Volume 30 | Issue 1 Article 7

3-1-2019

Ocean Acidification: Dealing with Uncharted Waters

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OCEAN ACIDIFICATION: DEALING WITH UNCHARTED WATERS

I. INTRODUCTION

There are ancient air bubbles trapped in ice that have allowed NASA to observe what Earth's atmosphere was like in the past 400,000 years.[1] Through research, NASA discovered the carbon dioxide (CO_2) levels in the atmosphere are higher than they have ever been.[2] Since the industrial revolution, it is no secret humans have contributed immensely to the significant increase of CO_2.[3] In fact, the Earth's oceans absorb an astonishing amount of CO_2 emissions.[4] Today, the Earth's oceans absorb twenty-two million tons of CO_2 every day.[5] To make things more troublesome, researchers are predicting CO_2 levels will continue to rise in the coming years, resulting in unprecedented effects to Earth.[6]

When the Earth's ocean absorbs an increase of CO_2, there is a corresponding increase in the acidity levels of the ocean's chemical makeup.[7] The astoundingly high levels of CO_2 have resulted in Earth's oceans becoming thirty percent more acidic than in recorded history.[8] This underappreciated issue is called ocean acidification, and its effects create profound consequences.[9] Ocean

1. *See Graphic: The relentless rise of carbon dioxide*, NASA GLOBAL CLIMATE CHANGE, https://climate.nasa.gov/climate_resources/24/ (last visited Jan. 16, 2018) (describing carbon dioxide research conducted by NASA).

2. *See id.* (stating severity of carbon dioxide levels today). The carbon dioxide levels during the ice age were "around 200 parts per million (ppm)", reaching 280 ppm during the warmer interglacial period. *Id.* Today, carbon dioxide levels have surpassed 400 ppm. *Id.*

3. *See* Raef Cogan, *Research and Development Contracts: The Key to Combating Ocean Acidification*, 46 PUB. CONT. L. J. 895, 901-03 (2017) (discussing humans' contribution to CO^2 in Earth's atmosphere).

4. *See id.* at 902-03 (explaining Earth's oceans absorption of atmospheric CO_2).

5. *See Ocean Acidification*, CTR. FOR BIOLOGICAL DIVERSITY, http://www.biologicaldiversity.org/campaigns/endangered_oceans/index.html?gclid=CjwKCAiA4vbSBRBNEiwAMorER6ubGK1JxzLytE-tbIY_DBhEqEnkJncaIS1QEUvvp73ulytx4iZlJxoCbp0QAvD_BwE (last visited Jan. 16, 2018) (stating Earth's oceans daily intake of carbon dioxide).

6. *See Graphic: The relentless rise of carbon dioxide*, NASA GLOBAL CLIMATE CHANGE, https://climate.nasa.gov/climate_resources/24/ (last visited Jan. 16, 2018) (stating future prediction of CO_2 levels).

7. *See* Cogan, *supra* note 3, at 902-03 (explaining correlation of CO_2 and acidity levels in Earth's oceans).

8. *See id.* at 902 (stating Earth's oceans acidification levels).

9. *See id.* at 903 (summarizing ocean acidification detrimental effects).

acidification is threatening the ocean's chemical makeup, ecosystems, marine organisms, and biodiversity.[10] "Absent immediate action, 'irreversible, catastrophic changes to marine ecosystems' are anticipated to occur[,]" even endangering human life.[11] Although these facts are troubling, humans have the resources and ability to mitigate our ocean's chemical makeup and change its terrifying future.[12]

II. BACKGROUND

For some time, researchers have realized oceans are absorbing a significant amount of carbon dioxide released into the atmosphere every day.[13] This Comment analyzes the ocean acidification problem and the domestic measures taken to combat its effects in the United States.[14] First, this Comment addresses what ocean acidification is, its impact on the environment, and prior legislative and executive action taken to understand this problem.[15] Next, this Comment discusses the current measures being taken to mitigate ocean acidification and the government's plan to regulate the problem.[16] Further, this Comment analyzes the government's plan and its alternatives.[17] Lastly, this Comment discusses the possible impacts of acidifying oceans in the future.[18]

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10. *See* Eric V. Hull, *Ocean Acidification: Legal and Policy Responses to Address Climate Change's Evil Twin*, 6 WASH. J. ENVTL. & POL'Y 349, 352 (2016) (describing impact of ocean acidification).

