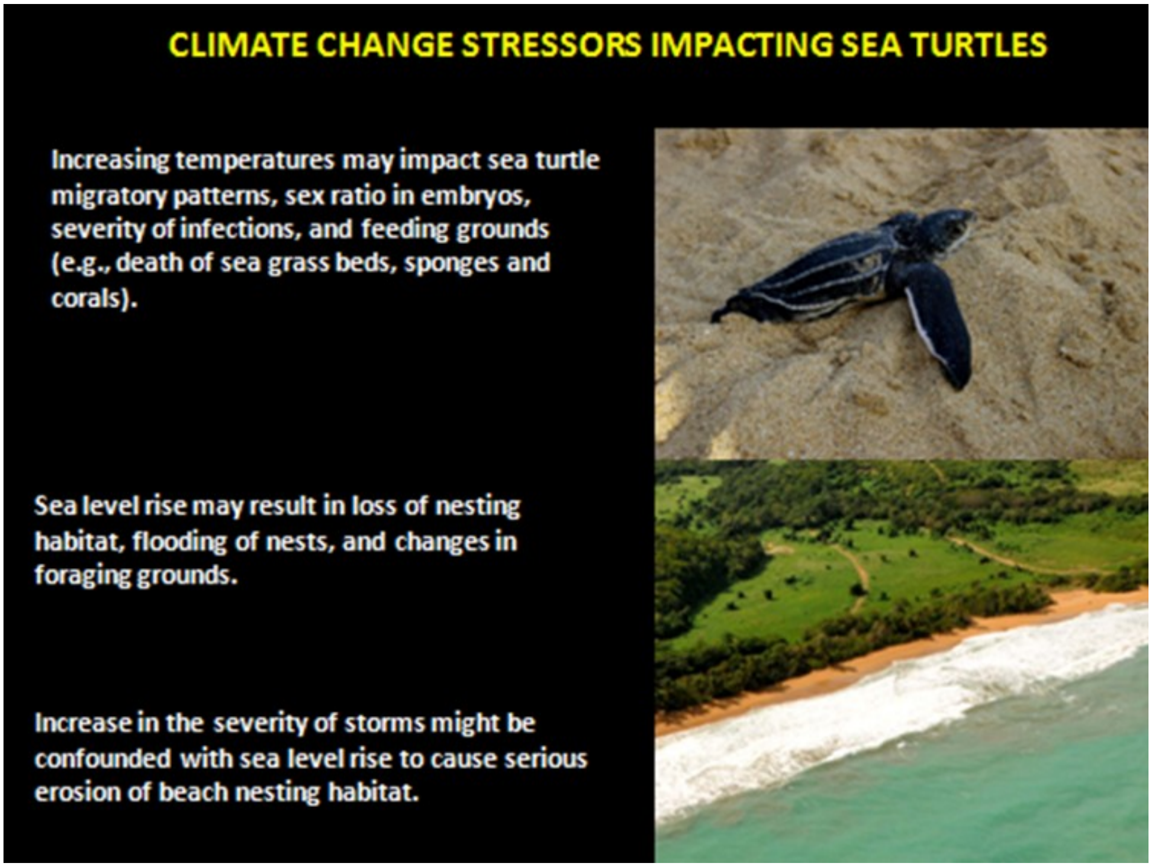
3. **Increased irradiation and mean temperatures** may alter adult nest attendance and prey fish behavior; indirectly contributing to nest failure.

