Levees Against the Rising Tide: Protecting Underwater Cultural Heritage From Climate Change Threats

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Abstract

The term "underwater cultural heritage," or "UCH," may call to mind sunken temple ruins or an ancient shipwreck languishing on the ocean floor. Although some UCH artifacts have been removed from the ocean, most UCH remains *in situ*, or in its original place. As such, UCH is very vulnerable to the effects of climate change, namely increased ocean temperatures, ocean acidification, sea level rise, and extreme weather. Thus, in order to protect UCH to the level that conservationists hope to achieve, it is necessary to protect the underwater environments in which UCH is preserved from the worst effects of climate change.

The first chapter of this paper explores the significant threats that climate change poses to *in situ* UCH. In underwater environments, various physical, chemical, and biological deteriorative agents cause the degradation of common UCH materials (i.e., wood, metal, and stone) over time. Although all of these modes of degradation are normal for materials preserved underwater, climate change will exacerbate the rate and intensity of this deterioration. This is because the effects of climate change on marine environments (i.e., sea surface temperature increase, ocean acidification, and increased storm severity) will disturb the equilibrium of preserved materials with their surrounding environment in various ways.

Luckily, a variety of U.S. federal laws exist for the protection of UCH. Thus, the second chapter of this paper examines the most prominent and substantive of these laws, namely, the National Marine Sanctuaries Act and the Antiquities Act. However, while the laws discussed herein do have the *capacity* to protect both UCH and the large marine areas in which they are preserved from certain effects of climate change (namely, agricultural-runoff-driven ocean acidification), they are currently unable to do so. Accordingly, this paper concludes by offering several specific recommendations on how existing U.S. legal frameworks can be extended to enhance UCH resilience and mitigate degradation due to the acidification of the surrounding marine environment.

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Introduction

It is said that a rising tide lifts all boats. However, to those interested in preserving underwater cultural heritage ("UCH"), that is very bad news. According to the Intergovernmental Panel on Climate Change ("IPCC"), ocean ecosystems are already suffering the consequences of climate change, including sea level rise, hot extremes, heavy precipitation events or regional decreases in precipitation, increased storm severity, ocean acidification, and widespread deterioration of ecosystem structure, resilience, and adaptive capacity.[1] With each year that goes by, "the magnitude and rate of climate change and associated risks," which have already resulted in the transformation of marine environments, "will continue to escalate with every increment of global warming."[2] In the next twenty years, the IPCC predicts that hotter temperatures and the increased frequency, severity, and duration of extreme weather will threaten many terrestrial, freshwater, coastal, and marine ecosystems.[3] If we allow global warming to exceed 1.5ºC, scientists predict that most ocean and coastal ecosystems will be threatened within the century by increases in the frequency, intensity, and severity of droughts, floods, heatwaves, and tropical storms, as well as by continued sea level rise.[4]

While scientists and policymakers have thus far been largely focused on the effects of climate change on natural ecosystems and the associated consequences for human societies, our underwater cultural heritage will also be a victim of the impending effects of climate change.

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[1] *Summary for Policymakers*, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, at 9, available at https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf.

[2] *Id.* at 14.

[3] *Id.* at 13. Kelp and seagrass ecosystems, Arctic sea-ice ecosystems, and warm-water coral reefs will be most affected. *Id.*

[4] *Id.*, at 14–15.

The United Nations Educational, Scientific and Cultural Organization ("UNESCO") defines UCH as:

> [A]ll traces of human existence having a cultural, historical, or archaeological character which have been partially or totally under water, periodically or continuously, for at least 100 years such as:
>
> i. sites, structures, buildings, artefacts and human remains, together with their archaeological and natural context;
> ii. vessels, aircraft, other vehicles or any part thereof, their cargo or other contents, together with their archaeological and natural context; and
> iii. objects of prehistoric [i.e., pre-Columbian contact] character.[5]

This definition is inclusive of all archaeological finds underwater, including underwater archaeological sites (such as sunken cities and submerged landscapes), shipwrecks, and sunken aircraft.[6] Currently, "the archaeological remains of more than three million vessels, as well as historic/archaeological monuments and whole cities" are preserved as UCH worldwide.[7] Perhaps the most famous UCH remains are those of shipwrecks, such as the famous *RMS Titanic*, which sank after a collision with an iceberg in 1912,[8] or the pirate Blackbeard's flagship the *Queen Anne's Revenge*, one of the most legendary ships of the Golden Age of Piracy, which is preserved today in North Carolina, where it ran aground in 1718.[9] However, despite being

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[5] United Nations Education Science Cultural Organization Convention on the Protection of Underwater Cultural Heritage, Nov. 2, 2001, 41 L.L.M. 40, 41 [hereinafter UNESCO Convention]; Ole Varmer, *Closing the Gaps in the Law Protecting Underwater Cultural Heritage on the Outer Continental Shelf*, 33 STAN. ENV'TL L. J. 251, 255–56 (2014).

[6] Aisling Tierney, *International Organisations and Legislation Affecting Underwater Cultural Heritage, Proceedings of Conference 2006*, ASS'N OF YOUNG IRISH ARCHAEOLOGISTS, at 82 (Feb. 2006), available at https://www.academia.edu/3633268/International_Organisations_and_Legislation_Affecting_Underwater_Cultural_Heritage?email_work_card=view-paper; Underwater cultural heritage, 60 MUSEUM INTERNATIONAL 4 (Dec. 2008), https://unesdoc.unesco.org/ark:/48223/pf0000181217; What is Underwater Cultural Heritage (UCH)?, MAJOR PROJECTS FOUNDATION, https://majorprojects.org.au/project/what-is-underwater-cultural-heritage/.

[7] Michela Ricca & Mauro Francesco La Russa, Challenges for the Protection of Underwater Cultural Heritage (UCH), from Waterlogged and Weathered Stone Materials to Conservation Strategies: An Overview, 3 HERITAGE 402, 402 (2020).

[8] Titanic (1997 Film), WIKIPEDIA, https://en.wikipedia.org/wiki/Titanic_(1997_film).

[9] *AIA Supports the Preservation of a Historical Underwater Shipwreck*, ARCHAEOLOGICAL INSTITUTE OF AMERICA (July 4, 2012), https://www.archaeological.org/aia-supports-the-preservation-of-a-historical-underwater-shipwreck/.

immortalized in film and in legend, these wrecks—along with other forms of UCH preserved on the ocean floor—are far from eternal.

Rather, UCH faces a suite of threats from human activity and the underwater environment itself as well as from climate change. In fact, the continued survival of UCH is very closely tied to our ability to mitigate the consequences of climate change, which will both further exacerbate the natural degradation of UCH via wood boring organisms, bacteria, corrosion, erosion, and scour, and create new problems, such as increased ocean temperatures, ocean acidification, and more extreme weather. While not the usual focus of climate activists' concern, the preservation of underwater cultural heritage is important and meaningful, as these artifacts offer a fragile window to the past that, once destroyed, can never be recovered. As Bradley Rodgers, the director of East Carolina University's maritime studies program, puts it: "These are nonrenewable resources. If they are destroyed, either by man or by nature, we lose a big chunk of our past. They are time capsules of the period for which they existed. If they disappear, we lose our knowledge of that period."[10]

Laws protecting UCH often prioritize the preservation of UCH *in situ*, a term of art meaning "in its original place."[11] This is largely for logistical reasons, namely, the size of some underwater ruins and the instability and fragility of certain objects, such as old wooden

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[10] Marion Blackburn, *The Science of Shipwrecks*, NORTH CAROLINA COASTWATCH (Winter 2013), https://ncseagrant.ncsu.edu/coastwatch/previous-issues/2013-2/winter-2013/the-science-of-shipwrecks/.

[11] Ricca & La Russa, *supra* note 7 ("Special attention [is] given . . . to preventive conservation in situ, including all actions and solutions to reduce the deterioration and loss of historical/archaeological sites and ancient material remains."); UNESCO Convention, *supra* note 5, at 41, 42, 51 ("The preservation *in situ* of underwater cultural heritage shall be considered as the first option before allowing or engaging in any activities directed at this heritage," such as intrusive research or recovery); Mariano J. Aznar, *In Situ Preservation of Underwater Cultural Heritage as an International Legal Principle*, 13 J. MARITIME ARCHAEOLOGY 67 (2018) ("The in situ preservation of underwater cultural heritage is [generally] conceived of as a mandatory rule that brooks no exception."); Varmer, *supra* note 5, at 262–63 ("The 2001 UNESCO Convention is based on four main principles: 1) the obligation to protect UCH; 2) in situ preservation policies and scientific rules for research and recovery; 3) a prohibition on commercial exploitation of this heritage; and 4) cooperation among States to protect this heritage, particularly with regard to training, education, and outreach.").

shipwrecks, which cannot be easily removed from the water without disintegrating.[12] Because these delicate relics of our past are largely unable to be removed from their underwater homes, the consequences of climate change for marine environments—such as temperature rise, ocean acidification, and storm severity—pose a threat to the continued *in situ* preservation of UCH.

Chapter one of this paper will discuss the threats to *in situ* UCH from environmental factors and climate change. This will include a discussion of deteriorative agents that act upon wood, metal, and stone materials preserved in underwater environments and an analysis of how the primary consequences of climate change (i.e., sea surface temperature increase, ocean acidification, and increased storm severity) will exacerbate current processes of deterioration. Chapter two will discuss the existing legal protections for UCH in the United States and will argue that, although certain U.S. federal laws theoretically have the *capacity* to mitigate the deterioration of UCH (specifically, by alleviating ocean acidification in the marine environments in which UCH is preserved), these legal frameworks are unable to do so in practice. Nevertheless, this paper argues that it remains possible for the existing legal framework protecting UCH to be extended to mitigate ocean acidification, and will make several specific recommendations on how to do so.

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[12] David Gregory, Poul Jensen, & Kristiane Strætkvern, *Conservation and in situ preservation of wooden shipwrecks from marine environments*, 13 J. OF CULTURAL HERITAGE 1, 1 (Mar. 2012), available at https://www.academia.edu/30834551/Conservation_and_in_situ_preservation_of_wooden_shipwrecks_from_marine_environments (explaining that waterlogged wooden materials must be dried under controlled conditions when they are removed from the water, lest they be damaged). *See also* Tiffany Piotti, *Voices from the Deep*, APPALACHIAN STATE UNIVERSITY (n.d.) at 14, available at https://www.academia.edu/29740201/Voices_from_the_Deep_Submerged_Shipwreck_Preservation ("In situ preservation was required due to the advanced deterioration of the [RMS Titanic]'s structure").

CHAPTER I: UNDERWATER ECOSYSTEMS

UCH faces threats on two primary fronts: From human activity and from nature itself. While the threats to UCH from human activities, such as looting, industrial trawling, and coastal development, are significant and should not be overlooked,[13] such considerations are outside the scope of this paper. Instead, this chapter will discuss the threats to UCH that arise from nature. To that end, Part 1 discusses the various factors that cause UCH to deteriorate when exposed to underwater environments, and Part 2 discusses the threats to UCH from climate change, which will exacerbate these modes of deterioration.

1. Underwater Deteriorative Agents

While *in situ* preservation of UCH is prioritized, often for the sake of practicality,[14] allowing delicate artifacts to remain exposed to the elements means that they will inevitably

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[13] *Protecting Underwater Cultural Heritage*, UNESCO, https://en.unesco.org/underwater-heritage. Looting in particular is a pervasive problem and often leads to the destruction of delicate heritage sites. *The Amphora war: looting of ancient shipwrecks is widespread, how can it be stopped?*, UNESCO (Nov. 1987), https://unesdoc.unesco.org/ark:/48223/pf0000076557 ("Today, treasure hunters spend more time searching under the sea than on land."); Timothy O'Hara, *'Take Only Photos' Sanctuary warns of looting from local shipwrecks*, KEYSNEWS (Dec. 18, 2022), https://www.keysnews.com/news/local/sanctuary-warns-of-looting-from-local-ship-wrecks/article_3e6767a4-4ee8-11ed-82ca-77c79599cc3b.html (discussing the significant disturbance and looting of a shipwreck at NOAA's Florida Keys National Marine Sanctuary, exposing wooden frames and planking which will now degrade much more quickly); *"Particularly rare" 2,200-year-old shipwreck looted and damaged off French coast*, CBS NEWS (April 28, 2022, 8:00 AM), https://www.cbsnews.com/news/shipwreck-fort-royal-1-looted-damaged-france/ (reporting that a particularly rare "ancient trading ship carrying wine that lay undiscovered at the bottom of the Mediterranean Sea for more than 2,000 years has been damaged and looted since being discovered by archaeologists"); Oliver Holmes, Monica Ulmanu & Simon Roberts, *The world's biggest grave robbery: Asia's disappearing WWII shipwrecks*, THE GUARDIAN (Nov. 3, 2017, 1:22 PM), https://www.theguardian.com/world/ng-interactive/2017/nov/03/worlds-biggest-grave-robbery-asias-disappearing-ww2-shipwrecks (discussing the destruction of up to 40 WWII-era ships salvage divers); Joshua Learn, *'Metal Pirates' Are Scrapping Parts From Sunken World War II Wrecks*, INSIDE SCIENCE (July 17, 2019), https://www.insidescience.org/news/metal-pirates-are-scrapping-parts-sunken-world-war-ii-wrecks (explaining that looters also sometimes seek to remove parts of the UCH themselves, as "metal and bronze and all the casings of the electrical components of the ship bring in large amounts of money").

[14] *See* sources cited *supra* notes 11–12.

continue to disintegrate over time due to interactions with the underwater environment.[15] However, after a certain period of time, UCH reaches an equilibrium with this environment, which dramatically slows deterioration, meaning that the rate of UCH degradation from the mechanisms discussed below is slower than it may at first appear.[16]

Sustaining these equilibrium conditions, however, is dependent on the natural conditions of the site remaining stable over time.[17] Thus, changes in environmental conditions such as the motion of waves or currents that can cyclically bury and re-expose UCH, changes in water pressure and temperature, the growth of communities of bacteria or other organisms, and hurricanes or earthquakes can disturb UCH sites and lead to increased deterioration.[18]

UCH is commonly composed of materials such as wood, metal, and stone, each of which is subject to various modes of deterioration in ocean environments. Each of these materials and its corresponding deteriorative processes is discussed in turn below.

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[15] The reality that marine environments invariably degrade UCH has led to some objections to the UNESCO Convention's preference for *in situ* preservation. *See e.g.*, James Sinclair, *Threats to Underwater Cultural Heritage–Real & Imagined, in* UNDERWATER CULTURAL HERITAGE & UNESCO IN NEW ORLEANS: AN INTRODUCTION, Odyssey Marine Exploration (2010), available at https://www.academia.edu/3597667/Sean_Kingsley_Underwater_Cultural_Heritage_and_UNESCO_in_New_Orleans_Introduction?email_work_card=view-paper ("One of the most outrageous statements that the UNESCO Convention advocates is that in situ preservation should be considered as a first option . . . [given that] [s]hipwrecks and lost cargos . . . undergo rapid chemical and natural deterioration once lost in the sea."); LAIRD MATTHEW CALLEN, UNESCO'S CONVENTION ON THE PROTECTION OF THE UNDERWATER CULTURAL HERITAGE, FIVE YEARS ON (Jan. 2014), available at https://www.academia.edu/7119241/UNESCOs_Convention_on_the_protection_of_the_Underwater_Cultural_Heritage_five_years_on?email_work_card=view-paper (acknowledging the conflict between leaving UCH *in situ* and long-term preservation of artifacts due to the effects of ocean currents and natural disasters).

[16] Piotti, *supra* note 12, at 3.

[17] *Id.* at 8.

[18] *Id.* at 3; A. J. Wheeler, *Environmental controls on Shipwreck Preservation: The Irish Context*, 29 JOURNAL OF ARCHAEOLOGICAL SCIENCE 1149, 1150–51 (2002).

a. Wood

Organic components of UCH, such as wood, are subject primarily to biotic deterioration in underwater environments.[19] A variety of marine organisms are able to attack and degrade wood, namely wood borers, fungi, and bacteria.[20] These wood degrading organisms can be separated into two categories: macroorganisms (i.e., bivalves and crustaceans) and microorganisms (i.e., fungi and bacteria).[21]

Macroorganisms cause erosion by physically consuming wood material. These macroorganisms include 'shipworms'—bivalves in the families *Teredinidae*, *Xylophagaidae* and *Pholadidae*—and 'gribbles'—isopod crustaceans in the families *Limnoriidae* and *Sphaeromatidae* and amphipod crustaceans in the family *Cheluridae*.[22] These organisms, collectively referred to as 'wood borers,' aggressively degrade wood by carving large tunnels through solid wooden structures using their calcareous shells.[23] This perforation causes wood materials to break down rapidly and significantly reduces their longevity underwater.[24] For example, wood boring organisms were able to achieve the complete disintegration of the

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[19] Gregory, Jensen, & Strætkvern, *supra* note 12.

[20] Kamil Roman, et al., *The Effects of Seawater Treatment on Selected Coniferous Wood Types*, 16 MATERIALS (Basel) 1 (Aug 25, 2023), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10488350/.

[21] Charlotte G. Björdal & Paul K. Dayton, *First evidence of microbial wood degradation in the coastal waters of the Antarctic*, 10 SCIENTIFIC REPORTS 1 (2020), https://www.nature.com/articles/s41598-020-68613-y.

[22] Juan A. Martín & Rosana López, *Biological Deterioration and Natural Durability of Wood in Europe*, 14 FORESTS 1 (Feb. 1, 2023), https://doi.org/10.3390/f14020283.

[23] Björdal & Dayton, *supra* note 21; E.B. Gareth Jones, Ruth D. Turner, S.E.J. Furtado, & H. Kühne, *Marine Biodeteriogenic Organisms I. Lignicolous Fungi and Bacteria and the Wood Boring Mollusca and Crustacea*, 48 INTERNATIONAL BIODETERIORATION & BIODEGRADATION 112 (2001), https://www.sciencedirect.com/sdfe/pdf/download/eid/1-s2.0-S0964830501000749/first-page-pdf; ROBERT A. ZABEL & JEFFREY J. MORRELL, CHAPTER TWO - WOOD DETERIORATION AGENTS IN WOOD MICROBIOLOGY at 19 (2020), https://doi.org/10.1016/B978-0-12-819465-2.00002-4.

[24] Björdal & Dayton, *supra* note 21.

Uluburun III, a replica of a real shipwreck that was dropped to the ocean floor in 2006 for divers to visit, within just two years.[25]

Microbial degradation of wood progresses much more slowly than macroorganism-dominated bioerosion, allowing wood to survive relatively intact for centuries.[26] The most prevalent microorganisms degrading submerged wood materials are bacteria and fungi.[27] Bacteria and fungi cause erosion by secreting enzymes that dissolve the cell walls of the wood in order to extract carbohydrates for metabolic use.[28] Wood-degrading bacteria include erosion bacteria, tunneling bacteria, and cavitation bacteria, while wood-degrading fungi include white-rot, brown-rot, and soft-rot.[29] Tunneling bacteria and white-rot are particularly damaging to wooden UCH as they cause degradation of lignin—the polymer responsible for the rigidity of the cell wall—in the middle lamella.[30] Degradation of lignin, known as 'delignification,' decreases the integrity of the cell wall, thereby increasing the likelihood that the wooden structure will collapse (see Figure 1).[31] Degradation of wood by erosion bacteria, cavitation bacteria, brown-rot, or soft-rot, on the other hand, typically allows wooden structures to retain their integrity,

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[25] Sarah Gilman, *How a Ship-Sinking Clam Conquered the Ocean*, SMITHSONIAN MAGAZINE (Dec. 5, 2016), https://www.smithsonianmag.com/science-nature/tunneling-clam-bedeviled-humans-sank-ships-conquered-oceans-180961288/.

[26] Björdal & Dayton, *supra* note 21.

[27] Charlotte G. Björdal, *Evaluation of Microbial Degradation of Shipwrecks in the Baltic Sea*, 70 INTERNATIONAL BIODETERIORATION & BIODEGRADATION 126 (May 2012), https://doi.org/10.1016/j.ibiod.2012.01.012.

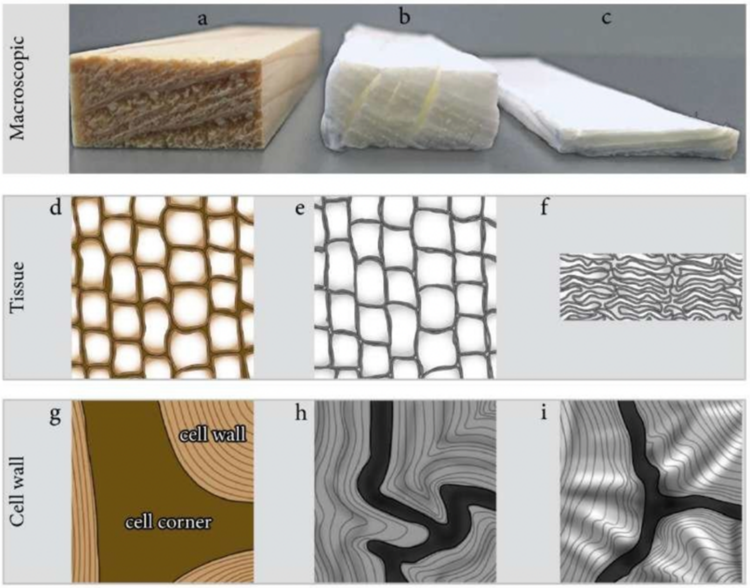
[28] Björdal & Dayton, *supra* note 21; Jones et al., *supra* note 23.