11. *Id.* (stating need for mitigating measures against carbon pollution).

12. *See Graphic: The relentless rise of carbon dioxide*, NASA GLOBAL CLIMATE CHANGE, https://climate.nasa.gov/climate_resources/24/ (last visited Jan. 16, 2018) (stating humans' ability to change CO_2 outlook).

13. *See* Amanda M. Carr, *"We Can Lead": Washington State's Efforts to Address Ocean Acidification*, 3 WASH. J. ENVTL. L. & POL'Y 188, 191 (2013) (stating known issue of ocean acidification).

14. For a discussion of what ocean acidification is and its effects, see *infra* notes 19-115 and accompanying text.

15. For a discussion of what ocean acidification is and the efforts in place to combat it, see *infra* notes 19-115 and accompanying text.

16. For a discussion of the efforts taken to combat the ocean acidification problem, see *infra* notes 73-115 and accompanying text.

17. For a discussion of the effectiveness of the government's plan and its alternatives, see *infra* notes 116-194 and accompanying text.

18. For a discussion of the future impacts of ocean acidification, see *infra* notes 195-228 and accompanying text.

A. What is Ocean Acidification?

Once CO_2 is released into the atmosphere, and it is partially absorbed by the ocean, it mixes with ocean water.[19] "More simply, the CO_2 mixes with the ocean water (H_2O) to create what is known as carbonic acid (H_2CO_3)."[20] Then, the carbonic acid partially breaks down into hydrogen ions that "lower the pH of the ocean's waters."[21] "The pH scale measures acidity; a lower pH means higher acidity."[22]

The Earth's oceans absorbs two of the seven billion metric tons of CO_2 released into the atmosphere each year.[23] Today, the ocean's chemical makeup is similar to that which existed 250 million years ago.[24] The alterations in "ocean chemistry resulted in massive changes in ocean ecology" that wiped out ninety percent of marine biodiversity.[25] Those devastating circumstances are no more perilous than what is to come if current CO_2 emissions continue to rise.[26] As ocean's pH levels continue to decrease, some estimate that oceans will intake up to five billion metric tons of CO_2 per year by 2100.[27] Moreover, "the ocean is acidifying ten times faster today than it has over the last fifty million years."[28] Troubling enough, this rate is only expected to accelerate in years to come.[29]

Ocean acidification has been referred to as "'the other CO_2 problem,' because it has received less attention than climate change but is similarly caused by rising levels of atmospheric car-

19. *See* Cogan, *supra* note 3, at 902-03 (detailing how ocean acidification is created).

20. *Id.* at 903 (breaking down carbonic acid's formation).

21. *Id.* (describing what carbonic acid breakdowns into).

22. *Id.* (explaining pH scale).

23. Harold F. Upton & Peter Folger, *Ocean Acidification*, CONG. RESEARCH SERV., at 2 (July 30, 2013) https://digital.library.unt.edu/ark:/67531/metadc227633/m1/1/high_res_d/R40143_2013Jul30.pdf (displaying ocean acidification rates over past decades).

24. *See Stanford scientists link ocean acidification to prehistoric mass extinction*, STANFORD NEWS (Apr. 27, 2010) https://news.stanford.edu/news/2010/april/prehistoric-mass-extinction-042710.html (discussing similar acidic conditions in prehistoric times).

25. Hull, *supra* note 10, at 362 (comparing ocean's chemistry to previous conditions); *Stanford scientists link ocean acidification to prehistoric mass extinction*, STANFORD NEWS (Apr. 27, 2010) https://news.stanford.edu/news/2010/april/prehistoric-mass-extinction-042710.html (explaining marine life in previous conditions).

26. *See* Hull, *supra* note 10, at 362-63 (explaining severity of future marine life conditions).

