Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Climate Change Impacts

Monitor

National Marine Sanctuary

April, 2021

Photo: Tane Casserley/NOAA

NATIONAL
Marine Protected Areas
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Monitor National Marine Sanctuary protects the USS *Monitor* including the possible remains of its crew. *Photo: Naval History and Heritage Command*

Our Changing Ocean

The impacts of climate change are intensifying both globally and locally, threatening America's physical, social, economic, and environmental well-being.[1] National marine sanctuaries and marine national monuments must contend with rising water temperatures and sea levels, water that is more acidic and contains less oxygen, shifting species, and altered weather patterns and storms.[1] While all of our sanctuaries and marine national monuments must face these global effects of climate change, each is affected differently.

Monitor National Marine Sanctuary

Monitor National Marine Sanctuary protects a column of water, from the bottom to the surface, one mile in diameter surrounding the shipwreck of the USS *Monitor*. Built in 1862 by the Continental Ironworks in Brooklyn, New York, *Monitor*'s revolutionary turreted, ironclad warship was the first of its kind, representing an entirely new type of warship, and built by the Union to counter the threat of the Confederate ironclad CSS *Virginia*. While under tow on December 31, 1862, *Monitor* encountered a storm off Cape Hatteras, North Carolina, and sank with the loss of 16 crew. The wreck now lies in 232 feet of water 16 nautical miles south-southeast of the Cape Hatteras Lighthouse. In 1975, NOAA designated *Monitor* as the nation's first national marine sanctuary. Today, climate change is affecting the surrounding region and could impact *Monitor* itself.

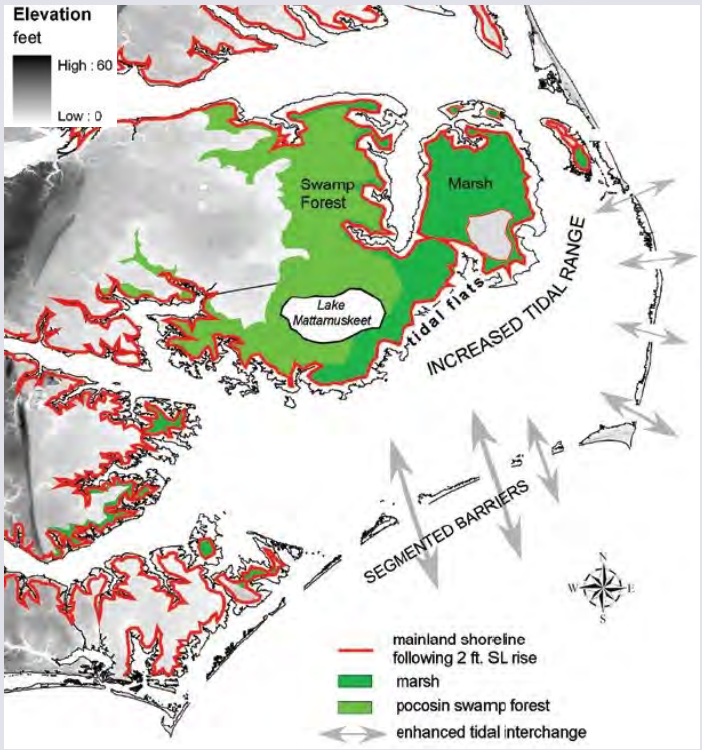
Ocean Acidification

About 30% of the carbon dioxide (CO_2) released into the atmosphere by humans is absorbed by the ocean,[2,3] causing a chemical reaction that leads to ocean waters becoming more acidic. Globally, the ocean has become 30% more acidic since the beginning of the industrial revolution.[4,5]

Water chemistry offshore of North Carolina makes the waters more resistant to acidification than the nearby waters of the Northeast.[6,7] However, acidification in the region of the sanctuary is occurring faster than in the open ocean.[8,9] This higher rate is due in part to the influence of river runoff, which is naturally more acidic than ocean water and contains dissolved carbon that contributes to acidification.[9,10] In offshore areas, such as the sanctuary, runoff may play an even greater role in the rate of acidification than atmospheric CO_2.[8] River runoff could further accelerate acidification in the sanctuary over the next century as both average

Ocean acidification can have negative impacts on shipwrecks and the organisms that live on them. Photo*: Doug Kesling/NOAA*