[29] Blanchette, Robert, *A Review of Microbial Deterioration Found in Archeological Wood From Different Environments*, 46 INTERNATIONAL BIODETERIORATION & BIODEGRADATION 189 (2000), 10.1016/S0964-8305(00)00077-9.

[30] In the process of extracting carbohydrates from wood cells, tunneling bacteria carve small tunnels through the cell walls which cause degradation of lignin. White-rot, on the other hand, consumes all components of the cell walls, with some species preferentially attacking the lignin, leading to the complete collapse of the wood structures. Blanchette, *supra* note 29.

[31] Marion Frey, Daniel Widner, Jana Segmehl, Kirstin Casdorff, Tobias Keplinger, & Ingo Burgert, *Delignified and Densified Cellulose Bulk Materials with Excellent Tensile Properties for Sustainable Engineering*, 10 ACS APPLIED MATERIALS & INTERFACES 1, 3 (2018), 10.1021/acsami.7b18646.

although they are still significantly weakened by the extraction of carbohydrate material from the cell walls.[32]



Delignification of native wood (a, d, g) results in a white cellulose scaffold (b, e). The matrix lignin is removed between the cells (e) and in the cell wall, which results in a flexible cell wall (h). Densification of the delignified cellulose scaffold (c) results in a homogenous folding of the earlywood cells (f) and in wrinkling of latewood cells (i).

Figure 1. The effects of the removal of lignin from wood cell walls.[33]

While the rate at which wood degrades underwater can depend on the species of wood and the duration of submersion, the chemistry of the surrounding water also plays a role.[34] Specifically, factors that enhance the rate of degradation include temperature, dissolved oxygen concentration, and salinity.

In general, erosion due to marine organisms is much more pronounced in warmer waters than in cold waters.[35] This may be because many species of wood boring macroorganisms—

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[32] Erosion bacteria carve large troughs into the surface of the wood while cavitation create cavities in the wood cell walls, but do not significantly degrade lignin in the middle lamella, which allows the cells to retain their structure. Brown-rot and soft-rot primarily extract carbohydrates with some lignin modification, which results in either the formation of cavities in or progressive erosion of the secondary cell wall, but no degradation of the middle lamella. Blanchette, *supra* note 29.

[33] Frey, et al., *supra* note 31.

[34] Björdal, *supra* note 27.

[35] Björdal & Dayton, *supra* note 21.

which cause the most rapid degradation—are warm-water or temperate-water species, leaving only soft-rot fungi and tunneling bacteria to conduct bioerosion in colder waters.[36] Given that wood borers like shipworms tend to breed and colonize wood during warmer seasons, increasing ocean temperatures may "increase [shipworms'] distribution and range, increase the animals' activity and extend the window of time in which they can reproduce."[37]

In addition, the metabolic reaction rates of fungi have been shown to increase with temperature, resulting in a twofold increase in rates of wood decay for every 10°C increase.[38] However, the overall effect of warmer waters on microbial degradation of wood is uncertain, given that the rate and severity of this degradation is also positively correlated with dissolved oxygen concentrations and nutrient availability,[39] both of which are reduced with increased water temperatures.[40]

The salinity and dissolved oxygen concentration of the marine area in which UCH is preserved also determines whether (and which) macroorganisms or microorganisms are primarily responsible for the degradation of wood. For example, wood boring macroorganisms are

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[36] Björdal & Dayton, *supra* note 21; Martín & López, *supra* note 22. Populations of wood borers are thus particularly high in warm, tropical waters. *Id.*

[37] Gilman, *supra* note 25.

[38] Martín & López, *supra* note 22.

[39] Björdal, *supra* note 27.

[40] Warmer waters have been linked to reductions in dissolved oxygen, H. Jesse Smith, *Less Oxygen in a Warmer Ocean*, 356 SCIENCE 919, 919 (June 2, 2017), 10.1126/science.356.6341.919-g, as well as to reductions in nutrient availability due to reduced upwelling from nutrient-rich deep ocean waters. A. Bakun, B.A. Black, S.J. Bograd, M. Garcia-Reyes, A.J. Miller, R.R. Rykaczewski, & W.J. Sydeman, *Anticipated Effects of Climate Change on Coastal Upwelling Ecosystems*, 1 CURRENT CLIMATE CHANGE REPORTS 85 (2015), https://link.springer.com/article/10.1007/s40641-015-0008-4; Sonia Fernandez, *Warmer Water, Less Nutrition*, THE CURRENT (Oct. 26, 2021), https://news.ucsb.edu/2021/020445/warmer-water-less-nutrition; *What is upwelling*?, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://oceanservice.noaa.gov/facts/upwelling.html; O. Hoegh-Guldberg, R. Cai, E.S. Poloczanska, P.G. Brewer, S. Sundby, K. Hilmi, V.J. Fabry, and S. Jung, 2014: The Ocean. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1655-1731. Available at https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap30_FINAL.pdf.

restricted to oxygenated and saline waters, as they cannot survive in low-oxygen and freshwater environments.[41] Thus, in freshwater, brackish water, and anoxic water, microorganisms are the dominant bio-deteriorators of wood materials.[42] In addition, white-rot and brown-rot fungi also require the presence of free oxygen in wood pores in order to colonize submerged wooden material and do not thrive in low-oxygen environments,[43] meaning that degradation of wood in anoxic environments is carried out primarily by bacteria and soft-rot fungi.[44]

Burial under sediment also creates anoxic conditions[45] and can thus protect wood materials from degradation by wood borers, white-rot, and brown-rot. Experiments have shown that wood materials buried under at least 10 cm of sediment are safe from the effects of wood borers, although they are still subject to degradation from soft-rot, tunneling bacteria, and erosion bacteria.[46] Wood materials buried at least 43 cm below the surface, however, are subject to degradation only from erosion bacteria, dramatically reducing their rate of decay.[47]

b. Metal

The primary deteriorative agent of metals present in UCH is corrosion, which can proceed either via abiotic or biotic processes. The process of abiotic metal oxidization in water is

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[41] Björdal & Dayton, *supra* note 21. Shipworms are capable of living in waters with salinities greater than 5–9 ppt (parts per thousand), while gribbles are only capable of living in salinities greater than 16–20 ppt. *Id.*

[42] Björdal & Dayton, *supra* note 21.

[43] Martín & López, *supra* note 22.

[44] Björdal & Dayton, *supra* note 21.

[45] Gregory, Jensen, & Strætkvern, *supra* note 12, at 1–2.

[46] Charlotte Gjelstrup Björdal & Thomas Nilsson, *Reburial of shipwrecks in marine sediments: a long-term study on wood degradation*, 35 J. OF ARCHAEOLOGICAL SCIENCE 862 (Apr. 2008), https://www.sciencedirect.com/science/article/abs/pii/S0305440307001239.

[47] *Id.* This is because the anoxic conditions under sediment cover prevent wood boring macroorganisms from breathing. Gregory, Jensen, & Strætkvern, *supra* note 12, at 1–2.

known as electrochemical corrosion.[48] Electrochemical corrosion involves the deterioration of metals via oxidation and reduction (or redox) reactions, in which the metal loses electrons (is oxidized), while oxygen and water gain electrons (are reduced).[49] For example, in the case of iron, metallic iron is oxidized to iron ions by oxygen and water.[50] This process of iron corrosion is represented as:[51]

$$2\ \mathrm{Fe(s)} + \mathrm{O_2(g)} + 4\ \mathrm{H^+(aq)} \longrightarrow 2\ \mathrm{Fe^{2+}(aq)} + 2\ \mathrm{H_2O(l)}$$

While most metals will eventually corrode when exposed to water, certain metals are more susceptible to corrosion than others. Among the most susceptible are ferrous (i.e., iron-based) metals, such as steel, stainless steel, and cast iron, which are often found in UCH.[52]

Characteristics of water that accelerate the process of electrochemical corrosion include high concentrations of dissolved ions, a lack of dissolved calcium and magnesium (i.e., "soft water"), acidity (i.e., low pH), salinity, higher temperature, and high concentration of dissolved oxygen.[53] Although corrosion can occur in either freshwater or saltwater, saltwater corrodes metal five times faster than fresh water.[54] This is because saltwater is an electrolyte, meaning that it contains more dissolved ions than freshwater, which allows electrons to move out of the metal more easily, thereby speeding up the corrosion reaction.[55] Rates of electrochemical

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[48] Bailey Rodriguez, *The Effects of Saltwater on Metals*, SCIENCING (Apr. 27, 2018), https://sciencing.com/effects-saltwater-metals-8632636.html.

[49] 19.9: Corrosion- Undesirable Redox Reactions, UNIVERSITY OF CALIFORNIA DAVIS, https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_A_Molecular_Approach_(Tro)/19%3A_Electrochemistry/19.09%3A_Corrosion-_Undesirable_Redox_Reactions.

[50] *Id.*

[51] *Id.*

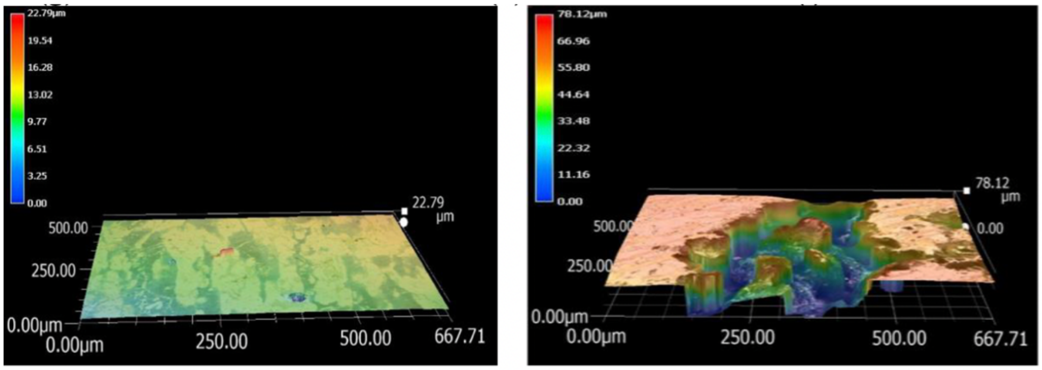
[52] *What Metals are Ferrous? (A Complete Guide)*, TWI GLOBAL, https://www.twi-global.com/technical-knowledge/faqs/what-metals-are-ferrous; *The Very Most Corrosion-Resistant Metals*, DAHLSTROM (Sept. 10, 2021), https://blog.dahlstromrollform.com/corrosion-resistant-metals.

[53] Ryan P. Gordon, *Corrosive Water – Facts, Common Questions, and Resources*, MAINE GEOLOGICAL SURVEY (Aug. 2016), https://www.maine.gov/dacf/mgs/explore/water/facts/corrosivity.pdf; Bailey Rodriguez, *The Effects of Saltwater on Metals*, SCIENCING (Apr. 27, 2018), https://sciencing.com/effects-saltwater-metals-8632636.html.

[54] *Id.*

[55] Julie Richards, *How Does Rust Form?*, SCIENCING (Apr. 24, 2017), https://sciencing.com/rust-form-4564062.html.

corrosion have been observed to accelerate both at higher temperatures (see Figure 2),[56] and higher levels of dissolved oxygen, respectively, despite the fact that higher temperatures are typically characterized by lower levels of dissolved oxygen and vice versa.[57] Notably, the correlation between corrosion rates and temperature is not present at dissolved oxygen levels below 2.0 ppm, with corrosion rates dropping to near zero around 1.0 ppm.[58]



3D microstructure of 40 °C   3D microstructure of 80 °C

Figure 2. 3D morphology of the corrosion of HDR (High Chromium, Duplex phase, Resists corrosion) duplex stainless steel at 40°C and 80°C.[59]

Corrosion can also be initiated and/or accelerated by the presence of biotic factors, namely bacteria and fungi, a process known as microbiologically influenced corrosion (MIC).[60]

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[56] Yufeng Lin, Xiaoqiang Wang, Zhuying Li, and Xiaodong Zhang, *The Effect of Temperature on Electrochemical Corrosion Behavior of HDR Duplex Stainless Steel*, 2541 J. PHYS.: CONF. SER. 1, 1 (2023), doi:10.1088/1742-6596/2541/1/012048.

[57] Gaius Debi Eyu, Geoffrey Will, Willem Dekkers, & Jennifer MacLeod, *Effect of Dissolved Oxygen and Immersion Time on the Corrosion Behaviour of Mild Steel in Bicarbonate/Chloride Solution*, 9 MATERIALS (BASEL) 1, (Sept. 1, 2016), doi: 10.3390/ma9090748; A. Ismail1 & N.H. Adan, *Effect of Oxygen Concentration on Corrosion Rate of Carbon Steel in Seawater*, 3 AMERICAN J. OF ENGINEERING RESEARCH 64 (2014), https://www.ajer.org/papers/v3(1)/J0316467.pdf; Nilay N. Khobragade, Ankur V. Bansod, and Awanikumar P. Patil, Effect of dissolved oxygen on the corrosion behavior of 304 SS in 0.1 N nitric acid containing chloride, 5 MATERIALS RESEARCH EXPRESS 1, 1 (2018), 10.1088/2053-1591/aab8de.

[58] E. Schaschl & G.A. Marsh, *The Effect of Dissolved Oxygen on Corrosion of Steel And on Current Required for Cathodic Protection*, 13 CORROSION 35 (Apr. 1, 1957), https://meridian.allenpress.com/corrosion/article-abstract/13/4/35/157162/The-Effect-of-Dissolved-Oxygen-on-Corrosion-of?redirectedFrom=fulltext.

[59] Lin et al., *supra* note 56, at 6.

[60] Edinson Puentes Cala, Valentina Tapia Perdomo, Daniela Espinosa-Valbuena, María Reyes-Reyes, Diego Quintero-Santander, Silvia Vasquez-Dallos, Henry Salazar, Pedro Santamaría-Galvis, Ramon Silva-Rodríguez, & Genis Castillo Villamizar, *Microbiologically Influenced Corrosion: The Gap in the Field*, 10 FRONTIERS IN ENV'TL SCIENCE (Sept. 15, 2022), https://www.frontiersin.org/articles/10.3389/fenvs.2022.924842/full.

Microbes that contribute to corrosion include sulfate-reducing bacteria (*Desulvovibrio* sp., *Desulfomonas* sp.), iron-reducing bacteria (*Pseudomonas* sp., *Shewanella* sp., *Geothermobacter* sp.), iron oxidizing/manganese oxidizing bacteria (*Gallionella* sp., *Leptothrix* sp., *Mariprofundus* sp.), sulfide-oxidizing bacteria (*Thiobacillus* sp.), acid producing bacteria and fungi (*Clostridium* sp., *Fusarium* sp., *Penicillium* sp., *Hormoconis* sp.), and slime forming bacteria (*Clostridium* sp., *Bacillus* sp., *Desulfovibrio* sp., *Pseudomonas* sp.).[61] Such corrosive bacteria are capable of fully degrading metal UCH within several hundred years. For example, the corrosive bacteria known as *Halomonas titanicae* is currently digesting the iron-based components of the *RMS Titanic* at a rate of 0.13 to 0.20 tons per day, meaning that the remains of the *Titanic* have a cumulative remaining lifespan of 280–420 years.[62]

MIC may be induced directly by the bacteria via acidic secretions, or indirectly via the formation of a biofilm.[63] Bacteria associated with direct corrosion of metals include sulfate-reducers, sulfur-oxidizers, iron reducers, and iron oxidizers/manganese oxidizers.[64] These bacteria can secrete corrosive substances such as hydrogen sulfide, nitric acid, and/or sulfuric acid that etch and dissolve metal surfaces.[65] For example, sulfur oxidizing bacteria induce corrosion according to the following reaction:[66]

$$SO_4^{2-} + H_2 \rightarrow S^{2-} + 4\ H_2O$$

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[61] Nardy Kip & Johannes A. van Veen, *The Dual Role of Microbes in Corrosion*, 9 THE ISME JOURNAL 542, Table 2 (2015), https://www.nature.com/articles/ismej2014169.

[62] Henrietta Mann, *The Appearance of New Bacteria (Titanic Bacterium) and Metal Corrosion, in* UNESCO SCIENTIFIC COLLOQUIUM ON FACTORS IMPACTING UNDERWATER CULTURAL HERITAGE 44 (2011);
D. Roy Cullimore, Charles Pellegrino, & Lori Johnston, *RMS Titanic and the emergence of new concepts on consortial nature of microbial events*, 173 REV. ENVIRON. CONTAM. TOXICOL., 117 (2002); Brenda J. Little, Jason S. Lee, Brandon R. Briggs, Richard Ray, & Andrew Sylvester, *Examination of archived rusticles from World War II shipwrecks*, 143 INTERNATIONAL BIODETERIORATION AND BIODEGRADATION 1, 1–6 (2019), https://doi.org/10.1016/j.ibiod.2016.12.005.

[63] Jaya Rawat, Neha Sharma, & Apoorve Khandelwal, *Microbiological Causes of Corrosion*, DIGITAL REFINING (Jul. 2014), https://www.digitalrefining.com/article/1000999/microbiological-causes-of-corrosion.

[64] *Id.*; Kip & van Veen, *supra* note 61, at 542.

[65] Kip & van Veen, *supra* note 61, Tables 1–2.

[66] *Id.*

Other bacteria known as slime forming bacteria induce corrosion via the formation of biofilms.[67] These slime forming bacteria secrete an extracellular polymeric substances (or biofilm) onto the metal surface.[68] This biofilm creates a protective environment for the bacteria to grow and alters the physical and chemical interactions between the metal and the environment, thereby enhancing corrosion rates by several orders of magnitude.[69] This is because biofilms are often "multispecies," hosting several communities of corrosive bacteria, resulting in higher rates of corrosion than one species would have been able to induce alone.[70]

Water temperature, dissolved oxygen levels, and pH have been shown to affect the abundance of corrosive bacteria. For instance, the abundance of sulfate-reducing and sulfur-oxidizing bacteria has been shown to correlate directly with temperature, indicating that the warmer the water, the greater the concentration of corrosion bacteria.[71] However, while sulfate-*reducing* bacteria has been positively correlated with low dissolved oxygen levels,[72] studies have found that sulfur-*oxidizing* bacteria and biofilm colonization is positively correlated with high dissolved oxygen levels.[73] Finally, various species of corrosive bacteria correspond to differing levels of pH—sulfate reducing bacteria tend to prefer a pH of around 7 (although it can still grow up to pH 9.6), while the anaerobic spore-forming bacteria *Sporomusa sphaeroides* does best in pH ranges between 6.4 and 7.6 (but can tolerate up to pH 8.7).[74]

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[67] Rawat, Sharma, & Khandelwal, *supra* note 63.
[68] *Id.*
[69] *Id.*
[70] Kip & van Veen, *supra* note 61, Table 1; Rawat, Sharma, & Khandelwal, *supra* note 63.
[71] Tian H, Gao P, Chen Z, Li Y, Li Y, Wang Y, Zhou J, Li G, Ma T, Compositions and Abundances of Sulfate-Reducing and Sulfur-Oxidizing Microorganisms in Water-Flooded Petroleum Reservoirs with Different Temperatures in China, 8 FRONT MICROBIOL. 1 (Feb. 2, 2017), doi: 10.3389/fmicb.2017.00143.
[72] Rawat, Sharma, & Khandelwal, *supra* note 63.
[73] Ming Sun, Weiwei Xu, Hui Rong, Jieting Chen, & Chenglong Yu, Effects of dissolved oxygen (DO) in seawater on microbial corrosion of concrete: Morphology, composition, compression analysis and transportation evaluation, 367 CONSTRUCTION AND BUILDING MATERIALS 1 (Feb. 27, 2023), https://www.sciencedirect.com/science/article/abs/pii/S0950061823000016.
[74] J. Knisz, R. Eckert, L.M. Gieg, A. Koerdt, J.S. Lee, E.R. Silva, T.L. Skovhus, B.A. An Stepec, & S.A. Wade, *Microbiologically influenced corrosion—more than just microorganisms*, 47 FEMS MICROBIOLOGY REVIEWS 1,

c. Stone

The primary mechanism of deterioration of stone materials underwater is bioerosion.[75] Like wood, agents of stone bioerosion include both macroorganisms (i.e., mollusks, echinoderms, bivalves, and sponges) and microorganisms (i.e., algae, bacteria, and fungi).[76] Macroorganisms can cause stone materials to degrade via either surface erosion or internal erosion.[77] Surface erosion is predominantly caused by herbivores, such as echinoderms, gastropod mollusks, and some fish, which graze on the surface of the carbonate rock.[78] Internal cavities are typically eroded by endolithic perforators, such as mollusks and some echinoderms,[79] which dig cavities or tunnels through the rock in which they live using their calcareous shells (in

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(July 12, 2023), https://doi.org/10.1093/femsre/fuad041; Jo Philips, Eva Monballyu, Steffen Georg, Kim De Paepe, Antonin Prévoteau, Korneel Rabaey, & Jan B.A. Arends, *An* Acetobacterium *strain isolated with metallic iron as electron donor enhances iron corrosion by a similar mechanism as* Sporomusa sphaeroides, 95 FEMS MICROBIOLOGY ECOLOGY 1, (Nov. 15, 2018), https://doi.org/10.1093/femsec/fiy222.

