OCEAN ACIDIFICATION: LEGAL AND POLICY RESPONSES TO ADDRESS CLIMATE CHANGE'S EVIL TWIN∇

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ABSTRACT: Much attention has been devoted to the problem of global climate change, but the effects of carbon dioxide on the world's oceans has been largely underappreciated. Oceanic absorption of carbon dioxide is working fundamental changes on ocean chemistry, increasing the acidity of the oceans, and threatening the stability of the oceans' ecosystems. The United States has responded to these emergent threats with a policy agenda heavily oriented toward data production, but light on action that might reverse the course of ocean acidification. This Article contends that this policy approach is ill-suited to the known risks of intensifying ocean acidification. The author recommends a shift toward a more action-oriented policy agenda aimed at preventing ocean acidification from reaching perilous levels. In particular, this article recommends using the statutory tools already available under the Clean Water Act to preserve coastal carbon sinks, to establish more protective marine water quality standards for pH, and to implement regional TMDLs for carbon dioxide. The cost of delay is simply too high to forgo direct action to combat ocean acidification.

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> *"Humankind faces an immediate and pressing choice between exerting ecological restraint and allowing global ecological catastrophe."*[1]

I. INTRODUCTION

Oceans play a critical role in controlling climate change by exchanging heat and absorbing atmospheric carbon dioxide.[2] Collectively, the world's oceans have absorbed more than 80 percent of the heat added to the climate system and approximately one-third of all the carbon dioxide emitted into the atmosphere since the industrial revolution.[3] Globally, oceans absorb approximately 300 tons of atmospheric carbon dioxide each second.[4] Once absorbed into ocean water,

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1. THE INT'L PROGRAMME ON THE STATE OF THE OCEAN, IMPLEMENTING THE GLOBAL STATE OF THE OCEANS REPORT 3 (2013), http://www.stateoftheocean.org/pdfs/ipso_report_051208web.pdf.

2. Robert Stewart, *Ocean and Climate*, OCEAN MOTION AND SURFACE CURRENTS, http://oceanmotion.org/html/background/climate.htm (last visited Feb. 5, 2014) (noting that oceans absorb heat when the air is warm and release heat when the air is cool); *see also* John Pickrell, *Oceans Found to Absorb Half of All Man-Made Carbon*, NAT'L GEOGRAPHIC NEWS (July 15, 2004), http://news.nationalgeographic.com/news/2004/07/0715_040715_oceancarbon.html; Christopher L. Sabine et al., *The Oceanic Sink for Anthropogenic CO_2*, 305 SCIENCE 367, 370 (2004) (predicting that over time approximately 90 percent of all anthropogenic CO_2 emissions will end up in the ocean).

3. *Diagnosing the State of the Ocean's Health*, INT'L PROGRAM ON THE STATE OF THE OCEAN, http://www.stateoftheocean.org/howbad.cfm (last visited Oct. 9, 2013).

4. *Coral Reef Conservation Act Reauthorization and Enhancement Amendments of 2009: Hearing on H.R. 860 and H.R. 934 Before the Subcomm. on Insular Affairs, Oceans & Wildlife of the H. Comm. on Natural Res.*, 111th Cong. (2009) (statement of

atmospheric carbon dioxide is converted to a weak acid that decreases the pH of the water.[5] Despite the critical importance of each of these processes, most climate change discussion has been directed at anticipated land-based impacts. However, changes in ocean chemistry driven largely by increased absorption of atmospheric carbon dioxide have the potential to fundamentally alter marine systems in ways that may be even more significant to humanity.

Atmospheric carbon dioxide concentrations have risen from 280 to 390 parts per million since the mid-18th century.[6] Approximately half of this increase has occurred over the last 30 years, an accelerated trend that persists.[7] This increase in atmospheric carbon dioxide has corresponded with changes in ocean chemistry. Since the Industrial Revolution, global average ocean pH has decreased by approximately 30 percent, and that downward trend is expected to continue and accelerate.[8] Under existing models, ocean pH is projected to decline from its current level of 8.1 to 7.7 or 7.8.[9] The world's oceans are more acidic today than they have been at any point in the last 20 million years, and under current emissions rates the oceans may become 150 percent more acidic by 2100.[10] Declines of this magnitude will likely impact marine systems in profound ways.[11] Perhaps more troubling is that existing models do not fully account for all known and potential causes of ocean acidification.[12] Therefore, the projected decline in pH could be greater than predicted.

Ken Caldeira, Dep't of Global Ecology, Carnegie Inst.).

5. John E. Dore et al., *Physical and Biogeochemical Modulation of Ocean Acidification in the Central North Pacific*, 106 PROCEEDINGS OF THE NAT'L ACAD. OF SCI. 12,235, 12,235 (2009).

6. NOAA, OCEAN AND GREAT LAKES ACIDIFICATION RESEARCH PLAN 4 (2010), http://www.research.noaa.gov/pdfs/noaa-ocean-acidification.pdf.

7. *Id.*

8. Dore, *supra* note 5, at 12,235 (noting that global mean pH has decreased from 8.2 to 8.1 in the last 250 years, with a corresponding increase of H+ ions by 30 percent).

9. *Id.*

10. *Id.* at 12,235 (noting that a substantial fraction of the CO_2 emissions is absorbed by the oceans, resulting in a reduction of seawater pH); *see also Ocean Acidification*, WOODS HOLE OCEANOGRAPHIC INST., http://www.whoi.edu/main/topic/ocean-acidification (last visited Nov. 5, 2013).

11. Dore, *supra* note 5, at 12,235.

12. For example, under existing emissions models, carbon dioxide sequestered in coastal ecosystems is not addressed. Disturbance of these large carbon sinks has the capacity to release huge volumes of carbon dioxide back into the atmosphere.

Ocean absorption of anthropogenic carbon dioxide has slowed the progression of climate change, but at substantial cost to the marine environment.[13] Changes in pH can negatively impact marine species by altering species behavior, predation, resilience, reproduction, metabolism, and immunity.[14] In some areas, changes in pH have resulted in decreased biodiversity and alterations in species composition within marine communities.[15] The rate at which ocean pH is declining is accelerating, and this rapid change in ocean chemistry threatens to fundamentally alter complex marine systems upon which humans depend. Within decades, damage to marine organisms, food webs, biodiversity, and fisheries will likely impact more than half of the world's population that depends on the ocean for its primary source of food.[16] Absent immediate action, "irreversible, catastrophic changes to marine ecosystems" are anticipated to occur.[17]

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13. Galen A. McKinley et al., *Convergence of Atmospheric and North Atlantic Carbon Dioxide Trends on Multidecadal Timescales*, 4 NATURE GEOSCIENCE 606, 606 (2011); *see also What is Ocean Acidification?*, NOAA PMEL CARBON PROGRAM, http://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F (last visited Nov. 5, 2013) (noting that acidic ocean environments have a dramatic effect on shelled organisms that could place the entire ocean food web at risk).

14. *See, e.g.*, D.J. McElroy et al., *Respiratory Response of the Intertidal Seastar* Parvulastra exigua *to Contemporary and Near-future Pulses of Warming and Hypercapnia*, 416-417 J. EXPERIMENTAL MARINE BIOLOGY & ECOLOGY 1, 1 (2012) (reviewing metabolic responses of *Parvulstra exigua* to warming and acidification); Al Catarino et al., *Sea Urchin* Arbacia dufresnei *(Blainville 1825) Larvae Response to Ocean Acidification*, 35 POLAR BIOLOGY 455, 455 (2011) (reporting that offspring from sub-Antarctic populations of *Arbacia dufresnei* are susceptible to development delay at low pH); Philip L. Munday et al., *Replenishment of Fish Populations is Threatened by Ocean Acidification*, 107 PNAS 12,930, 12,930 (2010) (reporting larvae exposed to elevated CO_2 were more active and exhibited riskier behavior in natural coral-reef habitat and had 5–9 times higher mortality from predation than current-day controls, with mortality increasing with CO_2 concentration). *But see* Christian Pansch et al., *Impacts of Ocean Warming and Acidification on the Larval Development of the Barnacle* Amphibalanus improvisus, 420–21 J. EXPERIMENTAL MARINE BIOLOGY & ECOLOGY 48, 48 (2012) (reporting remarkable tolerance of *Amphibalanus improvisus* larvae to 1250 µatm pCO_2, the level of ocean acidification predicted for the end of the century).

15. James P. Barry et al., *Effects of Ocean Acidification on Marine Biodiversity and Ecosystem Function*, *in* OCEAN ACIDIFICATION 192, 192 (Jean-Pierre Gattuso & Lina Hansson eds., 2011).

16. Prince Albert II of Monaco Found., *Monaco Declaration, Second International Symposium on the Ocean in a High-CO_2 World: Monaco—Oct. 6–9, 2008*, http://www.ocean-acidification.net/Symposium2008/MonacoDeclaration.pdf (last visited Apr. 7, 2014).

17. THE INT'L PROGRAMME ON THE STATE OF THE OCEAN, *supra* note 1, at 3.

This article addresses the legal and policy responses to ocean acidification in the United States and concludes that the proposed response is inadequate to effectively address ocean acidification on the time scale needed. Section I provides a brief overview of ocean acidification, and how ocean acidification may impact the marine environment and society. Section II addresses legal and policy responses to ocean acidification in the United States, with emphasis on how the Clean Water Act may be applied to address ocean acidification. Section III provides recommendations that should be considered in responding to ocean acidification.

II. OCEAN ABSORPTION OF CARBON DIOXIDE

Atmospheric carbon dioxide has increased by about 40 percent since the Industrial Revolution due to human activities.[18] As recently as the early 1950s, many scientists believed that carbon dioxide released from industrial processes would be absorbed by vegetation or transferred into the ocean through direct sea-air exchange.[19] In the mid-1950s, however, evidence emerged to show that oceanic absorption of carbon dioxide proceeded at a much slower rate than expected.[20] This evidence demonstrated for the first time that excess carbon dioxide that did not assimilate into the ocean would instead accumulate in the atmosphere and contribute to global warming.[21] Since then, most research on climate change has focused on identifying and addressing the impacts of rising atmospheric carbon dioxide on the natural and human environments. The now-famous Keeling Curve detailing the accumulation of carbon dioxide in Earth's atmosphere prompted intense study on global warming, but Keeling's work shed light on only part of the problem.[22] Changes in atmospheric concentrations of carbon dioxide are largely paralleled in the ocean, but with dramatically different

18. William G. Sunda & Wei-Jun Cai, *Eutrophication Induced CO_2-Acidification of Subsurface Coastal Waters: Interactive Effects of Temperature, Salinity, and Atmospheric PCO_2*, 46 ENVTL. SCI. & TECH. 10,651, 10,651 (2012).

