Vulnerability and Resilience of U.S. Coastal Wetlands to Sea Level Rise

CLIMATE CENTRAL

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Summary

- A new study conducted by Climate Central and published in Environmental Research Communications explores an array of possible futures for America's coastal wetlands—the most advanced national-scale analysis to date.
- Sea level rise threatens to destroy valuable coastal wetlands, but wetlands can sustain themselves by either migrating horizontally into undeveloped, previously dryland areas or by growing vertically due to sediment buildup and organic matter accumulation.
- Wetlands could increase in area by 25% or decline by 97% by 2100 depending on the pace of sea level rise, how fast wetlands can grow vertically, and especially how much land is conserved for wetlands migration. Each of these factors is controlled, to at least some extent, by human choices.
- Louisiana, home to a third of America's coastal wetlands, is the state most at risk of wetlands loss, followed by North Carolina and Texas. California and Florida face the added challenge of having little undeveloped dryland to accommodate wetlands migration.
- Climate Central has introduced a pair of new interactive online mapping tools showing the vulnerability and resilience of coastal wetlands to sea level rise under different scenarios.

Coastal wetlands are some of the world's most economically and ecologically valuable habitats. Unfortunately, the United States is rapidly losing coastal wetlands and their associated benefits. Sea level rise due to climate change threatens to accelerate this critical loss. Coastal wetlands have some natural defenses against rising waters, but they need human help to adapt to a rapidly changing climate. Climate Central analyzed the factors that will decide whether America's coastal wetlands thrive or drown. Depending on a combination of factors—how fast seas rise, how much undeveloped land is conserved, and how fast wetlands can accumulate sediment and grow vertically—coastal wetlands could either expand or almost entirely disappear. The future of wetlands in the U.S. depends largely on the choices humans make now.

A critical resource at risk

Despite occupying only a small fraction of America's landmass, coastal wetlands contribute outsized benefits. In the U.S. alone, they provide an estimated $746 billion of ecosystem services. Coastal wetlands provide flood protection and erosion control to inland communities, habitat for many endangered and commercially harvested species, water filtration, recreation, and carbon sequestration.

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The U.S. is a global hotspot for wetland loss—and the rate of loss is rapidly growing. Coastal wetlands by their very nature exist in low-lying coastal areas that are tidally flooded, putting them at high risk of submergence by rising seas. That risk is increasing as sea level rise accelerates due to climate change. Along the U.S. coastline, sea levels rose about a foot over the last hundred years; in the next 30, they are expected to rise about another foot. Seas will continue to rise for centuries, although how high and how fast depends on the choices humans make now.

Resilience against rising seas

While coastal wetlands are substantially threatened by sea level rise, they are also uniquely capable of resilience. Wetlands can sustain themselves in two ways: migrate horizontally or grow vertically.

When sea levels rise, wetlands can **migrate** into previously dryland areas, known as **refugia**. In some places, coastal wetlands encroach on forest, creating the visually striking phenomenon known as ghost forests—stands of dead trees killed by salt water. In other places, human development blocks the path of wetlands, squeezing the salt marsh between a rising sea and an unmoving bulkhead, road, or other structure. The ability of wetlands to sustain themselves via migration depends on how much land is reserved for wetlands to move into, and therefore on how society prioritizes preserving refugia versus other potential land uses.

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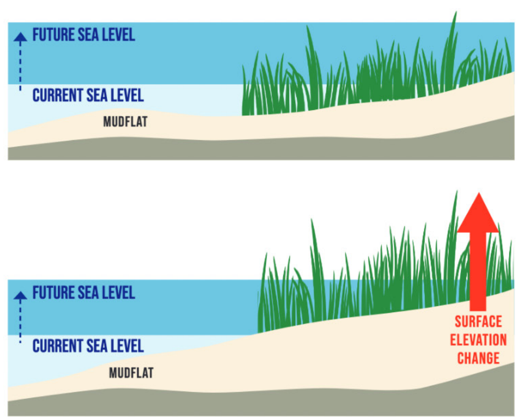