[75] Beatriz Cámara, Mónica Álvarez de Buergo, Manuel Bethencourt, Tomás Fernández-Montblanc, Mauro F. La Russa, Michela Ricca, & Rafael Fort, *Biodeterioration of Marble in an Underwater Environment*, 609 SCIENCE OF THE TOTAL ENVIRONMENT 109 (Dec. 31, 2017), https://doi.org/10.1016/j.scitotenv.2017.07.103; Ricca & La Russa, *supra* note 7; Sandra Ricci & Barbara Davidde, *Some Aspects of the Bioerosion of Stone Artefact Found Underwater: Significant Case Studies*, 14 CONSERVATION AND MANAGEMENT OF ARCHAEOLOGICAL SITES 1, 1–4, 28–34 (2012), 10.1179/1350503312Z.0000000003.

[76] Ricca & La Russa, *supra* note 7. See also S. Ricci, R. Sanfilippo, D. Basso, C.S. Perasso, F. Antonelli, and A. Rosso, Benthic Community Formation Processes of the Antikythera Shipwreck Statutes Preserved in the National Archaeological Museum of Athens (Greece), 14 J. Maritime Archaeology 81 (2018); R.G. Bromley, A Stratigraphy of Marine Bioerosion, 228 Geol. Soc. Lond. Spec. Publ. 455 (2004); B. Davidde Petriaggi, M. Bartolini, D. Poggi, & S. Ricci, Marine Bioerosion of Stone Artefacts Preserved in the Museo Archeologico dei CampiFlegrei in the Castle of Baia (Naples), 7 Archaeol. Maritima Mediterr. 1000 (2010); S. Ricci, C.S. Perasso, F. Antonelli, & B.D. Petriaggi, Marine Bivalves Colonizing Roman Artefacts Recovered in the Gulf of Pozzuoli and in the Blue Grotto in Capri (Naples, Italy): Boring and Nestling Species, 98 Int. Biodeterior. Biodegrad 89 (2015); S. Ricci, F. Antonelli, C.S. Perasso, D. Poggi, & E. Casoli, Bioerosion of Submerged Lapideous Artefacts: Role of Endolithis Rhizoids of Acetabularia Acetabulum (Dasycladales, Chlorophyta), 107 Int. Biodeterior. Biodegrad. 10 (2016).

[77] Ricca & La Russa, *supra* note 7, at 404.

[78] *Id.*

[79] Alexis Rudd, *The Sea Animal So Tough it Eats Rocks for Breakfast*, NATURE (Aug. 15, 2023), https://www.nature.com/scitable/blog/saltwater-science/the_sea_animal_so_tough/; *The Hole Story*, NEW SCIENTIST (May 24, 2017), https://www.newscientist.com/lastword/mg23431271-000-the-hole-story/.

the case of rock-boring mollusks) or their teeth.[80] This erosion of internal cavities, also called 'endolithic erosion,' is the most harmful to the longevity of underwater stone materials.[81]

Microorganisms that deteriorate stone materials typically do so by secreting organic acids that can etch or dissolve the stone, excreting organic chelating agents that can sequester metallic cations from the stone, or converting inorganic substances into inorganic acids that cause etching via redox reactions.[82] Anaerobic microorganisms also produce carbon dioxide through respiration, which forms carbonic acid when mixed with water, accelerating the dissolution of stone materials.[83] Finally, lichens–associations between fungi and photosynthetic green algae or cyanobacteria–that colonize stone materials anchor themselves via small root-like structures called rhizines, which penetrate deep into stone material via small cracks or weaknesses and introduce additional bacteria into the center of the stone.[84] Finally, microorganisms can also cause external damage to stone materials (i.e., abrasion) via colonization of the stone surface, a process known as biofouling or encrustation.[85] However, such encrustation can also, in some cases, act as a shield against other, more severe, forms of damage by obstructing the exposed stone surface, thereby bolstering conservation.[86] Thus, the most serious threat to long-term

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[80] *Id. See also* S. Golubic, R.D. Perkins, & K.J. Lukas, *Boring Microorganisms and Microborings in Carbonate Substrates, in* STUDY OF TRACE FOSSILS 259 (1975); *The Hole Story*, *supra* note 79; Rudd, *supra* note 79.

[81] Ricci & Davidde, *supra* note 75.

[82] P.S. Griffin, N. Indictor, & R.J. Koestler, *The Biodeterioration of Stone: a Review of Deterioration Mechanisms, Conservation Case Histories, and Treatment*, 28 INTERNATIONAL BIODETERIORATION 187, 188 (1991), available at https://repository.si.edu/bitstream/handle/10088/43127/mci32104.pdf.

[83] *Id.*

[84] Yufan Ding, Catia Sofia Clemente Salvador, Ana Teresa Caldeira, Emma Angelini, & Nick Schiavon, *Biodegradation and Microbial Contamination of Limestone Surfaces: An Experimental Study from Batalha Monastery, Portugal*, 2 Corrosion and Materials Degradation 31 (Jan. 13, 2021), https://www.mdpi.com/2624-5558/2/1/2; Christine C. Gaylarde & Jose Antonio Baptista-Neto, *Microbiologically induced aesthetic and structural changes to dimension stone*, 5 NPJ MATERIALS DEGRADATION 1 (June 17, 2021), https://www.nature.com/articles/s41529-021-00180-7.

[85] Ricca & La Russa, *supra* note 7, at 405.

[86] *Id.*

preservation of stone materials is endolithic erosion (i.e., perforation or excavation) (See Figure 3).[87]

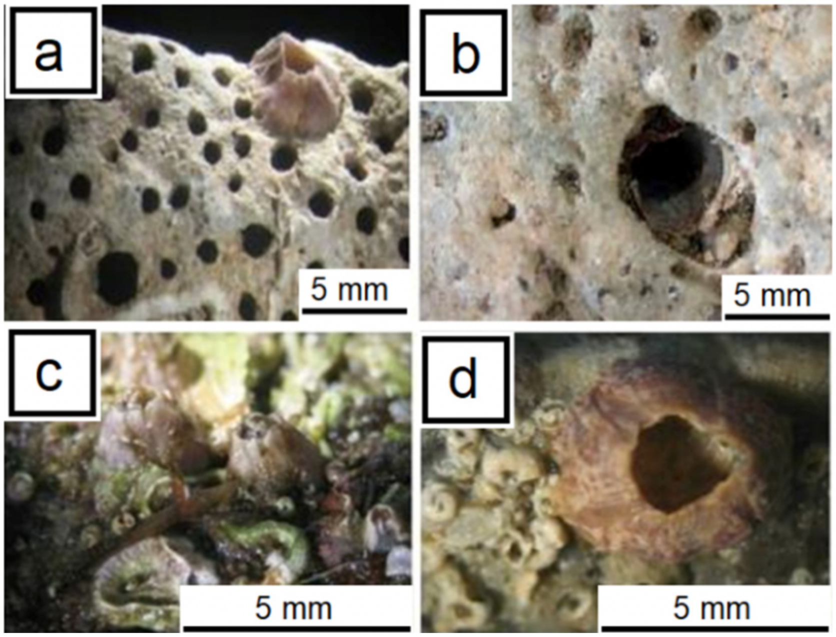

Figure 3. Stereomicroscopic observations of archaeological calcareous stone material. (a) and (b) show evidence of boring, while (c) and (d) show skeletal remnants of encrustation.[88]

Like wood and metal, the bioerosion of stone is moderated by environmental factors. For instance, the rate of stone weathering via biodeterioration tends to correlate with dissolved oxygen content, as many weathering organisms cannot survive in anoxic environments.[89] Thus, weathering of stone may proceed more quickly in colder waters than in warmer waters, and more quickly in shallower waters (which tend to be more saturated with oxygen due to their proximity to the surface) than in deeper waters.[90] Bioerosion also preferentially degrades some stone materials more than others. For instance, carbonate materials, such as limestone or dolomite, are

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[87] *Id.*
[88] Ricca & La Russa, *supra* note 7, at 405.
[89] Musa Tokmak & Murat Dal, *Types of Degradation Observed in Underwater Stone Artifacts, in* INTERNATIONAL SYMPOSIUM ON UNDERWATER RESEARCH 74 (June 2020), available at https://www.researchgate.net/publication/342171273_Types_of_Degradation_Observed_in_Underwater_Stone_Artifacts.
[90] *Id.*

the most vulnerable to bioerosion.[91] Of the carbonate rocks, marble is the most susceptible to biodeterioration, often suffering heavy biofouling (i.e., encrustation) and endolithic activity (see Figure 3).[92]

In addition, stone materials are also subject to direct weathering from environmental factors. For example, salt that is dissolved in water can enter small cracks or pores in the stone and crystallize, exerting pressure on the surrounding stone from within and causing cracks to form, either at the micro level or at the macro level.[93] Stones with larger pores or with preexisting damage are more vulnerable to this weathering.[94] Additionally, carbonate minerals dissolve when exposed to lower pH environments.[95]

2. Threats to UCH from Climate Change

Global climate change threatens to significantly disrupt equilibrium conditions of the underwater ecosystems in which UCH materials are preserved, thereby exacerbating the various mechanisms of UCH degradation discussed in Part 1.[96] In particular, sea surface temperature increase, ocean acidification, and increased storm severity pose the greatest threat to UCH

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[91] Mauro La Russa, Michela Ricca, Cristina Belfiore, Silvestro Ruffolo, Monica De Buergo, Ballester, & Gino Crisci, *The Contribution of Earth Sciences to the Preservation of Underwater Archaeological Stone Materials: An Analytical Approach*, 6 INT'L J. OF CONSERVATION SCIENCE 335 (Sept. 1, 2015), https://www.semanticscholar.org/paper/THE-CONTRIBUTION-OF-EARTH-SCIENCES-TO-THE-OF-STONE-Russa-Ricca/e4b0753d00312f1c933c78156da66587f9ba4439; Cámara et al., *supra* note 75; Ricca & La Russa, *supra* note 7, at 404.

[92] La Russa et al., *supra* note 91; Cámara et al., *supra* note 75.

[93] Tokmak & Dal, *supra* note 89, at 73–74.

[94] *Id.*, at 73.

[95] Ricca & La Russa, *supra* note 7. *Carbonate Rock*, SCIENCE DIRECT, https://www.sciencedirect.com/topics/earth-and-planetary-sciences/carbonate-rock.

[96] Protection of Underwater Cultural Heritage, UNESCO, https://en.unesco.org/underwater-heritage; Stephen Macko, Global Warming and Other Challenges to the Underwater Cultural Heritage by Global Change, in THE LEGAL REGIME OF UNDERWATER CULTURAL HERITAGE AND MARINE SCIENTIFIC RESEARCH 259 (2020); SPECIAL REPORT ON THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (2019), available at https://www.ipcc.ch/srocc [hereinafter IPCC 2019].

preservation. This section will examine the consequences of each of these effects for underwater ecosystems in U.S. territorial waters and for the continued preservation of UCH.

a. Sea Surface Temperature Increase

The most well-known consequence of global climate change for the preservation of UCH is temperature increase. Over the past half century, hundreds of studies have been conducted that show that the world's oceans are warming at an unprecedented rate and scale.[97] The last century saw increases in global sea temperatures between 0.5 and 1°C, and the IPCC predicts further increases of 0.3–2°C by the end of this century (see Figure 4).[98]

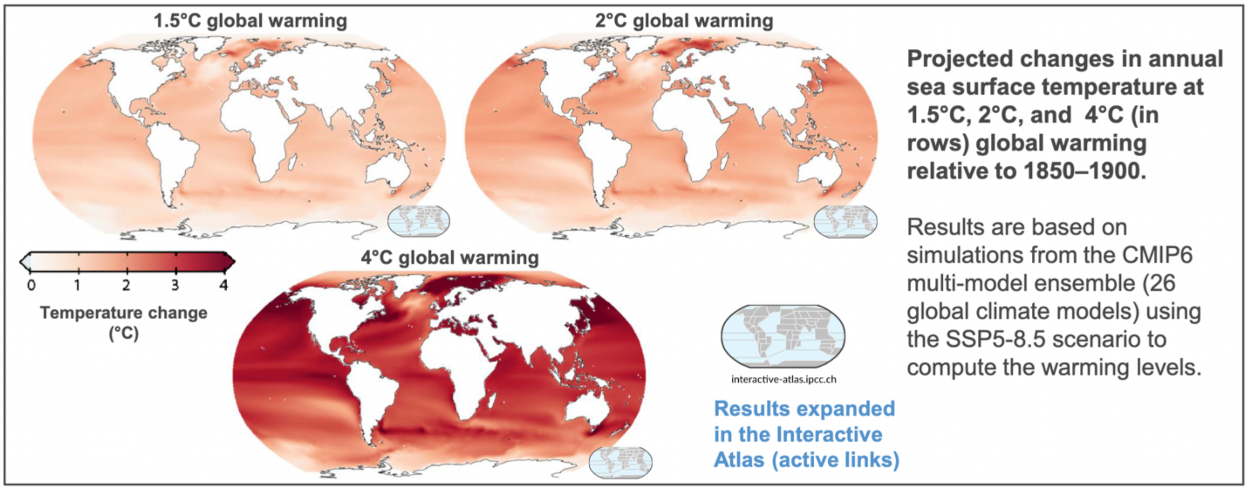

Figure 4. IPCC climate models predicting changes in annual sea surface temperature for three global warming scenarios—1.5°C, 2°C and 4°C.[99]

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[97] Elahe Akbari, Seyed Kazem Alavipanah, Mehrdad Jeihouni, Mohammad Hajeb, Dagmar Haase, and Sadroddin Alavipanah, *A Review of Ocean/Sea Subsurface Water Temperature Studies from Remote Sensing and Non-Remote Sensing Methods*, 9 WATER 936, 937–38 (2017), https://doi.org/10.3390/w9120936.

[98] David Gregory, Tom Dawson, Dolores Elkin, Hans Van Tilburg, Chris Underwood, Vicki Richards, Andrew Viduka, Kieran Westley, Jeneva Wright, & Jørgen Hollesen, *Of time and tide: the complex impacts of climate change on coastal and underwater cultural heritage*, 96 Antiquity 1396, 1401 (Nov. 2, 2022), available at https://doi.org/10.15184/aqy.2022.115. *See also* IPCC 2019, *supra* note 96; *Regional Fact Sheet – Ocean, in* SIXTH ASSESSMENT REPORT: WORKING GROUP I – THE PHYSICAL SCIENCE BASIS, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, available at https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Ocean.pdf.

[99] *Regional Fact Sheet – Ocean*, *supra* note 98.

In addition, higher and higher percentages of the global oceans have been dominated by significant warming trends in recent years.[100] For example, between 1950 and 2016, sea surface temperatures of the Indian, Atlantic, and Pacific Oceans have increased by 0.11°C, 0.07°C and 0.05°C per decade, respectively.[101] As climate change progresses, warming will also occur at increasing depths as the ocean stores more heat energy.[102] The greatest overall temperature increase is in the top 100 meters of the Pacific Ocean.[103] In deeper waters, however, the Atlantic shows the greatest temperature increase averaged over the top 2,000 meters.[104] Much less heat is stored at even deeper depths—for instance, only about 5% of the heat in the Pacific Ocean is stored below 3,000 meters, but even this storage has increased dramatically since 1999.[105]

Such increased ocean temperatures will have a variety of effects, including shifts in rainfall, air temperatures, and wind systems, more severe tropical cyclones, more rapid chemical reaction rates underwater, and changes in the population and distribution of marine organisms.[106] Thus, trends in sea surface temperature can reveal how marine environments will change as climate change progresses.[107]

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[100] Gregory C. Johnson & John M. Lyman, *Warming trends increasingly dominate global ocean*, 10 NATURE CLIMATE CHANGE 757, 757 (2020), https://doi.org/10.1038/s41558-020-0822-0.

[101] *Impacts of 1.5ºC global warming on natural and human systems, in* SPECIAL REPORT: GLOBAL WARMING OF 1.5 ºC 3.3.7, available at https://www.ipcc.ch/sr15/chapter/chapter-3/; Hoegh-Guldberg et al., *supra* note 40.

[102] Akbari et al., *supra* note 97, at 940; *Impacts of 1.5ºC global warming on natural and human systems*, *supra* note 101.

[103] Akbari et al., *supra* note 97, at 940.

[104] *Id.*

[105] *Id.*, at 940–41.

[106] Gregory et al., *supra* note 98, at 1399–1402.

[107] Augustin Kessler, Nadine Goris, & Siv Kari Lauvset, *Observation-based Sea surface temperature trends in Atlantic large marine ecosystems*, 208 PROGRESS IN OCEANOGRAPHY 1, 1 (2022), https://doi.org/10.1016/j.pocean.2022.102902.

However, global trends of sea surface temperature are not necessarily reflective of local spatial variability in sea surface temperature.[108] Because sea surface temperature change will not be globally, or even regionally, uniform,[109] it is necessary to examine sea surface temperature trends on a more local scale—specifically, along the Atlantic and Pacific coastlines of the U.S.—in order to determine how UCH preserved in U.S. waters will be affected by warming temperatures.

Atlantic coastline

Multiple generations of models have shown repeatedly and with high confidence that the Atlantic Ocean is experiencing significant warming over time.[110] However, this warming is not uniform across the Atlantic Ocean. In the areas of concern for this project (i.e., along the east coast of the U.S.), average sea surface temperature largely tracks general sea surface temperature trends in the Atlantic, although sea surface temperatures nearer to the coast tend to fluctuate more than in the open ocean.[111]

At Cape Hatteras and northward, sea surface temperature has increased about 0.5°–1.3°C from the prior century's average, warming at a rate 1.8–2.5 times the regional atmospheric

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[108] C.M. Robles-Tamayo, J.E. Valdez-Holguín, R. García-Morales, G. Figueroa-Preciado, H. Herrera-Cervantes, J. López-Martínez, L.F. Enríquez-Ocaña, *Sea Surface Temperature (SST) Variability of the Eastern Coastal Zone of the Gulf of California*, 10 REMOTE SENSING 1434, 1435 (2018), https://doi.org/10.3390/rs10091434; K.D. Friedland & J.A. Hare, *Long-term trends and regime shifts in sea surface temperature on the continental shelf of the northeast United States*, 27 CONTINENTAL SHELF RESEARCH 2313, 2313 (2007), https://doi.org/10.1016/j.csr.2007.06.001.

[109] M. Collins, R. Knutti, J. Arblaster, J.L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver, & M. Wehner, *Long-term Climate Change: Projections, Commitments and Irreversibility, in* CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 1031 (T.F. Stocker, D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P.M. Midgley eds. 2013). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[110] Collins et al., *supra* note 109, at 1064; Kessler et al., *supra* note 107, at 1.

[111] Friedland & Hare, *supra* note 108, at 2313.

temperature trend.[112] In fact, one study identifies several northern U.S. coastal areas as zones of "superfast" warming, particularly the North Atlantic, the Northeast U.S. Continental Shelf, and the Gulf of Mexico (see Figure 5).[113] South of Cape Hatteras, studies have found temperature increases of approximately 0.8°C over the last century near the Florida Keys,[114] with sea surface temperatures in the Gulf of Mexico warming at a rate 2 times that of the global ocean (approximately 0.193° per decade).[115] Interestingly, this recent warming to the south of Cape Hatteras represents a regime change from yearly trends prior to 2010, which showed constant and even cooling coastal ocean temperatures, with some places decreasing between 1–2 °C per decade in January (potentially due to changes in the path of the Gulf Stream in winter).[116]

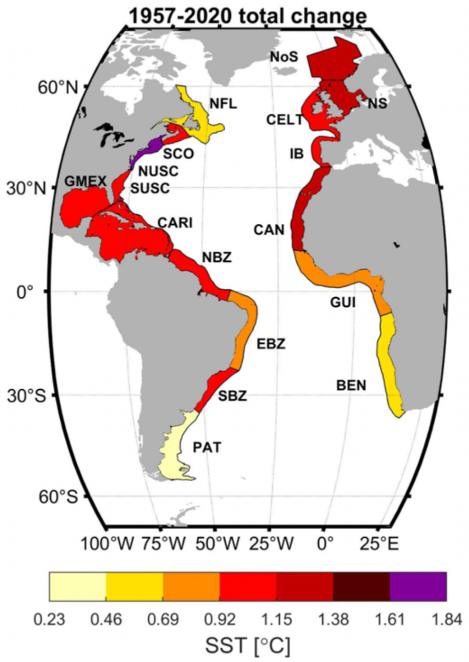

Figure 5. Total mean sea surface temperature change from 1957 to 2020 in Atlantic coastal areas.[117]

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[112] R. Kipp Shearman & Steven J. Lentz, *Long-Term Sea Surface Temperature Variability along the U.S. East Coast*, 40 J. OF PHYSICAL OCEANOGRAPHY, 1004, 1004 (2010), https://doi.org/10.1175/2009JPO4300.1.