19. NAT'L RESEARCH COUNCIL, OCEAN ACIDIFICATION: STARTING WITH THE SCIENCE 4, http://nas-sites.org/oceanacidification/booklet-starting-with-the-science.

20. *Id.*

21. *Id.*

22. *Id.*

consequences.[23] To understand the impact of rising atmospheric carbon dioxide on the marine environment, it is important to understand the basic chemistry of ocean acidification and how it poses complex problems for species and marine systems.

A. *Overview: The Chemistry of Ocean Acidification*

The disequilibrium between the partial pressure of gases in the ocean and the atmosphere results in a constant movement of gases at the intersection of each area.[24] At this so-called air-sea interface, atmospheric carbon dioxide freely passes from the air into the sea.[25] Once absorbed into the ocean, carbon dioxide undergoes a series of chemical reactions, as shown below.

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3 \rightarrow\leftarrow 2H^+ + CO_3^{2-}$$

Carbon dioxide (CO_2) reacts with seawater to form carbonic acid (H_2CO_3).[26] This acid quickly dissociates into bicarbonate ions (HCO_3) and hydrogen ions (H^+).[27] As the concentration of hydrogen ions increases, the pH of water decreases.[28] Under normal conditions, the bicarbonate ions quickly break down in a reversible reaction into hydrogen ions and carbonate ions (CO_3^{2-}).[29] However, under conditions of rapid absorption of carbon dioxide similar to those that exist today, the reversible chemical reaction favors production of bicarbonate ions.[30] The chemistry of this process is well understood and the impact it

23. *Id*. at 5.

24. *Ocean Carbon Uptake*, NOAA PMEL CARBON PROGRAM, http://www.pmel.noaa.gov/co2/story/Ocean+Carbon+Uptake (last visited Nov. 5, 2013) (noting that air-sea gas exchange is primarily controlled by the air-sea difference in gas concentrations and the exchange coefficient, which determines how quickly a molecule of gas can move across the ocean-atmosphere boundary).

25. *Air-sea Exchanges of CO_2*, MCCIP, http://www.mccip.org.uk/annual-report-card/2010-2011/climate-of-the-marine-environment/air-sea-exchanges-of-co2.aspx (last visited Feb. 5, 2014) (noting that the partial pressure of CO_2 (pCO_2) in the surface ocean is expected to increase to double its pre-industrial value by the middle of this century, driven by increasing concentrations of atmospheric CO_2).

26. Dore, *supra* note 5, at 12,235.

27. *Id*.

28. *Id*.

29. *Id*.

30. *Id*. (showing that over the last 250 years ocean pH has decreased from 8.2 to 8.1 as a result of increased [H^+] ions, which are released in conjunction with creation of bicarbonate ions).

has on ocean pH is measurable.[31]

Ocean pH has declined by approximately 30 percent since pre-industrial times as a result of the continuous absorption of atmospheric carbon dioxide.[32] That downward trend is expected to continue and may accelerate to cause larger pH declines than at any other time in recorded history.[33] In some isolated areas, the pH of ocean water has declined to the point of becoming corrosive to shells and skeletons of marine organisms.[34] As pH continues to decline, the availability of carbonate ions needed by many marine species to survive is also expected to decline.[35] The current rate of carbon dioxide emission continues to drive pH declines throughout the marine environment and will lead to significant alterations in ocean chemistry in some areas within the next twenty years.[36] These changes may act synergistically with existing marine stressors, such as pollution, nutrient loading, and overfishing.[37] Ocean acidification has already been shown to interfere with critical marine processes and to impact marine systems at the species and community levels.

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31. *Id.*

32. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, FOURTH ASSESSMENT REPORT 52 (2007) (noting that surface ocean pH today is already 0.1 unit lower than pre-industrial values and that ocean pH is projected to decrease by another 0.3 to 0.4 units under the IS92a scenario by 2100).

33. *Id.* (noting that pH is projected to decrease by another 0.3 to 0.4 units under the IS92a scenario by 2100); *see also* Ken Caldeira & Michael Wickett, *Anthropogenic Carbon and Ocean pH*, 425 NATURE 365, 365 (2003) (noting that anticipated changes in ocean pH may be greater than at any time in the geological record of the past 300 million years, with the possible exception of changes caused by extreme natural events).

34. Richard A. Feely et al., *Evidence of Upwelling of Corrosive "Acidified" Water Onto the Continental Shelf*, 320 SCIENCE 1490, 1490–92 (2008).

35. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *supra* note 33 (noting that under scenario IS92a, projections show large decreases in carbonate ion concentrations throughout the world's oceans).

36. Ben I. McNeil & Richard J. Matear, *Southern Ocean Acidification: A Tipping Point at 450 ppm Atmospheric* CO_2, 105 PNAS 18,860, 18,860 (2008) (noting that under-saturation of calcium carbonate will cause shell dissolution in the Southern Ocean sometime between 2030 and 2038); *see also* Nicholas Gruber et al., *Rapid Progression of Ocean Acidification in the California Current System*, 330 SCIENCE 220, 220 (2012) (finding that as a result of continued oceanic absorption of carbon dioxide, the sea floor along many parts of the California coast is likely to become exposed to year-round aragonite under-saturation within the next 20 to 30 years).

37. Scott C. Doney et al., *Climate Change Impacts on Marine Ecosystems*, 4 ANN. REV. MARINE SCI. 11 (2012), http://www.joss.ucar.edu/cwg/july12/doney_et_al_2012.pdf.

B. Biogeochemical Impacts of Ocean Acidification

Biogeochemical cycling of substances in the ocean is critical to the health of marine ecosystems.[38] For example, the amount and availability of macro- and micro-nutrients such as nitrogen and phosphorus play critical roles in the rate of primary production of organic material by marine phytoplankton.[39] Changes in ocean chemistry that interfere with these important processes at the base of the ocean food chain can have a rippling effect that causes significant impacts all the way up the food chain.[40] The absorption of carbon dioxide and the corresponding decline in pH play important roles in these ocean processes.[41] Recent studies suggest that as pH declines, cycling of biogeochemical elements may be significantly altered.[42] One recent study, for example, reported that as pH declines, nitrogen cycling could decline by as much as 44 percent in some areas within the next few decades.[43] Such a change could fundamentally alter how nitrogen is cycled and used by organisms in the sea.[44] As oceans absorb more carbon dioxide, ocean water becomes under-saturated with minerals critical to the survival of planktonic organisms that form the base of the ocean food chain.[45] These changes have important implications for oceanic food webs and fisheries.

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38. Biogeochemical cycling includes movement of substances such as water, nitrogen, carbon, and oxygen through systems. *See Biogeochemical Processes*, RYAN INST., http://www.ryaninstitute.ie/research/marine-and-coastal-processes/biogeochemical-processes/ (last visited Nov. 5, 2013) (noting that biogeochemical cycling of substances forms a network of processes fundamental to the development and survival of marine ecosystems).

39. *Id.*

40. *Id.*

41. Press Release, Nat'l Sci. Found., Ocean Acidification Changes Nitrogen Cycling in World Seas (Dec. 20, 2010), http://www.nsf.gov/news/news_summ.jsp?cntn_id=118233&org=NSF (noting that as a result of increasing ocean acidification caused by decreasing pH, biogeochemical cycling of nitrogen will likely be impacted).

42. *Id.*

43. J. Michael Beman et al., *Global Declines in Oceanic Nitrification Rate as a Consequence of Ocean Acidification*, 108 PNAS 208, 208 (2011).

44. *Id.*

45. Long Cao et al., *Effects of Carbon Dioxide and Climate Change on Ocean Acidification and Carbonate Mineral Saturation*, 34 GEOPHYSICAL RESEARCH LETTERS L05607, L05607 (2007) (predicting future changes in ocean chemistry as a result of increased CO_2 concentrations).

C. *Species Impacts*

The world's oceans are imperiled.[46] Human activities have already caused the collapse of entire fisheries, created ocean dead zones devoid of life, and significantly degraded the health of entire marine systems.[47] These changes have crippled the ability of many species to successfully respond to alterations in the marine environment.[48] Ocean acidification will likely cause further impacts to already-stressed species. As ocean pH decreases, the threats to marine species increase, including potential harms to acid-base regulation critical to many physiological functions, nutrient acquisition, growth, respiration, energy expenditure, and metabolism.[49] The impacts of reduced ocean pH on marine organisms will likely be species-specific, with some organisms benefiting from the change and others negatively impacted, based on their differential vulnerability.[50] For example, some species of sea grasses and algae that require carbon dioxide to survive will likely benefit from increased ocean absorption of carbon dioxide.[51] Other organisms, such as calcifying organisms,[52] may

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46. *How Bad Is It?*, THE INT'L PROGRAMME ON THE STATE OF THE OCEAN, http://www.stateoftheocean.org/howbad.cfm (last visited Nov. 5, 2013) (asserting that ecosystems are collapsing as species are pushed to extinction and natural habitats are destroyed).

47. *See, e.g.*, *'Illusion of Plenty' Masking Collapse of Two Key Southern California Fisheries*, SCRIPPS INST. OF OCEANOGRAPHY, http://scrippsnews.ucsd.edu/Releases/?releaseID=1199 (last visited Nov. 5, 2013) (noting the two most important recreational fisheries off Southern California have collapsed); *see also "Dead Zone" is a More Common Term for Hypoxia, Which Refers to a Reduced Level of Oxygen in the Water*, NOAA NAT'L OCEAN SERVICE, http://oceanservice.noaa.gov/facts/deadzone.html (last visited Nov. 5, 2013) (discussing dead zones that occur along the East Coast, the Gulf of Mexico, and the Great Lakes). The northern Gulf of Mexico is home to the second largest Dead Zone in the world and is located in the United States.

48. *See, e.g.*, Maria Byrne, *Impact of Ocean Warming and Ocean Acidification on Marine Invertebrate Life History Stages: Vulnerabilities and Potential for Persistence in a Changing Ocean*, 49 OCEANOGRAPHY & MARINE BIOLOGY: AN ANN. REV. 1, 9 (2011).

49. Andrew J. Esbaugh et al., *Impacts of Ocean Acidification on Respiratory Gas Exchange and Acid–based Balance in a Marine Teleost, Opsanus Beta*, 182 J. COMP. PHYSIOLOGY B 921 (2012) (reporting respiratory gas transport and acid–base impacts of reduced pH environment on fish).

50. Rachel Hale et al., *Predicted Levels of Future Ocean Acidification and Temperature Rise Could Alter Community Structure and Biodiversity in Marine Benthic Communities*, 120 OIKOS 661, 661 (2011); *see also* Samantha J. Gibbs et al., *Species-Specific Growth Response of Coccolithophores to Palaeocene–Eocene Environmental Change*, 6 NATURE GEOSCIENCE 218 (2013).