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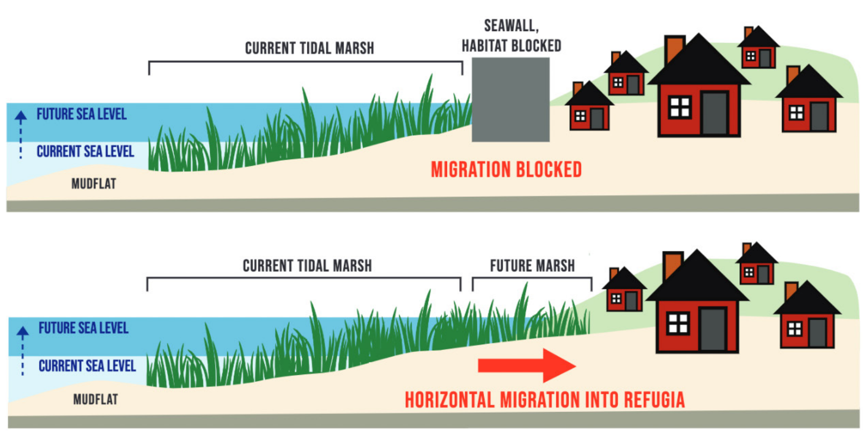


Additionally, wetlands can **accrete**, or grow vertically due to accumulation of sediment and organic matter. Sediments carried in by flowing water get trapped by plants or settle out of slowing water. Wetland plants grow and then die, piling up and raising the elevation of the marsh. Accretion can be countered by near-surface or "shallow" sediment compaction and other causes of vertical land motion. The net result of these factors is the

surface elevation change rate. This rate varies geographically, but typically falls between -2 and 8 millimeters per year (-0.08 inches to 0.3 inches per year) in the United States. Human activities can affect this rate by altering sediment availability—for example, damming rivers reduces sediment supply. To persist in the face of sea level rise through net vertical growth, a wetland must be able to grow upward at least as fast as the sea level is rising.

Choices to make: will wetlands thrive or drown?

Whether or not wetlands have refugia to migrate to, how fast wetlands can grow vertically, and how fast sea levels rise are all determined, at least in part, by people. Humans can help preserve coastal wetlands even in the face of sea level rise, but only if we understand how these factors cumulatively impact wetlands preservation or loss. Climate Central's research provides a localized, rigorous analysis of how various surface elevation change rates, sea level rise rates, and development scenarios will impact the resilience of America's coastal wetlands. Our goal is to empower communities with information to make decisions about their wetlands conservation strategies.

This research builds upon prior analyses of wetlands' responses to sea level rise by filling a gap. Earlier studies were either large scale analyses that use data that is too coarse or models that are too simplistic to inform local decision making, or localized models that cover only a small area. Our analysis works at an intermediate scale to provide the most accurate assessment of wetland exposure for the contiguous U.S. to date. Assessing two coastal development scenarios, three sea level rise scenarios, and eight different surface elevation change rates, Climate Central modeled the extent of coastal wetlands in the U.S. from 2000 to 2100.

We found a broad range of possible outcomes for U.S. coastal wetlands. In an optimistic scenario—one in which all refugia are conserved, emissions are sharply reduced (formally, RCP 2.6), and there is a high maximum vertical growth rate (8 mm/yr)—coastal wetlands may increase by 25% by 2100. This translates to an additional $222 billion in ecosystem services, assuming that the total value of ecosystem services scales linearly with area. However, in a more pessimistic scenario—one in which all refugia are developed, there is a moderate maximum vertical growth rate (3 mm/yr), emissions grow unchecked (RCP 8.5), and there is higher than expected sea level rise due to ice sheet instability—97% of coastal wetlands may be lost, along with $732 billion in ecosystem services.