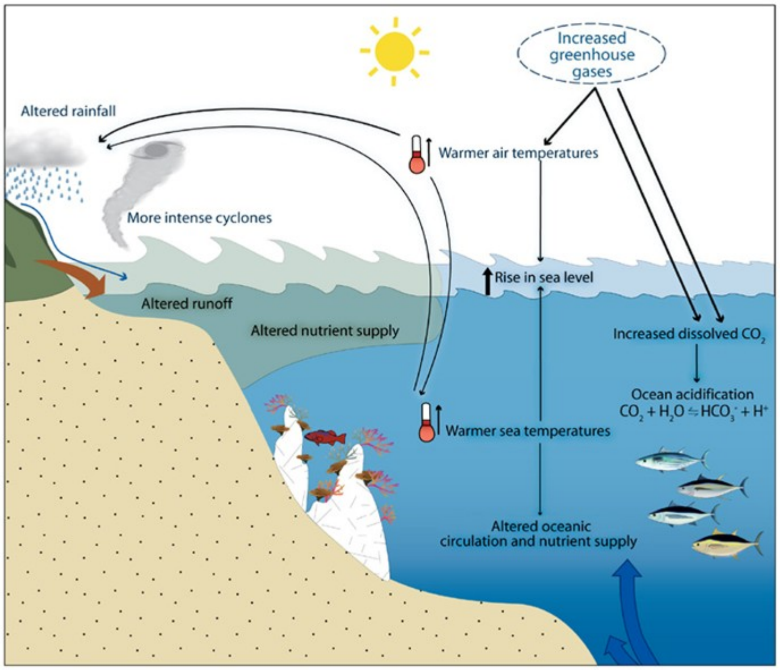
4. **Ocean acidification** (declining pH) could interfere with critical processes such as reef building, carbon sequestration via phytoplankton sedimentation, and consumer-resource interactions.

5. **Sea Level Rise** Indirect effects of the expected sea level rise on seabirds and shorebirds include starvation during migration stopovers for re-fueling, displacement into less optimal habitat, potential increase in predation in less optimal habitat, and nest abandonment and mortality of eggs and chicks.



SEA TURTLES


CLIMATE CHANGE STRESSORS IMPACTING SEA TURTLES
Increasing temperatures may impact sea turtle migratory patterns, sex ratio in embryos, severity of infections, and feeding grounds (e.g., death of sea grass beds, sponges and corals).
Sea level rise may result in loss of nesting habitat, flooding of nests, and changes in foraging grounds.
Increase in the severity of storms might be confounded with sea level rise to cause serious erosion of beach nesting habitat.



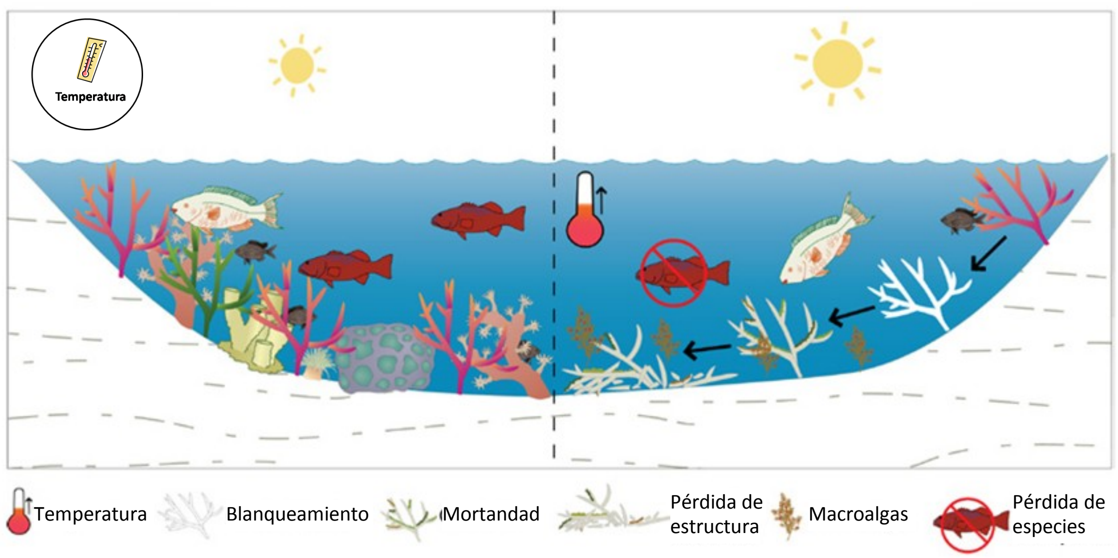
MARINE SYSTEMS

Efectos generalizados de un incremento de gases de invernadero en ecosistemas oceánicos y costeros en ecosistemas tropicales.