51. NOAA PMEL CARBON PROGRAM, note 13 (noting that photosynthetic algae and seagrasses may benefit from higher CO_2 conditions in the ocean, as they—just like

experience significant negative impacts.

As ocean pH declines, many species, including reef-building corals, mollusks, and several types of calcareous plankton at the base of marine food webs, become increasingly vulnerable.[53] This is because these calcifying organisms depend upon available carbonate ions as essential building blocks to construct protective calcium carbonate shells or skeletons through a process of calcification. Under current and projected rates of carbon dioxide emission, ocean water is expected to continue to become under-saturated with these ions.[54] To survive, these organisms will be required to expend a larger portion of their limited energy budget to find and acquire available carbonate ions.[55] This, in turn, will reduce the energy available to carry out other essential life functions, which makes them more vulnerable to other stressors in the environment. These impacts have already been observed in some species exposed to low pH ocean surface waters.[56]

In the Pacific Northwest, for example, reproductive failure in oysters has been tied directly to exposure to acidic ocean water.[57] Studies revealed that exposure to low pH water under-saturated with aragonite, a form of calcium carbonate, prevented oyster larvae from forming shells during the early stages of development.[58] The authors reported that because the organism had to expend more energy to obtain the limited aragonite needed to build its shell, it did not have enough energy to survive to the next stage of development.[59] When these problems were coupled with existing stressors such as

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plants on land—require CO_2 to live).

52. NOAA PMEL CARBON PROGRAM, *supra* note 13 (noting that an acidic environment has a dramatic effect on some calcifying species, including oysters, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton).

53. *CO_2 Emissions Causing Ocean Acidification to Progress at Unprecedented Rate*, NAT'L ACAD. SCIENCES (Apr. 22, 2010), http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=12904.

54. *See generally* Alan Barton et al., *The Pacific Oyster,* Crassostrea gigas*, Shows Negative Correlation to Naturally Elevated Carbon Dioxide Levels: Implications for Near-Term Ocean Acidification Effects*, 57(3) LIMNOLOGY & OCEANOGRAPHY 698, 698–710 (2012).

55. *Id*. at 707.

56. *Id*.

57. *Id*. at 699.

58. *Id*.

59. *Id*.

agricultural runoff and sewage, the impact was more significant.[60]

While the long-term impact of ocean acidification is not entirely clear, it is clear that slower rates of calcification will negatively impact many marine species and the entire marine system.[61] Most significantly, critical calcifying planktonic species that form the base of the ocean food chain may suffer significant declines as ocean pH declines.[62] One study recently reported that as ocean pH declines to a mean pH level of 7.8, calcifying organisms begin to disappear.[63] Under current projections, ocean pH will decline to this level, and possibly further, by 2100.[64]

In some areas, declining ocean pH may actually reverse the process of calcification and cause existing shells and skeletons to dissolve.[65] The level of under-saturation required to reverse calcification and cause dissolution is unknown, and may be different in different areas.[66] However, in high-latitude ecosystems where carbon dioxide most readily dissolves into ocean water, it is expected that this tipping point will be reached within the next few decades.[67] One recent study of pteropods (pelagic marine mollusks) found in polar regions revealed "severe levels" of shell dissolution.[68] When these

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60. *Id*. at 706.

61. INT'L UNION FOR CONSERVATION OF NATURE, OCEAN ACIDIFICATION: SEAS TURNING SOUR (2008), http://cmsdata.iucn.org/downloads/ocean_acidification_fact_sheet_08cropped.pdf.

62. *Id*.

63. Bruna Dias, et al., *Modern Seawater Acidification: The Response of Foraminifera to High-CO_2 Conditions in the Mediterranean Sea*, 167 J. GEOLOGICAL SOC'Y 843, 846 (2010).

64. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: WORKING GROUP I: THE PHYSICAL SCIENCE BASIS, 10.4.2 OCEAN ACIDIFICATION DUE TO INCREASING ATMOSPHERIC CARBON DIOXIDE (2007), http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-4-2.html (noting that pH is projected to decrease from its current state by another 0.3 to 0.4 units by 2100). Ocean pH is currently 8.1.

65. McNeil & Matear, *supra* note 37, at 18,860 (noting that when atmospheric carbon dioxide levels reach 450 ppm the under-saturation of calcium carbonate will cause shells to dissolve); *see also* Dore, *supra* note 5, at 12,235 (noting that as ocean carbon dioxide accumulates, seawater becomes more corrosive to calcium carbonate and those organisms that utilize structural components made of calcium carbonate are especially at risk of reduced ocean pH).

66. *Id*. at 18,860–64.

67. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *supra* note 33, at 214.

68. Nina Bednaršek et al., *Extensive Dissolution of Live Pteropods in the Southern Ocean*, 5 NATURE GEOSCIENCE 881, 881–85 (Nov. 25, 2012) (reporting that specimens

pteropods were exposed to ocean water adjusted to seawater chemistry projected for the year 2100, the results showed that the shell completely dissolved after just forty-five days.[69] Pteropods sit at the base of the polar ocean food chain, so any impact that affects their ability to grow and reproduce will have a cascade of effects throughout the food chain. For example, pteropods comprise more than 50 percent of the diet of pink salmon in the open ocean during their first year of life.[70] A 10 percent drop in pteropods production would likely correspond with a 20 percent drop in mature body weight of pink salmon. As carbon dioxide absorption increases, ocean regions where shelled organisms are affected by dissolution are likely to expand.[71] Because these planktonic organisms are among the most abundant forms of life in the ocean, when they are at risk, the entire food web may also be at risk.[72] The impacts of ocean acidification are not restricted to calcifying organisms. Similar impacts may be observed with other non-calcifying organisms. For example, some areas may experience a 20 to 35 percent reduction in fish catch by 2050 in certain species, based on the species' sensitivity to ocean acidification.[73]

D. Impact of Ocean Acidification on the Marine Community

While changes in pH have measurable effects on individual species, they also have significant impacts on community structure and system biodiversity. Some calcifiers, such as reef building corals, create complex structures that provide habitat for one quarter of all marine species.[74] Under anticipated carbon dioxide emissions scenarios, ocean acidification may

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of the pteropod *Limacinahelicina antarctica* that were extracted live from the Southern Ocean exhibited severe shell dissolution).

69. NOAA, *supra* note 6.

70. *See* Craig Welch, *Sea Changes Harming Ocean Now Could Someday Undermine Marine Food Chain*, SEATTLE TIMES (Nov. 25, 2012), http://seattletimes.com/html/localnews/2019765681_pteropods26m.html.

71. Bednaršek, *supra* note 70.

72. NAT'L RESEARCH COUNCIL, *supra* note 19, at 6–7.

73. Media Release, Univ. of British Columbia, Ocean Acidification Turns Climate Change Winners into Losers: UBC Research (Feb. 18, 2012), http://www.publicaffairs.ubc.ca/2012/02/18/ocean-acidification-turns-climate-change-winners-into-losers-ubc-research/.

74. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *supra* note 33, at 235.

progress to the point where it could devastate coral reefs.[75]

To build healthy reefs, warm water corals require waters that are supersaturated with aragonite.[76] Prior to the industrial revolution, more than 98 percent of these coral species were surrounded by waters that met these conditions.[77] Today, approximately 40 percent of coral reefs are surrounded by waters that are saturated with aragonite.[78] Under current carbon dioxide emissions scenarios, by the end of the century more than 90 percent of warm water coral species will be surrounded by ocean waters that are under-saturated with aragonite and therefore insufficient to promote the rapid growth and development of strong skeletons needed to build healthy reefs.[79]

Small-scale studies have already demonstrated significant pH-related shifts in community composition among coral species.[80] In one such study, for example, as ocean pH declined from 8.1 to 7.8, researchers observed reductions in biodiversity and recruitment of reef fish.[81] Changes in species composition can impact predator-prey dynamics even for species not directly impacted by declining pH.[82] These changes impact successful fertilization, larval settlement, and survivorship of some species of corals, which in turn render those species more vulnerable to other marine stressors.[83] Such changes may impact the ability of coral reefs to recover from disturbance.[84]

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75. *Id.*

76. *Effects of Ocean Acidification on Corals*, OCEANA, http://oceana.org/en/our-work/climate-energy/ocean-acidification/learn-act/effect-of-ocean-acidification-on-corals (last visited Nov. 5, 2013).

77. Press Release, Carnegie Institution, Modest CO_2 Cutbacks May Be Too Little, Too Late (Sept. 22, 2008) [hereinafter Carnegie], http://www.eurekalert.org/pub_releases/2008-09/ci-mcc092208.php.

78. *Effects of Ocean Acidification on Corals*, *supra* note 78.

79. Carnegie, *supra* note 79.

80. Katharina E. Fabricius et al., *Losers and Winners in Coral Reefs Acclimatized to Elevated Carbon Dioxide Concentrations*, 1 NATURE CLIMATE CHANGE 165, 165–69 (2011).

81. *Id.*

82. *Ocean Acidification: A Q&A with NOAA Scientist Shallin Busch*, NOAA FISHERIES (Sept. 26, 2012), http://www.nmfs.noaa.gov/stories/2012/09/09_26_12ocean_acifidication_qa.html.

83. Rebecca Albright et al., *Ocean Acidification Comprises Recruitment Success of the Threatened Caribbean Coral* Acropora palmata, 107 PNAS 1, 1 (2010).

84. *Id.*

This is particularly troubling because coral reefs are already imperiled by other marine stressors including pollution, physical impacts from human activities (such as vessel anchoring and groundings, and coral harvesting), and from ocean warming. In 2010, the National Oceanic and Atmospheric Administration (NOAA) announced that there is "substantial" scientific information to support listing eighty-two species of coral found in U.S. waters as either threatened or endangered under the Endangered Species Act.[85] In reaching this conclusion, NOAA found that ocean acidification posed a threat to the species.[86] These impacts are expected to continue, as most reefs will continue to experience higher levels of acidification that impair calcification of corals and reef growth.[87] Perhaps more troubling, one study has found that, as ocean pH falls below 7.7, reef development could cease entirely.[88] A decline in pH to that level is projected under current emissions rates.