27. Upton & Folger, *supra* note 23, at 2 (stating estimation of future ocean's CO_2 level).

28. Carr, *supra* note 13, at 194 (comparing acidifying rate of change today to past rate).

29. *Id.* (explaining future acceleration rates of acidification).

bon dioxide."[30] Consequently, the causes of ocean acidification are stretched far and wide.[31] Since the industrial revolution, humanity has caused the Earth's oceans to absorb more than 530 billion tons of CO_2.[32] Burnt fossil fuels and other atmospheric gases dissolve into the Earth's oceans, but also find their way into the Earth's oceans directly by acidic rainfalls and the disposal of industrial waste and sewage.[33] When land is poorly managed, chemicals are washed downstream into the ocean directly affecting its chemical makeup.[34]

Ocean acidification is a global problem.[35] Beyond just the coastal states whose shores are directly at risk, one report estimates that "[m]ore than one third of the world's population will be strongly affected by acidification."[36] Many countries have acted similarly to the United States.[37] Countries such as Germany, China, Japan, and Korea have programs designed to sponsor research exploring acidifying oceans and marine ecosystem effects.[38] Other countries have even banded together to attack the issue.[39]

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30. Ryan P. Kelly & Margaret R. Caldwell, *Ten Ways States Can Combat Ocean Acidification (and Why They Should)*, 6 WASH. J. ENVTL. L. & POL'Y 288, 289-90 (2016) (explaining atmospheric carbon dioxide effects on ocean).

31. *See What is Ocean Acidification?*, CONSERVE ENERGY FUTURE, https://www.conserve-energy-future.com/causes-effects-solutions-of-ocean-acidification.php (last visited Jan. 30, 2018) (discussing causes of ocean acidification).

32. Upton & Folger, *supra* note 23, at 2 (stating rough estimate of carbon dioxide absorbed by Earth's oceans from 1800 to 1994).

33. *See What is Ocean Acidification?*, CONSERVE ENERGY FUTURE, https://www.conserve-energy-future.com/causes-effects-solutions-of-ocean-acidification.php (last visited Jan. 30, 2018) (discussing atmospheric carbon dioxide journey into Earth's oceans). Industrialization has also caused other dangerous emissions of acidic gases, such as sulfur dioxide and nitrogen oxides, that also contribute to the high acidic levels in Earth's oceans. *Id.*

34. *See id.* (discussing improper land management effects on oceans).

35. *See* Kelly & Caldwell, *supra* note 30, at 302 (discussing international response to ocean acidification).

36. *Id.* at 290 (stating worldwide estimated effects of ocean acidification).

37. *See id.* at 302 (explaining other actions taken by researchers and scientists in other countries).

38. *See id.* (discussing international response to ocean acidification problem).

39. *See id.* (noting European Project on Ocean Acidification collaboration among twenty-seven European organizations focused on research and education about acidification).

B. The Effects of Ocean Acidification

"Coral reefs are the largest living structures on the planet."[40] Coral reefs undergo a calcification process.[41] During this process, such organisms use minerals, including aragonite, to form their skeletons and shells.[42] Consequently, in order to maintain healthy reefs, the ocean's waters need to be "supersaturated with aragonite."[43] "Prior to the industrial revolution, more than 98 percent" of the ocean's water met those conditions.[44] As carbonic acid continues to form in Earth's oceans from higher levels of CO_2, the level of saturation decreases.[45] Today, only "[forty] percent of coral reefs are surrounded by waters that are saturated with aragonite."[46] As a result of current CO_2 emissions, that number is expected to drop to ten percent, leaving ocean waters unequipped to promote the growth and development of coral reefs.[47]

The need for supersaturated oceans also plays a critical role in the reproduction of marine phytoplankton, the ocean's microscopic plants.[48] When oceans become under-saturated, marine phytoplankton's reproduction levels decrease.[49] Moreover, these organisms also undergo a calcification process.[50] So, not only do phytoplankton have difficulty reproducing, but they also have trouble forming into healthy plants.[51] Corals, along with marine

40. *Hull*, *supra* note 10, at 363 (stating coral reefs' immense structure).

41. *See* Scott C. Doney ET AL., *Ocean Acidification: The Other CO2 Problem*, 6 WASH. J. ENVTL. L. & POL'Y 213, 221 (2016) (discussing calcification of shellfish and coral reefs).

