Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Climate Change Impacts

Thunder Bay National Marine Sanctuary

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Thunder Bay National Marine Sanctuary protects over 100 of the country's most well-preserved and nationally significant shipwrecks. *Photo: NOAA*

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 national monuments must face these global effects of climate change, each is affected differently.

Thunder Bay National Marine Sanctuary

For more than 12,000 years, people have traveled on the Great Lakes. From Native American dugout canoes to huge steel freighters, millions of voyages crossed the Inland Seas. In the last 150 years, the region has grown into one of the world's busiest waterways. Yet, with growth comes adversity. Fire, ice, collisions, and storms have claimed nearly 200 vessels in and around Thunder Bay. Today, through research, education, and engagement, the 4,300-square-mile Thunder Bay National Marine Sanctuary protects one of America's best-preserved and nationally significant collections of shipwrecks and inspires Great Lakes conservation. These sites possess great historical, archaeological, and recreational value and capture moments that transformed America, illuminating an era of national growth and reminding us of risks taken and tragedies endured.

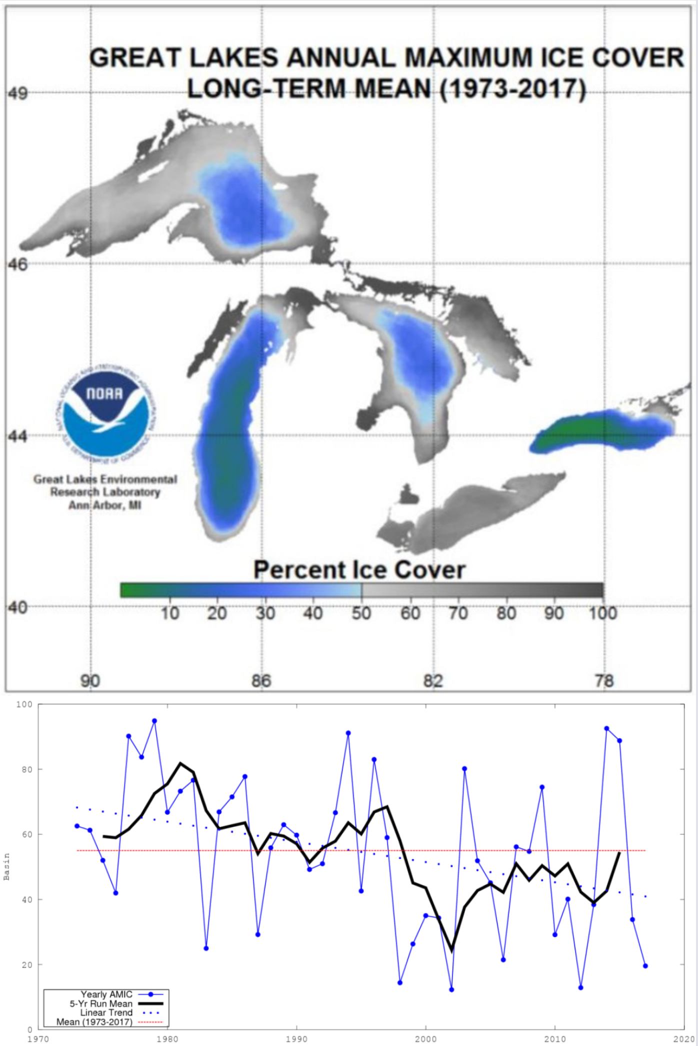
Changing Lake Levels

Climate change is altering water levels in lakes world wide.[1] While the number of factors affecting lake level make future levels difficult to predict, fluctuations are expected to become more intense with higher highs, lower lows, and less time between these extremes.[1,2] Lake level fluctuations are driven by variability in precipitation and evaporation.[1,3] These processes are fundamental to the Great Lakes water cycle and are expected to be influenced by climate change.

The *Portland* is just one of the shallow wrecks in Thunder Bay that could be affected by changing lake levels. *Photo: Tane Casserley/NOAA*

Annual evaporation is expected to increase in the region while the supply of water to Lake Huron is projected to become more variable.[4] Wetter springs and a decrease in summer rainfall by up to 15% are expected by 2100.[4,5] Further, periods of extreme rain[1,6] and extreme drought[4] are expected to become more

Case Study 1— Changing Lake Ice



Top: Long-term average ice cover. Bottom: Yearly Great Lakes average ice cover. Black line is 5-year average, dotted blue line is long-term trend, red line is long-term average. *Photo: Adapted from Wang et al.*[10]