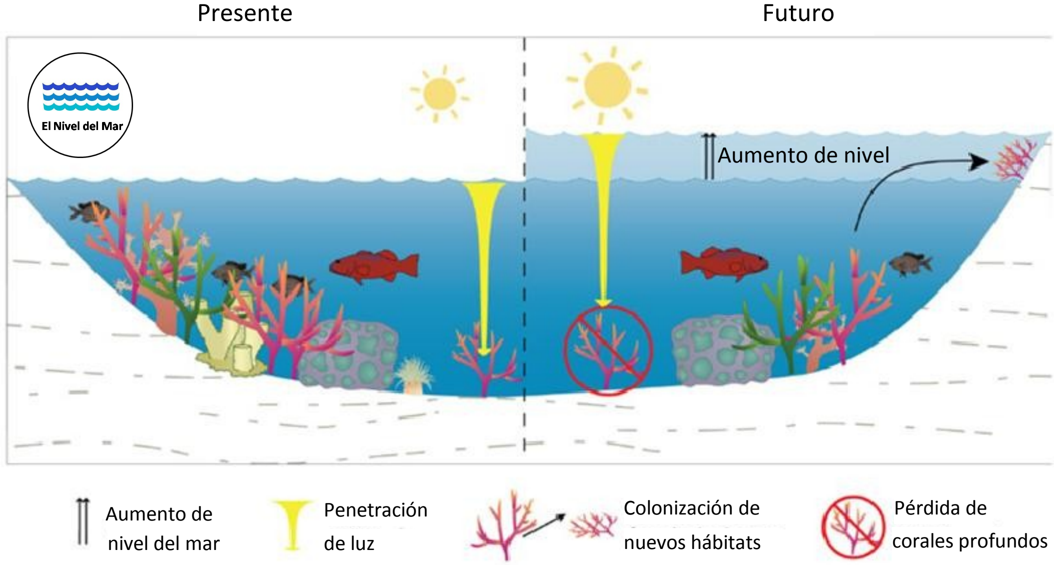
CORAL REEFS

Generalized effects of increased greenhouse gases on oceanic and coastal ecosystems in the tropics.