Conservation is key

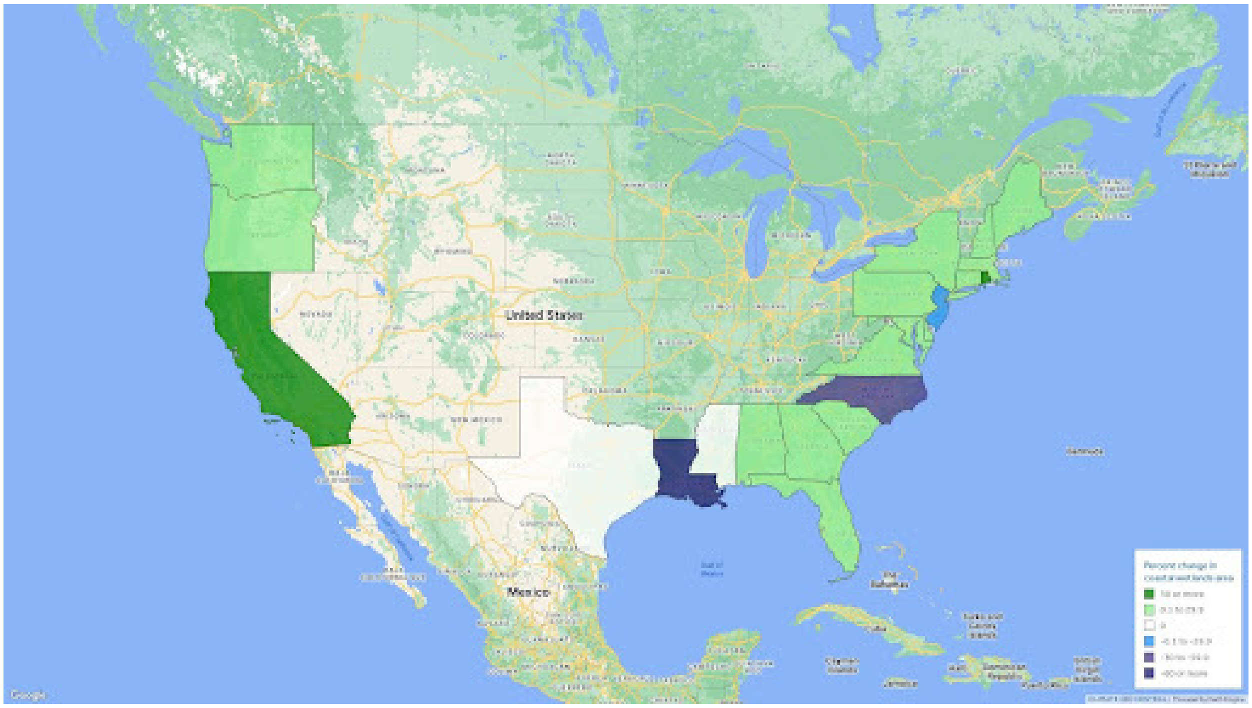
Land conservation to accommodate wetlands migration is a critical factor in whether coastal wetlands in the U.S. will expand or shrink as sea levels rise. If all possible refugia are conserved for coastal wetlands migration, wetlands will expand in most U.S. counties in a broad range of scenarios. A widespread reduction in wetlands would only occur in situations with both moderate or lower vertical growth rates and very fast sea level rise as a result of high greenhouse gas emissions and ice-sheet instability.