In view of this accelerating decline in ocean pH, it is instructive to consider what the historical record reveals about impacts caused to marine communities in low pH environments. The physical changes to ocean chemistry occurring today are similar to those that occurred 55 million years ago through natural events.[89] Then, changes in ocean chemistry resulted in massive changes in ocean ecology that led to the extinction of between 35 and 50 percent of deep-water marine species.[90] Under current carbon emission scenarios, more serious consequences for the marine environment may be expected.[91] Today, changes in ocean

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85. Notice of 90–Day Finding on a Petition to List 83 Species of Corals as Threatened or Endangered Under the Endangered Species Act (ESA), 75 Fed. Reg. 6616, 6616–21 (Feb. 10, 2010). As a result of this finding, NOAA is in the process of conducting status reviews on each species to determine whether listing any of the coral species under the ESA is in fact warranted. *Id.*

86. *Id.*

87. *See Consensus Statement on Climate Change and Coral Reefs*, INT'L SOC'Y FOR REEF STUDIES, http://www.icrs2012.com/Consensus_Statement.htm (last visited Nov. 5, 2013).

88. Fabricius et al., *supra* note 82.

89. Dias et al., *supra* note 64.

90. *Id.*; *see also* JELLE BIJMA, IPSO PRELIMINARY REPORT ON OCEAN STRESS AND IMPACTS: CASE STUDY 1 (2011), http://www.stateoftheocean.org/pdfs/1806_IPSO-extinction-threat.pdf.

91. Dias et al., *supra* note 65. During the last mass extinction in the ocean,

chemistry are occurring at a much faster rate than they did 55 million years ago.[92] The implications for such rapid change are significant. Coral reefs are the largest living structures on the planet, and are second only to rainforests in biodiversity. According to some researchers, loss of coral reefs could cause the collapse of the entire marine system. Given that hundreds of millions of people rely on coral reef ecosystems for food, income, tourism, and shoreline protection, the impact associated with reef loss is significant.[93] These possibilities, coupled with the limited government response to the problem, prompted coral reef scientists to issue a consensus statement urging governments to "take action for the preservation of coral reefs for the benefit of present and future generations."[94] To address these problems, action is needed. Under the current plan, such action may come too late.

III. THE U.S. LEGAL AND POLICY RESPONSE TO OCEAN ACIDIFICATION

A. *Overview*

In the United States, activities tied either directly or indirectly to ocean and coastal resources support millions of jobs and contribute trillions of dollars annually to the economy.[95] These areas also play a critical role in promoting the public health and in preserving national security.[96] Climate change and its associated ocean acidification pose real and substantial threats to ocean and coastal systems. The United States has only recently responded to calls from the

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approximately 2.2 Gt of carbon dioxide was released into the atmosphere through natural events each year, much of which was absorbed by the ocean. Today, approximately 30 Gt of carbon dioxide is released into the atmosphere per year through natural events and anthropogenic actions, most of which is absorbed by the ocean. *Id*. The increased uptake of carbon dioxide in the ocean has exceeded the ocean's ability to neutralize the acid formed during the chemical breakdown of carbon dioxide in waters. This has led to an unprecedented increase in ocean acidification. *Id*.

92. *Id*.

93. Newsbulletin, Nat. Scis. and Engineering Research Council of Canada, *Will Coral Reefs Disappear?* (Feb. 21, 2010), http://www.nserc-crsng.gc.ca/Media-Media/Newsbulletin-BulletinDeNouvelles_eng.asp.

94. *See* INT'L SOC'Y FOR REEF STUDIES, *supra* note 89.

95. NOAA, THE OCEAN AND COASTAL ECONOMY: A SUMMARY OF STATISTICS 1, http://www.ppi.noaa.gov/wp-content/uploads/coastal-economy-pocket-guide-429.pdf.

96. *Id*.

scientific community to recognize the risk of ocean acidification and to develop plans to address its anticipated impacts. These policies generally address three critical areas: reducing emissions of carbon dioxide, understanding how ocean acidification will impact marine environments, and promoting ecosystem resilience by eliminating other non-climate related stressors that impact marine systems.[97] However, these plans for action are still being formulated.

B. Current U.S. Policy Framework for Ocean Acidification

As part of the Magnuson-Stevens Reauthorization Act of 2006, Congress, for the first time, publicly requested a study of ocean acidification.[98] As part of that request, the National Research Council of the National Academies carried out a study to examine how declining ocean pH was impacting the United States.[99] While that study was underway, in 2009, Congress passed the Federal Ocean Acidification Research and Monitoring Act (FOARAM).[100] This represented the first formal effort to address ocean acidification directly through creation of an interagency research and monitoring program.[101] Through FOARAM, Congress directed federal agencies to work collaboratively to develop and coordinate a comprehensive interagency plan to: (1) engage in studies designed to understand the processes and likely impacts of declining ocean pH on marine organisms and ecosystems; and (2) establish an interagency research and monitoring program on ocean acidification.[102] Congress also called on NOAA to establish an

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97. G.H. Rau et. al., *The Need for New Ocean Conservation Strategies in a High-Carbon Dioxide World*, 2 NATURE CLIMATE CHANGE 720, 720 (2012).

98. Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006, Pub. L. No. 109-479, § 701, 120 Stat. 3575, 3649 (2007) ("The Secretary of Commerce shall request the National Research Council to conduct a study of the acidification of the oceans and how this process affects the United States.").

99. NAT'L RESEARCH COUNCIL, OCEAN ACIDIFICATION: A NATIONAL STRATEGY TO MEET THE CHALLENGES OF A CHANGING OCEAN 5 (National Academies Press ed., 2010), http://www.nap.edu/catalog.php?record_id=12904 [hereinafter NRC Report].

100. Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act), 33 U.S.C. §§ 3701-3708 (2012).

101. *Id.*

102. *Id.* Agencies involved include NOAA, NSF, Bureau of Ocean Energy Management (BOEM), Department of State (DOS), Environmental Protection Agency (EPA), NASA, USFWS, USGS, and U.S. Navy. *See* INTERAGENCY WORKING GRP. ON OCEAN ACIDIFICATION ET AL., DRAFT STRATEGIC PLAN FOR FEDERAL RESEARCH AND

ocean acidification program, and on all relevant agencies to assess and consider the impacts of increased ocean acidification on regional and national ecosystems and its impacts on socioeconomic factors.[103] Further, Congress called for research directed to developing adaptation strategies and techniques capable of conserving marine ecosystems impacted by ocean acidification.[104]

On June 12, 2009, President Obama issued a memorandum to the heads of executive departments and agencies establishing the Interagency Ocean Policy Task Force.[105] In that memorandum, the President charged the Task Force with, among other things, developing recommendations for a national policy capable of ensuring the "protection, maintenance, and restoration of the health of ocean, coastal, and Great Lakes ecosystems and resources and . . . provid[ing] for adaptive management to enhance our understanding of and capacity to respond to climate change."[106] In response, the Task Force presented nine priority objectives that should be pursued to implement the national policy, including action to "[s]trengthen resiliency of coastal communities and marine and Great Lakes environments and their abilities to adapt to climate change impacts and ocean acidification."[107] It also recommended that action be taken to "[e]nhance water quality in the ocean, along our coasts and in the Great Lakes by promoting and implementing sustainable practices on land."[108] In April of 2010, the National Research Council (NRC) released its conclusion on the study of ocean acidification, finding: "Ocean acidification has demonstrated impacts on many marine organisms. While the ultimate consequences are still unknown, there is a risk of ecosystem changes that threaten coral reefs, fisheries, protected species, and other natural

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MONITORING OF OCEAN ACIDIFICATION 2 (2012), http://www.st.nmfs.noaa.gov/iwgoa/pages/research_strategy.html.

103. *See generally* 33 U.S.C. § 3701(a).

104. *Id.* § 3701(a)(4).

105. National Policy for the Oceans, Our Coasts, and the Great Lakes, 74 Fed. Reg. 28,591, 28,591 (June 17, 2009).

106. *Id.*

107. EXEC. OFFICE OF THE PRESIDENT, INTERIM REPORT OF THE INTERAGENCY OCEAN POLICY TASK FORCE 7 (2009), http://www.whitehouse.gov/ assets/documents/09_17_09_Interim_Report_of_Task_Force_FINAL2.pdf.

108. *Id.* at 8.

resources of value to society."[109]

The NRC recognized that changes in ocean chemistry caused by increasing carbon dioxide are well understood.[110] It also noted while the long term impacts to marine biota from ocean acidification are yet unknown, "changes in many ecosystems and the services they provide to society appear likely."[111] These changes will likely lead to "shifts in the composition and functioning of many marine ecosystems."[112] It further noted that while research on ocean acidification is in its infancy, "there is already growing evidence of changes in ocean chemistry and ensuing biological impacts."[113] Perhaps most troubling is NRC's finding that the concentration of atmospheric carbon dioxide is rising too rapidly for natural calcium carbonate processes to prevent further reduction of ocean pH.[114] In fact, the NRC noted:

> The chemistry of the ocean is changing at an unprecedented rate and magnitude due to anthropogenic carbon dioxide emissions; the rate of change exceeds any known to have occurred for at least the past hundreds of thousands of years. Unless anthropogenic CO_2 emissions are substantially curbed, or atmospheric CO_2 is controlled by some other means, the average pH of the ocean will continue to fall.

In June of 2010, President Obama adopted the recommendations of the Task Force and established through Executive Order a new national policy for stewardship of the marine environment.[115] A primary goal of the new policy is to "protect, maintain, and restore the health and biological diversity of ocean, coastal, and Great Lakes ecosystems and resources."[116] In 2012, the National Ocean Council (NOC) prepared, and released in draft form, a National Ocean Policy Implementation Plan.[117] The draft Plan described more than

109. NRC Report, *supra* note 101.

110. *Id*. at 1.

111. *Id*. at 2.

112. *Id*. at 4.

113. *Id*. at 2.

114. *Id*. at 4.

115. Exec. Order 13,547, 75 Fed. Reg. 140 (July 22, 2010).

116. *Id*.

117. NAT'L OCEAN COUNCIL, DRAFT NATIONAL OCEAN POLICY IMPLEMENTATION PLAN (2012), http://www.whitehouse.gov/sites/default/files/microsites/ceq/national_ocean_policy

fifty actions the Federal Government will take to improve the health of the ocean, coasts, and Great Lakes.[118] It provides a framework whereby stakeholders at the national, regional, and local levels, along with members of the general public, can work collaboratively toward achieving a healthier, sustainable marine environment.[119] The plan adopts the same nine national priority objectives, including an objective to "strengthen resiliency of coastal communities and marine and Great Lakes environments and their abilities to adapt to climate change impacts and ocean acidification."[120] The draft plan recognized that ocean acidification is "expected to have significant impacts on many marine species, food webs, and ocean ecosystem structure and function, and the many benefits they provide."[121] NOC recognized that the "best scientific information must be accessible and relevant to inform decisions that enhance the resiliency" to ocean acidification.[122] It further noted that "coordinated vulnerability assessments of ecosystems, communities, and economies will inform adaptation actions."[123] To address the anticipated impacts from ocean acidification, the NOC recommended the following actions:

> (1) monitor and track changes in the condition of ocean, coastal, and Great Lakes environments and communities; (2) determine the impacts of climate change, ocean acidification, and interacting stressors on ecological, economic, and social systems; (3) provide critical projections of climate change impacts on coasts and oceans at decision-relevant scales; (4) assess the vulnerability of coastal and ocean environments and communities to climate change and ocean acidification; (5) strengthen interagency coordination on the development and provision of information, training, guidance, tools, and support for adaptation practitioners; and (6) design, implement, and evaluate adaptation strategies to reduce vulnerabilities and

_draft_implementation_plan_01-12-12.pdf.