Presente | Futuro



Presente | Futuro



COASTAL AND PELAGIC FISHES

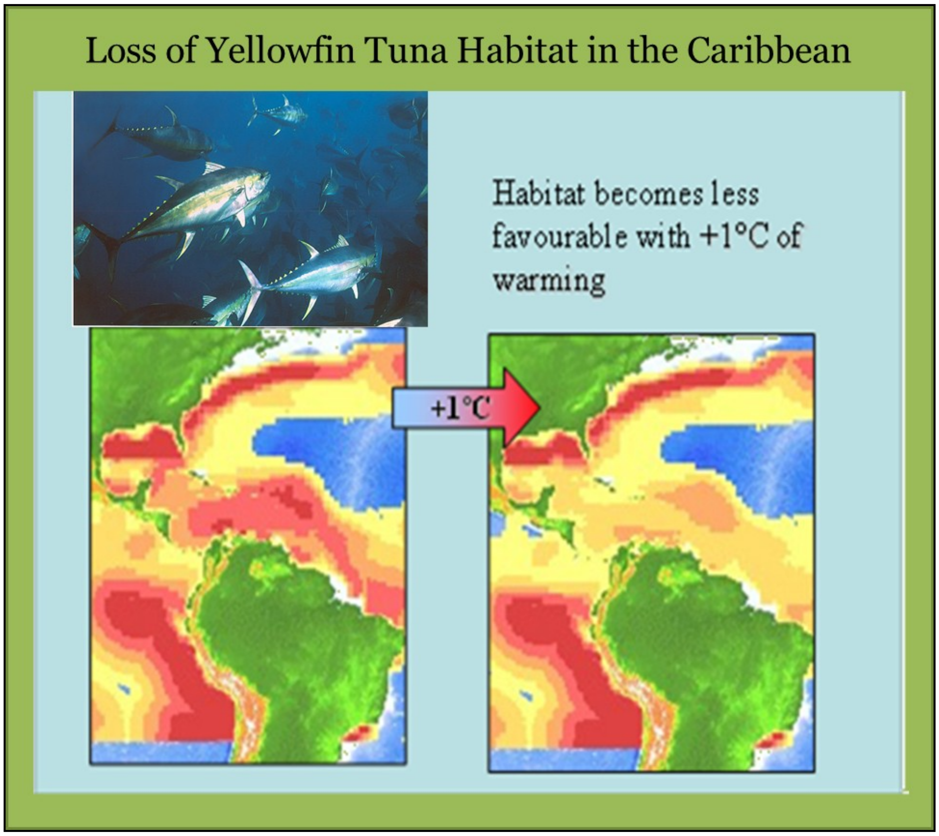
Climate and Coastal Fishes

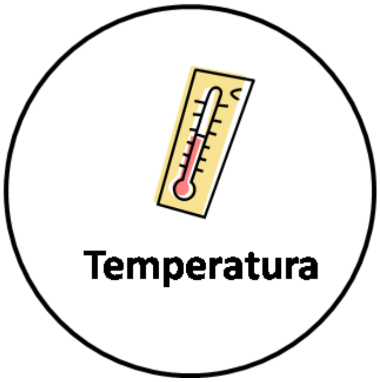
- Potential loss of nursery habitat
- Decrease fish biodiversity with habitat degradation
- Species driven towards colder waters resulting in extinction
- Changes in distribution and abundance due to changes in life history
- Impacts on the nature and value of commercial fisheries
- Acidification- effects on calcification
- Loss of habitat with increasing storm intensity
- Stock and fisheries impact due to increase harmful algal blooms