42. Upton & Folger, *supra* note 23, at 4 (explaining coral reefs' needs to calcify). Aragonite is "a form of calcium carbonate" needed for shell forming organisms to build healthy, strong shells and skeletons. Hull, *supra* note 10, at 358. Without it, these organisms are forced to expend more energy to survive the next stage of development. *Id.*

43. *See* Hull, *supra* note 10, at 361 (discussing coral reefs' survival); *What Is Ocean Acidification & Why Does It Matter?*, CTR. FOR CLIMATE AND LIFE, http://climateandlife.columbia.edu/2015/12/03/what-is-ocean-acidification-why-does-it-matter/ (last visited Jan. 28, 2018) (discussing importance of aragonite for calcification).

44. Hull, *supra* note 10, at 361(discussing coral reef needs).

45. Upton & Folger, *supra* note 23, at 4 (explaining decrease in saturation from increase of CO_2).

46. Hull, *supra* note 10, at 361 (explaining today's coral reef conditions).

47. *See id.* (explaining future of coral reefs).

48. *See id.* at 356 (discussing phytoplankton survival).

49. *See id.* (explaining negative impacts of CO_2 to marine phytoplankton).

50. *See id.* at 358 (stating that marine phytoplankton are also calcifying organisms).

51. *See* Hull, supra note 10, at 358 (discussing ocean acidification effects on phytoplankton survival).

phytoplankton, form the base of the ocean's food chain.[52] Consequently, the loss of these basic food chain organisms "could cause the collapse of the entire marine system."[53]

Ocean acidification has also adversely impacted many other forms of calcifying species, including oysters, clams, mussels, snails, scallops, crabs, sea urchins, sea stars, and squid.[54] These mollusks also need saturated oceans filled with aragonite to build their shells and skeletons.[55] Without these building blocks, such organisms cannot fully form hard, strong skeletons and shells to protect themselves from predators.[56] High acidity levels also lead to slower growth and rising health issues of mollusks' internal organs.[57] In the Pacific Northwest, the oyster population has been in turmoil.[58] The oyster population has gone into a state of "reproductive failure" from exposure to low pH water, preventing oysters from forming shells during the early stages of development.[59] As a result of the ocean's declining pH levels, by 2100 calcifying organisms will disappear.[60] Worse, "[i]n some areas, declining ocean pH may actually reverse the process of calcification and cause existing shells and skeletons to dissolve."[61] Such an "interfere[nce] with these important processes . . . can have a rippling effect that causes significant impacts all the way up the food chain."[62]

The ocean acidification impact reaches further than impairing calcifying species' ability to build shells or skeletons.[63] The observed effects of "mussels grown in acidified conditions have weaker

52. *Id.* at 356 (discussing need for corals and phytoplankton in marine ecosystem).

53. *Id.* at 363 (explaining loss of coral reefs impact).

54. Cogan, *supra* note 3, at 903-04 (discussing other basic organism effects by ocean acidification); Carr, *supra* note 13, at 194 (listing marine life effected by ocean acidification).

55. Carr, *supra* note 13, at 194-95 (explaining calcifying species' need for certain minerals).

56. *See* Cogan, *supra* note 3, at 904 (explaining mollusks' need for hard shells to protect themselves).

57. *Id.* (discussing effects of ocean acidification on marina animals' internal organs).

58. Hull, *supra* note 10, at 358 (discussing reproductive failure of oysters in Pacific Northwest).

59. *See id.* (explaining studies of oyster population in Pacific Northwest and its effects of ocean acidification).

60. *Id.* at 359 (stating studies of future predicted population of calcifying organisms).

61. *Id.* (discussing effects of ocean's declining pH levels).

62. *Id.* at 356 (breaking down ocean acidification's effects on food chain).

63. *See* Carr, *supra* note 13, at 195 (confronting extent of other issues of marine life due to ocean acidification).

byssal threads, the mechanisms that allows them to attach to rocks, docks and other hard surfaces."[64] Multitudes of species are affected by this change in the chemical makeup of the oceans.[65] Some fish may even lose their hearing and sense of smell, which will affect their ability to evade predators.[66]

Ocean acidification has even found its way in impacting human life.[67] When shellfish die and become sparse, humans who depend on them experience food shortages.[68] This also contributes immensely to socio-economic problems in places where these food shortages occur.[69] Moreover, when water becomes more acidic, agricultural production takes a hit.[70] "Acidic water results in the increase in the soil acidity," which "makes it impossible for the cultivation and production of certain crops."[71] As this results in low food production, ocean acidification becomes another contributor to food shortages around the world.[72]