118. *Id. passim*.

119. *Id.* at 1.

120. *Id.* at 8.

121. *Id.* at 54.

122. *Id.*

123. *Id.* at 55.

promote informed decisions.[124]

These proposed actions largely track the requirements in the FOARAM Act.[125] However, whereas the FOARAM Act called for development of a 10-year plan of action for ocean acidification, the National Research Council found that the ocean acidification program may actually take as long as twenty years to fully implement.[126] Following public comment on the draft plan, the NOC released its final Implementation Plan in 2013. That Plan largely tracks the draft Plan, and includes actions the Federal Government will take in conjunction with state and local governments to improve the health of the ocean, coasts, and Great Lakes.[127] However, the final Plan also includes a mandate to "[a]ssess the vulnerability of coastal communities and ocean environments to climate change and ocean acidification . . . and implement adaptation strategies to reduce vulnerabilities."[128] Thus, the current approach is clearly focused on engaging in long-term, comprehensive ocean acidification research with the hope that such research will provide insight into how to address accelerating changes occurring in the marine environment.

Comprehensive ocean acidification research poses substantial financial challenges. For example, the FOARAM Act authorized total appropriations of $27 million ($12 million for NSF, $15 million for NOAA) for ocean acidification research for fiscal year 2011.[129] However, federal funding for all ocean acidification research conducted in 2011 by NASA, NOAA, NSF, USGS, BOEM, and EPA only totaled approximately $23,192,000.[130] Thus, authorization has not equated with actual appropriation. Moreover, even if all funds authorized

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124. NAT'L OCEAN COUNCIL, *supra* note 119, at 55–61.

125. *See* Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act), 33 U.S.C. §§ 3701–3708 (2012).

126. *See id.* § 3704(b)(2) (requiring priorities for Federal research and monitoring over a ten-year period); *see also* NRC Report, *supra* note 101.

127. NAT'L OCEAN COUNCIL, NATIONAL OCEAN POLICY IMPLEMENTATION PLAN (2013), http://www.whitehouse.gov/sites/default/files/national_ocean_policy_implementation_plan.pdf.

128. *Id.* at 17.

129. 33 U.S.C. § 3708.

130. LARA LEVISON, NAT'L MARINE SANCTUARY FOUND., FEDERAL POLICY AND FUNDING RELATING TO OCEAN ACIDIFICATION 3 (2012), http://nmsfocean.org/files/OA_Report.pdf.

were released, current funding levels may be inadequate to achieve the goals envisioned under the national plan. To carry out the comprehensive research program envisioned, approximately $50–$100 million per year is needed.[131] These figures do not include the cost of responding to the impacts discovered.

The current response framework requires no direct action to stop the process of acidification, despite clear recognition that ocean acidification will impact marine environments, and will require mitigation strategies that slow acidification sufficiently to allow for adaptation to occur. Instead, the plan is directed towards long-term studies designed to provide evidence of harm, and methods to adapt to those harms. Given the short time frame in which measurable change from declining pH is expected, long-term studies may be inadequate. As a result of the absence of direct action to combat acidification in current federal planning, it is worthwhile to examine other means for taking immediate action. Because ocean acidification impairs water quality, action under the Clean Water Act may be warranted.

C. Application of Clean Water Act to Ocean Acidification

The Clean Water Act (CWA) is the primary federal law governing ocean and coastal water quality in the United States.[132] In promulgating the Act, Congress declared a national goal of restoring and maintaining the "chemical, physical, and biological integrity of the Nation's waters."[133] It also set an interim goal of attaining, wherever possible, water quality that provides for the "protection and propagation of fish, shellfish, and wildlife."[134] Unfortunately, despite measurable progress toward those goals, none has been fully

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131. SUBCOMM. ON OCEAN ACIDIFICATION, OCEAN CARBON & BIOGEOCHEMISTRY PROGRAM, OCEAN ACIDIFICATION—RECOMMENDED STRATEGY FOR A U.S. NATIONAL RESEARCH PROGRAM 8 (2009), http://www.us-ocb.org/publications/OCB_OA_white paper.pdf ("$30 million may be appropriate for the first 2–3 years, while large-scale efforts are still being planned, but once the program is fully engaged, $50–$100 million per year is considered the *minimum* if scientists are to provide useful information regarding how the oceans are responding to acidification, and how we should change our mitigation and adaptation policies.").

132. *See* Federal Water Pollution Control Act, 33 U.S.C. §§ 1251–1387 (2006).

133. *Id.*§ 1251(a).

134. *Id.* § 1251(a)(2).

realized. The inability to meet these goals has contributed to the decline in the health and stability of marine waters and the organisms that inhabit them.[135] Climate change and its associated ocean acidification threaten to further impair marine environments in potentially significant ways.[136]

While ocean acidification is primarily linked to ocean absorption of atmospheric carbon dioxide, effluent discharges and nutrient runoff also play a role.[137] The CWA clearly applies to both effluent discharges and nutrient runoff, but its application to control air emissions is less clear because the emission of pollutants into the air is addressed under the Clean Air Act.[138] However, because declining pH impairs water quality, an issue that is addressed under the Clean Water Act, the CWA may be an effective tool to address ocean acidification.

1. CWA: Overview

Ocean acidification is progressing at different rates based on location, but its impact in the United States is clearly evident in waters that fall under the jurisdiction of the CWA.[139] The Act applies, *inter alia*, to state coastal waters to the extent of state jurisdiction, and to ocean waters beyond that, to the extent of U.S. jurisdiction.[140] The Act prohibits all discharges of

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135. THE INT'L PROGRAMME ON THE STATE OF THE OCEAN, THE OCEAN IN CRISIS, http://www.stateoftheocean.org/pdfs/ipso_leaflet6.pdf.

136. Ove Hoegh-Guldberg et. al., *The Impact of Climate Change on the World's Marine Ecosystems*, 328 SCIENCE 1523, 1524 (2010).

137. *See* Sunda & Cai, *supra* note 18, at 10,657. This study showed that pollution of ocean water with nutrient runoff from fertilizer, human and animal waste, and other sources is adding carbon dioxide via the biological breakdown of organic matter formed during algal blooms, which also depletes oxygen from the water. The authors also noted that absorption of atmospheric carbon dioxide and release of carbon dioxide from decaying organisms will interact synergistically to substantially increase the acidity of ocean waters. These changes could impact commercial fisheries in coastal regions receiving nutrient inputs, such as the northern Gulf of Mexico and Baltic Sea. Clams, oysters, scallops and mussels could be the most heavily impacted. *Id*.

138. *See* 42 U.S.C. §§ 7401–7671 (2012).

139. *See, e.g.*, *Ocean Acidification Killing Oysters by Inhibiting Shell Formation*, OREGON STATE UNIV., http://ceoas.oregonstate.edu/features/ acidification/ (last visited Nov. 5, 2013) (discussing the failure of oyster seed production in Northwest Pacific coastal waters as one of the most graphic examples of ocean acidification's effects on important commercial shellfish).

140. The Act applies to navigable waters of the United States, which are generally defined to include those waters subject to state jurisdiction. *See* 38 Fed. Reg. 34,165

pollutants from point sources into receiving waters, and discharges to marine waters, unless otherwise permitted.[141] Where needed to affect a particular desired use of certain water bodies, the EPA must impose more stringent water quality based standards.[142] These standards typically establish numerical or narrative water quality criteria for a given water body based on the desired use of that water body.[143] Because ocean acidification degrades water quality, state water quality standards are relevant to any effort to address ocean acidification.

2. *State Water Quality Standards*

Water quality standards set forth criteria necessary to maintain the water quality of a water body based on the designated use (e.g., public water supply, recreational use, industrial use) of that water body.[144] These criteria are based on the chemical, physical, and biological state of the water and are typically sufficiently protective to prevent impacts to species' reproductive capacity, development, or population structure.[145] State standards must specify the desired water body uses to be achieved and adopt water quality criteria necessary to protect those specified uses consistent with the goals of the CWA.[146] Thus, wherever attainable, such standards should provide for water quality that promotes the

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(Dec. 11, 1973) (defining navigable waters of the United States). The Act also applies to the territorial sea, typically subject to state jurisdiction. *See* 33 U.S.C. § 1362(7) (2012). Beyond state waters, the Act applies to the contiguous zone and to the ocean, which generally provides, with limited exceptions, jurisdiction of the limits of the United States Exclusive Economic Zone. *See* Proclamation 5030: Exclusive Economic Zone of the United States of America, 48 Fed. Reg. 10,605 (Mar. 10, 1983) (claiming a 200 mile exclusive economic zone).

141. 33 U.S.C. §§ 1311(a), 1342(a) (2012).

142. *Id.* § 1312(a).

143. 40 C.F.R. § 131.11(b)(1), (2) (2013); 33 U.S.C. § 1313(c)(2)(A) (requiring that water quality standards take into consideration a number of factors including their use and value for public water supplies, propagation of fish and wildlife, recreational purposes, and agricultural, industrial and other purposes, and their use and value for navigation).

144. 33 U.S.C. § 1313(c)(2)(A).

145. *National Recommended Water Quality Criteria*, EPA, http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm (last visited Nov. 7, 2013); *see also* 33 U.S.C. § 1313(c)(2); 33 U.S.C. § 1314(a).

146. 40 C.F.R. §§ 131.10(a), 131.11(a).

"protection and propagation of fish, shellfish and wildlife."[147]

In 1976, the EPA published recommended water quality criteria for marine waters.[148] The criteria for marine water bodies suggest that marine pH be maintained between 6.5 and 8.5, but not vary more than 0.2 units from the naturally occurring range of pH for that water body.[149] These are guidelines and are not binding on states. While states may adopt water quality standards that differ from the EPA's recommendations, states have developed specific water quality criteria for pH for their respective water bodies that largely follow the national recommendations. States are responsible for reviewing, establishing, and revising water quality standards at least once every three years.[150] Despite this, pH criteria have remained unchanged.