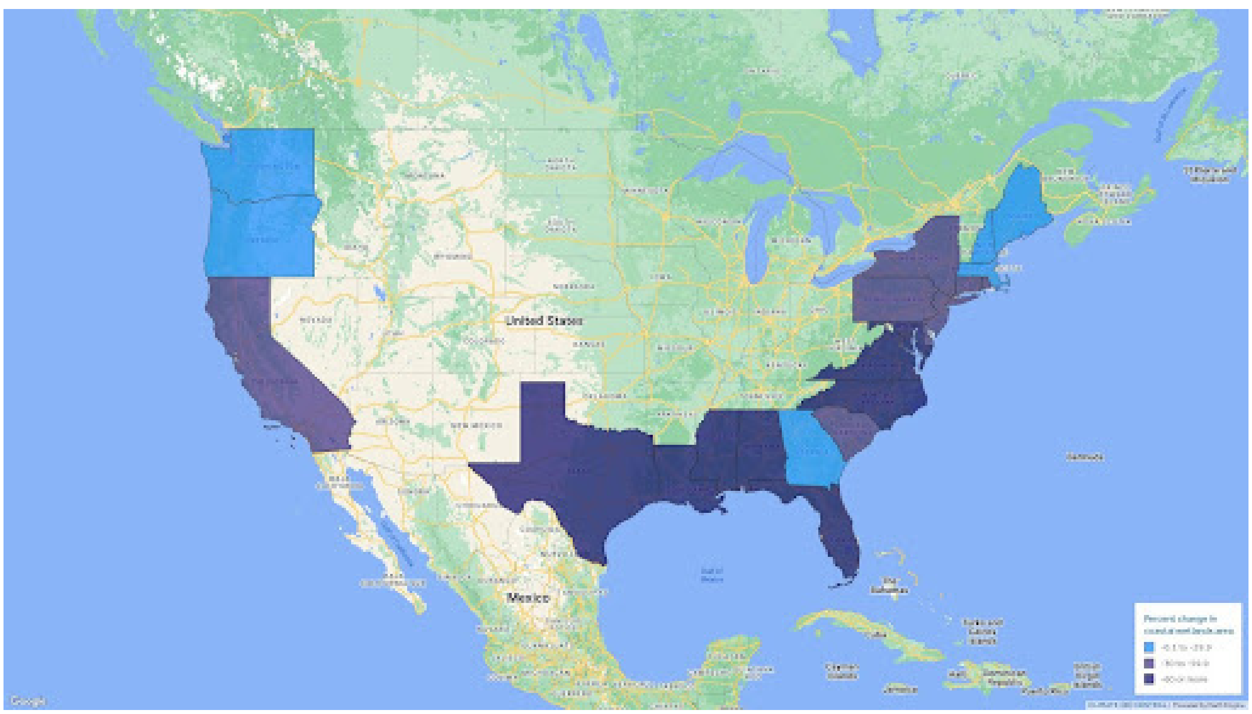
However, if no refugia are conserved for migration, wetlands can only be maintained or shrink. In scenarios without any land conservation, wetland loss can only be prevented by a combination of high vertical growth rates and low greenhouse gas emissions. In fact, many counties would face the complete loss or widespread reduction of their wetlands even without high-end sea level rise caused by ice-sheet instability.

To support local and regional planning, Climate Central calculated the minimum percentage of refugia that would need to be conserved to fully avoid wetland loss for each coastal county in the U.S. under a high carbon-

[1] This report uses RCPs, or representative concentration pathways, not SSPs, or shared socioeconomic pathways, because the peer-reviewed research upon which this report was based was conducted before the latest IPCC report formally introduced SSPs. RCP 2.6 is most similar to SSP1-2.6, while RCP 8.5 is most similar to SSP5-8.5. For more explanation of the relationship between RCPs and SSPs check out this explainer from Carbon Brief.

emissions scenario (RCP 8.5)—essentially, the potential conditions if pollution grows unchecked. If wetlands are able to grow upwards quickly and sea level rise follows moderate projections, nearly ten percent of counties need to preserve more than half of their refugia to avoid wetland loss. If vertical growth rates are only moderate and sea levels rise faster due to ice-sheet instability, this fraction grows to seven out of ten counties.





Percent change in wetlands area with (top) and without (bottom) conservation of refugia for wetlands to migrate to. Assumes a moderate surface elevation change rate (3 mm/yr), high emissions scenario (RCP 8.5), and mid-range sea level rise. Green represents an increase in wetlands, while blue represents a decrease.

Table 1. Top ten states at risk of wetlands loss under a high emissions (RCP 8.5), moderate surface elevation change rate, and full development scenario. For the complete list and county-level projections, see our interactive web tool.

State	Percentage change in wetland area by 2100
LA	-100
TX	-100
NC	-89
MS	-52
DC	-49
FL	-49
RI	-45
AL	-43
VA	-42
NY	-41

Table 2. Top ten states at risk of wetlands loss under a high emissions (RCP 8.5), moderate surface elevation change rate, and full conservation scenario.

State	Percentage change in wetland area by 2100
LA	-76
NC	-18
ME	+5
RI	+6
DC	+9
MA	+10
NH	+12
NY	+12
CT	+14
NJ	+16

Some counties are expected to lose at least some wetland area even if all possible refugia are conserved; if wetlands are able to grow upwards quickly and sea level rise follows moderate projections, one of ten counties face wetland loss even with full conservation. If vertical growth rates are only moderate and sea levels rise faster due to ice-sheet instability, nearly half of counties face wetland loss despite full refugia conservation.