[113] Kessler et al., *supra* note 107, at 1.

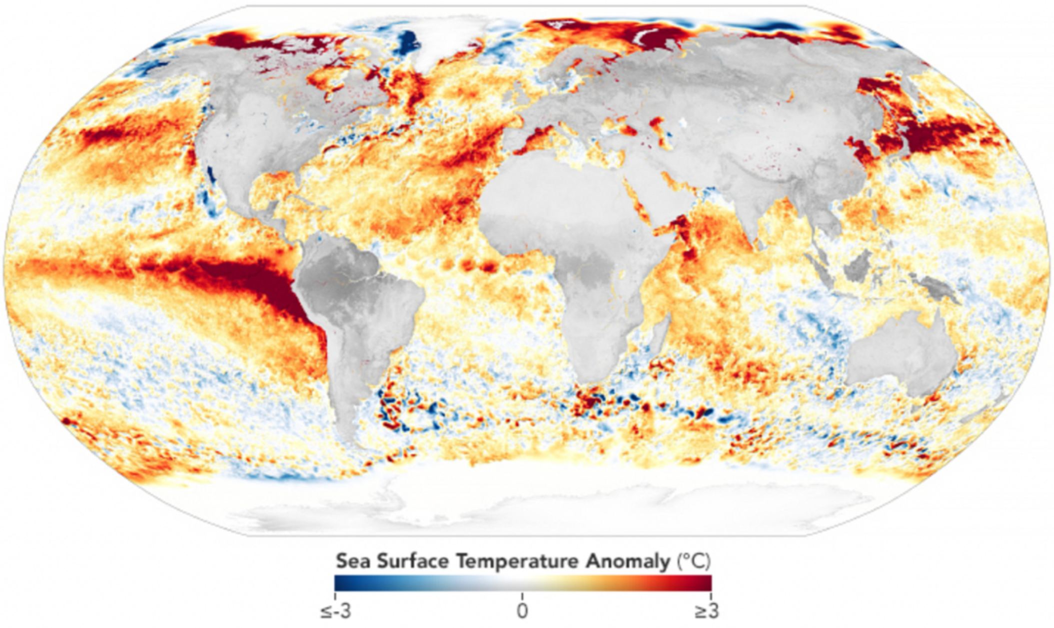
[114] Ilsa B. Kuffner, Barbara H. Lidz, J. Harold Hudson, & Jeffrey S. Anderson, *A century of ocean warming on Florida Keys coral reefs: Historic in situ observations*, 38 ESTUARIES COASTS, 1085, 1085 (Sept. 5, 2014), https://doi.org/10.1007/s12237-014-9875-5.

[115] Z. Wang, T. Boyer, J. Reagan, & P. Hogan, *Upper Oceanic Warming in the Gulf of Mexico between 1950 and 2020*, 36 JOURNAL OF CLIMATE 2721, 2725 (March 17, 2023), https://journals.ametsoc.org/view/journals/clim/aop/JCLI-D-22-0409.1/JCLI-D-22-0409.1.xml.

[116] Shearman & Lentz, *supra* note 112, at 1004; Fernando P. Lima & David S. Wethey, *Three decades of high-resolution coastal sea surface temperatures reveal more than warming*, 3 NATURE COMMUNICATIONS 704 (Feb. 28, 2012), https://doi.org/10.1038/ncomms1713.

[117] Kessler et al., *supra* note 107, at 5.

Comprising this overall heating of the Atlantic are marine heatwave events—defined as ocean temperatures exceeding the 90th percentile for the season for 5 or more days in a row.[118] Marine heatwaves have become more frequent over the last 40 years, and, as overall sea surface temperatures in the Atlantic increase, the IPCC expects that marine heatwaves will increase in frequency, duration, spatial extent, and intensity, although these trends will not be globally uniform (see Figure 6).[119] Therefore, while marine heatwaves are already a component of overall sea surface temperature trends at particular areas of interest along the U.S. coastline, their contribution to sea surface warming may become more significant as climate change progresses.



August 21, 2023

Figure 6. Sea surface temperature anomalies (reflecting satellite measurements of sea surface temperatures by NASA, NOAA, and international satellites, as well as ship and buoy data) in August 2023.[120]

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[118] *The Data Behind Our Warming Oceans*, NOAA, https://www.ncei.noaa.gov/news/data-behind-our-warming-oceans.

[119] M. García-Reyes, A. Leising, R. Asch, S. Bograd, & T.M. Hill, *Indicators of Climate Change in California, in* OFFICE OF ENVIRONMENTAL HEALTH HAZARD ASSESSMENT 57 (2022), https://oehha.ca.gov/media/epic/downloads/03coastaloceantemps.pdf; *Regional Fact Sheet – Ocean*, *supra* note 98.

[120] Adam Voiland, *The Ocean Has a Fever*, NAT'L AERONOTICS AND SPACE ADMIN. (Aug. 21, 2023), https://earthobservatory.nasa.gov/images/151743/the-ocean-has-a-fever.

One marine heatwave that contributed significantly to the overall warming trends on the eastern U.S. coastline occurred in 2012.[121] This heatwave was more intense than any in the preceding 30 years, raising temperatures 1–3°C above the 1982–2011 average from Cape Hatteras to Iceland and into the Labrador Sea.[122] This level of warming alone is on par with the global mean sea surface temperature change projected for the end of the century.[123] In fact, just this summer, temperatures near the Atlantic coast of the U.S. reached record daily highs, nearly 2 degrees above average.[124] Likely contributing to this dramatic warming was the massive marine heatwave that formed off the coast of Florida in the summer of 2023, with ocean temperatures reaching the triple digits, the warmest temperatures on record since 1981.[125]

Pacific coastline

Sea surface temperature across the Pacific has also been increasing fairly linearly over the last 60 years.[126] Near the western coast of the U.S., in particular, waters have demonstrably warmed over the past century, with the area near Southern California exhibiting the fastest

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[121] Katherine E. Mills, Andrew J. Pershing, Curtis J. Brown, Yong Chen, Fu-Sung Chiang, Daniel S. Holland, Sigrid Lehuta, Janet A. Nye, Jenny C. Sun, Andrew C. Thomas, & Richard A. Wahle, *Fisheries management in a changing climate: Lessons from the 2012 ocean heat wave in the Northwest Atlantic*, 26 OCEANOGRAPHY 191, 191 (2013), https://doi.org/10.5670/oceanog.2013.27.

[122] *Id.*

[123] *Id.*

[124] Hayley Smith, *Ocean temperatures are off the charts, and El Niño is only partly to blame*, THE LOS ANGELES TIMES (June 13, 5:00 AM, 2023), https://www.latimes.com/california/story/2023-06-13/rising-temps-in-the-north-atlantic-have-startled-researchers.

[125] *Extreme Ocean Temperatures Are Affecting Florida's Coral Reef*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN. (Aug. 18, 2023), https://www.nesdis.noaa.gov/news/extreme-ocean-temperatures-are-affecting-floridas-coral-reef; *The ongoing marine heat waves in U.S. waters, explained*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN. (July 14, 2023), https://www.noaa.gov/news/ongoing-marine-heat-waves-in-us-waters-explained.

[126] Michelle L. L'Heureux, Dan C. Collins & Zeng-Zhen Hu, *Linear trends in sea surface temperature of the tropical Pacific Ocean and implications for the El Niño-Southern Oscillation*, 40 Climate Dynamics 1223, 1223–24 (2013), https://doi.org/10.1007/s00382-012-1331-2.

warming over the last four decades (see Figure 7).[127] Sea surface temperatures have also risen rapidly off the western coast of Alaska, increasing by more than 1.0 °C per decade in the summer (see Figure 8).[128]

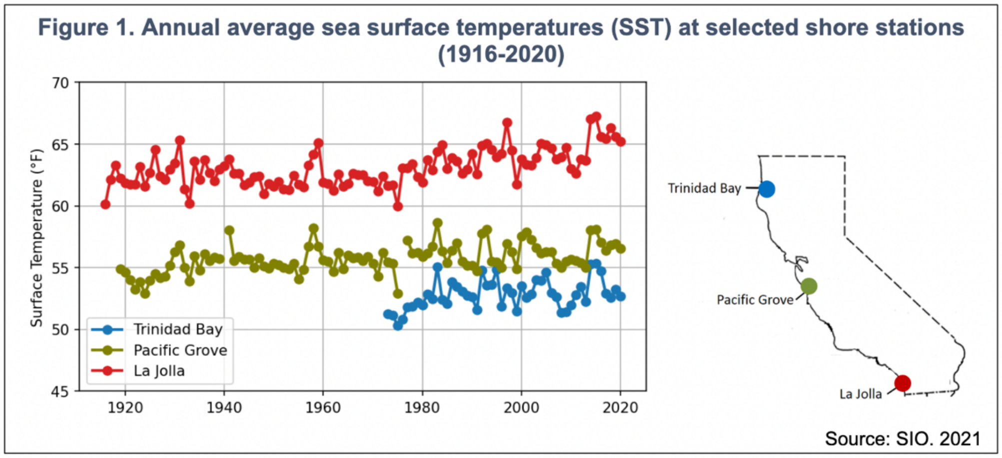

Figure 7. Annual average sea surface temperatures at selected shore stations from 1916-2020.[129]

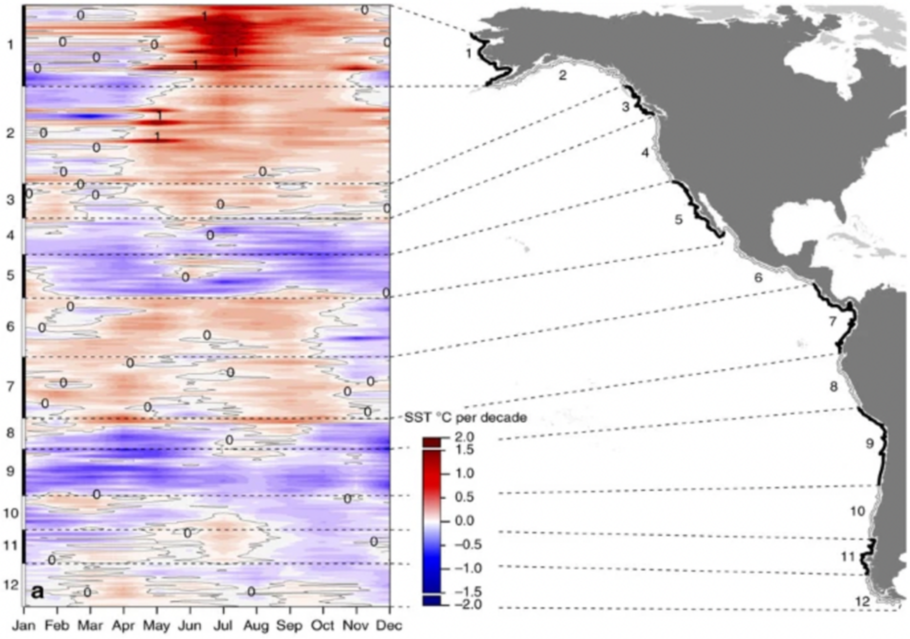

Figure 8. Linear trends of sea surface temperature change from 1982–2010, measured in °C per decade along the west coast of the U.S.[130]

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[127] Garcia-Reyes et al., *supra* note 119, at 51–53, 60.
[128] Lima & Wethey, *supra* note 116.
[129] Garcia-Reyes et al., *supra* note 119, at 51.
[130] Lima & Wethey, *supra* note 116.

Despite these recent trends of increasing sea surface temperature, coastal waters in California had previously been cooling by up to 0.4 °C per decade prior to 2013, largely due to upwelling driven by the California Current.[131] However, this trend was dramatically reversed in 2013, with the formation of a marine heatwave in the Northeast Pacific that persisted from 2013 to 2015. Known as "The Blob," this warm anomaly extended from the south-central Gulf of Alaska to the continental shelf in the winter, and expanded into the coastal zone and into the Northeast Pacific Ocean by summer 2014, leading to significant warming of U.S. near-coastal waters (see Figure 9).[132] Since then, more recent marine heatwaves in 2019 and 2020 have further contributed to warming temperatures near the U.S. Pacific coast,[133] with another intense marine heatwave developing just this summer.[134]

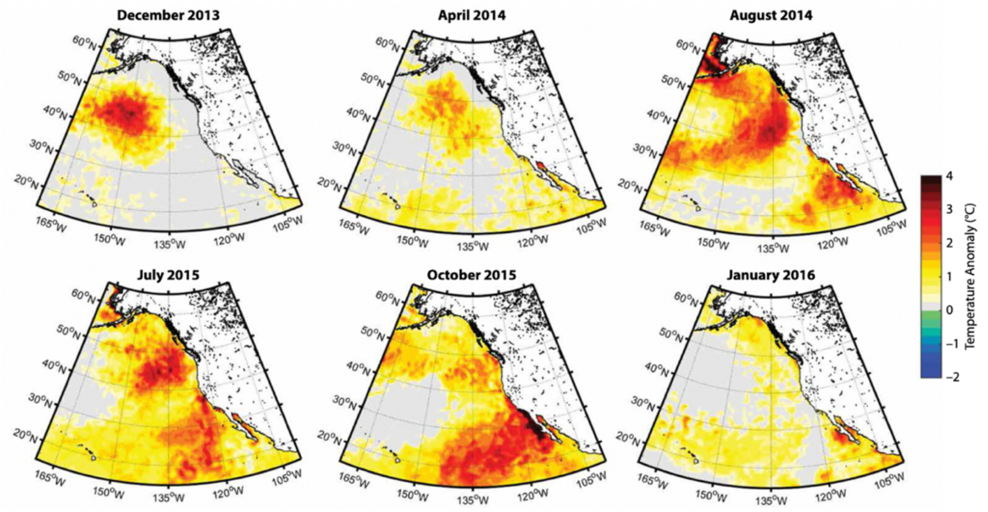

Figure 9. Sea surface temperature anomalies showing the progression of "the Blob" from December 2013 to January 2016 in the northeastern Pacific Ocean.[135]

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[131] *Id.*

[132] Nicholas A. Bond, Meghan F. Cronin, Howard Freeland, & Nathan Mantua, *Causes and impacts of the 2014 warm anomaly in the NE Pacific*, 42 GEOPHYSICAL RESEARCH LETTERS 3414, 3414 (2015), doi:10.1002/2015GL063306.

[133] Garcia-Reyes et al., *supra* note 119, at 54.

[134] Denise Chow, *A West Coast ocean heat wave adds to a summer of extremes*, NBC (Aug 7, 2:34 PM, 2023), https://www.nbcnews.com/science/environment/west-coast-ocean-heat-wave-adds-summer-extremes-rcna98530.

[135] Leticia M. Cavole, Alyssa M. Demko, Rachel E. Diner, Ashlyn Giddings, Irina Koester, Camille M.L.S. Pagniello, May-Linn Paulsen, Arturo Ramirez-Valdez, Sarah M. Schwenck, Nicole K. Yen, Michelle E. Zill, &

With rising global temperatures, scientists predict that the frequency and duration of marine heatwaves will increase.[136] The magnitude of marine heatwaves in the Pacific will also continue to increase over time, until, by the end of the century, they will all be equivalent in magnitude to the sea surface temperatures observed in "the Blob"— between 1°C and 4°C above 1956–2005 average temperatures (see Figure 10).[137] Like in the Atlantic, this predicted higher rate and intensity of marine heatwaves will likely contribute significantly to overall sea surface temperature trends along the western U.S. coastline.

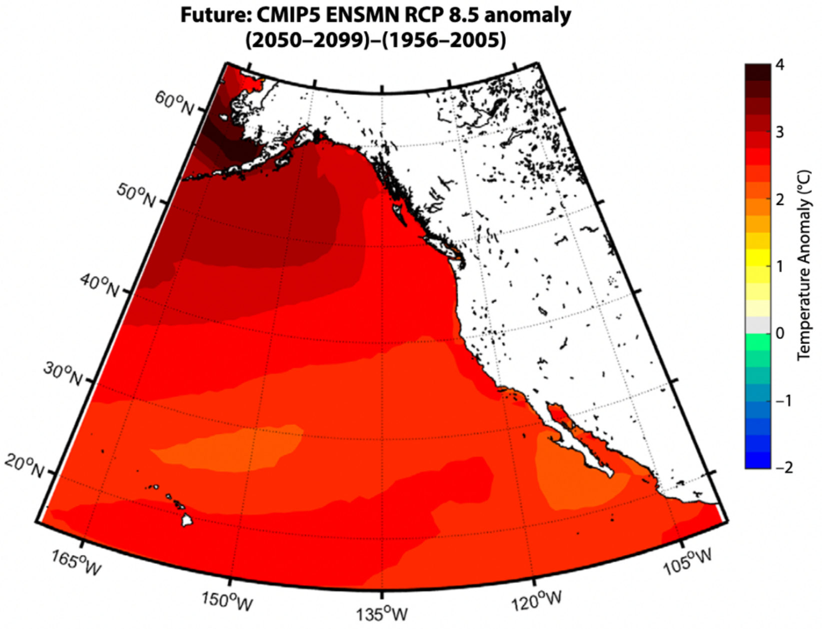

Figure 10. Predicted temperature anomalies for 2050–2099 relative to temperature records from 1956–2005.[138]

Peter J.S. Franks, *Biological impacts of the 2013–2015 warm-water anomaly in the Northeast Pacific: Winners, losers, and the future*, 29 OCEANOGRAPHY 273, 275 (June 27, 2016), http://dx.doi.org/10.5670/oceanog.2016.32.

[136] *Id.*, at 281; Tongtong Xu, Matthew Newman, Antonietta Capotondi, & Emanuele Di Lorenzo, *The Continuum of Northeast Pacific Marine Heatwaves and Their Relationship to the Tropical Pacific*, 48 GEOPHYSICAL RESEARCH LETTERS 1, 1 (2020), https://doi.org/10.1029/2020GL090661.

[137] Cavole et al., *supra* note 135, at 281–82.

[138] *Id.*, at 281.