Case Study 1— Islands in Flux



Conceptual model of Outer Banks, North Carolina, under two feet of sea level rise and increased storm intensity. *Photo: Adapted from Mallinson et al. 2008*[18]

The islands of the Outer Banks of North Carolina are an important access point to the sanctuary for visitors, scientists, and sanctuary managers. Thus, changes to the islands as a result of climate change could inhibit access to the sanctuary. The inlets and islands of the Outer Banks naturally change in size and location over time, moving, growing, and shrinking dependent on factors such as sand movement, storms, sediment supplies, and changes in sea level.[18,19] As sea level rises, islands naturally disappear or move landward over time as wind and currents move sediment to create deposits behind the islands (in the sound).[18] However, these dynamics often conflict with human uses and infrastructure, which sometimes leads to decisions that inhibit the deposition of, or remove the naturally -accumulating sediment, hindering this migration.[18] There is evidence that large portions of the Outer Banks, particularly south of Cape Hatteras, disappeared or were breached during the last period of climate warming approximately 1000 years ago.[19-22] Today's warming is more extreme and occurring even faster. Thus, as sea level rise continues to accelerate and hurricane intensity increases, the islands may change more quickly than in the past and the Outer Banks could return to a more segmented condition in the coming century.[18,19]

rainfall and the frequency of extreme rain events are expected to increase.[1,11,12]

Ocean acidification accelerates metal corrosion,[13-15] and could increase the corrosion of *Monitor*. The full extent of acidification-driven corrosion will depend on many factors including temperature, dissolved oxygen, organisms found on the wreck, water movement, and water chemistry.[15] The ways these factors interact to affect the stability and corrosion rates of underwater maritime heritage resources are not yet well understood.[15] While more information is needed to better understand the exact impacts of acidification on maritime heritage resources such as *Monitor*, its known effects on materials that make up shipwrecks suggest it will accelerate their deterioration.[15,16]

The corrosion rate of *Monitor*'s iron hull may be relatively unaffected by levels of acidification expected for the next century because iron is resilient in the face of changing acidity.[15] However, more acid-soluble metals, such as the copper alloy piping associated with the steam and bilge systems, could be more susceptible to increased corrosion.[13] Warming waters could further accelerate the corrosion of *Monitor*, as higher temperatures increase rates of chemical and biological deterioration.[15] In contrast, decreasing oxygen[17] could slow corrosion. Acidification could also degrade *Monitor*'s calcium carbonate layer, called concretion, formed by animals such as corals, sponges, and bivalves.[15] Concretions slow corrosion by providing a protective barrier between *Monitor* and seawater.[15] Thus, any degradation to the concretion could increasingly expose *Monitor* to deterioration.

The protective calcium carbonate concretion of *Monitor* could be degraded by ocean acidification. *Photo: Joe Poe*/Monitor *Collection*

Case Study 2— Climate Change and the Graveyard of the Atlantic

The World War II German U-boat U-*352* is one of many historically significant shipwrecks in the region. *Photo: Tane Casserley/NOAA*

Monitor National Marine Sanctuary protects only *Monitor*. However, the region contains numerous shipwrecks and maritime heritage resources of historical importance that represent the pre-colonial through modern eras, including the Revolutionary War, Civil War, and both world wars. Known as the "Graveyard of the Atlantic," this region is important to our collective history and one of the most popular shipwreck diving locations on Earth. While the depth of *Monitor* protects it from many impacts of climate change, much of the other maritime heritage in this region is likely to be affected.

Rising water temperatures increase the rate of chemical and biological deterioration of maritime heritage, particularly organic materials, such as wood and cloth.[14,15] Warming also accelerates the impacts of ocean acidification, which quickens the corrosion of metal,[13-15] especially copper.[13]

Possible changes to the coastline of the Outer Banks due to sea level rise and storms[18,19] could decrease access to popular dive sites.[15] Shallow wrecks could also be damaged by the strong waves and storm surge associated with increasingly strong storms,[15,23] or by fast water flow and debris carried by flood waters[15] that are expected to become increasingly common as extreme rain events occur more frequently.[11,24,25] Storms and floods can also move large volumes of sediment, covering or uncovering maritime heritage resources.[15] Ultimately, while every shipwreck will be impacted differently, climate change has the potential to greatly affect the maritime heritage resources in the unique and historic Graveyard of the Atlantic.