Without conservation, wetlands must race rising seas

When coastal development removes the potential for wetlands migration, the rate at which wetlands can grow upwards due to sediment and organic matter accumulation becomes especially important to their survival. The wetlands essentially enter a race with sea level rise—if the wetlands can grow upwards faster than seas rise, they will persist. If the wetlands fail to keep up with rising waters, they will drown—converting permanently to open waters.

If greenhouse gas emissions are sharply cut (RCP 2.6), keeping the sea level rise rate low, and if wetlands can grow upwards quickly, most coastal counties would avoid wetlands loss. However, fewer than 15% of coastal counties avoid wetlands losses even if wetlands can grow at the fairly high rate of 5 mm/year, and about half of counties could lose at least a third of their wetlands if wetlands growth tops out at the moderate rate of 3 mm/year.

If greenhouse gas emissions are allowed to grow unchecked (RCP 8.5), the resilience of wetlands declines substantially unless wetlands are able to grow extremely quickly—at rates that are rarely observed naturally. More than half of coastal counties could lose at least a third of their wetland area even under the relatively fast rate of 5 mm/year. And if rapid ice-sheet loss causes sea levels to rise even faster, essentially all coastal counties face wetlands losses at almost any previously observed growth rate.

Hotspots of risk

Both coastal wetlands and the impacts of sea level rise on them are not evenly distributed. The southern Atlantic and Gulf coasts are particularly at risk of wetlands loss. The state most at risk is Louisiana, which contains a third of the coastal wetlands in the contiguous U.S. North Carolina and Texas also are at high risk if coastal development prevents wetlands from migrating into refugia. If all potential refugia are conserved, areas that have already been widely developed, like some counties in California and Florida, will face comparatively higher wetlands losses.

Wetlands conservation examples and resources

In the race against sea level rise, wetlands have two inherent defenses—they can move inland (migration) and build up (accretion).

Enhancing wetlands defenses is part of nature-based or green infrastructure, landscape management approaches that rely on natural processes and materials to support ecosystem resilience and adaptability to climate impacts. For example, living shorelines refers to the application of nature-based infrastructure along coastlines. This may include planting native vegetation or using natural materials to stabilize shorelines.

Strategic landscape management techniques can bolster wetlands' natural defenses. Broadly speaking, strategies to sustain wetlands include conserving undeveloped dry land for future wetlands expansion, converting developed areas for reclaimed wetlands, and supporting or enhancing sediment supply to existing wetlands.

Here are examples of organizations working to enhance and conserve coastal wetlands:

> The **American Littoral Society** **(ALS)** educates and encourages communities to take action to protect coastlines, and conducts habitat restoration projects along the East Coast. One example is the restoration of Thompson's Beach in New Jersey, where ALS and partners replanted native vegetation and raised marsh elevation by adding sediment. In another along New Jersey's Shark River, ALS employs a mix of natural and human-made materials to slow erosion and extend the marsh.
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> **Ducks Unlimited (DU)** works to conserve North American land that is most significant for waterfowl populations, including coastal wetlands. The organization directly protects wetlands by securing conservation easements (voluntary agreements to permanently give up certain development rights on a parcel of land). In some situations, DU works with landowners to implement limited-term management agreements, in which landowners agree to maintain habitat conditions or conduct conservation practices. Most DU easements are located in the southern U.S., specifically along the Atlantic Coast and inland throughout the Mississippi Alluvial Valley.
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> **Theodore Roosevelt Conservation Partnership (TRCP)** works with 61 partners representing hunting, fishing, and conservation groups across the U.S. TRCP advocates for bipartisan legislation to protect ecosystems enjoyed by outdoor recreationists. The organization's climate coalition identifies ways that natural infrastructure can support resilience and preserve public access, including to coastal wetlands.
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> **Wetlands Watch** partners with other groups to employ nature-based solutions in coastal Virginia to address climate change. The organization produces research, policy recommendations, and strategies to support local stakeholders' conservation projects. Wetlands Watch's resilience-focused initiatives include providing comprehensive planning tools and resources for local governments, resources for floodplain management and green infrastructure, and a professional certification program for sustainable landscapers in the Chesapeake Bay region. In Virginia's Tidewater region, Wetlands Watch is leading a pilot program to conserve land for wetlands migration by connecting land conservation organizations with local land use planners.