Temperature trends nearer to the shore, however, tend to be more complex due to the interactions between surface warming and upwelling (which has a cooling effect).[139] In the future, surface temperatures are expected to increase offshore and in sheltered coastal waters (where upwelling is weaker).[140] However, surface temperatures in open shelf water (i.e., off the coasts of Central and Northern California) where upwelling is stronger may continue to remain stable or may once again begin to decrease due to upwelling from the California Current.[141]

Effects of sea surface temperature increase on UCH

First, warming sea surface temperatures are likely to increase rates of electrochemical and microbiologically influenced corrosion, both of which correlate directly with temperature.[142] To compound this effect, melting ice sheets due to warming at higher latitudes also release more iron atoms into the ocean, causing a further population boom for iron-consumptive bacteria.[143] Second, warming climates also increase the likelihood that populations of wood borers like shipworms will expand into new areas.[144] Historically, shipworm populations have been highest in the warm tropical waters around the Caribbean.[145] However, as ocean temperatures rise,

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[139] Garcia-Reyes et al., *supra* note 119, at 59.
[140] *Id.*
[141] *Id.*; Lima & Wethey, *supra* note 116.
[142] Gregory et al., supra note 98, at 1402. See, e.g., W. K. Li & P. M. Dickie, Temperature characteristics of photosynthetic and heterotrophic activities: seasonal variations in temperate microbial plankton, 53 APPLIED AND ENV'TL MICROBIOLOGY 2282, 2282 (Oct. 1, 1987), https://doi.org/10.1128/aem.53.10.2282-2295.1987 (finding that growth of photoautotrophic and heterotrophic microbes was highest in late summer). Bacteria can be classified as Psychrophiles, which grow best between -5ºC (23ºF) and 20ºC (68ºF), Mesophiles, which grow best between 20ºC (68F) and 45ºC (113ºF), or Thermophiles, which grow best at temperatures above 45ºC (113ºF). Physical Factors that Affect Microbial Growth, UNIVERSITY OF HAWAII, https://www2.hawaii.edu/~johnb/micro/m140/syllabus/week/handouts/m140.9.1.html; Mann, supra note 62. See also Cullimore et al., supra note 62.
[143] Maxsimo Salazar & Brenda Little, Review: Rusticle Formation on the "RMS Titanic" and the Potential Influence of Oceanography, 12 J. OF MARITIME ARCHAEOLOGY 25, 30 (2017).
[144] Gilman, *supra* note 25. In general, warming sea surface temperatures and marine heatwave events have also been shown to shift the geographic distribution of warm-water based marine species northward, extending the seasonal cycles and increasing the abundance of these species. Mills et al., *supra* note 121, at 192; Cavole et al., *supra* note 135, at 276–280.
[145] Gilman, *supra* note 25.

warm-water and subtropical species of wood borers are likely to expand toward the poles.[146] Such a range shift may already be occurring, as shipworms have been discovered at higher latitudes than previously observed and have been active later into the season than hitherto seen, a trend which strongly correlates with higher ocean water temperatures.[147]

b. Ocean Acidification

Due to rising atmospheric CO_2 levels, the ocean has become increasingly acidic over the past four decades.[148] Approximately one third of atmospheric carbon dioxide is absorbed by ocean waters as dissolved carbon dioxide.[149] The presence of dissolved carbon dioxide decreases concentrations of carbonate ions (CO_3^{2-}) and increases concentrations of bicarbonate ions (HCO_3^-) in seawater, thereby lowering the ocean's pH, a phenomenon otherwise known as ocean acidification.[150] Ocean acidification is represented according to the following stoichiometry:[151]

$$CO_2 + CO_3^{2-} + H_2O = 2\ HCO_3^-$$

According to the IPCC, this chemical response to increased CO_2 dissolving into the atmosphere is known with very high confidence.[152] Since the beginning of the Industrial Revolution, surface ocean pH has decreased by approximately 0.1, at a rate of 0.0013–0.0024 pH units per year.[153]

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[146] *Id.*
[147] *Id.*
[148] *Regional Fact Sheet – Ocean*, *supra* note 98.
[149] Macko, *supra* note 96, at 260.
[150] *Id.* at 260–61; Hoegh-Guldberg et al., *supra* note 40.
[151] Rik Wanninkhof, Leticia Barbero, Robert Byrne, Wei-Jun Cai, Wei-Jen Huang, Jia-Zhong Zhang, Molly Baringer, & Chris Langdon, *Ocean acidification along the Gulf Coast and East Coast of the USA*, 98 CONTINENTAL SHELF RESEARCH 54, 54 (Apr. 15, 2015), http://dx.doi.org/10.1016/j.csr.2015.02.008.
[152] Hoegh-Guldberg et al., *supra* note 40, at 1673.
[153] *Id.*

As atmospheric CO_2 levels continue to rise, the IPCC has determined that it is virtually certain that the ocean will continue to acidify.[154] According to the IPCC, a doubling of atmospheric CO_2 will decrease pH by 0.1 units relative to current levels.[155] By 2100, models predict an overall pH decrease of between 0.14–0.43 units.[156] However, while the IPCC predicts acidification across all global oceans by 2100,[157] the rate and extent of this acidification is not uniform worldwide (see Figure 11), tending to be more pronounced at high latitudes and in areas of upwelling (i.e., coastal regions).[158] Thus, local trends in pH along the Atlantic and Pacific coastlines of the U.S., where UCH is preserved, must be examined more closely.

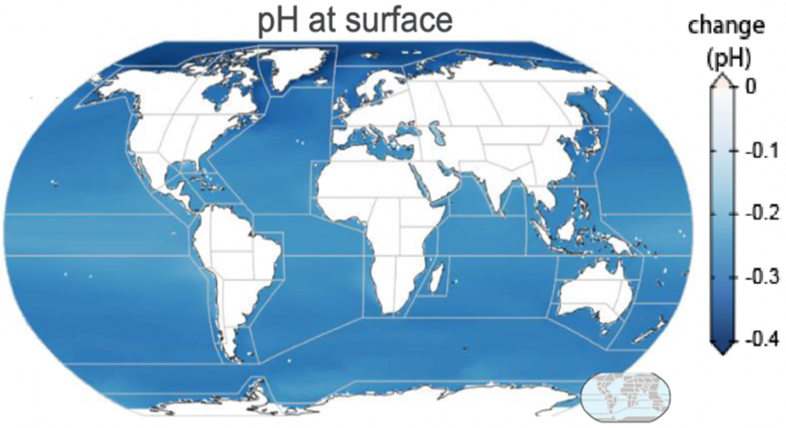

Figure 11. The IPCC's projected changes in annual pH at the surface of the ocean by 2081–2100, under the SSP2-4.5 scenario for global warming, relative to 1850–1900.[159]

Unlike sea surface temperature, however, the study of ocean acidification is relatively recent. For instance, more than two-thirds of all scientific articles investigating ocean

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[154] *Id.*; *Regional Fact Sheet – Ocean*, *supra* note 98.
[155] Hoegh-Guldberg et al., *supra* note 40, at 1674.
[156] *Id.*
[157] *Regional Fact Sheet – Ocean*, *supra* note 98.
[158] Hoegh-Guldberg et al., *supra* note 40.
[159] *Regional Fact Sheet – Ocean*, *supra* note 98.

acidification have been published since 2011.[160] Thus, while the IPCC has developed models of general pH increase along the eastern and western U.S. coastlines, less is known about long-term trends in pH at particular sites along each of those coastlines.[161] Moreover, there is some evidence that local to regional scale (~1 to 1,000 km) coastal processes can either exacerbate or mitigate the severity of ocean acidification.[162] As a result, it is possible that there are local variations in pH trends along the U.S. coastlines that are not being picked up by the IPCC's models.

For example, one process that can exacerbate the severity of ocean acidification is discharge of nutrient-rich runoff from land surfaces.[163] This runoff, often from agricultural sources,[164] fuels large algal blooms that convert dissolved oxygen into CO_2 via respiration, thereby causing the pH of the water to drop.[165] One study that modeled future pH trends

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[160] Alexandria B. Boehm, Mark Z. Jacobson, Michael J. O'Donnell, Martha Sutula, W. Waldo Wakefield, Stephen B. Weisberg, & Elizabeth Whiteman, *Ocean Acidification Science Needs for Natural Resource Managers of the North American West Coast*, 28 THE OCEANOGRAPHY SOCIETY 170, 172 (June 2015), https://www.jstor.org/stable/pdf/24861879.pdf?refreqid=fastly-default%3A571b36b4aa440ff334334241a4fd19cb&ab_segments=&origin=&initiator=&acceptTC=1.

[161] *Id.*

[162] *Id.*, at 171. Processes that can exacerbate ocean acidification include coastal upwelling, local respiration, and discharge of nutrient-laden runoff from land surfaces which can lead to algal blooms and lower pH. On the other hand, carbon assimilation by seagrass or kelp can mitigate local acidification. *Id.*

[163] William G. Sunda & Wei-Jun Cai, Eutrophication induced CO_2—Acidification of subsurface coastal *waters: Interactive effects of temperature, salinity, and atmospheric* P_{CO2}, 46 ENVIRONMENTAL SCIENCE & TECHNOLOGY 10651 (Aug. 13, 2012), http://dx.doi.org/10.1021/es300626f.

[164] A substantial amount of nutrient-rich runoff into coastal waters comes from agricultural operations. According to the Food and Agriculture Organization of the United Nations (FAO), agricultural pollution in the U.S. is "the main source of pollution in rivers and streams, the second main source in wetlands and the third main source in lakes." Worldwide, agricultural pollution (and the resulting eutrophication) is the major factor in the degradation of inland and coastal waters, surpassing contamination from settlements and other industries. Javier Mateo-Sagasta, Sara Marjani Zadeh, & Hugh Turral, WATER POLLUTION FROM AGRICULTURE: A GLOBAL REVIEW, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS at 3 (2017), https://www.fao.org/3/i7754e/i7754e.pdf. Because nutrient-rich runoff due to agriculture is a recognized problem, causing approximately $2.4 billion in damage to marine habitats every year since 1980, NOAA has created a tool to help farmers minimize the amount of fertilizer runoff generated from agricultural operations. Katharine Gammon, *Dead zones spread along Oregon coast and Gulf of Mexico, study shows*, THE GUARDIAN (Aug. 6, 5:00 PM, 2021), https://www.theguardian.com/environment/2021/aug/06/dead-zones-oregon-coast-gulf-mexico-study.

[165] Sunda & Cai, *supra* note 163. When concentrations of dissolved carbon dioxide in water are increased, the concentration of carbonate ions (CO_3^{2-}) decreases. This, in turn, increases the concentration of bicarbonate ions (HCO_3^-) in seawater, causing the water to acidify. Macko, *supra* note 96, at 260; Wanninkhof et al., *supra* note 151, at 54.

according to this nutrient runoff predicted that CO_2 inputs from algal respiration would cause a decrease in pH of 0.25 to 1.1 units from current levels—much higher than the IPCC's predictions.[166] Additionally, the models generated by this study agreed with field data from hypoxic zones in the northern Gulf of Mexico and the Baltic Sea—both highly nutrient-rich ecosystems characterized by large algal blooms.[167] This biogeochemical amplification of ocean acidification is strengthened at intermediate to high water temperatures, threatening to decrease local pH even further as the climate warms.[168]

In addition, certain areas along the U.S. coastlines are more vulnerable to ocean acidification than others. For instance, the near-shore region of the west coast of the U.S. from California to Washington, part of what is known as the California Current System (CCS),[169] is dominated by coastal upwelling, which brings nutrient-rich, low-pH waters up from the deep ocean, resulting in the lowering of nearshore pH below the levels induced by atmospheric CO_2.[170] Washington and Oregon, in particular, are characterized by hotspots of highly acidic conditions—there, ocean pH reaches a minimum of 7.5 and 7.7, respectively, 0.7–0.5 units below the average ocean pH of 8.2 (see Figure 12).[171] Across the CCS overall, studies of pH trends have revealed significant seasonal pH variability of around 0.14 units within 50 km from the shore, resulting from a combination of upwelling and local respiration.[172]

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[166] Sunda & Cai, *supra* note 163.

[167] *Id.*

[168] *Id.*

[169] C. Hauri, N. Gruber, M. Vogt, S.C. Doney, R.A. Feely, Z. Lachkar, A. Leinweber, A.M.P. McDonnell, M. Munnich, & G.K. Plattner, *Spatiotemporal variability and long-term trends of ocean acidification in the California Current System*, 10 BIOGEOSCIENCES, 193, 193–216 (2013), https://doi.org/10.5194/bg-10-193-2013.

[170] Boehm et al., *supra* note 160, at 171; Richard A. Feely, Christopher L. Sabine, J. Martin Hernandez-Ayon, Debby Ianson, & Burke Hales, *Evidence for Upwelling of Corrosive "Acidified" Water onto the Continental Shelf*, 320 SCIENCE 1490 (June 13, 2008), https://www.science.org/doi/10.1126/science.1155676.

[171] Boehm et al., *supra* note 160, at 171–72.

[172] Hauri et al., *supra* note 169; Richard A. Feely, Simone Alin, Brendan Carter, Nina Bednaršek, Burke Hales, Francis Chan, Tessa M. Hill, Brian Gaylord, Eric Sanford, Robert H. Byrne, Christopher L. Sabine, Dana Greeley, & Lauren Juranek, *Chemical and biological impacts of ocean acidification along the west coast of North America*, 183 ESTUARINE, COASTAL AND SHELF SCIENCE 260 (Dec. 2016), doi:10.1016/j.ecss.2016.08.043.

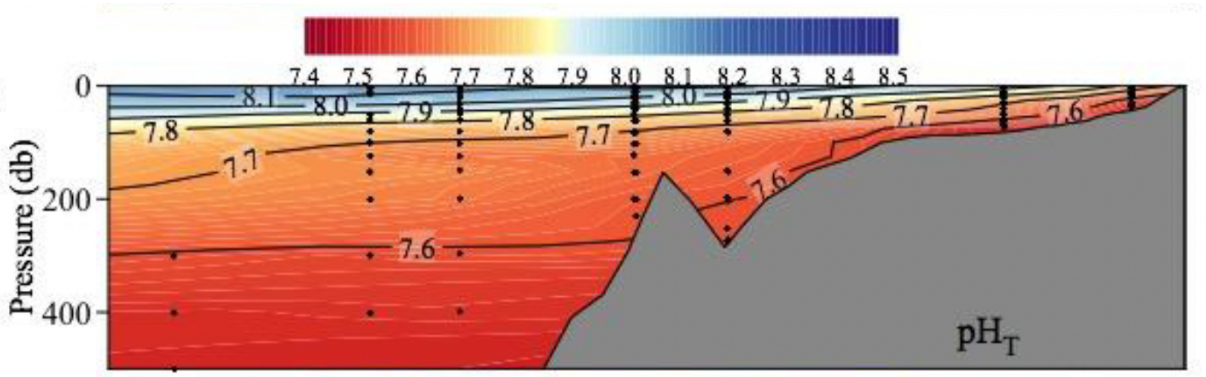

Figure 12. Vertical sections of pH along the 2013 Line 6 stations off Newport, OR. Black dots indicate measurement locations.[173]

Effects of ocean acidification on UCH

Ocean acidification and the corresponding loss of CO_3^{2-} ions causes the shells of calcifying organisms to dissolve or become thinner, making it difficult for them to grow, reproduce, and survive.[174] In particular, shipworms and stone-boring mollusks rely on their hard shells made of calcium carbonate to bore through wood.[175] Similarly, the spiky shells of stone-boring sea urchins are also composed of calcium carbonate.[176] However, while increasing ocean acidity may alleviate UCH degradation from wood- and stone-boring macroorganisms, it will likely exacerbate UCH degradation from corrosive bacteria. For instance, sulfate-reducing and anaerobic spore-forming bacteria thrive in hypoxic areas and in acidic areas as low as pH 6.4.[177]

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[173] Feely et al., *supra* note 172.

[174] *Effects of Ocean and Coastal Acidification on Marine Life*, U.S. ENV'TL PROTECTION AGENCY (Nov. 2, 2023), https://www.epa.gov/ocean-acidification/effects-ocean-and-coastal-acidification-marine-life; *Ocean Acidification*, INTEGRATED OCEAN OBSERVING SYSTEM, https://ioos.noaa.gov/project/ocean-acidification/.

[175] Effects of Ocean and Coastal Acidification on Marine Life, supra note 187.

[176] *Id.*; Björdal & Dayton, *supra* note 21; Jones et al., *supra* note 23; Tim Pearce, *(Not So) Boring Clams*, CARNEGIE MUSEUM OF NATURAL HISTORY, https://carnegiemnh.org/not-boring-clams/; ZABEL & MORRELL, *supra* note 23; Wanninkhof, *supra* note 151, at 54; Rudd, *supra* note 79; *The Hole Story*, *supra* note 79; Paula Gould, *Sea Urchins Reveal Spiky Secret*, NATURE (Nov. 11, 2004), https://www.nature.com/articles/news041108-15.

[177] Knisz et al., *supra* note 74; Philips et al., *supra* note 74.

Finally, more acidic conditions in the waters surrounding UCH will cause direct degradation of carbonate minerals, such as limestone, dolomite, or marble.[178]

c. Severe Weather

Global warming may also be associated with increases in the intensity and frequency of severe weather.[179] Some correlation has been detected between global warming and weather extremes since 1950, although the IPCC attributed only medium confidence to this relationship.[180] For instance, high temperatures on the surface of the sea have been linked to the formation of tropical cyclones, and higher sea levels resulting from global warming may cause exceptionally high tides, storm surges, and more violent tidal currents and waves.[181] However, the magnitude of the effect of temperature changes on weather patterns remains uncertain (see Figures 13 and 14). For example, Collins et al. (2013) reports substantial uncertainty and low confidence in projecting changes in winter storm tracks in the North Atlantic basin.[182]

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[178] *Id.*, at 261; Ricca & La Russa, *supra* note 7; *Carbonate Rock*, *supra* note 95.

[179] *Summary for Policymakers, in* SPECIAL REPORT: GLOBAL WARMING OF 1.5 ºC, available at https://www.ipcc.ch/sr15/chapter/spm/.

[180] *Id.*

[181] Gregory et al., *supra* note 98, at 1399, 1401. *See also* Gilman, *supra* note 25.

[182] Collins et al., *supra* note 109, at 1074.

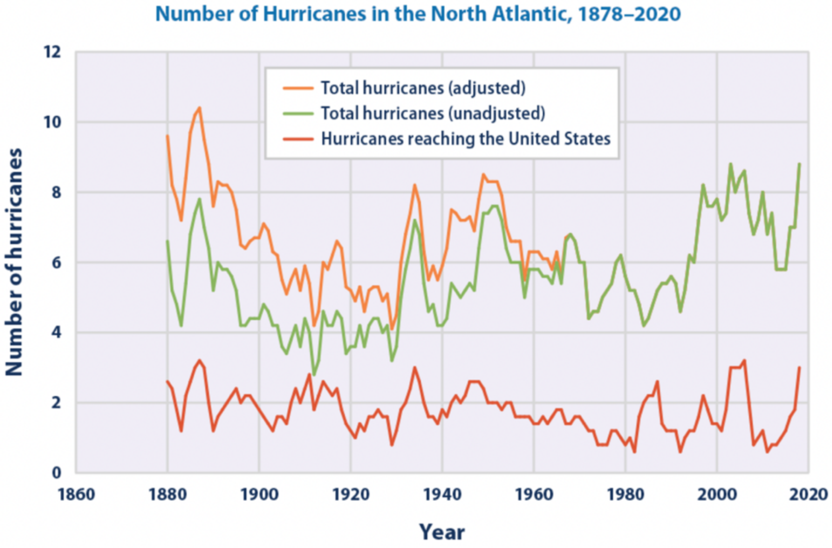

Figure 13. The number of hurricanes that formed and made landfall in the North Atlantic Ocean each year between 1878 and 2020, along with the number that made landfall in the United States. The green curve represents the raw number of hurricanes recorded by NOAA, while the orange curve attempts to adjust for hurricanes missed due to the lack of aircraft and satellite observations prior to 1970.[183]

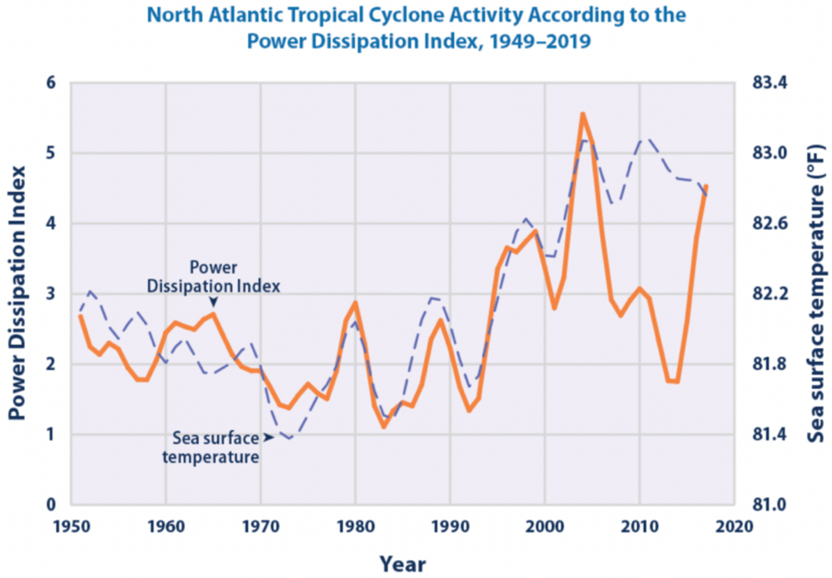

Figure 14. Annual values of hurricane Power Dissipation Index, which accounts for strength, duration, and frequency of cyclones, plotted alongside Tropical North Atlantic sea surface trends.[184]

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[183] *Climate Change Indicators: Tropical Cyclone Activity*, U.S. ENV'TL PROTECTION AGENCY (Nov. 1, 2023), https://www.epa.gov/climate-indicators/climate-change-indicators-tropical-cyclone-activity.
[184] *Id.*

Effects of severe weather events on UCH

Tropical cyclones are capable of significantly disturbing subsurface archaeological artifacts to a depth of 20 cm, resulting in abrasion, etching, and polishing of shallowly submerged wrecks, even those buried under sediment.[185] Strong winds, waves, and seabed currents generated by cyclones also threaten to unbury some coastal UCH sites, making them vulnerable to wood borers, such as shipworms.[186] As a result, strong storms can easily damage the integrity of near-surface UCH, even when buried under sediment, and can even threaten to wash UCH artifacts away entirely.[187] For example, the delicate remains of Blackbeard's legendary *Queen Anne's Revenge*, preserved off the coast of North Carolina, are located in an area that is vulnerable to storms and hurricanes.[188] If one such storm were to hit the site of the wreck directly, the fragile remains of Blackbeard's flagship would be utterly destroyed.[189]

3. *Looking Forward*

According to the IPCC, even if we were to stop all CO_2 emissions today, climate change would still continue to progress until at least the 2050s.[190] Thus, it is inevitable that UCH will

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[185] Torben C. Rick, Eolian processes, ground cover, and the archaeology of coastal dunes: a taphonomic case study from San Miguel Island, California, 17 GEOARCHAEOLOGY 811, 811 (2002), https://doi.org/10.1002/gea.10047 (explaining that heavy winds are capable of significantly disturbing subsurface archaeological artifacts to a depth of at least 20 cm, resulting in abrasion, etching, and polishing).

[186] Björdal & Nilsson, *supra* note 46. This is because the anoxic conditions under sediment cover prevent wood boring macroorganisms from breathing. Gregory, Jensen, & Strætkvern, *supra* note 12, at 1–2.