Lake ice formation is a key process that affects Great Lakes water levels. Low ice cover can lead to high evaporation, lowering lake levels,[11] and potentially exposing shallow shipwrecks. In contrast, high ice cover can scour shallow wrecks but may also keep lake levels high and prevent excessive growth of invasive mussels.[12,13] Due to the many factors that determine ice cover year-to-year, and even decade-to-decade, trends in ice cover can be highly variable.[10] Across the Great Lakes, ice cover has declined since 1973,[10] despite high year-to-year variability, and average ice cover decreased by 69% from 1973 to 2017.[10] Warming temperatures and other factors are expected to lead to a long-term decline in lake ice duration and area.[1,13-16] If the extent and duration of ice cover continues to decline, it could lead to the exposure and increased degradation of some shallow shipwrecks.

common.[1] Drought can expose shipwrecks and extreme rain events can damage cultural resources through wind, waves, and flooding, which create strong water flows that damage shallow and beached shipwrecks.

Past events demonstrate the importance of evaporation and precipitation. In the 1990s, Lake Huron's water temperatures rose 3.6°F, causing evaporation rates 30% above normal which led to record low lake levels.[7,8] In contrast, the 2014 polar vortex brought high ice cover, greatly decreasing evaporation and leading to high lake levels. Further, several consecutive wet years led to record high lake levels in early 2020.

Lake Huron's cold, freshwater helps preserve shipwrecks. However, changing water levels could accelerate degradation of these sites, particularly those in shallow water. Lower lake levels can damage shipwrecks by further exposing shallow sites to the elements and accelerating natural degradation. Shipwrecks located on the beach or in shallow water are more visible and susceptible to increased human impact. Lower lake levels can increase sunlight and water temperatures leading to accelerated macroalgae and plant growth. This can impede access to sanctuary researchers and the public. Fluctuating water levels could further harm shallow and partially submerged wrecks as repeated wetting and drying can damage historic wood and other materials.[9]

While the ultimate future trend in lake level is uncertain, projected increases in water level variability and extreme events pose a threat to the cultural heritage protected by the sanctuary.

The *Albany* and other shallow wrecks could be impacted by changes to water levels in Lake Huron. *Photo: David Ruck/NOAA*

Case Study 2—Climate Change and the *Joseph S. Fay*

The *Joseph S. Fay* was lost to a strong gale on October 19, 1905. *Photo: NOAA*

On the night of October 19, 1905, the 216-foot bulk freighter *Joseph S. Fay* wrecked when it ran aground at Forty Mile Point during a strong gale. The lower hull of the *Fay* rests just off shore in 17 feet of water. Some of its iron ore cargo is still present, as are the ship's rudder, copper hull sheathing, portside engine mount, and other machinery. In addition, a 134-foot portion of the *Fay*'s starboard side rests on the beach not far from the lighthouse. Both the submerged and beached sections of the shipwreck are popular recreational sites. The beached section is also used as a training site for students interested in archaeology. More than a century after it wrecked, the *Fay* is again in danger.

The *Fay*'s location, with sections both underwater and on the beach, may make it particularly vulnerable to changes in lake level. Falling lake levels could expose the lower hull to more wave action, sunlight, and higher water temperatures, all of which could increase degradation. Higher light levels may also encourage macroalgal (seaweed) growth,[17] obscuring the wreck. Further, expected increases in lake level fluctuations could threaten the beached hull by exposing it to more wave action and increased wetting and drying, which can damage historic wood.[9] High water levels have already lifted the beached section and driven it further inland, damaging the structure, and uncovering areas of the hull that were previously buried and protected.

Chemical degradation of the *Fay* could also be accelerated by lake acidification, an increase in the acidity of water due to uptake of carbon dioxide.[9,18,19] Metallic portions of the wreck are the most likely to be impacted by acidification.[9,20] Copper, such as in the *Fay*'s hull sheathing, is particularly sensitive to acidity.[9,20] Warming waters also increase the rate of chemical reactions, accelerating chemical and biological degradation.[6]

The beached starboard hull of the *Joseph S. Fay* could be impacted by increasingly fluctuating lake levels. *Photo: NOAA*

Changing Ecological Communities

Together, invasive species and climate change are changing the natural ecology of the Great Lakes, which alters ecosystem functions and services.[21,22] While invasive species are not direct result of climate change, climate impacts, such as warming waters, can lead to the invasion of new areas or give invaders advantages over native species.[23-25]

Zebra and quagga mussels are invasive species of particular concern in Lake Huron. These mussels colonize shipwrecks, making it more difficult to see and study archaeological details.[26] They also reduce the structural integrity of wrecks by chemically accelerating degradation of wood and metal,[9,26,27] and encouraging the growth of bacteria that further degrade artifacts.[9,27] These mussels can also cause breakage through added weight and by providing an uneven surface that increases water turbulence.[9,26,28] There is also evidence that quagga mussels may be altering the chemistry of Lake Huron and contributing to lake acidification,[29] which could further degrade shipwrecks.[9,18-20] These mussels are already well-established on shipwrecks in the sanctuary and could potentially become more abundant as waters warm.[30]

Changing conditions also affect native species in the Great Lakes. The macroalgae *Cladophora* creates thick mats that obscure shipwrecks. While native to Lake Huron, *Cladophora* is becoming a nuisance by benefiting from the clearer waters and increased bottom nutrients produced by invasive zebra and quagga mussels. These conditions allow *Cladophora* to grow in deeper habitats, increasing the number of wrecks it may obscure.