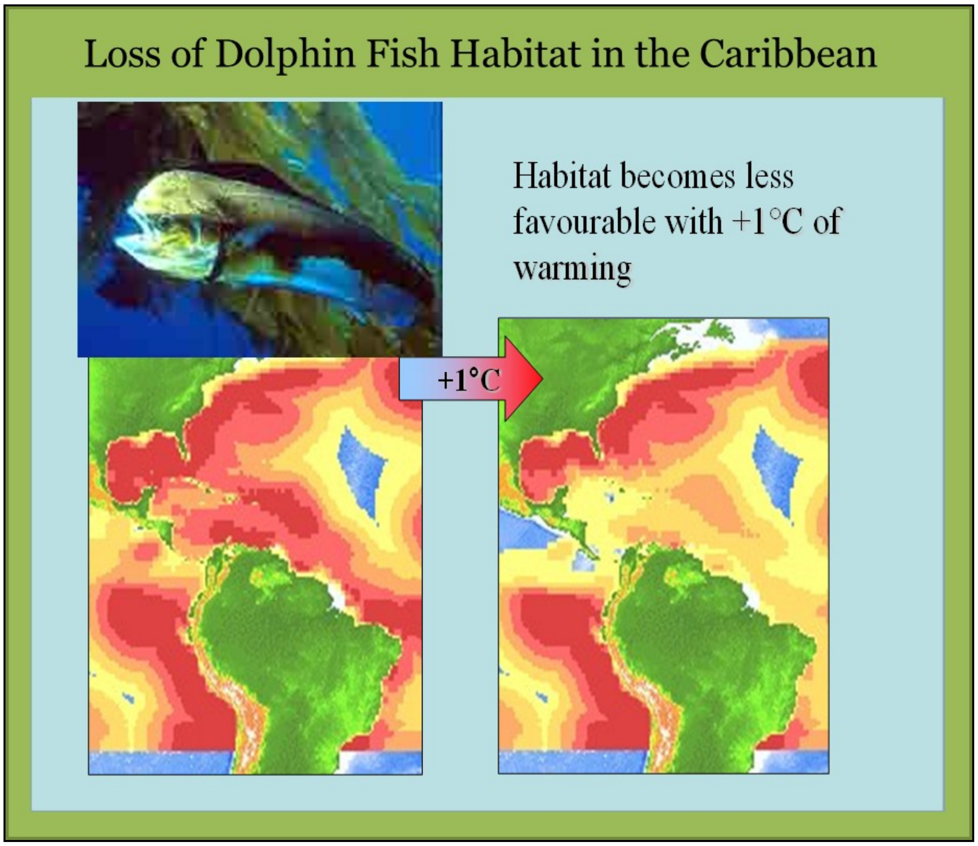
Climate and Pelagic Fishes

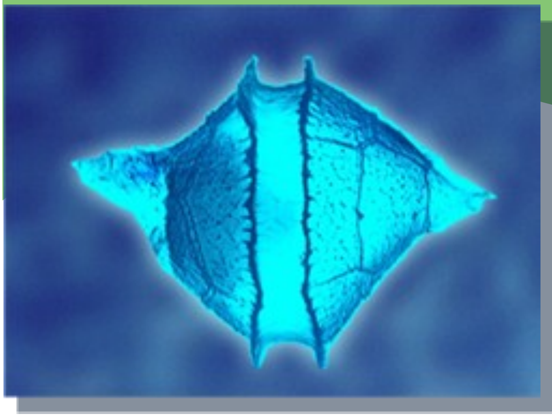
- Impact on fish stocks due to changes in plankton
- Distribution change due to change in temperature
- Loss of established fisheries and rise of new ones
- Larval growth rate could increase while the age of metamorphosis decrease improving survival of larval fish

COASTAL AND PELAGIC FISHES









BIOLUMINESCENT BAYS

The main potential stressors to bioluminescent systems due to climate changes are the increases in heavy precipitation, storms and hurricanes. The expectation of increases in heavy precipitation and storms, lead to increases on land runoff to these systems that can trigger increments in sediment and nutrient loadings affecting water quality due to changes in the sedimentation (turbidity), productivity and frequency and extension of salinity shifts. In the case of Bahía Fosforescente this problem might be compounded do to the decreased vegetation cover along the adjacent watershed. Phytoplankton organisms can also be affected due to the warmer temperatures expected from global climate change. Temperature is considered one of the most important physical factors that affect the growth of phytoplankton species by regulating the metabolic processes of these organisms. It has been proposed and observed that as temperature of the oceans gets warmer, small cell size phytoplankton dominate the community. However, others have reported that dinoflagellates populations and diatoms will be favored with increases in temperature. Moreover, all these studies have been conducted in the open ocean, and different results can be observed in coastal ecosystems such as bioluminescent bays. Laboratory experiments are necessary in order to evaluate the impacts of increases in temperature over the phytoplankton community in bioluminescent systems.

MARINE MAMMALS

Population abundance and distribution

- Not much data
- Some species may increase abundance or their range
- Increase risk of extinction of vulnerable species

Food supply

- Effect of environmental conditions on abundance and distribution of prey species (fish, cephalopods and plankton)

Disease

- Increase in diseases related to temperature changes

Contaminants and metabolisms

- Thermal stress may combine with toxicological stresses to increase mortality
- Thinning blubber-transportation toxic environmental contaminants stored- compromised immune function
- Support old and new pathogens
- Reduce host resistance
- Increase the duration of exposure

56% of Puerto Rico's population (2,317,189 people) lives in the coastal municipalities. Puerto Rico has an area of 9,497 km^2 (3,508 mi^2) and a population density of almost 449 inhabitants per km^2 (449 inhabitants per ~0.4mi^2). This represents one of the highest population densities in the World. Puerto Rico's population reflects high levels of vulnerability to hazards. The most vulnerable are those who are economically disadvantaged, less prepared, and under social inequitable conditions, such as insufficient infrastructure and services. Today, more than half of the population lives in the San Juan Metropolitan Area. The metropolitan municipalities, like San Juan and Carolina, are where activities and services are concentrated: Puerto Rico's main seaport and airport; the most important healthcare center of Puerto Rico and the Caribbean (Centro Médico) and the major universities. Government services are also highly concentrated in San Juan. The coastal zone of the San Juan Metropolitan Area as well as other coastal areas is where most hotels, essential infrastructure, and electric power plants are located (some power plants are less than 160 feet from the waterline and less than six feet above sea level). Most businesses and other forms of economic activity are located in the coastal zone as well. The Commonwealth's rapid urbanization that occurred during past decades has drastically covered Puerto Rico's watersheds with impervious surfaces. As a result, there are thousands of people living in flood-prone areas. Landslide hazards are also a growing concern in Puerto Rico. Bursts of heavy rainfall from intense storms trigger numerous landslides in the mountain areas of the island every year, causing substantial property damage and sometimes loss of life. Construction on vulnerable slopes exposes population particularly in rural areas to these hazards. In 2010, it was estimated that 49% of the population in Puerto Rico lives in areas ranging from moderate susceptibility to landslides to the highest susceptibility.