[187] Gregory et al., *supra* note 98, at 1400; Wilde-Ramsing et al., *supra* note 188; *AIA Supports the Preservation of a Historical Underwater Shipwreck*, *supra* note 9. In fact, several hurricanes and strong ocean currents have already inflicted significant damage to the Queen Anne's Revenge in the late 1990s, scattering planks and ballast stones and destroying the reconstructed hull of the ship. Piotti, *supra* note 12, at 16.

[188] Mark U. Wilde-Ramsing & Charles R. Ewen, *Beyond Reasonable Doubt: A Case for "Queen Anne's Revenge*", 46 HISTORICAL ARCHAEOLOGY 110, 115 (2012), https://www.jstor.org/stable/23264632.

[189] AIA Supports the Preservation of a Historical Underwater Shipwreck, supra note 9.

[190] CLIMATE CHANGE 2021: SUMMARY FOR ALL, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (Dec. 12, 2022), https://www.ipcc.ch/report/ar6/wg1/downloads/outreach/IPCC_AR6_WGI_SummaryForAll.pdf; David Herring & Rebecca Lindsey, *Can we slow or even reverse global warming?*, NAT'L OCEANIC AND ATMOSPHERIC

suffer degradation from the effects of climate change as their equilibrium with underwater environments is disrupted. How, then, can we hope to protect *in situ* UCH from destruction by a changing climate? To determine whether conservation of *in situ* UCH is possible, we must turn to our legal regime.

ADMIN. (Oct. 12, 2022), https://www.climate.gov/news-features/climate-qa/can-we-slow-or-even-reverse-global-warming.

CHAPTER II: THE LEGAL REGIME

Nearly every aspect of climate change poses a threat to the continued survival of *in situ* UCH. Therefore, in order to truly ensure the longevity of these heritage sites, we would need to halt climate change entirely—a difficult task, to say the least. Despite the clear and present threat posed by climate change,[191] solutions to the problem of global warming have proven exceedingly hard to get off the ground, largely due to humanity's established "status quo" of reliance on fossil fuels and to political disagreement about the realities of climate change.[192] Climate change itself is also a highly abstract problem due to its diffuse effects, delayed consequences, and disproportionate causes and effects.[193] This complexity and uncertainty makes climate change a "wicked" policy problem,[194] resulting in a political deadlock that has made it challenging to pass new legislation mitigating the effects of global warming.[195]

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[191] One scholar has even argued that climate change poses a threat to national security, pointing out that a National Intelligence Council report described climate change as "a threat to the United States comparable only to international terrorism." *See generally* Maximilan Mayer, *Chaotic Climate Change and Security*, 6 INTERNATIONAL POLITICAL SOCIOLOGY 165, 165 (2012), available at https://www.academia.edu/2144174/Chaotic_Climate_Change_and_Security?email_work_card=view-paper.

[192] Amy Harder, *Why climate change is so hard to tackle: The global problem*, AXIOS (Aug. 19, 2019), https://www.axios.com/2019/08/19/why-climate-change-is-so-hard-to-tackle-the-global-problem. Statistics show that 94% of Democrats and 67% of Republicans believe global warming has been happening, that 94% of Democrats and 56% of Republicans think warming will continue in the future if nothing is done to address it, that 88% of Democrats and 40% of Republicans believe that the warming that has happened over the past 100 years was bad, and that 84% of Democrats and 50% of Republicans believe that a 5-degree Fahrenheit increase in world temperature over the next 75 years would be bad. *Climate Insights 2020: Partisan Divide*, RESOURCES FOR THE FUTURE, https://www.rff.org/publications/reports/climateinsights2020-partisan-divide/.

[193] Richard Ling and Cat Conran, *De-Abstracting Climate Change*, RISK MANAGEMENT AND DECISION PROCESSES CENTER (Apr. 22, 2020), https://riskcenter.wharton.upenn.edu/studentclimaterisksolutions/de-abstracting-climate-change/.

[194] Cary Coglianese, *Solving Climate Risk Requires Normative Change*, RISK MANAGEMENT AND DECISION PROCESSES CENTER (n.d.), https://riskcenter.wharton.upenn.edu/climate-risk-solutions-2/solving-climate-change-requires-normative-change-2/.

[195] Coral Davenport & Lisa Friedman, *Five Decades in the Making: Why It Took Congress So Long to Act on Climate*, THE NEW YORK TIMES (Aug. 7, 2022), https://www.nytimes.com/2022/08/07/climate/senate-climate-law.html.

Thus, the next best option for protecting UCH artifacts is to bolster their resilience to changes in the ecosystems around them by alleviating one of the factors causing degradation. As established in Chapter 1, sea surface temperature increase and ocean acidification contribute most strongly to UCH degradation. Sea surface temperature is inextricably tied to atmospheric CO_2 levels,[196] which have already proven difficult to tackle. However, while ocean acidification is also due in large part to increasing levels of atmospheric CO_2, pH decreases at local scales are often exacerbated by algal blooms that thrive in coastal areas marked by high upwelling and nutrient-rich runoff.[197] This nutrient-rich runoff, in particular, is primarily attributable to fertilizer used by agricultural operations, which is frequently carried into coastal areas.[198] Runoff-driven ocean acidification can, therefore, be regulated, especially since it has been shown that local and regional management decisions are capable of slowing, limiting, and/or mitigating its effects.[199]

Therefore, the deteriorative effects of ocean acidification on UCH can be reduced by taking steps to mitigate the amount of nutrient runoff that enters marine areas in which UCH is preserved. Due to mixing from ocean currents and ecosystem connectivity, it is impossible to

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[196] For example, increased levels of greenhouse gases in the atmosphere will further increase global temperatures and accelerate melting of glaciers and ice sheets. This, in turn, will continue to cause warming of the oceans, sea level rise, and altered ocean circulation. Reduced snow and ice cover also reduces the Earth's Albedo (i.e., the proportion of solar radiation that is reflected back out of the Earth's atmosphere by snow and ice cover). Thus, as polar icecaps melt, global warming accelerates. In addition, Arctic ice cover shrinkage will be accompanied by increased release of methane into the atmosphere from Arctic and permafrost regions, contributing to the ongoing effects of global warming. Gregory et al., *supra* note 98, at 1396, 1405; IPCC 2019, *supra* note 96; Gregory, Jensen, & Strætkvern, *supra* note 12; Macko, *supra* note 96, at 259.

[197] Sunda & Cai, *supra* note 163.

[198] According to the Food and Agriculture Organization of the United Nations (FAO), agricultural runoff is the major factor in the degradation of inland and coastal waters, surpassing contamination from settlements and other industries. Javier Mateo-Sagasta, Sara Marjani Zadeh, & Hugh Turral, *Water pollution from agriculture: a global review in* FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS 3 (2017), https://www.fao.org/3/i7754e/i7754e.pdf.

[199] Boehm et al., *supra* note 160, at 171–72. *See also* Katharine Gammon, *Dead zones spread along Oregon coast and Gulf of Mexico, study shows*, THE GUARDIAN (Aug. 6, 5:00 PM, 2021), https://www.theguardian.com/environment/2021/aug/06/dead-zones-oregon-coast-gulf-mexico-study ("NOAA has . . . created a tool – the runoff risk forecast – to help farmers apply fertilizer at optimum times to ensure it stays on fields, with the hopes of limiting nutrient runoff to the Gulf.").

separate the acidification of particular areas of water immediately surrounding UCH from the broader underwater environment. Thus, the laws that can successfully mitigate damage to UCH from ocean acidification must be capable of extending environmental protections to the large areas of the ocean that are affected by nutrient runoff. The following section will examine whether such mitigation is possible under the current U.S. legal regime.[200]

1. Existing Legal Protections for UCH

In the U.S., according to a study generated by the Department of the Interior, the Bureau of Ocean Energy Management ("BOEM"), the Department of Commerce, and the National Oceanic and Atmospheric Administration. ("NOAA"), the following federal laws can be wielded to protect UCH: The National Marine Sanctuaries Act ("NMSA"),[201] the Antiquities Act,[202] the Archaeological Resource Protection Act,[203] the Abandoned Shipwreck Act,[204] the Sunken Military Craft Act,[205] the National Historic Preservation Act,[206] the National Environmental Policy Act ("NEPA"),[207] and the National Stolen Properties Act.[208]

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[200] Laws governing UCH have been put in place at the local, regional, state, national, and international level. Wheeler, *supra* note 18. In the interest of scope, this paper will focus primarily on U.S. federal laws.

[201] 16 U.S.C. § 1431 *et seq.*

[202] 16 U.S.C. § 431 *et seq.*

[203] 16 U.S.C. § 470aa *et seq.*

[204] 43 U.S.C. § 2101 et seq.; Ole Varmer & Brian A. Jordan, Study on Protection of Underwater Cultural Heritage in U.S. Waters and the 2001 UNESCO Convention, UNDERWATER ARCHAEOLOGY PROCEEDINGS 243, 243 (2014); Ricardo Elia, US protection of underwater cultural heritage beyond the territorial sea: problems and prospects, 29 INT'L J. OF NAUTICAL ARCHAEOLOGY 43, 43 (2000), available at https://www.academia.edu/1048694/US_protection_of_underwater_cultural_heritage_beyond_the_territorial_sea_problems_and_prospects?email_work_card=view-paper (explaining that the ASA "only covers certain categories of abandoned, historic shipwrecks within a 3-mile territorial sea[,] except in the waters of the Gulf of Mexico, where a 9-mile limit is historically observed").

[205] 10 U.S.C. § 113 *et seq.*

[206] 16 U.S.C. § 470a *et seq.*

[207] 42 U.S.C. § 4321 *et seq.*

[208] 18 U.S.C. § 2314 *et seq.*

Despite this proliferation of U.S. federal statutes protecting UCH, this paper will focus only on the NMSA and the Antiquities Act. This is because these two statutes provide protections for all UCH, rather than simply for shipwrecks (unlike the Abandoned Shipwreck Act[209]), contain language that is also capable of protecting large marine areas rather than simply regulating salvage and outlawing looting (as opposed to the National Stolen Properties Act[210]), and have the power to establish substantive protections for UCH rather than being procedural in nature (unlike the National Environmental Policy Act[211]). Thus, the language of these two laws allows for the establishment of protections both for the UCH artifacts themselves and for large marine areas.[212]

The following section will detail the protections provided to UCH and to large marine areas by the NMSA and the Antiquities Act. The primary purpose of the NMSA is the protection of marine ecosystems, although UCH still fall within the scope of protections established under the statute. Similarly, the Antiquities Act has historically been wielded for the protection of both cultural artifacts and marine ecosystems. However, in order to truly minimize the degradation faced by UCH due to decreased pH, these legal regimes must be able to manage rates of acidification of the large coastal areas subject to nutrient-rich runoff. In other words, these

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[209] 43 U.S.C. § 2101 *et seq.*; Varmer & Jordan, *supra* note 204.

[210] 18 U.S.C. § 2314 *et seq.*

[211] 42 U.S.C. § 4321 *et seq.*

[212] The potential for mitigating environmental harm to large marine areas and underwater ecosystems in the name of UCH preservation is not unique to these U.S. federal laws. For example, Articles 2 and 5 of the 2001 United Nations Educational, Scientific and Cultural Organization Convention on the Protection of Underwater Cultural Heritage ("UNESCO Convention"), the most significant international protection for UCH, mandate, respectively, that "States Parties . . . all appropriate measures . . . necessary to protect underwater cultural heritage" and "prevent or mitigate any adverse effects that might arise from activities under its jurisdiction incidentally affecting underwater cultural heritage." UNESCO Convention, *supra* note 5. Such language could easily be interpreted to require mitigation or control of activities that exacerbate climate change, such as agricultural runoff or carbon dioxide emissions. Piotti, *supra* note 12, at 5. *See also* Tullio Scovazzi, *The 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage, in* ART AND CULTURAL HERITAGE: LAW, POLICY AND PRACTICE 286 (Barbara T. Hoffman ed., 2006) (discussing Article 149 of the United Nations Law of the Sea Convention, held in 1982). *But see* Callen, *supra* note 15 (stating that the UNESCO convention "is in no way legally binding and cannot be enforced by UNESCO").

statutes must be able to regulate agricultural runoff into large marine areas. As this section will argue, although the NMSA and the Antiquities Act are theoretically capable of such protection and mitigation, these current legal regimes are ill equipped to actually safeguard large marine areas as effectively as their texts imply.

As a threshold matter, the location of UCH determines which nations or states have jurisdiction over UCH, which laws can apply, and against whom those laws may be enforced.[213] Relevant locations include: Internal waters;[214] territorial seas;[215] contiguous zones;"[216] Exclusive Economic Zones ("EEZ");[217] and the continental shelf.[218] While much ink has been spilled over these jurisdictional boundaries,[219] the focus of this paper is on the ability of federal UCH-protection laws to mitigate the effects of ocean acidification on the UCH and associated marine

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[213] Varmer, *supra* note 5, at 256.

[214] Internal waters refer to "the waters on the landward side of the [low-water line along the coast] from which the breadth of the territorial sea is measured," such as rivers, canals, and lakes. *Maritime Zones and Boundaries*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://www.noaa.gov/maritime-zones-and-boundaries#internal.

[215] The territorial sea refers to the area extending seaward up to 12 nautical miles from the coastline, over which the coastal nation exercises sovereignty. *Maritime Zones and Boundaries*, *supra* note 214; Proclamation No. 5928 (Dec. 27, 1988) (claiming a 12 nautical mile territorial sea for the U.S.).

[216] The contiguous zone refers to the area adjacent to and beyond the territorial sea extending seaward up to 24 nautical miles from the coastline, over which a coastal nation exercises sufficient control to prevent and punish "the infringement of its customs, fiscal, immigration or sanitary laws and regulations. *Maritime Zones and Boundaries*, *supra* note 214; *See also* Department of State Public Notice 358, 37 Fed. Reg. 11906 (June 15, 1972) (proclaiming a contiguous zone extending from 3 to 12 miles offshore); Proclamation No. 7219 (Aug. 2, 1999) (extending the contiguous zone from 12 to 24 miles offshore).

[217] EEZ refers to the area "beyond and adjacent to the territorial sea" extending seaward up to 200 nautical miles from the coastline or out to a maritime boundary with another coastal nation, within which the coastal nation has sovereign rights to explore, exploit, conserve, and manage natural resources and to protect and preserve the marine environment. *Maritime Zones and Boundaries*, *supra* note 214; *See also* Proclamation No. 5030 (Mar. 10, 1983) (claiming a 200 nautical mile EEZ which overlaps the 12–24 nautical mile contiguous zone).

[218] The continental shelf refers to the area of the seabed and subsoil that extends beyond the territorial sea either to the edge of the continental margin or to a distance of 200 nautical miles from the coastline, whichever is longer, or to a maritime boundary with another coastal nation, under which the coastal nation has sovereign rights and exclusive jurisdiction for the purpose of exploration and exploitation of natural resources. *Maritime Zones and Boundaries*, *supra* note 214; *See also* Proclamation No. 2667 (Sept. 28, 1945) (proclaiming jurisdiction and control over the U.S. continental shelf).

[219] Varmer, *supra* note 5 (discussing the gaps in protection of UCH on the outer continental shelf and recommending ways to fill those gaps); Varmer & Jordan, *supra* note 204, at 243 (identifying gaps in protection of UCH on the outer continental shelf); Mark Staniforth, James Hunter, & Emily Jateff, *International Approaches to Underwater Cultural Heritage in* MARITIME LAW ISSUES, CHALLENGES AND IMPLICATIONS (Jack W. Harris ed., 2009), https://www.academia.edu/385246/International_Approaches_to_Underwater_Cultural_Heritage?email_work_card=view-paper (discussing how nations determine property rights over certain kinds of UCH (i.e., military ship and aircraft wrecks) in certain locations (i.e., in internal seas, territorial waters, or international waters)).

areas that they *do* protect (i.e., within the present jurisdictional limits of the U.S.). Therefore, while it is certainly the case that there are some areas in which protection of UCH is not as strong as we would hope, such as on the outer continental shelf or otherwise outside of state/national jurisdictional submerged lands,[220] such concerns are outside the scope of this paper.

a. The National Marine Sanctuaries Act

Ostensibly, the NMSA offers very strong protection for both *in situ* UCH and large marine areas, given its clear statutory language establishing those protections, its thirty-year history of managing marine areas, and its legislative history, which strongly indicates Congressional intent to create broad power to protect marine resources.[221] However, due to its high procedural complexity, the NMSA has been unable to prevent increasing acidification of the marine areas and degradation of the UCH artifacts therein that it is supposed to protect.

i. Protections for UCH and Large Marine Areas

The NMSA provides for the designation and management of certain areas of the marine environment as national marine sanctuaries.[222] To do so, the NMSA grants authority to the

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[220] Varmer, *supra* note 5. *See also* Hance D. Smith & Alastair D. Couper, *The management of the underwater cultural heritage*, 4 J. OF CULTURAL HERITAGE 23, 23–33 (2003), available at https://www.academia.edu/22229550/The_management_of_the_underwater_cultural_heritage?email_work_card=view-paper (arguing that domestic and international laws protecting UCH are inadequate because they fail to adequately adjudicate between commercial and scientific interests and calling for increased public awareness of the new threats to UCH in the modern technological age).

[221] Jeff Brax, Zoning the Oceans: Using the National Marine Sanctuaries Act and the Antiquities Act to Establish Marine Protection Areas and Marine Reserves in America, 29 ECOLOGY L.Q. 71, 81–82 (2002).

[222] 16 U.S.C. § 1431(b)(1). Once designated, these sanctuaries become a part of the National Marine Sanctuary System. 16 U.S.C. § 1431(c).

Secretary of Commerce—who has since delegated this authority to the NOAA Administrator[223]—to "designate any discrete area of the marine environment[224] as a national marine sanctuary and promulgate regulations implementing the designation" if the Secretary determines that the "conservation, recreational, ecological, historical, scientific, cultural, archaeological, educational, or esthetic qualities" of the area, "the communities of living marine resources it harbors," or "its resource of human-use values" are of special national significance.[225]

Thus, it is within the Secretary's discretion to designate a national marine sanctuary for the protection of UCH, which are easily objects of "historical," "cultural," and "archaeological" significance under the language of the NMSA.[226] This has been borne out in practice: The first national marine sanctuary to be established was created to prevent looting and unscientific salvage of the USS Monitor, the Union's first ironclad warship used during the Civil War.[227]

However, the primary focus of the NMSA is on marine ecosystem protection. For example, in determining whether a particular area meets the requirements for designation as a

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[223] 79 FR 33851, 33851 (2014). The U.S. Congress also has the authority to designate national marine sanctuaries under the NMSA, however, the primary party in charge of new designations is usually NOAA. *How does NOAA designate a national marine sanctuary?*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN. (June 1, 2016), https://www.noaa.gov/explainers/how-does-noaa-designate-national-marine-sanctuary. *See also The National Marine Sanctuaries Act*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://sanctuaries.noaa.gov/about/legislation/welcome.html; Marine Sanctuaries, Program Guidelines, 39 Fed. Reg. 10,255 (Mar. 19, 1974) (noting the delegation to the NOAA Administrator of authority under Title III of the Marine Protection, Research, and Sanctuaries Act of 1972). Such management involves "facilitating the public and private use of resources not otherwise prohibited by law through regulations and permitting." Brian Jordan, *Underwater Cultural Heritage Law Study*, BUREAU OF OCEAN ENERGY MANAGEMENT 35 (2014–2015), available at https://www.academia.edu/69547728/Underwater_Cultural_Heritage_Law_Study?email_work_card=view-paper.

[224] The "marine environment" is defined as "those areas of coastal and ocean waters, the Great Lakes and their connecting waters, and submerged lands over which the United States exercises jurisdiction, including the exclusive economic zone, consistent with international law." 16 U.S.C. § 1432(3).

[225] 16 U.S.C. § 1433(a); *The National Marine Sanctuaries Act*, *supra* note 223. *See also* Varmer, *supra* note 5, at 270–71.

[226] 16 U.S.C. § 1433(a).

[227] Varmer, *supra* note 5, at 270–71; *USS Monitor*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://monitor.noaa.gov/shipwrecks/uss_monitor.html. In fact, following the designation of the USS Monitor as a national marine sanctuary, the NMSA was amended to "expressly include the protection and management of historic and cultural resources." Jordan, *supra* note 223, at 34.

national marine sanctuary, the NMSA directs the Secretary to consider, among other things,[228] "the area's natural resource and ecological qualities, including its contribution to biological productivity, maintenance of ecosystem structure, maintenance of ecologically or commercially important or threatened species or species assemblages, maintenance of critical habitat of endangered species, and the biogeographic representation of the site."[229] To that end, the NMSA has been used primarily to establish national marine sanctuaries over large areas of ocean in order to protect marine resources and environments such as coral reefs, kelp forests, and breeding and feeding grounds for endangered whales.[230]

The NMSA's Purposes and Policies section also clearly states that the Act was passed in order to "maintain the natural biological communities in the national marine sanctuaries, and to protect, and, where appropriate, restore and enhance natural habitats, populations, and ecological processes,"[231] to "develop and implement coordinated plans for the protection and management of these areas with appropriate Federal agencies, State and local governments, Native American tribes and organizations, international organizations, and other public and private interests concerned with the continuing health and resilience of these marine areas,"[232] and to "cooperate with global programs encouraging conservation of marine resources."[233] Accordingly, the mission of the NMSA is ambitiously broad.[234]

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[228] Notably, although the ecological considerations are listed first (and more extensively), the second-listed factor for the Secretary to consider in making a designation is "the area's historical, cultural, archaeological, or paleontological significance," indicating that, while protection of UCH might be a slightly lesser concern than environmental conservation, it is still very much within the scope of NMSA protections. 16 U.S.C. § 1433(b)(1)(B).