Like many of the shipwrecks in the region, the USS *Tarpon* is susceptible to the impacts of climate change. *Photo: Tane Casserley/NOAA*

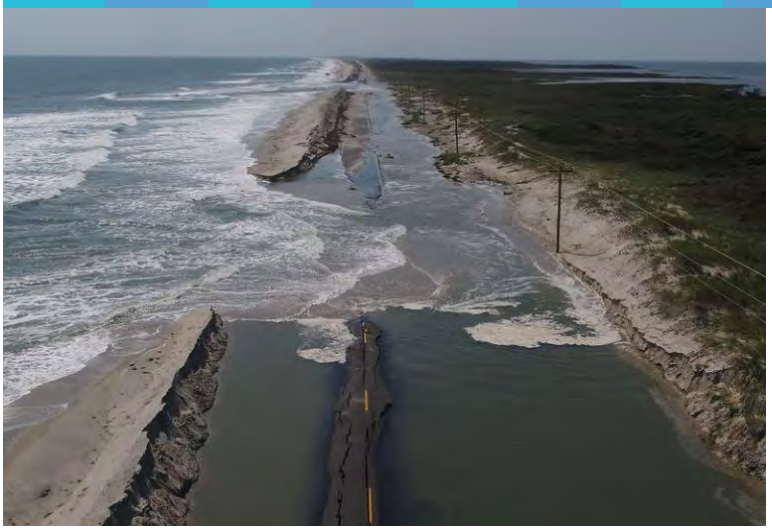
Changing Weather and Storms

Weather patterns around the world are being altered by climate change. Changes to wind and evaporation impact rainfall while rising ocean temperatures fuel stronger, wetter storms.[1,23] Altered weather and storms could indirectly affect *Monitor* and have a direct impact on coastal communities and other maritime heritage resources in the region.

In the region of the sanctuary, the frequency of extreme rainfall events has increased in recent years and is expected to continue to increase in the coming century.[1,11] Some climate models predict that by 2100 the region will experience double the number of heavy rainfall days each year as well as a more than 20% increase in the amount of rain during those events.[11,12] Such extreme rainfall events lead to higher river runoff, which can exacerbate the impacts of ocean acidification.[9,10] Further, the fast water flows associated with runoff events can scour the bottom and move large amounts of sediment, covering or uncovering maritime heritage resources.[15]

Tropical storms and hurricanes also bring high rainfall, strong winds, waves, and storm surge that can damage maritime heritage resources and cause coastal flooding, impeding access. These powerful storms can also move sediment, burying or uncovering shipwrecks.[15] The overall number of tropical storms and hurricanes in the Atlantic is projected to decrease in the coming century.[15] However, the storms that form are expected to be stronger, intensify more rapidly, and produce 10-15% more rainfall.[23,26,27] Further, the impacts of these storms in the region of the sanctuary could increase as a result of a projected northward shift in the path of storms.[28] The depth of *Monitor* is likely to protect it from direct impacts of storms and extreme runoff, but these events could have large impacts on coastal communities and maritime heritage resources in shallower waters.[15]

Top to bottom: Fish use *Monitor* as an artificial reef; USS *Schurz* is a popular dive site; sediment around U-*701* and other shallow wrecks could be shifted by the impacts of climate change. *Photos: NOAA; Tane Casserley/NOAA; Steve Sellers/NOAA*



Flooding caused by storms, sea level rise, and extreme rain could continue to damage the Outer Banks infrastructure like NC Hwy 12. *Photo: NCDOT*

Changing Coastlines

While the sanctuary does not include coastline, North Carolina's Outer Banks are an important access point for visitors, scientists, and managers. Changes to the inlets, islands, and coast of the Outer Banks could impede access, endanger sanctuary infrastructure, and harm coastal communities.

Sea level rise is changing coastlines around the world. Numerous factors contribute to rising global sea levels including melting glaciers and thermal expansion of seawater. However, differences in factors like winds, currents, and changing land height cause sea level to rise relative to land at different rates in different locations.[1,29] In the past 40 years, the rate of sea level rise has increased to the north of Cape Hatteras and decreased to the south,[30] likely due to a combination of changing wind patterns and a northward shift in the Gulf Stream.[30-33] By some estimates, sea level could rise by 4.3 feet in Wilmington[30] and 2.5 feet along the Outer Banks by 2100.[34] As waters continue to rise, the coast will be more susceptible to erosion from waves, tides, and storms.