Through PRCCC partner, Puerto Rico Emergency Management Agency, the PRCCC was able to collect most of the hazard mitigation plans for the 78 municipalities of Puerto Rico. In brief, existing hazards that affect Puerto Rico today are: riverine and coastal inundation, landslides, tropical storms and hurricanes, earthquakes, tsunamis, winter swells, coastal erosion and drought. Structures that are considered at-risk due to the already existing hazards listed are: residential homes, power generation plants, sewage systems, cemeteries, recreational areas, community centers/libraries, government buildings and facilities, schools, and hospitals. Working Group 3 determined through discussions and the use of the municipal hazard mitigation plans that, according to the historically observed climate trends, Puerto Rico is currently at-risk from:

- Continuing development in high hazard areas or poor drainage areas
- Increasing land use change and area of impermeable surfaces
- Inappropriate use of shoreline stabilization structures in certain areas
- Poor maintenance of existing shoreline stabilization structures
- Poor maintenance and dredging of rivers, canals and reservoirs
- Inadequate capacity and poor maintenance of storm-water management systems
- Poor soil management practices on land and coastal watersheds
- Inadequate construction practices that do not follow established codes
- Elimination of dunes, reefs, mangroves, and other naturally protective features

HAZARDS IN PUERTO RICO

Of all the hazard mitigation plans for Puerto Rico's municipalities only Naguabo, Peñuelas, Yauco, Hatillo, Salinas, and Toa Baja mention the terms "climate change", "global warming", or "sea level rise".

Hazards in Puerto Rico

Tropical Storms & Hurricanes

Coastal & Riverine Flooding

Storm Surges

Winter Swells from Atlantic Winter Storms

Landslides

Earthquakes, Liquefaction & Ground Shaking

Tsunamis

Erosion

Drought

The socioeconomic conditions and existing vulnerabilities in Puerto Rico described above are the most important considerations when addressing how to meet the new challenge of climate change. The changes in climate that the PRCCC's Working Group 1 report described will not necessarily create new vulnerabilities for Puerto Rico, but rather are expected to exacerbate the existing vulnerabilities Puerto Rico already faces today. The high proportion of population living in areas vulnerable to natural hazards, growing numbers of the elderly and other at-risk groups, and a relatively high poverty rate (by U.S. if not Caribbean standards) increase the island's social and economic vulnerability to climate change impacts.

At the same time, Puerto Rico's relatively high per capita fuel and energy consumption – in electricity and transportation (one automobile per 1.3 Puerto Ricans) – contributes to the causes of global climate change. Municipalities in Puerto Rico are already concerned about climate change as evidenced by the following excerpt from one coastal municipality's hazard mitigation plan: "It is expected that as the years pass the likelihood of flooding in [the municipality] and Puerto Rico in general will increase because of all the climate changes that are occurring in the world." When assessing how climate change could affect Puerto Rico it is important to consider that the real concern is how Puerto Rico's way of life will change, rather than the change itself.

Our "First Lines of Defense" are Disappearing

- Loss and alteration of wetlands and floodways leads to increased flooding
- Loss of natural coastal barriers increases storm impacts on the coastline
- Loss or degradation of marine habitats such as reefs increases wave impacts and erosion along the coast

HISTORICAL & CULTURAL SITES

Puerto Rico has a wide variety of buildings that have historic and cultural significance, many of which are located on the coast. A sampling of these would include the Spanish forts of Old San Juan, as well as the series of light houses and churches located around the island. Many coastal towns, such as Cataño, Hatillo, and Arecibo, have their historic city centers located adjacent to the water and vulnerable to the effects of climate change. Information collected by Working Group 3 during risk assessment workshops with the coastal municipalities indicates that certain historic properties in Puerto Rico are already exposed to flooding events, such as the Catholic church Santa Rosa de Lima in Rincón and remnants of the old train along the west coast, Antigua Casa de la Real Aduana in Fajardo, numerous archaeological sites of Taino and Spanish artifacts (e.g., cooking areas and canons), the ruins of Hacienda María Antonia in Guanica, and Castillo Villa del Mar in Naguabo. In fact, the remains of the Castillo in Naguabo, located on route 3 and one of the few examples of late Victorian architectural style in Puerto Rico, has already suffered serious damage from Hurricane Hugo in 1989. Despite that tragedy and a subsequent fire the municipality and other government agencies are hoping to restore the building. Increased frequency of flooding from sea level rise and heavy precipitation events could cause more structural damage to this historic building and many others, perhaps even complete loss of such treasures.