The EPA retains authority to review and to approve or disapprove any state-adopted water quality standards.[151] If the state's standards are inadequate, the EPA can reject the standards and implement its own standards.[152] In reviewing the standard, the EPA is required to evaluate whether the standard is consistent with the goals of the CWA and whether the criteria proposed will actually protect the designated water uses.[153] Each standard must also include an anti-degradation policy that ensures that a level of water quality necessary to protect the existing uses shall be maintained and protected.[154]

3. *Enforcement of State Water Quality Standards*

In 2007, the Center for Biological Diversity (CBD) petitioned the EPA to reevaluate its water quality criteria for pH in view of the mounting evidence of ocean acidification.[155] The CBD

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147. *Id.* § 131.2.

148. EPA, QUALITY CRITERIA FOR WATER (1976), http://water.epa.gov/scitech/swguidance/standards/criteria/current/upload/2009_01_13_criteria_redbook.pdf.

149. *Id.* at 337.

150. 40 C.F.R. §§ 131.4(a), 131.20(a).

151. *Id.* § 131.5(a).

152. *Id.* § 131.5(b).

153. *Id.* § 131.5(a)(1), (2).

154. *Id.* §§ 131.6(d), 131.12(a)(1).

155. CTR. BIOLOGICAL DIVERSITY, PETITION FOR REVISED PH WATER QUALITY CRITERIA UNDER SECTION 304 OF THE CLEAN WATER ACT, 33 U.S.C. § 1314, TO ADDRESS OCEAN ACIDIFICATION (2007), http://www.biologicaldiversity.org/programs/oceans/pdfs/section-304-petition-12-18-07.pdf.

requested that the EPA update water quality criteria to reflect the latest scientific knowledge, which, according to the CBD, mandates use of a standard that would prohibit any measurable change in pH of marine waters from naturally occurring pH levels.[156] The EPA did not immediately respond to the petition. The EPA subsequently approved the state of Washington's list of impaired water even though Washington had not listed its coastal waters as impaired by ocean acidification.[157] In response, the CBD sued the EPA, alleging that the EPA failed to meet its obligations under the CWA "to protect the state of Washington's ocean waters from the threat of ocean acidification."[158] The CBD argued that in view of the mounting evidence of ocean acidification, the EPA's decision to approve Washington's list was arbitrary and capricious.[159]

Because ocean acidification is due largely to absorption of atmospheric carbon dioxide, the lawsuit was an indirect attempt to force the EPA to regulate emissions of carbon dioxide under the Clean Water Act due to carbon dioxide's water quality impacts.[160] The EPA settled the lawsuit after acknowledging that states should list waters whose pH levels become impaired.[161] But the EPA elected not to mandate such action despite recognizing the seriousness of ocean acidification and its impacts on marine life.[162] Instead, the EPA concluded that states should voluntarily list water bodies not meeting water quality standards for marine pH on their section 303 lists.[163] The EPA noted that it would provide more specific information on action that should be taken when future research efforts provided that information.[164] Importantly, the

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156. *Id.* at 13–14.

157. Complaint for Declaratory and Injunctive Relief at 2, Center for Biological Diversity v. U.S. EPA, No. 2:09-cv-00670-JCC (W.D. Wash. May 14, 2009), 2009 WL 1390743.

158. *Id.*

159. *Id.* at 3.

160. *See id.*

161. Memorandum from Denise Keehner, Dir., Office of Wetlands, Oceans and Watersheds to Water Division Directors, Regions 1-10 of the EPA (Nov. 15, 2010), http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/oa_memo_nov2010.pdf.

162. *See id.*

163. *See id.*; *see also* 33 U.S.C. § 1313(d)(1)(A) (2012) (requiring states to identify those waters within state boundaries for which effluent limitations are not stringent enough to implement any water quality standard applicable to such water).

164. *See* Keehner, *supra* note 163.

EPA did not assert that it had no authority to regulate carbon dioxide emissions under water quality standards of the Clean Water Act.

4. *Establishment of Total Maximum Daily Load*

Water bodies that fail to meet state water quality standards despite the application of effluent limitations for a particular pollutant are deemed "water quality limited."[165] For such water bodies, states are required to establish a total maximum daily load (TMDL) limit for the pollutant of concern.[166] The TMDL represents the total amount of the pollutant from all contributing (point, nonpoint, and natural) sources that a water body can assimilate without violating the state-established water quality standard for that water body.[167] Stated differently, the TMDL establishes the total amount of a pollutant that may be legally discharged into the subject water from all sources of that pollutant and still safely meet water quality standards.[168] The TMDL allocates amounts of pollutants attributed to point sources and nonpoint sources, and then specifies where and when reductions will be required to ensure that the daily load identified is not exceeded.

In identifying those waters that are impaired, states are required to take into consideration all available scientific data.[169] In the context of ocean acidification, where there is evidence that absorption of carbon dioxide into water causes a reduction of water pH, the state would have to include that information in its analysis of whether to list a water segment as impaired or explain why it has chosen to ignore that data.[170]

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165. 40 C.F.R. §§ 130.2(j), 130.7(d) (2013).

166. 33 U.S.C. § 1313(d)(1)(C); *see also* 40 C.F.R. § 130.2(j) (defining a Water Quality Limited Segment as "[a]ny segment where it is known that water quality does not meet applicable water quality standards, and/or is not expected to meet applicable water quality standards, even after the application of the technology-based effluent limitations required by sections 301(b) and 306 of the Act").

167. 33 U.S.C. § 1313(d)(1)(C).

168. 40 C.F.R. § 130.7.

169. *See* EPA, EPA REVIEW OF WASHINGTON 2010 303(D) INTEGRATED REPORT 1, http://www.epa.gov/region10/pdf/water/303d/washington/final_WA_303d_2010_approval_letter_enclosure_1.pdf (noting that in developing Section 303(d) lists, states are required to assemble and evaluate all existing and readily available water quality-related data and information).

170. 40 C.F.R. § 130.7(b)(6).

If the state fails to identify a water body as impaired, and the EPA approves the state's list of impaired water, the EPA's decision may be challenged.[171]

In setting the TMDLs to meet water quality standards, the actual source of the pollution is irrelevant.[172] By limiting the amount of the pollutant released from all sources, in theory, the desired water quality can be achieved. Importantly, because achievement of water quality standards is the goal, the TMDLs apply to all sources of the pollutant of concern such that a TMDL implemented in one area necessarily affects the regulation of other water bodies that may indirectly affect the achievement of the water quality standard. When implemented, TMDLs can be effective mechanisms for restoring an impaired water body.[173]

In the context of climate change, use of TMDLs is significant because once a TMDL is established and approved for a pollutant, all sources of that pollutant are subject to the limits set forth. Thus, if an unregulated entity is releasing a pollutant that degrades water quality with respect to the state standard, that entity may be subject to regulation. Listing a water body as water quality limited also has larger implications that may impact planning for ocean acidification. Under the CWA, once a TMDL has been established for a water quality limited segment, absent proof that the water body can accept additional loading without further degradation, neither the state nor federal government may issue a permit to a "new source or new discharger" if doing so will "cause or contribute to the violation of water quality standards."[174]

Because TMDLs apply to nonpoint sources of pollution regardless of the source, they may be used to address

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171. The Clean Water Act mandates that EPA identify impaired water bodies omitted on the state's list. *See* 33 U.S.C. § 1313(d)(2). Thus, approval of a state list omitting impaired water bodies violates the Clean Water Act and may be challenged. Further, any such decision may be challenged as arbitrary and capricious in violation of the Administrative Procedure Act. *See* 5 U.S.C. § 706(2)(A) (2006).

172. Pronsolino v. Nastri, 291 F.3d 1123, 1137 (9th Cir. 2002) (noting that "water quality standards reflect a state's designated *uses* for a water body and do not depend in any way upon the source of pollution" (emphasis in original)).

173. *See generally Total Maximum Daily Loads (TMDLs) at Work*, EPA, http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/TMDLsWork.cfm (last visited Nov. 7, 2013).

174. 40 C.F.R. § 122.4(i).

atmospheric deposition of material emitted into the air.[175] In fact, TMDLs are now utilized to reduce atmospheric deposition of mercury into ocean waters.[176] Mercury emitted into the air by coal-fired power plants, municipal waste, combustors, sewage sludge incinerators, and other sources is deposited into ocean water where it is converted into methyl mercury that bio-accumulates in fish and poses a risk to humans who consume the fish.[177]

One of these plans, the Northeast Regional Mercury TMDL, is designed to reduce mercury deposition in ocean waters from all sources to reduce mercury concentrations in fish so that water quality standards can be achieved.[178] The plan covers the states of Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont, and was developed in recognition of the fact that mercury emissions do not respect political boundaries and are often deposited far from their sources.[179] Because the TMDL applies to the pollutant, without regard to its source, this plan acts to reduce emissions that would otherwise be regulated under the CAA.

As leaders on the national and international stage debate the proper response to climate change and its associated ocean acidification, the oceans are being impacted by changes in ocean chemistry. These changes are occurring faster than expected, and the absence of scientific consensus on how these changes will ultimately impact the marine environment does not justify inaction. The current approach to addressing ocean acidification will not be adequate to address the change occurring in the ocean rapidly enough to protect marine ecosystems from significant impacts. A more aggressive response is warranted.

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175. *What is Nonpoint Source Pollution?*, EPA, http://water.epa.gov/polwaste/nps/whatis.cfm (last visited Nov. 5, 2013); *see also* CONN. DEP'T OF ENVTL. PROT. ET AL., NORTHEAST REGIONAL MERCURY TOTAL MAXIMUM DAILY LOAD (2007), http://www.neiwpcc.org/mercury/mercury-docs/FINAL_Northeast_Regional_Mercury_TMDL.pdf.

176. *See id.* at 35.

177. NEW ENGLAND INTERSTATE WATER POLLUTION CONTROL COMMISSION, NORTHEAST REGIONAL MERCURY TOTAL MAXIMUM DAILY LOAD FACT SHEET (2007), http://www.neiwpcc.org/mercury/mercury-docs/FINAL_Northeast_Regional_Mercury_TMDL_Fact_Sheet.pdf.

178. *Id.*

179. *Id.*

IV. RECOMMENDATIONS

Climate change is a global phenomenon because carbon dioxide and other greenhouse gases, once released into the atmosphere, do not respect political boundaries. Rather, they migrate across boundaries, which creates significant jurisdictional problems regarding accountability. In a similar way, ocean acidification is unbounded due to ocean circulation, upwelling, and other factors. Thus, addressing either problem is extremely complex. The fact that they are interrelated adds to this complexity. The difficulty inherent in eliminating either problem has been used as a basis to withhold direct action to halt their primary cause—carbon dioxide and other greenhouse gas emissions. While more research would be helpful in understanding the problem more fully, there is already sufficient evidence that harm to the oceans is underway, making it imprudent to withhold action until the current studies are complete.