Many of the shipwrecks in Thunder Bay have already been colonized by zebra and quagga mussels. Ship IDs (top to bottom): *Lucinda Van Valkenburg*, *Grecian*, *Kyle Spangler*. *Photo: Tane Casserley/NOAA; NOAA; NOAA*

Climate change could alter the extent and duration of ice cover on Lake Huron with consequences for sanctuary resources. *Photo: Kate Thompson/NOAA*

Changing Water Temperatures

As global temperatures rise, lakes absorb the heat.[1] The number of factors that control lake temperature make future changes difficult to predict. However, the air temperature in the region of Lake Huron, which lake surface temperature often follows, could increase up to 7.2°F by 2100.[5] Warming waters may impact cultural resources located in shallow water where temperatures fluctuate the most. The overall deterioration of shipwrecks could occur more quickly as rising temperatures increase the rate of both chemical and biological degradation.[9,18,31]

Increasing temperatures will also affect ice on Lake Huron. Ice cover can damage shallow shipwrecks but may also prevent the formation of thick beds of invasive mussels.[12,13] Further, low ice cover can lead to increased evaporation, lowering lake levels.[32] Ice cover on the Great Lakes has decreased slightly since 1973.[10] While this decline in the extent and duration of ice cover is expected to continue to over the coming century,[1,13-16] the number of factors that determine ice cover make it difficult to predict; some recent years (2018 and 2019) have brought high ice cover to Lake Huron.

Warming water temperatures are also increasing evaporation. Evaporation over the Great Lakes is expected to increase over the next century,[4] which could decrease lake levels and expose shallow or partially submerged cultural resources.[18] Warmer temperatures may also favor invasive species[23-25] that damage shipwrecks.

Lake Acidification

As carbon dioxide (CO_2) is released into the atmosphere, it is absorbed by lake and ocean waters, causing a chemical reaction that leads to waters becoming more acidic. Lake acidification differs from ocean acidification as the chemistry of most lakes, and the potential for acidification, is mostly driven by the chemistry of the water they receive from their watershed. However, much like the ocean, the Great Lakes are projected to experience increased acidification largely as a result of absorbed atmospheric CO_2[11] rather than from acid rain and other watershed inputs, although the effects could be cumulative.

Metallic portions of cultural resources, such as the wreck of the *F.T. Barney* experience increased corrosion in increasingly acidic lake waters. *Photo: Tane Casserley/NOAA*

While scientists predict that the acidification of Lake Huron is highly likely, the relative lack of information on lake acidity makes it difficult to determine if it has already begun.[32] Regardless of whether acidification has begun, Lake Huron is projected to increase in acidity by as much as 40% by 2100.[32] This increased acidification could accelerate the corrosion of shipwrecks and other cultural resources.[1,9,18-20,31] Metal is especially vulnerable to higher corrosion under increasingly acidic conditions,[4,18-20] particularly copper.[20] In addition to direct damage, the higher rates of metal corrosion due to lake acidification could further harm shipwrecks by weakening their structural integrity, increasing the possibility of damage by waves, currents, and the weight of invasive mussels.

What is being done?

NOAA is addressing climate change and other impacts specific to the Great Lakes, the sanctuary, and surrounding communities. Through education and outreach, research and monitoring, and sanctuary operations, staff, volunteers, and partners are working to mitigate climate and non-climate impacts alike. Sanctuary staff are finding ways to lower their own greenhouse gas emissions. All sanctuary buildings have geothermal HVAC, a low-carbon alternative. In addition, the Great Lakes Marine Heritage Center in Alpena, Michigan is a LEED gold certified building.

Communicating about climate change is important to build understanding of threats and changing conditions in the sanctuary and Great Lakes region. NOAA actively participates in outreach and education with students, teachers, and the public throughout the region to enhance understanding of the causes and impacts of climate change. One program, called "visualizing climate change," allows docents to use NOAA's innovative Science on a Sphere to communicate the global and local impacts of climate change in a way that is engaging, informative, and fun. In addition to the ways the sanctuary is addressing the impacts of climate change, there are many ways you can help.

The cultural resources protected by the sanctuary are an irreplaceable connection to our collective past. *Photo: David J Ruck/NOAA*

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