Examples of *Potentially Vulnerable Historical Sites in Puerto Rico*

- *Spanish forts in Old San Juan*
- *Various archaeological sites of Taino and Spanish artifacts (e.g., cooking areas and canons)*
- *Historic city centers (e.g., Cataño, Hatillo, and Arecibo)*
- *Rincón church: Santa Rose de Lima*
- *Fajardo's Antigua Casa de la Real Aduana*
- *Ruins of Hacienda María Antonia in Guanica*
- *Castillo Villa del Mar in Naguabo*
- *Church San Carlos Borromeo of Aguadilla*
  Old Municipal Cemetary of Aguadilla

INDUSTRY & MANUFACTURING

Storms and hurricanes are a good way to test the entire system of manufacturing as related to climate change (Puerto Rico Manufacturer's Association, *personal communication*, July 17, 2012). Past events, specifically Hurricanes Hugo and Georges, disrupted transportation systems and thus disrupted many industries' operations greatly. However, there are few reports of atmospheric conditions causing structural damage to company infrastructure. Yet on a regular basis there are floods regionally in Puerto Rico and these events do disrupt industry production. Examples include, business being interrupted when workers are absent because their children's' schools are closed due to flooding. Or if workers are unable to reach the manufacturing plants due to impassable roads. Or if communication lines are down due to the majority of areas having above ground lines the company might lose business. Depending on the industry and its size the companies might be able to sustain two to three days of service interruption. Chances are higher of resistance to events if there is sufficient time to prepare. Some industries in Puerto Rico require specific equipment that cannot shut down without corrupting whole batches of raw materials and these businesses are more susceptible to being negatively affected by service interruptions. Furthermore, the ability of industry to ship their products off island is an important consideration. As previously mentioned, flooding events from sea level rise, storms, and heavy rains, might shut down air and seaports. Most products are flown out via airports and not seaports, like pacemakers and pills, however, certain items like alcoholic beverages from the rum distilleries or beer bottling plants cannot be exported via airports and rely on functioning sea ports.

Currently there are no water quality or quantity restraints for the manufacturing industry, a plus for Puerto Rico in terms of economic competitiveness. Many companies have their own wells and are not connected to the public utility. An independent study is needed to determine how future droughts in the Caribbean will affect Puerto Rico's water resources and dependent industries, like manufacturing. Adaptive capacity of Puerto Rico's manufacturing industry may be sufficient to deal with climate change as there is a functioning network for emergency management. This network may prove useful in the future as sites become more exposed to climate changes. However, this network, and therefore the industry's adaptive capacity, has not yet been tested by a large hurricane.

From the experience of past storm events it can be inferred that climate change may affect manufacturing indirectly, like human resource issues and service interruptions, and to a lesser extent from direct structural damages. This highly depends on the location of the industry facilities, their method of export (i.e., air versus sea), their connection to the network for emergency management, and the type of industry.

Tourism

Climate Stressor	Implications for Tourism
Warmer temperatures	Altered seasonality Heat stress for tourists Increased cooling costs Changes in plant-wildlife-insect populations and distribution range Health impacts such as infectious and vector-borne disease ranges
Increasing frequency and intensity of extreme storms	Risk for tourism facilities Increased insurance costs/loss of insurability Business interruption costs
Reduced precipitation and increased evaporation in some regions	Water shortages Competition over water between tourism and other sectors Desertification Increased wildfires threatening infrastructure and affecting demand
Increased frequency of heavy precipitation	Flooding damage to historic architectural and cultural assets Damage to tourism infrastructure Altered seasonality (beaches, biodiversity, river flow)
Sea Level Rise	Coastal erosion Loss of beach area Higher costs to protect and maintain waterfronts and sea defenses
Sea Surface Temperature Rise	Increased coral bleaching Marine resource aesthetic degradation in dive and snorkel destinations
Changes in terrestrial and marine biodiversity	Loss of natural attractions and species from destinations Higher risk of diseases in tropical-subtropical countries
More-frequent and larger forest fires	Loss of natural attractions Increase of flooding risk Damage to tourism infrastructure
Soil changes (moisture levels, erosion, acidity)	Loss of archaeological assets and other natural resources, with impacts on destination attractions and agriculture