Unlike other areas of climate change where the science is less clear, the absorption of carbon dioxide into the ocean water and the resulting reduction in pH can be measured with precision. Scientists have understood the impacts of declining pH on organisms for a long time, and there is no question that changes in ocean pH affect living organisms in profound ways. The changes currently observed in ocean chemistry are virtually irreversible on a time scale of centuries due to the slow biogeochemical processes in the ocean.[180] But that does not warrant inaction. Under the current strategic plan to address ocean acidification, the U.S. has adopted a research-driven response agenda anticipated to take up to twenty years.[181] However, there is currently no requirement to actively address the causes of ocean acidification directly. In fact, under the current approach, a primary goal is to understand the changes occurring sufficiently to develop effective adaptation strategies.[182] This reactive approach is insufficient, given the current understanding of how the ocean is changing. More importantly, the current approach significantly undermines the primary goals of the national policy because the impacts of

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180. NRC Report, *supra* note 101, at 16.

181. *Id.* at 126–27.

182. *Id.* at 127.

ocean acidification are occurring now and opportunities to take action are closing. An increasing number of scientists now believe that actions proposed by policymakers will not be sufficient to prevent significant harm to the marine environment within the current time frame for action.[183]

Because carbon dioxide emitted into the atmosphere is retained there for a period of time, even if global carbon dioxide emissions ceased, the oceans would continue absorbing carbon dioxide. Ostensibly, this may suggest that any action is meaningless. The same was once said about the effort to close the huge hole in the ozone layer caused by human activity. However, as a result of strong political will and meaningful action, significant progress has been made to repair and possibly close the hole.[184] Given that EPA, NRC, NOC, NOAA, and other reputable scientific bodies have acknowledged that ocean acidification is occurring now, faster than expected, and its impacts are likely to interfere with marine systems in disruptive ways over the next several decades, additional action is warranted.[185] Because it is unlikely that the United States will diverge from its current research-driven course, it is important that policymakers examine and utilize existing legal and policy tools available that may mitigate the ocean impacts of rising atmospheric carbon dioxide concentrations. These include preserving coastal carbon sinks, reevaluating water quality standards for marine waters, and utilizing regional TMDLs for carbon dioxide.

A. Preserve Coastal Carbon Sinks

Coastal ecosystems such as mangroves, salt marshes, and sea grasses act as large carbon sinks by sequestering enormous quantities of carbon in their soil, living tissue, and biomass.[186]

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183. G.H. Rau et al., *The Need for New Ocean Conservation Strategies in a High-Carbon Dioxide World*, 2 NATURE CLIMATE CHANGE 720 (2012).

184. THE VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER & THE MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER (2000); *see also* UNEP, HANDBOOK FOR THE MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER xi (2007), http://ozone.unep.org/Publications/MP_Handbook/MP-Handbook-2012.pdf (noting that as a result of the Montreal Protocol, consumption of over 98 percent of harmful ozone-depleting chemicals has been successfully phased out).

185. NRC Report, *supra* note 101, at 5.

186. BRIAN C. MURRAY ET AL., GREEN PAYMENTS FOR BLUE CARBON: ECONOMIC

This sequestration plays a significant role in controlling atmospheric concentrations of carbon dioxide.[187] Current estimates suggest that carbon sequestration in these habitats has an annual climate change mitigation potential of between 300 and 900 million tons of carbon dioxide equivalents.[188] Per hectare, an intact coastal marsh sequesters an amount of carbon equivalent to the emissions from 488 cars on U.S. roads each year.[189] Unfortunately, these habitats are being lost at an alarming rate. Worldwide, approximately 29 percent of all sea grass beds, 67 percent of salt marshes, and 35 percent of mangroves have been lost to human activities.[190] It has been estimated that somewhere between 340,000 and 980,000 hectares of these critical habitats are lost each year.[191]

Despite occupying only one to two percent of the area covered by forests globally, coastal ecosystems play a critical role in the regulation of carbon.[192] For example, one hectare of land within a coastal ecosystem can store up to five times more carbon than a hectare of land within a mature tropical forest.[193] Because of this difference in carbon storage, when these areas are disturbed by human activity they have the potential to become massive carbon dioxide emission sources.[194] For example, conversion of 1,800 square kilometers of wetlands in the Sacramento-San Joaquin Delta in California released approximately 900 million tons of carbon dioxide back into the atmosphere.[195] Just as troubling is the rate at which this carbon was released. Carbon sequestered over the last

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INCENTIVES FOR PROTECTING THREATENED COASTAL HABITATS ES-1 (2011).

187. *Id.*

188. *Id.* at ES-2. The authors note that these are equivalent to the annual carbon dioxide emissions from energy and industry for Poland and for Germany, respectively. *Id.*

189. *Id.* at 7. A hectare of land is about 2.471 acres.

190. *Id.* at 3.

191. *Id.* at ES-2.

192. *Id.* at 6.

193. *Id.*

194. SAMANTHA SIFLEET ET AL., STATE OF THE SCIENCE ON COASTAL BLUE CARBON: A SUMMARY FOR POLICY MAKERS 6 (2011). Once disturbed, this carbon reacts with oxygen and quickly reenters the atmosphere where it adds to the existing atmospheric carbon dioxide.

195. STEPHEN CROOKS ET AL., MITIGATING CLIMATE CHANGE THROUGH RESTORATION AND MANAGEMENT OF COASTAL WETLANDS AND NEAR-SHORE MARINE ECOSYSTEMS: CHALLENGES AND OPPORTUNITIES 2 (2011).

4,000 years was released in just over 100 years.[196] Today, that area continues to release between 5 and 7.5 million tons of carbon dioxide per year, which is equivalent to between 1 and 1.5 percent of California's total annual greenhouse gas emissions. Some of this released carbon dioxide may eventually enter the ocean to impact ocean pH.[197] This carbon is currently not considered in emissions projections.

The final ocean plan recognizes the valuable sequestration service provided by coastal habitats and includes a requirement that federal agencies evaluate the value of coastal systems in future policies.[198] But there is no firm commitment to preserve coastal carbon sinks. In fact, no federal statute directly addresses coastal carbon sinks or the need to preserve them as a frontline strategy against climate change and ocean acidification.[199] This remains true despite the fact there is growing awareness that atmospheric carbon dioxide is increasing and there is a growing need for carbon sinks to protect marine ecosystems.[200] There is now clear evidence to support action to include emissions and removal of carbon by these systems in any response to climate change and ocean acidification.[201] Just as importantly, keeping these systems intact or restoring disturbed systems should be considered in any response to sea level rise. Communities that plan to prevent sea level inundation by building structures along the coastline should consider how disturbing these carbon sinks

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196. *Id.*

197. SIFLEET, *supra* note 196, at 6 (noting that development of coastal systems can release carbon trapped in coastal habitats and release CO_2 directly into the atmosphere through various processes). Once in the atmosphere, this CO_2 adds to the existing atmospheric carbon dioxide and could re-enter the ocean at the air-sea interface. *Id.*; *see also* Sabine, *supra* note 2 (noting that most CO_2 emissions into the atmosphere will end up in the ocean); Dore, *supra* note 5, at 12,235 (noting that CO_2 emissions absorbed by the oceans cause a reduction in seawater pH).

198. NAT'L OCEAN COUNCIL, *supra* note 129, at 14–16.

199. Linwood H. Pendleton et al., *Considering "Coastal Carbon" in Existing U.S. Federal Statutes and Policies*, 41 COASTAL MGMT. 3, 3 (2013), http://nicholasinstitute.duke.edu/sites/default/files/publications/considering-coastal-carbon-in-existing-u.s.-federal-statues-and-policies-paper.pdf.

200. *Solutions, Our Best Lines of Defense*, THE INT'L PROGRAMME ON THE STATE OF THE OCEAN, http://www.stateoftheocean.org/solutions.cfm (last visited Oct. 9, 2013) ("There is also a pressing need to develop carbon sinks to reduce current CO_2 levels in the atmosphere. The current target of 450ppm CO_2 in the atmosphere and/or 2°C temperature will not guarantee the viability of some marine ecosystems.").

201. CROOKS, *supra* note 197, at 3.

might undermine their goals.

One method employed to convince landowners to forgo development of valuable coastal land is to provide incentives to avoid converting the land. There is some evidence that market-based incentives that encourage landowners to avoid habitat conversion can be viable strategies in some areas to mitigate the impact of climate change.[202] These incentives typically involve land-based emissions, and have not yet been applied to carbon sequestration in coastal systems.[203] While this should be evaluated as a possible strategy, its effectiveness would be limited under current carbon markets valuation protocols because the cost of carbon credits in the United States is high compared to other nations.[204] Moreover, for coastal systems, the valuation approach utilized under existing carbon markets would undervalue these resources because it would not consider the multitude of other unique ecosystem services these systems provide, such as tourism, fisheries, coastal protection, biodiversity, water quality, and other services that add value to the land.[205] The nation's coastal wetlands provide resting, feeding, and breeding habitat for 85 percent of waterfowl and other migratory birds, and nearly 45 percent of the nation's endangered and threatened species are dependent on coastal habitats.[206] These systems are among the most productive ecosystems on Earth.[207] More than half of all commercially harvested fish in the United States depend on these systems at some stage of their lifecycle.[208] Additionally, these ecosystems provide physical services, such as protection against hurricanes, storm surge, damage to water supplies,

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202. MURRAY, *supra* note 188, at ES 3; *see also* WORLD BANK ET AL., CAPTURING AND CONSERVING NATURAL COASTAL CARBON: BUILDING MITIGATION, ADVANCING ADAPTATION 6 (2010); CROOKS, *supra* note 197, at 32.

203. MURRAY, *supra* note 188, at ES-3, 13.

204. MURRAY, *supra* note 188, at 32 (reporting that the United States ranked 24th out of 25 countries in the cost of carbon, showing that investors in carbon credits would not be likely to buy carbon credits from the U.S. given the high price per credit).

205. *See generally* CONSERVATION INT'L ET AL., ECONOMIC VALUES OF CORAL REEFS, MANGROVES, & SEAGRASSES: A GLOBAL COMPILATION (2008), http://coralreef.noaa.gov/aboutcrcp/strategy/reprioritization/wgroups/resources/climate/resources/econvalue.pdf.

206. *What are Coastal Wetlands?*, NOAA, http://www.habitat.noaa.gov/protection/wetlands/index.html (last visited Oct. 30, 2013).