Conclusion

Even with their natural defenses against rising seas, most coastal wetlands need human help to persist and continue providing their many valuable ecosystem services. Understanding how the rate of sea level rise, the amount of land conserved, and the rate at which wetlands can grow upwards will affect the sustainability of coastal wetlands at a granular level will be essential to setting priorities and making the management decisions necessary to protect this essential resource.

Terminology

Coastal wetlands - also widely known as tidal or salt marshes, defined here as undeveloped land with an elevation between the average local sea level (Mean Tide Level; MTL) and the mean peak water height during spring tides (Mean High Water Springs; MHWS).

Accretion - the process in which a wetland grows vertically due organic matter and sediment accumulation.

Surface Elevation Change - the net surface elevation change based on the positive and negative contributing factors of sediment buildup, organic matter growth and accumulation, and near-surface (shallow) sediment compaction.

Migration - the movement of coastal wetlands into low-lying, undeveloped dryland areas that become available to colonize as seas rise.

Refugia - low-lying, undeveloped dryland areas that could become inundated and turn into wetlands.

Resilience - the capacity for an ecosystem to absorb, recover from, and respond to intermittent disturbances and damage

Wetland drowning - occurs when the wetland's elevation fails to keep up with rising sea levels via net surface elevation change and thus falls below the average local sea level and becomes open water.

Methodology

We define coastal wetlands as undeveloped areas with elevations between the average local sea level (Mean Tide Level) and the mean peak water height during spring tides (Mean High Water Springs; MHWS). Starting in 2000, we model the upper bound of the wetlands elevation band tracking the rate of sea level rise, allowing migration to adjacent undeveloped land that becomes lower than MHWS. We model the movement of the lower bound of the wetlands elevation band as a function of the rate of sea level rise minus the surface elevation change of the wetland, which is bounded by the lesser of the maximum surface elevation change rate and the sea level rise rate. We then calculate the extent of coastal wetlands from 2000 to 2100 under two bounding coastal development scenarios (all refugia are conserved or all are developed), three sea level rise scenarios (low emissions, high emissions, and high emissions with rapid ice sheet collapse), and eight maximum surface elevation change rates (-1, 0, 1, 3, 5, 8, 10, and 15 mm/yr).

Land elevation data comes from NOAA's coastal topographic lidar and land cover data comes from NOAA's Coastal Change Analysis Program (C-CAP) Land Cover Atlas. The sea level rise models used are described in Kopp et al. 2014 and Kopp et al. 2017.

We note that our methodology may produce a notably conservative assessment of the risks sea level rise poses to wetlands. Our analysis does not consider the effect climate change may have on increasing floods which may erode wetland, nor tidal basin dynamics that may cause local variations in tidal levels and cause our model to find greater wetland extents than warranted. Additionally, in areas where shallow sediment compaction is an important factor, such as in Louisiana, actual surface elevation change rates may be on the low end of the spectrum explored in this analysis. Finally, the model allows that wetlands can both migrate landward and grow upward independently, increasing the total wetlands area. However, to support such a growth in wetlands, there would need to be an increased sediment supply, which would likely require substantial intervention.

For more detail, see Climate Central's peer-reviewed paper. To explore wetlands vulnerability and resilience given a range of sea level rise pathways, maximum vertical growth rates, and coastal development scenarios, see the online tool and map.

About Climate Central

Climate Central is an independent organization of leading scientists and journalists researching and reporting the facts about our changing climate and its impact on the public. Climate Central's Program on Sea Level Rise provides accurate, clear, and granular information about sea level rise and coastal flood hazards both locally and globally, today and tomorrow. We offer user-friendly maps and tools, datasets, and high-quality visual presentations.

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