Film and Entertainment Industry

The last few years Puerto Rico has promoted the film industry like never before, managing to put Puerto Rico on the map as a unique and attractive destination for film and television production. The film industry is one of the most important lines, not only for economic development, but for cultural development. This in turn influences other activities like the rental equipment and hotel industries, ultimately greatly impacting the consumption of goods. The filming, the core of the film industry, has the characteristics of a mass consumer product, also as an economic and cultural phenomenon, presents a great opportunity to advance jobs and economic development, especially with the competitive advantages of our island: our professional technicians, our localities, our world-renowned artists and actors, the natural and cultural resources of our beautiful island. The implications of climate change for tourism, natural resources, and the services industry could deter filmmakers from choosing Puerto Rico as a filming locations.

LIVELIHOODS

- Increases could cause shifts in coastal habitats based on vegetation tolerance or loss of these natural barriers
- Loss of habitat for fishery species, for example, could lead to the loss of this livelihood

- Impacts to livelihoods from increased flooding that could lead to losses in coastal structures
- Flooding damages to coastal infrastructure could affect manufacturing and other industries if utilities and transportation services are damaged

- Increases can lead to coastal erosion and related damage to structures that can affect livelihoods
- Increases could result in the loss of coastal habitat that serve as natural barriers

- Increased magnitude and/or frequency can lead to damage to structures affecting livelihoods and the economy
- Increased magnitude and/or frequency can lead to loss of or damage to natural barriers

- Increases in ocean acidity affects marine habitats and livelihoods that depend on these such as commercial fishing
- Increases in ocean acidity that result in the loss or degradation of habitat such as coral reefs can increase damages to coastal structures due to the loss of natural protective features

RISK MATRIX

Área de planificación	Average Risk Score	Climate Driver
Características naturales que protejan la costa (Barreras naturales, como manglares, dunas, rocas o arrecifes de coral)	**High** 11.63	No consistent answers (all 4)
Estructuras de propiedad privada (viviendas unifamiliares y múltiples, edificios de oficinas, hoteles, edificios comerciales, estaciones de gasolina, y centros comerciales)	**High** 11.38	Sea Level; Storms
Instalaciones y Edificios Públicos (gobierno, educación, salud, parques culturales, áreas recreativas, etc)	**High** 10.90	Sea Level; Storms
Infraestructura de aguas usadas y escorrentía (Estructuras de recolección y transporte (canales, tuberías, bombas, alcantarillas, arroyos urbanos, quebradas); estructuras de captación (estanques, lagos urbanos, y sistemas de recolección de agua de lluvia), estructuras de control de calidad (por ejemplo, desarenadores); estructuras de almacenamiento, sistemas de desbordamiento de aguas residuales y pluviales, plantas de tratamiento y sistemas de descarga de aguas tratadas)	**High** 10.60	Precipitation; Temperature; Storms
Transporte (puertos, carreteras, puentes)	**High** 10.31	Precipitation; Sea Level
Infraestructura de Generación de Energía (Plantas de generación de energía; infraestructura de transmisión e infraestructura de distribución)	**High** 9.57	Sea Level; Storms
Servicios de Agua (estructuras de almacenamiento, procesamiento y distribución de agua potable (tuberías principales de agua, etc.)	**Medium** 8.86	Precipitation; Temperature; Storms
Suministro de Agua (recursos de agua superficial, aguas subterráneas y del subsuelo; acuíferos costeros; represas y energía hidroeléctrica)	**Medium** 8.65	Precipitation; Temperature
Recursos de Agua para Irrigación y Drenaje	**Medium** 8.55	Precipitation; Temperature
Recursos Históricos y Culturales (lugares de interés histórico y significado cultural)	**Medium** 7.64	Sea Level; Storms

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