207. *Id.*

208. *Id.*

and property loss from inundation.[209] Unfortunately, many of these critical ecosystem services are not reflected in current market valuations and decisions are made without consideration of the real economic value these systems provide.[210] When properly evaluated, the value can be quite high. For example, one study showed that the value of wetland ecosystem services in Louisiana is between $8,437 and $15,763 per acre.[211] Based on the current wetland acreage in Louisiana, the value provided by these ecosystem services in Louisiana amounts to between $33 billion and $63 billion.[212] These systems are rapidly disappearing. Of Louisiana's 3,800 square miles of wetlands, more than 1,000 will be converted by 2050 to facilitate development.[213] This conversion will impact the ecosystem services provided, and likely release large quantities of sequestered carbon back into the atmosphere, where some will inevitably get deposited into the ocean to impact pH. Therefore, any action to address ocean acidification should address the loss of coastal wetlands by creating market-based incentives to preserve these systems. This can only be achieved when all ecosystem services provided are fully valued.

B. *Establish Protective Marine Water Quality Standards for pH*

In 1976, the EPA first promulgated recommended water quality standards for pH in marine waters.[214] The EPA

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209. NOAA COASTAL SERVICES CENTER, INTRODUCTION TO ECONOMICS FOR COASTAL MANAGERS 19 (2009), http://www.csc.noaa.gov/digitalcoast/_/pdf/economics.pdf (noting that wetland services on an annual per-acre basis include protection from hurricane damage ($186), storm surges ($280 to $904), damage to the water supply ($84 to $157), and property losses from inundation ($6,599 to $7,116).

210. Lawrence H. Goulder & Donald Kennedy, *Interpreting and Estimating the Value of Ecosystem Services*, *in* NATURAL CAPITAL: THEORY & PRACTICE OF MAPPING ECOSYSTEM SERVICES (Gretchen Daily et al. eds., 2011), http://www.stanford.edu/~goulder/Goulder%20and%20Kennedy%20-%20Ecosystem%20Service%20Values.pdf.

211. Stephen Farber, *Welfare Loss of Wetlands Disintegration: A Louisiana Study*, XIV CONTEMPORARY ECONOMIC POLICY 92, 92 (1996).

212. Clare Davis-Wheele, *The Louisiana Environment, Louisiana Coastal Land Loss*, TULANE, http://www.tulane.edu/~bfleury/envirobio/enviroweb/LandLoss/LandLoss.htm (last updated Jan. 7, 2000) (noting that Louisiana has 4 million acres of wetlands).

213. LA. COASTAL WETLANDS CONSERVATION & RESTORATION TASK FORCE AND THE WETLANDS CONSERVATION & RESTORATION AUTH., COAST 2050: TOWARD A SUSTAINABLE COASTAL LOUISIANA, EXECUTIVE SUMMARY 3 (1998), http://www.coast2050.gov/products/docs/orig/2050execsumm.pdf.

214. EPA, *supra* note 150.

recommended a range of between 6.5 and 8.5, but not to exceed 0.2 units outside the naturally occurring range.[215] The EPA was strongly interested in how discharges of low pH effluent to receiving waters might act synergistically to alter the toxicity of metals such as copper, zinc, cadmium, and others in receiving water.[216] The EPA did not consider how absorption of carbon dioxide could change ocean pH and did not consider how small changes in pH might be deleterious to marine species. It did, however, recognize that pH in natural waters is largely regulated by the carbonate system.[217] Given that the ocean carbonate system is changing in fundamental ways as oceans absorb more carbon dioxide, the EPA and states should reevaluate the basis for their current pH ranges.

For marine waters, the EPA acknowledged that normal pH levels were between 8.0 and 8.2 for surface waters and between 7.7 and 7.8 in deeper waters.[218] Given this recognition, and the EPA's recommendation that state marine waters not exceed 0.2 units outside the naturally occurring range, it seems clear that the EPA was primarily focused on the synergistic impacts of pH on substances in receiving waters when it recommended a range far outside the range it deemed to be normal for marine waters. Interestingly, the EPA noted that larval oysters would be "adversely affected at the extremes of the pH range of 6.5 to 9.0."[219] This conclusion should be reevaluated based on recent evidence. For example, in the North Pacific the collapse of oyster seed production at a commercial oyster hatchery was linked to the oysters' exposure to upwelled water that had a pH between 7.6 and 8.2.[220] At the lowest pH, exposure proved lethal, but even those oysters raised in water that was acidic but non-lethal had significantly less growth in later stages of their lives.[221] In another study, researchers showed that with decreasing pH, survival of oyster larvae

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215. *Id.* at 337.

216. *Id.* at 343.

217. *Id.* at 347.

218. *Id.* at 342.

219. *Id.* at 342.

220. *Hatchery, OSU Scientists Link Ocean Acidification to Larval Oyster Failure*, OR. STATE UNIV. (Apr. 11, 2012), http://oregonstate.edu/ua/ncs/archives/2012/apr/hatchery-managers-osu-scientists-link-ocean-acidification-larval-oyster-failure.

221. *Id.*

decreased, and growth and development were retarded.[222] Larval survival decreased by 43 percent at a pH of 7.8 and by 72 percent at a pH of 7.6.[223] Under current emissions rates, global average ocean pH could decline to these levels by 2100. These studies and others show that the EPA promulgated recommendations for marine pH in 1976 with inaccurate information regarding the range of pH tolerance for many marine species. States that adopted these recommendations wholly or with minor revisions effectively adopted these errors. Despite acknowledging that the net effect of declining ocean pH "is likely to disrupt the normal functioning of many marine and coastal ecosystems," the EPA did not find sufficient data to support changing its recommended standards.[224]

The changes in ocean chemistry currently occurring require a reevaluation of pH ranges for marine waters. Such reevaluation would be fully consistent with the current ocean policy, which recommends action to enhance water quality in the ocean based on the best scientific evidence.[225] Existing science now clearly shows significant impacts on marine species occur at the organismal and community levels when pH declines to 7.8, and that additional significant impacts result for some species as the pH declines further. Such changes are anticipated to occur by the end of this century without action. The EPA itself, at a time when pH measurements were considerably less accurate than today, stated that the natural variability of ocean water pH is between 7.9 and 8.3 (taking into consideration the 0.2 unit variation). However, it recommended pH limits far in excess of these outer limits. Based on the available science, pH could fall past the point at which many calcifying animals would cease to exist, without violating the EPA's current standards. Given the compelling evidence that these limits may not be protective of many

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222. Sue Ann Watson et al., *Early Larval Development of the Sydney Rock Oyster Saccostrea Glomerata Under Near-future Predictions of CO_2-driven Ocean Acidification*, 28(3) J. SHELLFISH RESEARCH 431, 431 (2009).

223. *Id.*

224. Ocean Acidification and Marine pH Water Quality Criteria, 74 Fed. Reg. 17,485 (Apr. 15, 2009).

225. WHITE HOUSE COUNCIL ON ENVTL. QUALITY, INTERIM REPORT OF THE INTERAGENCY OCEAN POLICY TASK FORCE 7 (2009), http://www.whitehouse.gov/assets/documents/09_17_09_Interim_Report_of_Task_Force_FINAL2.pdf/; *see also* NAT'L OCEAN COUNCIL, *supra* note 119, at 54.

marine species, these values must be revised to reflect levels that are protective.

C. Implement Regional TMDLs for Carbon Dioxide

Carbon dioxide emitted into the air through human activities is a pollutant when it enters the ocean because it alters ocean chemistry by reducing pH.[226] Because carbon dioxide emissions are considered a nonpoint source of pollution, they may be subject to control by states under the CWA. Pollution that results from atmospheric deposition may be prevented through use of TMDLs.[227] This approach been used to control the deposition of mercury emitted from coal power plants and other sources into certain ocean waters.[228] Like mercury, carbon dioxide emitted into the air enters the ocean to cause harm to the marine community. Like mercury, carbon dioxide emissions emanate from a wide variety of sources and across many states. Thus, any approach to controlling carbon dioxide emissions must consider the value of regional management through multistate cooperation. Should water quality standards for pH in marine waters be revised as suggested, it is likely that many states would have some waters that are impaired with respect to pH. Consequently, the use of TMDLs would be required to ensure that each state can meet its water quality standards. Site-specific TMDLs would likely be ineffective to address the problem; however, the development of a regional TMDL to control carbon dioxide emissions has significant promise if implemented appropriately. The Northeast Regional Mercury TMDL currently in use provides a useful model to guide the process.[229]

Establishing regional TMDLs that address carbon dioxide deposits into ocean waters would have important co-benefits. For example, regional TMDLs may provide a new rationale to control nutrient loading into the ocean. Nutrient runoff from fertilizer and human and animal waste is typically considered problematic because it can lead to large algal blooms that can eventually strip ocean water of oxygen and contribute to the

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226. *See* 3 U.S.C. § 1362 (2008) (defining pollution as the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water).

227. CONN. DEP'T OF ENVTL. PROT. ET AL., *supra* note 177, at vi.

228. *Id*. at 37.

229. *See generally id*.

formation of dead zones. Moreover, new evidence shows that as organic matter formed during algal blooms decays, it will release additional carbon dioxide that will interact synergistically to substantially increase the acidity of ocean waters.[230] This change may be large enough in coastal regions receiving nutrient inputs to harm valuable commercial fisheries, such as clams, oysters, scallops, and mussels.[231] Creation of a regional TMDL to control carbon dioxide would provide an opportunity for states to reevaluate the impacts of nutrient runoff into the ocean.

Establishment of regional TMDLs for carbon dioxide is fully consistent with the national priority objective to "strengthen resiliency of coastal communities and marine and Great Lakes environments and their abilities to adapt to climate change impacts and ocean acidification."[232] It is also consistent with the calls for action to: (1) "reduce rural sources of excessive nutrients"; (2) "reduce urban sources of excessive nutrients"; and to (3) "minimize impacts of harmful algal blooms."[233]

V. CONCLUSION

Policymakers in the United States are faced with a profound question with regard to ocean acidification: In the face of uncertainty, what should be done? While there are many unknowns regarding the ultimate fate of the marine environment as global ocean pH declines, policymakers must consider the implications of using the lack of scientific certainty to delay action. Ocean absorption of anthropogenic carbon dioxide continues to alter ocean chemistry, and that process is anticipated to continue. While it is possible that marine life may prove resilient to anticipated declines in ocean pH, emerging science suggests that the alternative is more likely. Marine species and communities are already exhibiting vulnerabilities to declining pH and those changes may be greater as ocean pH declines further. Moreover, ocean acidification may act synergistically with other marine

230. *See* Sunda & Cai, *supra* note 18, at 10,651.

231. *Id*. at 10,657.

232. WHITE HOUSE COUNCIL ON ENVTL. QUALITY, *supra* note 227, at 8.

233. NAT'L OCEAN COUNCIL, *supra* note 119, at 65–66, 69 (outlining actions 1, 2, and 4).

stressors to magnify these harms. If the United States is to successfully meet its national priorities, the government must take direct action to confront ocean acidification and begin to modernize ocean regulation to reflect the reality of climate change, without further delay.