[229] 16 U.S.C. § 1433(b)(1)(A).

[230] *National Marine Sanctuaries*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://oceanservice.noaa.gov/ocean/sanctuaries/.

[231] 16 U.S.C. § 1431(b)(3).

[232] 16 U.S.C. § 1431(b)(7).

[233] 16 U.S.C. § 1431(b)(9).

[234] Dave Owen, The Disappointing History of the National Marine Sanctuaries Act, 11 N.Y.U. ENVTL. L.J. 711, 719 (2003).

Finally, the legislative history indicates that Congress clearly intended for the NMSA—which was passed *specifically* in response to concerns about agricultural runoff, oil spills, and ocean dumping—to be a comprehensive solution to threats to ocean ecosystems.[235] Various Representatives made sweeping statements about the scale of the problem that the NMSA hoped to tackle and the scope of the solution that it would present, claiming that the bill would result in "considerable environmental protection" against the effects of agricultural runoff on ocean waters, emphasizing the importance of comprehensive management,[236] and putting a stop to "indiscriminate and thoughtless utilization of the oceans"[237] in order to "immediately preserve vital areas of our coastline from further damage."[238]

Thus, the text and legislative history of the NMSA clearly reveal that national marine sanctuaries can and should be established for the simultaneous preservation of UCH—which has, at the very least, "historical," "cultural," and "archaeological" value[239]—and of the marine ecosystems and environments which are being disrupted by ocean acidification.[240] Since the NMSA's primary purpose is the preservation of marine environments and since the NMSA can be used to establish national marine sanctuaries with the conservation of UCH in mind, it stands to reason that the environmental protections offered by the statute can also be wielded to prevent the further ocean acidification of large marine areas specifically for the protection of UCH contained therein.

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[235] *Id.*, at 714–16.

[236] 117 Cong. Rec. 30,856-57 (1971) (statement of Rep. Lennon); Owen, *supra* note 234, at 717.

[237] 117 Cong. Rec. 30,855 (1971); Owen, *supra* note 234, at 716.

[238] 117 Cong. Rec. 30,855, 31,155 (1971); Owen, *supra* note 234, at 717.

[239] 16 U.S.C. § 1433(a).

[240] 16 U.S.C. § 1433(a); *Coral bleaching and ocean acidification are two climate-related impacts to coral reefs*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://floridakeys.noaa.gov/corals/climatethreat.html; *Effects of Ocean Acidification on Corals*, OCEANA, https://usa.oceana.org/effects-ocean-acidification-corals/.

To protect the UCH and marine areas that it manages, NOAA's Office of National Marine Sanctuaries—to which management of marine sanctuaries has been delegated by the Secretary[241]—issues regulations specifying what activities can and cannot occur within each sanctuary[242] as well as regularly updated management plans guiding day-to-day activities at each sanctuary.[243] For example, one regulation that NOAA commonly issues in order to protect UCH within national marine sanctuaries forbids "the removal of, or injury to, historic sanctuary resources."[244] This regulation has survived every legal challenge to date.[245]

There is nothing in the language of the NMSA that prohibits NOAA from qualifying ocean acidification due to agricultural runoff as a threat to national marine sanctuary resources and issuing regulations accordingly. Because the acidifying effect of toxic algal blooms resulting from nutrient-rich runoff threatens both the continued survival of *in situ* UCH as well as the biotic integrity of the marine area in which that UCH is preserved—both resources that the NMSA ostensibly exists to protect—regulating agricultural runoff into marine sanctuaries would be justified under the NMSA.

In fact, regulating such runoff may already be required under the language of existing NOAA regulations. For instance NOAA's emergency regulations require that:

> Where necessary to prevent or minimize the destruction of, loss of, or injury to a Sanctuary resource or quality, or minimize the imminent risk of such destruction, loss or injury, any and all activities, including those not listed in section 1 of this Article, are subject to immediate temporary regulation, including prohibition.[246]

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[241] *The National Marine Sanctuaries Act*, *supra* note 223; Marine Sanctuaries, Program Guidelines, 39 Fed. Reg. 10,255 (Mar. 19, 1974) (noting the delegation to the NOAA Administrator of authority under Title III of the Marine Protection, Research, and Sanctuaries Act of 1972). Such management involves "facilitating the public and private use of resources not otherwise prohibited by law through regulations and permitting." Jordan, *supra* note 223, at 35.

[242] 16 U.S.C. § 1439; *The National Marine Sanctuaries Act*, *supra*, note 319.

[243] 16 U.S.C. §§ 1435(a), (e); *The National Marine Sanctuaries Act*, *supra*, note 319.

[244] Varmer, *supra* note 5, at 271; 15 C.F.R. § 922 (2014) (setting forth regulations for each national marine sanctuary).

[245] Varmer, *supra* note 5, at 271.

[246] 15 C.F.R. § 922.165 (2014).

As used here, mitigating agricultural runoff into national marine sanctuaries would certainly fall within the scope of the regulation's mandate, as doing so would minimize the destruction of or injury to sanctuary resources—a term that, under the NMSA's language, encompasses both UCH and the large marine areas in which they are preserved.[247]

ii. Drawbacks in Practice

Despite apparently being perfectly suited to protecting both UCH and their surrounding marine areas from runoff-driven acidification, the NMSA has not been as successful as Congress hoped in achieving the comprehensive and balanced protection of ocean habitats and the marine resources contained therein.[248] Rather, the NMSA has failed to make significant headway on its broad goals, as coastlines are increasingly being eyed for oil and natural gas drilling and runoff continues to increase nutrient and pollution loads in coastal waters, leading to algal blooms, fish kills, and dead zones.[249] The failure of the NMSA to live up to these lofty conservation goals is due both to Congress's failure to manifest these goals in the language of the Act that it actually drafted and its failure to provide NOAA with the tools necessary to accomplish the task of designating marine sanctuaries and subsequently protecting the resources therein that were delegated to it.[250] As a result, the NMSA has, thus far, been too constrained to provide the kind of large-scale conservation that large marine areas need in order to alleviate the impact of ocean acidification.

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[247] 15 C.F.R. § 922 (2014).
[248] Owen, *supra* note 234, at 711–12.
[249] *Id.* at 711.
[250] *Id.* at 712–13.

While the text of the NMSA itself provides for the protection of large marine areas, the detailed criteria and the complex procedural requirements for sanctuary designation have made the actual designation of marine sanctuaries complex and difficult.[251] For instance, Section 303 and 304 of the NMSA set forth a list of factors that must be considered before a designation can be made,[252] require the Secretary, through NOAA, to consult with the relevant House and Senate Committees, with the Secretaries of State, Interior, Transportation, and Defense, any other interested federal, state, or local agencies, as well as Regional Fishery Management Councils and any other interested persons.[253] After passing this gauntlet of consultation, the Secretary must subsequently publish a notice of the proposed designation,[254] prepare a draft environmental impact statement (a complex and expensive process),[255] and hold public hearings, at least one of which must take place in the areas that will be most affected by the designation.[256] Then, the Secretary must submit the draft environmental impact statement along with all other documentation to other federal agencies and to the House and Senate committees,[257] and, if approved by the committees, publish a final notice and final regulations for management of the sanctuary.[258] The designation will not take effect until Congress has had an additional forty-five days to consider it after the final notice publication.[259]

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[251] *Id.* at 718–19.
[252] These factors include the "ecological qualities" of the area, the present and potential future uses of the area that could adversely affect such ecological qualities, "the public benefits to be derived from sanctuary status, with emphasis on the benefits of long-term protection of nationally significant resources, vital habitats, and resources which generate tourism," the "socioeconomic effects of sanctuary designation," and "the negative impacts produced by management restrictions on income-generating activities such as living and nonliving resources development." Brax, *supra* note 221, at 86; 16 U.S.C. §§ 1433(b)(1) (1994).
[253] 16 U.S.C. § 1433(b)(2).
[254] 16 U.S.C. § 1434(a)(1).
[255] 16 U.S.C. § 1434(a)(2).
[256] 16 U.S.C. § 1434(a)(3).
[257] 16 U.S.C. § 1434(a)(6).
[258] 16 U.S.C. § 1434(b)(1).
[259] Pub. L. 98-498 § 304, 98 Stat. 2296, 2300.

These various requirements compound to result in a procedurally complex process for the designation of marine sanctuaries—a process which stands in stark contrast to that of national monuments designated under the Antiquities Act, discussed below. In addition, the NMSA provides no impetus for the Secretary (or NOAA, in most cases), to pursue such a designation, as it states only that the Secretary "may designate" such sanctuaries, at his or her discretion.[260] This discretionary designation process coupled with the complexity of the process itself provides very little incentive for the creation of a large number of marine sanctuaries, and has, predictably, resulted in minimal protection of large marine areas, as there are only fifteen national marine sanctuaries under the NMSA.[261] In addition, only the first of the marine sanctuaries—the USS Monitor—was designated without pressure from Congress or the President, evidencing NOAA's inability to proactively designate sanctuaries.[262] As a recent audit by the congressionally authorized National Academy of Public Administration concluded, "the [National Marine Sanctuaries] program is uncertain, ineffective and pitifully small."[263]

The NMSA has also struggled to live up to its broad goals due to the fact that designation authority has been delegated by the Secretary to an administrative agency that is not equipped to deal with the political challenges of designating such sanctuaries.[264] Reserving marine areas has

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[260] 16 U.S.C. § 1433(a).

[261] Owen, *supra* note 234, at 721; *National Marine Sanctuaries*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://sanctuaries.noaa.gov/.

[262] Owen, *supra* note 234, at 747. Although some effort was made to strengthen the NMSA via Executive Order 13158, which requires the Department of the Interior and the Department of Commerce to "develop a national system of MPAs and jointly manage a website for information on MPAs," this executive order still fails to delineate any substantive requirements or any binding process which might survive through future administrations. Thus, as one scholar argues, this executive order will likely result only in "a comprehensive catalogue of all national MPAs and some impetus for bringing those marine areas under one governing statute and regulating agency." Brax, *supra* note 221, at 81; E.O. 13158, 65 Fed. Reg. 34909 (May 26, 2000).

[263] John Balzar, *Shoring Up Little Slices of the Seas*, L.A. TIMES (Sept. 4, 2000, 12:00 AM), available at https://www.latimes.com/archives/la-xpm-2000-sep-04-mn-15339-story.html; Brax, *supra* note 221, at 91–92.

[264] Owen, *supra* note 234, at 749. Delegating such power to as administrative agency is unprecedented in other preservation statutes. For example, national parks, wilderness areas, and wild and scenic rivers are designated directly by Congress, and national monuments are designated by the President by proclamation. *Id. See also* GEORGE CAMERON COGGINS ET AL., FEDERAL PUBLIC LAND AND RESOURCES LAW 140, 144 (5th ed. 2002); 54

the potential to generate a significant amount of political controversy, which can result in expensive and extended litigation.[265] NOAA, a relatively small agency, has very little political clout and very little leverage compared to other actors within the executive branch, and is frequently overruled by executive agencies such as the State Department, the Department of the Interior, and the Office of Management and Budget regarding resource management decisions.[266]

Because the NMSA's ambitious goals and promises of sweeping and comprehensive protection of underwater environments have been hampered by the complex procedural requirements of the Act and by the improper delegation of authority to an agency without the political power to zealously pursue further designations, the NMSA has resulted in providing very little actual environmental protection.[267] Therefore, despite its promising goals and language, the NMSA is not currently equipped to offer meaningful mitigation of the harmful effects of runoff-induced ocean acidification on *in situ* UCH or associated marine areas.

b. The Antiquities Act

Where the NMSA falls short, the Antiquities Act may present a solution. The Antiquities Act is a very powerful statute that provides significant protection with very little procedural restraint. However, it is extremely politically controversial, which may provide a barrier to its aggressive implementation for the mitigation of ocean acidification across large marine areas.

U.S.C. § 100101 *et seq.* (discussing the requirements for designation of national parks); BENJAMIN HAYES, CONG. RSCH. SERV., R45718, THE ANTIQUITIES ACT: HISTORY, CURRENT LITIGATION, AND CONSIDERATIONS FOR THE 116TH CONGRESS 1, 28 (2019), https://sgp.fas.org/crs/misc/R45718.pdf (discussing the designation of national monuments by presidential proclamation).

[265] Owen, *supra* note 234, at 750.

[266] *Id.*, at 750.

[267] *Id.*, at 713.

i. Protections for UCH and Large Marine Areas

While the NMSA is an inherently collaborative statute that, even if the levels of review are simplified, can still easily inspire political controversy and deadlock, the Antiquities Act places sole power in the hands of the President, who is subsequently empowered to cut through the red tape of more complex designation processes.[268] The Antiquities Act, also known as the American Antiquities Act of 1906, authorizes the President to establish marine national monuments by proclamation for the protection of "objects of historic or scientific interest"—a category which is easily capable of encompassing both UCH and large marine areas.[269]

Unlike the NMSA, the declaration of national monuments is a very straightforward process, requiring only the issuing of a presidential proclamation.[270] In fact, this process is so simple that past presidents have sometimes used the Antiquities Act to declare monuments as a way to bypass the more complex process of establishing a national park (which must be done via an Act of Congress, a lengthy procedure).[271] Furthermore, the Antiquities Act does not contain any requirements for notice, public participation, or congressional oversight, nor are any presidential proclamations issued under the Act subject to NEPA or any other form of review.[272] Once designated, proclamations establishing national monuments have been rarely challenged in court.[273] And even when such challenges have been brought, the Supreme Court has routinely

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[268] Brax, *supra* note 221, at 123.

[269] 54 U.S.C. § 320301 (1906).

[270] HAYES, *supra* note 264, at 28. National monuments can also be declared by Congress under the Property Clause of the U.S. Constitution. U.S. Const. art. IV, § 3, cl. 2.

[271] 54 U.S.C. § 100101 *et seq.*

[272] Brax, *supra* note 221, at 125. *See e.g.,* Alaska v. Carter, 462 F. Supp. 1155, 1159–60 (D. Alaska 1978) (holding that the President is not subject to environmental impact statement requirements when proclaiming monuments under the Antiquities Act).

[273] Brax, *supra* note 221, at 125.

upheld the designation and dismissed the challenge.[274] Thus, in comparison to the NMSA, the Antiquities Act is a very agile and unfettered statute.

The scope of protection that the Antiquities Act is capable of offering to UCH and associated large marine areas is also much broader than under the NMSA. Although the legislative history of the Antiquities Act suggests that the term "objects" was initially intended to refer only to archaeological artifacts located on terrestrial archaeological sites in the American Southwest (such as cliff dwellings, prehistoric towers, communal houses, shrines, and burial mounds),[275] the Antiquities Act has long been wielded for the protection of a much broader range of "objects," largely due to Congress's failure to translate this intent into the text of the Antiquities Act itself.[276] The text of subsection (a) of the Antiquities Act of 1906 reads: "The President may, in the President's discretion, declare by public proclamation historic landmarks, historic and prehistoric structures, *and* other objects of historic or scientific interest that are

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[274] Catarina Conran, *Monumental Change? Rethinking the Role of the Courts in the Antiquities Act*, 40 VA. ENVTL. L.J. 169, 180–83 (2022); Brax, *supra* note 221, at 125; *See e.g.,* Cameron v. United States, 252 U.S. 450, 455-56 (1920) (upholding President Roosevelt's designation of the Grand Canyon National Monument); Cappaert v. United States, 426 U.S. 128, 141-42 (1976) (upholding President Truman's designation of the Devils Hole National Monument); United States v. California, 436 U.S. 32, 35-36 (1978) (upholding President Truman's proclamation enlarging the Channel Islands National Monument); *Anaconda Copper Co. v. Andrus,* 14 Env't Rep. Cas. (BNA) 1853, 1855 (D. Alaska July 1, 1980) (upholding President Carter's creation of national monuments in Alaska); Wyoming v. Franke, 58 F. Supp. 890, 894 (D. Wyo. 1945) ("In this respect, this Court feels that it has a limited jurisdiction to investigate and determine whether or not the Proclamation is an arbitrary and capricious exercise of power under the Antiquities Act so as to be outside of the scope and purpose of that Act by which the President in the exercise of its provisions has exceeded or violated a discretion thereby conferred.").

[275] Conran, *supra* note 274, at 177–78; Varmer, *supra* note 5, at 254. As the legislative history reveals, the Antiquities Act was passed specifically in response to a surge in unregulated looting and destruction of archaeological sites in the Southwest between the 1880s and the 1890s. RONALD F. LEE, NAT'L PARK SERV., THE ANTIQUITIES ACT OF 1906, at 90 (1970). *See also* Richard H. Seamon, *Dismantling Monuments*, 70 FLA. L. REV. 553, 562–63 (2019) ("Both amateur and professional antiquity hunters—'pot hunters'—were removing antiquities from the public lands and vandalizing the sites on which they were located."); H.R. REP. NO. 58-3704, at 2 (1905) ("These ruins have been frequently mutilated by people seeking the relics for the purpose of selling them. Such excavations destroy the valuable evidence contained in the ruins themselves, and prevent a careful and scientific investigation by representatives of public institutions interested in archaeology."); S. REP. NO. 59-3797, at 1 (1906) ("[T]he historic and prehistoric ruins and monuments on the public lands of the United States are rapidly being destroyed by parties who are gathering them as relics.").

[276] Conran, *supra* note 274, at 178–183.

situated on land owned or controlled by the Federal Government to be national monuments."[277] The inclusion of an oxford comma and the word "and" before the "other objects" clause clearly identifies these "other objects" as something distinct from "historic and prehistoric structures."[278] In addition, the wording of the Act implies that these objects may include not only those of historic interest, as the 59th Congress intended, but also those of scientific interest—a much broader category that is open to significant interpretation and lies entirely within the President's discretion.[279] As a result, the Antiquities Act is capable of providing protections to a very broad range of "objects." The agility and broad scope of the Antiquities Act has been borne out in practice, as the Act has been used to designate over 150 national monuments since its passage in 1906.[280]

The language of the Act imposes no real limitation on the discretion granted to the President to declare national monuments. In the century since the Act's passage, this has led to the establishment of very large national monuments both "above and below the sea"[281] for the protection of a wide variety of "objects," such as "cultural, prehistoric, and historic legacy and . . . diverse array of natural and scientific resources,"[282] "daytime scenery" and "night skies,"[283] and "vari[ations] . . . in elevation and topography."[284] One limitation on the scope of the President's discretion does exist in subsection (b) of the Act, which provides that "[t]he President may reserve parcels of land as a part of the national monuments. The limits of the parcels shall be confined to the smallest area compatible with the proper care and management of

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[277] 54 U.S.C. § 320301(a) (emphasis added); Conran, *supra* note 274, at 179.
[278] 54 U.S.C. § 320301(a).
[279] *Id.*; Conran, *supra* note 274, at 179.
[280] Conran, *supra* note 274, at 176; HAYES, *supra* note 264, at 1.
[281] Mass. Lobstermen's Ass'n v. Raimondo, 945 F.3d 535 (D.C. Cir. 2019), *cert. denied*, 141 S. Ct. 979, 981 (2021) (Roberts, C.J., statement respecting the denial of certiorari).
[282] Proclamation No. 9558, 82 Fed. Reg. 1139, 1142 (Jan. 5, 2017).
[283] Proclamation No. 9476, 81 Fed. Reg. at 59125.
[284] Proclamation No. 6920, 61 Fed. Reg. 50223, 50224 (Sept. 24, 1996).

the objects to be protected."[285] However, because subsection (b) imposes this "smallest area compatible" requirement on "the objects to be protected," which subsection (a) has already clearly established to be a very broad category, "this restriction has ceased to pose any meaningful restraint."[286] Thus, the Antiquities Act is a very powerful tool for the protection of UCH.

Establishing a monument for either the protection of UCH or of the large marine areas in which *in situ* UCH is preserved is well within the scope of the Antiquities Act. For example, the Antiquities Act has been used several times to protect "imprecisely demarcated"[287] and wide-ranging "objects" such as "submerged lands" and "ecosystems,"[288] and UCH itself definitively falls within the scope of the "historic and prehistoric structures" mentioned in the Act.[289] This is particularly true given that the intent of the 59th Congress was to protect archaeological sites and relics (albeit terrestrial rather than marine),[290] and given that the Antiquities Act has been used to protect marine resources (both cultural and natural) since as far back as 1938, via the establishment of marine national monuments.[291]

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[285] 54 U.S.C. § 320301(b).