Along the Outer Banks, the combination of sea level rise with increased extreme rainfall,[11] tidal height,[35] and storm intensity[23] is expected to result in more coastal flooding[24,25] and 100-year floods occurring yearly by 2100.[36] This coastal flooding can lead to increased erosion and put coastal infrastructure at risk, including low-lying roads and the bridges that connect the Outer Banks to the mainland.[1]

Changing Ocean Uses

Humans are adapting to climate change by altering their behavior and use of the ocean. These changes could have impacts on the sanctuary and maritime heritage resources in the surrounding region.

The many shipwrecks in the region of the sanctuary make it one of the top shipwreck diving destinations in the world.[37,38] In fact, many in the wreck diving community consider *Monitor* a "holy grail" of wreck diving.[37,38] Increasing strong storms[23] and rain events[11] can move sediment, covering dive sites.[15] These same events, along with sea level rise, are expected to increase coastal flooding[24,25,36] and could damage infrastructure, impeding access for scientific and recreational divers alike.

Climate change may make diving *Dixie Arrow* and other shipwrecks more difficult in coming decades. *Photo: Joe Hoyt/NOAA*

Climate change is also altering living resources, driving changes in human uses. Many shipwrecks, including *Monitor*, act as artificial reefs, providing habitat for ecologically and economically important species such as black sea bass and spiny lobster.[38,39] The location of the sanctuary near the northern extent of many warm water species and the southern extent of many temperate species makes it biologically diverse with both groups present.[38] However, as waters warm, many species are moving northward or to deeper waters.[40] This movement could lead to changes in the species targeted and techniques used by fisheries. Such changes could result in increasing or decreasing impacts on maritime heritage resources dependent on the techniques used and species targeted.

What Is Being Done?

NOAA studies and monitors the condition of *Monitor*, including the biological community that uses it as habitat and the deterioration of its concretion, hull, and other materials. This monitoring is undertaken to better understand and preserve *Monitor*, but any changes that are detected could also provide an early warning that it is being affected by climate change. In 2002, NOAA and the U.S. Navy raised *Monitor*'s turret and brought it to The Mariners' Museum and Park in Newport News, Virginia, where it continues to undergo conservation and preservation. While climate change was not a consideration in this effort, this conservation will help protect the turret from the impacts of climate change it may have otherwise experienced at the wreck site.

In addition to direct conservation and monitoring of *Monitor*, NOAA's National Data Buoy Center maintains a scientific buoy just outside of the sanctuary's boundary. The environmental data this buoy collects, including wind speed, air temperature, and water temperature, is of tremendous value to local coastal communities and provides the type of long-term data needed to track and understand climate change in the region. Ultimately, the data gathered in and near the sanctuary can help NOAA better understand the rate and impacts of climate change in the region for improved management and protection of *Monitor* and the benefit of local coastal communities.

Conservation of *Monitor*'s turret is one of many ways the sanctuary is acting to protect the historic shipwreck. *Photo: Shannon Ricles/NOAA*