[286] Conran, *supra* note 274, at 179–80; Mass. Lobstermen's Ass'n v. Raimondo, 945 F.3d 535 (D.C. Cir. 2019), *cert. denied*, 141 S. Ct. 979, 981 (2021) (Roberts, C.J., statement respecting the denial of certiorari).

[287] Mass. Lobstermen's Ass'n, 141 S. Ct. at 981 (Roberts, C.J., statement respecting the denial of certiorari).

[288] Alaska v. United States, 545 U.S. 75, 103 (2005) (allowing the expansion of Glacier Bay National Monument via the inclusion of additional lands comprising the Glacier Bay ecosystem); Tulare Cnty. v. Bush, 306 F.3d 1138, 1142 (D.C. Cir. 2002) (holding that ecosystems qualify as "objects" under the Antiquities Act); Mass. Lobstermen's Ass'n, 141 S. Ct. at 981 (Roberts, C.J., statement respecting the denial of certiorari).

[289] 54 U.S.C. § 320301(a).

[290] Conran, *supra* note 274, at 177–78; Varmer, *supra* note 5, at 254.

[291] Such monuments include the Channel Islands National Monument, Proclamation No. 2281, 52 Stat. 1541 (Apr. 26, 1938), the Santa Rosa Island National Monument, Proclamation No. 2337, 3 C.F.R. 88 (1938-1943), the Buck Island Reef National Monument, Proclamation No. 3443, 3 C.F.R. 152 (1959-1963), and the Northeast Canyons and Seamounts Marine National Monument, Proclamation No. 9496, 81 Fed. Reg. 65161 (Sept. 21, 2016). In addition, the Antiquities Act has been used to establish several marine national monuments that extend beyond the 12-nautical-mile limit of the U.S. territorial sea. These monuments include the Papahānaumokuākea Marine National Monument, the Marianas Trench Marine National Monument, the Pacific Remote Islands Marine National Monument, and the Rose Atoll Marine National Monument, which together encompass nearly 214,777,000 acres of submerged land (more than Texas and Florida combined). Jordan, *supra* note 223, at 31.

Due to the breadth of discretion that the Antiquities Act grants to the President in terms of the "objects" for which a national monument is created to protect, the Antiquities Act is a powerful tool for protecting UCH from ocean acidification. Once a national monument is established, the lands and resources therein are subject to the protections specified by each individual presidential proclamation, as well as other sources of law, such as the Mineral Leasing Act (prohibiting the establishment of new mineral leases within national monument boundaries) and other management plans imposed by the agency responsible for overseeing the national monument, usually the National Park Service or the Bureau of Land Management.[292] If a national monument is established for the protection of objects such as "underwater cultural heritage," "large marine areas," or even "underwater ecosystems," specific management plans could subsequently be adopted to protect UCH and their associated marine areas from pH decreases resulting from agricultural runoff.[293]

ii. Drawbacks in Practice

Despite its strengths, however, the Antiquities Act is not as perfect a solution as it seems. Presidential proclamations, by which national monuments are established, do not carry the force

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[292] Conran, *supra* note 274, at 175; HAYES, *supra* note 264, at 1, 6–7.

[293] Although such protections are theoretically possible under the language of the Antiquities Act, it is important to note that regulations have not been aimed at regulating agricultural runoff into coastal marine areas. Even in the Northeast Canyons and Seamounts National Monument—which was established explicitly for the protection of the underwater "ecosystem"—made no mention of agricultural runoff or its impacts. Nevertheless, the regulations that were issued prohibit "[r]emoving, moving, taking, harvesting, possessing, injuring, disturbing, or damaging, or attempting to remove, move, take, harvest, possess, injure, disturb, or damage, any living or nonliving monument resource, except as provided under regulated activities below"—a definition which could easily be read to include runoff-driven ocean acidification. *Northeast Canyons and Seamounts Marine National Monument Frequently Asked Questions*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://www.fisheries.noaa.gov/new-england-mid-atlantic/ecosystems/northeast-canyons-and-seamounts-marine-national-monument.

of law.[294] In addition, all national monuments designated by presidents are subject to alteration by Congress, which can adjust the size, use, and management of a monument, or revoke the designation entirely.[295] However, Congress has historically been very reluctant to exercise its power to revoke these designations.[296] This is especially true since Congressional alteration of a monument must be accomplished via legislation, which requires presidential approval—approval which is unlikely to be forthcoming from the same president that designated the monument in the first place.[297] Furthermore, the impetus to revoke a designation may also decrease the longer that the monument has existed, as impetus to challenge the status quo decreases—unlike the NMSA, which requires continued effort (and funding) to support the National Marine Sanctuaries program.[298] Nevertheless, some national monuments may prove to be controversial enough to prompt attempts at revocation even years later.[299]

As one further stumbling block, the broad discretion that the Antiquities Act grants to the President has recently come under fire. For instance, Chief Justice John Roberts recently suggested in a statement respecting the denial of certiorari in *Massachusetts Lobstermen's Ass'n v. Raimondo* that past presidents have gone overboard in their designations of marine national monuments on submerged lands, arguing that recently declared monuments have been much too

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[294] Brax, *supra* note 221, at 126.

[295] *Id.*; Conran, *supra* note 274, at 175.

[296] Brax, supra note 221, at 126; David Negri, Grand Staircase-Escalante National Monument: Presidential Discretion Plus Congressional Acquiescence Equals a New National Monument, 20 UTAH BAR J. 20, 22 (1997) (noting "Congressional acquiescence in a broad reading of presidential authority under the Antiquities Act"). Importantly, the handful of monument revocations by Congress have occurred under fairly limited and infrequent circumstances: "1) the objects that the monument was established to protect became diminished . . . 2) the sites were less-significant examples of objects already protected in other national monuments, . . . or 3) "the sites were publicly inaccessible and unable to be developed into parks." Conran, supra note 274, at 193.

[297] Brax, *supra* note 221, at 126.

[298] *Id.*, at 127.

[299] Conran, *supra* note 274, at 170–74.

large.[300] This opposition could lead to the imposition of restrictions on the President's broad power by the Supreme Court.[301] In fact, Chief Justice Roberts has implied that the President's power under the Act should be limited via strengthening the "smallest area compatible" limitation in subsection (b).[302] Thus, it is possible that the Antiquities Act will not long remain as unfettered and discretionary as it currently is.

Although such a restriction would primarily affect the *size* of certain national monuments rather than the objects being protected, the size of a national monument is very closely linked to the objects that it exists to protect, especially if those objects are "imprecisely demarcated concept[s]"[303] such as large marine areas subject to agricultural runoff. As established in Chapter 1, one such area along the western U.S. coastline stretches from above Washington state to beyond southern California—a very large "object" indeed. Thus, if a size restriction is imposed on the designation of national monuments under the Antiquities Act, it is possible that marine national monuments will be unable to adequately protect large marine areas (and their associated *in situ* UCH) to the extent necessary to safeguard them from ocean acidification.

Thus, while the Antiquities Act is powerful, it likely cannot be wielded prolifically for the mitigation of agricultural runoff into large marine areas. Although it is theoretically capable of filling the hole created by the NMSA's complex and impractical designation process, using the Antiquities Act to designate a large number of monuments for the protection of large marine areas subject to acidification due to agricultural runoff would likely ignite further political controversy and instigate challenges to both the monuments and the Antiquities Act itself, which

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[300] 945 F.3d 535 (D.C. Cir. 2019), *cert. denied*, 141 S. Ct. 979, 980 (2021) (Roberts, C.J., statement respecting the denial of certiorari) (critiquing the use of the Antiquities Act "to designate an area of submerged land about the size of Connecticut as a monument").

[301] *Id.*, at 981.

[302] *Id.*; Conran, *supra* note 274, at 196.

[303] *Mass. Lobstermen's Ass'n*, 141 S. Ct. at 981 (Roberts, C.J., statement respecting the denial of certiorari).

may ultimately result in a narrowing of the Act.[304] This is especially true given the warning shot recently fired across the bow of the Antiquities Act specifically over the designation of large marine monuments established for the protection of "ecosystems."[305] Thus, although the NMSA and the Antiquities act both show significant promise, they have proven to be unable to safeguard large marine areas, such as the west coast of the U.S., and the UCH preserved therein from the harmful effects of enhanced ocean acidification from agricultural runoff.

2. Closing the Gaps in UCH Protection in the U.S.

Because it is likely that public opinion would be very strongly opposed to the use of the Antiquities Act to protect large swaths of the U.S. coastline, the NMSA presents a better avenue through which to mitigate agriculturally-driven ocean acidification.[306] To that end, some adjustments should be made to the text and implementation of the NMSA in order to increase its power and reach. However, the Antiquities Act should not be discounted entirely as a protective measure, and can still be used, provided that certain precautions are taken in the designation of national monuments under the Antiquities Act in the event that the Supreme Court narrows the scope of the presidential discretion that the Act currently permits.

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[304] Conran, *supra* note 274, at 195–203.

[305] *Mass. Lobstermen's Ass'n*, 141 S. Ct. at 981 (Roberts, C.J., statement respecting the denial of certiorari).

[306] Outside of the legal frameworks themselves, authors have also suggested policy solutions that could bolster ecosystem management. Although the policy question is outside the scope of this paper, it is nevertheless a very important part of the framework that will ultimately need to be developed to ensure comprehensive protection for UCH and underwater ecosystems. *See e.g.,* Stafan Claesson, *An ecosystem-based framework for governance and management of maritime cultural heritage in the USA*, 33 MARINE POLICY 698, 698–706 (2009), available at https://www.academia.edu/22746889/An_ecosystem_based_framework_for_governance_and_management_of_maritime_cultural_heritage_in_the_USA?email_work_card=view-paper (suggesting the "implementation of a regional governance structure based on the tenets of ecosystem-based management" in order to conserve maritime heritage and "contribute to the well-being, economic growth and development of coastal communities").

a. The National Marine Sanctuaries Act

Although the NMSA has been prevented from reaching its full potential by procedural complexity and improper delegation to NOAA, the NMSA is likely still the best option for "comprehensively managing marine activities by designating and assuring the protection of marine areas of environmental value."[307] This is largely because, of the many UCH conservation statutes in the United States, the NMSA most closely parallels the organic acts protecting terrestrial environments, thereby offering the best statutory platform from which to establish protection for large marine areas.[308] However, the NMSA, as currently written, is unable to live up to this potential.

First and foremost, the NMSA's complex review requirements should be streamlined.[309] At the moment, the NMSA is a far cry from providing the strong protection that it would otherwise be capable of due to the complexity of the sanctuary designation process. In order to make these designations simpler and more feasible, several of the levels of review should be removed via a congressional amendment of the procedural requirements delineated in the statute.[310] Second, Congress could further strengthen the NMSA by increasing the scope of the Act's protections. One way of doing so is for the National Marine Sanctuaries program to be expanded to include marine protected areas ("MPAs") in addition to national marine sanctuaries.

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[307] Michael C. Blumm & Joel G. Blumstein, *The Marine Sanctuaries Program: A Framework for Critical Areas Management in the Sea*, 8 ENVTL. L. REP. 50016, n.14 (1978); Brax, *supra* note 221, at 82.

[308] Brax, *supra* note 221, at 90.

[309] Although it is reasonable for the NMSA to require review of potential sanctuaries by interest groups due to the fact that these areas are subject to a wide variety of uses, the levels of review currently required by the Act are excessive. *Id.*

[310] This is particularly pertinent since national marine sanctuaries are increasingly being designated by Congress or by the President (bypassing the statutory process). *Id.*, at 92. For example, the Florida Keys National Marine Sanctuary was designated through direct legislation by Congress in 1993, and the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve was designated by President Clinton via executive order. *Id.*

MPAs, established under the authority of Executive Order 13158, are defined as any area that is the subject of measures guaranteeing "lasting protection for part or all of the natural and cultural resources therein" while simultaneously being available for multiple uses, similar to the multiple use-sustainable yield governance of National Forests.[311] While there are only fifteen national marine sanctuaries in existence,[312] there are a total of 979 MPAs.[313] Including these MPAs within the National Marine Sanctuaries program would make the NMSA the dominant statute governing the management of marine resources, thereby increasing the power and influence of the Act.[314] Extending the NMSA to include MPAs is supported by the Act's legislative history, its language, and its broadly stated purpose.[315] In order to do so, Congress should consider passing legislation transferring governance of MPAs to the National Marine Sanctuaries program under the NMSA.[316]

Alternatively, Congress should consider strengthening NOAA's authority so as to better empower it to adequately administer the NMSA. To that end, the NMSA should be amended to grant NOAA the power to impose criminal sanctions.[317] In addition, the NMSA should be amended to require agencies to actually implement any reasonable and prudent alternatives

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[311] *Id.*, at 76; Exec. Order No. 13,158, 65 Fed. Reg. 34,909 (May 26, 2000); *Marine Protected Areas of the United States: The Challenges*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., available at http://mpa.gov/mpadescriptive/challenges.html. *See also Marine Protected Areas as Climate Solutions*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://storymaps.arcgis.com/stories/1c86c55bfa624643aa376e49fa571c85 ("MPAs provide long term protection to important marine and coastal ecosystems that provide a wide range of benefits, including biodiversity conservation, coastal protection, food and livelihoods for local communities, and carbon storage. As such, they can provide natural solutions to climate impacts through mitigation, adaptation and resilience, complementing essential efforts to reduce greenhouse gas emissions.").

[312] *National Marine Sanctuaries*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://sanctuaries.noaa.gov/.

[313] *The MPA Inventory*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://marineprotectedareas.noaa.gov/dataanalysis/mpainventory/.

[314] Brax, *supra* note 221, at 92.

[315] *Id.*, at 74. Doing so would also streamline the current system of governance of various types of marine resources, as the current regime is fairly uncoordinated and governed by "divergent statutory authority." *Id.*

[316] *Id.*, at 92.

[317] *Id.* Currently, the NMSA authorizes NOAA only to impose civil penalties for violations of the NMSA or of its regulations. These penalties can reach up to $130,000 per day for each violation. *Legislation*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://sanctuaries.noaa.gov/about/legislation/.

suggested by the Secretary (or NOAA) to certain agency actions which the Secretary is required by the NMSA to review, as long as those suggestions are "feasible," "reasonable," or "cost-effective."[318] At the moment, although the NMSA requires any federal agency whose actions are "likely to destroy, cause the loss of, or injure a sanctuary resource" to consult with NOAA prior to taking any action,[319] these agencies are not actually required to implement NOAA's subsequent recommendations of "reasonable and prudent alternatives to protect sanctuary resources,"[320] thereby leaving NOAA unable to prevent the actions of other, more powerful, federal agencies.

Outside of congressional amendments, other measures should also be considered to increase the NMSA's ability to effectively mitigate ocean acidification within national marine sanctuaries. For instance, NOAA could implement more monitoring programs in order to assess pH in marine sanctuary waters. Since NOAA is not able to regulate what they do not know about, it is important to establish a robust network of pH monitoring stations throughout NMSA-protected waters. Currently, many national marine sanctuaries host monitoring programs to track natural processes within their boundaries.[321] However, only five of these monitoring programs currently track changes in pH.[322]

In addition, NOAA could issue specific regulations requiring changes in agricultural practices near national marine sanctuaries in order to reduce runoff entering protected waters, or impose specific requirements that any activities with the potential to affect pH within sanctuary

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[318] Brax, *supra* note 221, at 92–93.

[319] 16 U.S.C. §§ 1435(d); *The National Marine Sanctuaries Act*, *supra* note 223.

[320] 16 U.S.C. §§ 1435(d); *The National Marine Sanctuaries Act*, *supra* note 223.

[321] *Monitoring Programs and Resources*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://sanctuaries.noaa.gov/science/monitoring/.

[322] *Subject Areas Monitored by Each Sanctuary*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://sanctuaries.noaa.gov/science/monitoring/topic_areas.html; *Ocean Acidification Sentinel Site*, OASeS, http://www.olympiccoastsentinelsite.org/home.php.

waters receive permits from NOAA's office of National Marine Sanctuaries. Currently, regulations issued by NOAA for each national marine sanctuary under the NMSA make no mention of runoff generally, or agricultural runoff in particular.[323] However, under the language of the NMSA—which requires the protection of the sanctuary's "conservation" . . . "ecological, historical . . . cultural, [and] archaeological" qualities[324]—and the broader purpose of the Act,[325] such regulations are theoretically possible, even though the agricultural sites being regulated are not themselves within sanctuary boundaries.

Finally, a full inventory of UCH within U.S. territorial waters should be compiled, along with the extent to which each of these artifacts are threatened by climate change, ocean acidification in particular. Although NOAA does host a dataset recording shipwrecks and other obstructions in U.S. coastal waters, this dataset has not been updated since 2016 and may not include all materials that could be classified as UCH.[326] Thus, expanding and updating this database would help NOAA make informed decisions about whether and when to use the NMSA to extend protections to areas in which UCH is preserved.

In order to adequately implement these programs and regulations or to enforce their new authority, NOAA as an agency should be expanded (so that management of the now larger NMSA is not too much of a lift for an understaffed agency).[327] In addition, the federal government should be willing to consistently commit to designating marine sanctuaries under the NMSA across various presidential administrations in order to imbue the sanctuary program with a life of its own outside the whims of successive administrations.[328]

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[323] 15 C.F.R. § 922 (2014).

[324] 16 U.S.C. § 1433(a).

[325] 16 U.S.C. § 1431(b); Owen, *supra* note 234, at 714–16.

[326] *Wrecks and Obstructions Database*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., https://www.nauticalcharts.noaa.gov/data/wrecks-and-obstructions.html.

[327] Brax, *supra* note 221, at 93.

[328] *Id.*, at 90–91.

b. The Antiquities Act

While the NMSA fails to adequately protect *in situ* UCH and the associated underwater ecosystems in its *current* form, the Antiquities Act faces potential *future* roadblocks to such protection. Thus, the Antiquities Act can be used freely in its current form for the protection of both UCH and large marine areas, but some precautions must be taken in the event that the discretionary scope of the Act is restricted.[329] If this occurs, a monument designated under the Antiquities Act could be revoked by the Supreme Court.[330] To avoid such revocation, national monuments declared for the purpose of mitigating ocean acidification over a large marine area should establish an evidence-based, scientific record that clearly demonstrates why all the land included in newly declared monuments is compatible with the protection of the objects identified.[331] Generating such a record for both past monuments protecting UCH and their associated ecosystems may also help to protect them from any challenges which may arise.[332]

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[329] Although there has never been a successful legal challenge to the Antiquities Act to date, it is possible that a conservative Supreme Court may take action to narrow the scope of the Act. Conran, *supra* note 274, at 195–203 (arguing that Chief Justice Roberts' recent statement may herald a change in Antiquities Act jurisprudence, which could negatively affect the size of monuments that can be declared under the Act).

[330] Revocations by Congress are always possible under the Antiquities Act, however, Congress rarely exercises this power. HAYES, *supra* note 264, at 8.

[331] Marissa Grenon, Are Marine National Monuments in Danger? Examining Chief Justice Roberts's Statement Denying Certiorari for Massachusetts Lobstermen's Association, AM. BAR ASS'N: SECTION OF ENV'T, ENERGY, & RES. (Aug. 12, 2021), https://www.americanbar.org/groups/environment_energy_resources/publications/mr/20210812-are-marine-national-monuments-in-danger/.

[332] Conran, *supra* note 274, at 202.

CONCLUSION

Within the next twenty years, the world will be a very different place. The IPCC predicts a range of climate change-related effects, such as hotter temperatures, acidification of our oceans, more severe weather, and deterioration of ecosystems around the globe.[333] Of these, addressing ocean acidification is the most legally feasible avenue for securing the long-term protection and resilience of *in situ* UCH.

In the United States, the National Marine Sanctuaries Act and the Antiquities Act provide the best chance of protecting UCH from the effects of near-shore ocean acidification by mitigating agricultural nutrient runoff into federally protected marine areas. However, while the text of these statutes allows for such mitigation, these federal laws are currently unable to do so in practice. The NMSA is far too unwieldy and NOAA too politically underpowered to establish meaningful restrictions on runoff into large marine areas; and the Antiquities Act is potentially facing an impending tightening of its scope from the U.S. Supreme Court. Nevertheless, these two statutes do still have the potential to mitigate ocean acidification in large marine areas, provided that Congress first amends the NMSA to be less unwieldy and places more power in the hands of the agency tasked with administering it, and that some precautionary measures are taken when declaring national monuments under the Antiquities Act in case the scope of the act is narrowed.

Mobilizing these two statutes to decrease the rate and intensity of ocean acidification in certain coastal areas can help to alleviate the deterioration and increase the resilience of UCH artifacts preserved therein. While doing so will certainly not alleviate the “wicked” problem[334] of

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[333] *Summary for Policymakers*, *supra* note 1.
[334] Coglianese, *supra* note 194.

climate change entirely, this paper presents one avenue through which the UCH preserved *in situ* in U.S. coastal waters can be protected from the rising tide of climate change.