Photo: Joe Hoyt/NOAA

Citations

1. USGCRP (2018) Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. *U.S. Global Change Research Program*
2. DeVries et al. (2017) Recent increase in oceanic carbon uptake driven by weaker upper-ocean overturning. *Nature*
3. Gruber et al. (2019) The oceanic sink for anthropogenic CO2 from 1994 to 2007. *Science*
4. Haugan & Drange (1996) Effects of CO2 on the ocean environment. *Energy Conv. Manag.*
5. Doney et al. (2009) Ocean acidification: The other CO2 problem? *Annu. Rev. Mar. Sci.*
6. Wang et al. (2013) The marine inorganic carbon system along the Gulf of Mexico and Atlantic coasts of the United States: Insights from a trans regional coastal carbon study. *Limnol. Oceanogr.*
7. Hall et al. (2020) Acidification in the U.S. southeast: Causes, potential consequences and the role of the Southeast Ocean and Coastal Acidification Network. *Front. Mar. Sci.*
8. Reimer et al. (2017) Time series pCO_2 at a coastal mooring: Internal consistency, seasonal cycles, and interannual variability. *Cont. Shelf Res.*
9. Reimer et al. (2017) Multidecadal fCO_2 increase along the United States southeast coastal margin. *J. Geophys. Res. Oceans*
10. Xue et al. (2017) Sea surface aragonite saturation state variations and control mechanisms at the Gray's Reef time-series off Georgia, USA (2006-2007). *Mar. Chem.*
11. Easterling et al, (2017) Precipitation change in the United States. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I. U.S. Global Change Research Program*
12. Allan & Soden (2008) Atmospheric warming and the amplification of precipitation extremes. *Science*
13. Spalding (2011) Perverse sea change: underwater cultural heritage in the ocean is facing chemical and physical changes. Cultural and heritage arts review. *The Ocean Foundation*
14. Perez-Alvaro (2016) Climate change and underwater cultural heritage: Impacts and challenges. *J. Cult. Herit.*
15. Wright (2016) Marine archaeology and climate change: An invitation. *J. Mari. Arch.*
16. Dunkley (2015) Climate is what we expect, weather is what we get: managing the potential effects of climate change on underwater cultural heritage. In: *Water and Heritage: material, conceptual, and spiritual connections*
17. Stramma and Schmidtko (2019) Global evidence of ocean deoxygenation. In: *IUCN: Ocean deoxygenation: Everyone's problem*
18. Mallinson et al. (2008) Past, present and future inlets of the Outer Banks barrier islands, North Carolina. *East Carolina University, NC*
19. Mallinson et al. (2018) Barrier island and estuary co-evolution in response to Holocene climate and sea-level change: Pamlico Sound and the Outer Banks barrier islands, North Carolina, USA. *Barrier Dynam. Resp. Chang. Clim.*
20. Culver et al. (2007) Late Holocene barrier island collapse: Outer Banks, North Carolina, USA. *Sed. Rec.*
21. Grand Pre et al. (2011) Rapid Holocene coastal change revealed by high-resolution micropaleontological analysis, Pamlico Sound, North Carolina, USA. *Quat. Res.*
22. Mallinson et al. (2011) Barrier island response to late Holocene climate events, North Carolina, USA. *Quat. Res.*
23. Knutson et al. (2019) Tropical cyclones and climate change assessment: Part II. Projected response to anthropogenic warming. *Bull. Am. Mar. Sci.*
24. Sweet & Park (2014) From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level. *Earth's Future*
25. Sweet et al. (2014) Sea level rise and nuisance flood frequency changes around the United States. *Technical Report NOS CO-OPS 073. NOAA Center for Operational Oceanographic Products and Services Technical Report NOS CO-OPS 073*
26. Thibeault & Seth (2014) Changing climate extremes in the Northeast United States: observations and projections from CMIP5. *Clim. Change*
27. Kossin et al. (2017) Extreme storms. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I. U.S. Global Change Research Program*
28. Baldini et al. (2016) Persistent northward North Atlantic tropical cyclone track migration over the past five centuries. *Sci. Rep.*
29. Slagen et al. (2014) Projecting twenty-first century regional sea-level changes. *Clim. Change*
30. Kopp et al. (2015) Past and future sea-level rise along the coast of North Carolina, USA. *Clim. Change*
31. Yin and Goddard (2013) Oceanic control of sea level rise patterns along the East Coast of the United States. *Geophys. Res. Lett.*
32. Rhamstorf et al. (2015) Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. *Nature Clim. Change*
33. Valle-Levinson et al. (2017) Spatial and temporal variability of sea level rise hot spots over the eastern United States. *Geophys. Res. Lett.*
34. Caffrey et al. (2018) Sea level rise and storm surge projections for the National Park Service. *Natural Resource Report NPS/NRSS/NRR—2018/1648. National Park Service*
35. Sweet et al. (2017) Global and regional sea level rise scenarios for the United States. *NOAA Technical Report NOS CO-OPS 083*
36. Marsooli et al. (2019) Climate change exacerbates hurricane flood hazards along US Atlantic and Gulf Coasts in spatially varying patterns. *Nat. Commun.*
37. Broadwater (2012) USS Monitor: A historic ship completes its final voyage. *Texas A&M University Press, College Station, TX*
38. ONMS 2020. Monitor National Marine Sanctuary designation draft environmental impact statement. *U.S. Department of Commerce, NOAA, Office of National Marine Sanctuaries*
39. Dixon (1990) Biology of the USS Monitor. *NOAA Center for Coastal Fisheries and Habitat Research*
40. Poloczanska et al. (2013) Global imprint of climate change on marine life. *Nature*

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