C. Government Response to Ocean Acidification

> While it is our oceans' contours that shape our coastlines, it is what we decide and do here that will shape our oceans' future . . . in a contest between us and the oceans, eventually the oceans will win one way or the other. So it's us that has to adapt. Not the other way around.[73]

In 2005, the first sign of ocean acidification appeared in the United States.[74] Two commercial shellfish hatcheries in Washington and Oregon experienced an oyster crash.[75] While the hatcher-

64. *Id.* (discussing acidification effects on mussels).

65. *See id.* (discussing range of species affected by high acidic levels).

66. *See id.* (explaining effects of acidification of some fish).

67. *See What is Ocean Acidification?*, CONSERVE ENERGY FUTURE, https://www.conserve-energy-future.com/causes-effects-solutions-of-ocean-acidification.php (last visited Jan. 31, 2018) (explaining ocean acidification effects on human life).

68. *Id.* (discussing need for shellfish for humans).

69. *See id.* (explaining chain of events from ocean acidification).

70. *Id.* (explaining extent of ocean acidification on food shortages across world).

71. *Id.* (explaining how agriculture is affected by ocean acidification).

72. *See What is Ocean Acidification?*, CONSERVE ENERGY FUTURE, https://www.conserve-energy-future.com/causes-effects-solutions-of-ocean-acidification.php (last visited Jan. 31, 2018) (stating starvation issues by acidic water).

73. Ed Yong, *Obama: The Ocean President*, THE ATL. (Jan. 14, 2017) https://www.theatlantic.com/science/archive/2017/01/obama-the-ocean-president/512135/ (quoting former President Barack Obama).

74. *See* Carr, *supra* note 13, at 192 (explaining beginning of ocean acidification effects).

75. *Id.* (discussing an oyster die-off in 2005 to 2009).

ies were suffering from a massive die-off of Pacific oyster larvae, "wild Pacific oysters in areas of the Pacific Northwest where they have naturalized failed to successfully reproduce."[76] Accordingly, such a die-off threatened the viability of much of the West Coast's shellfish industry that was dependent on the naturalization process and hatcheries for seed.[77] As a result of the oyster crash, hatchery operators took a look at the causes for such decline.[78] Researchers discovered the increasing CO_2 issue in the atmosphere was increasing the concentration of hydrogen ions and reducing the pH, saturation, and aragonite levels in coastal marine waters.[79] The researchers concluded this change in the ocean's chemical makeup and hatchery waters caused a "significant and adverse effect" on "oysters' ability to form shells."[80]

In response to the 2005 oyster crash, in 2006 "Congress, for the first time, publicly requested a study of ocean acidification" as part of the Magnuson-Stevens Reauthorization Act.[81] In 2009, Congress passed the Federal Ocean Acidification Research and Monitoring Act (FOARAM) to address the ocean acidification issue.[82] FOARAM mandated additional studies and monitoring of pH levels on marine organisms and ecosystems.[83] Through FOARAM, Congress also required the National Oceanic and Atmospheric Administration (NOAA) to establish an ocean acidification program.[84]

Former President Barack Obama, also known as "the ocean president," has taken more measures to safeguard the ocean than

76. *Id.* (explaining extent of oyster die-off in Pacific Northwest).

77. *See id.* (stating extent of ocean acidification effects on shellfish industry).

78. *See id.* at 192-93 (discussing first finding of ocean acidification effects).

79. *See* Carr, *supra* note 13, at 192-93 (explaining effects of ocean acidification).

80. *Id.* (explaining beginning of ocean acidification effects).

81. Hull, *supra* note 10, at 364 (explaining government's first effort made to research ocean acidification). The Magnuson-Stevens Reauthorization Act was "created to promote the conservation and management of [United States] fishery resources and ensure sustainable domestic fisheries in federal waters." *Magnuson-Stevens Act Reauthorization*, HOUSE COMM. ON NAT. RES., https://naturalresources.house.gov/magnusonstevens/ (last visited Feb. 20, 2018).

82. Cogan, *supra* note 3, at 906 (discussing congressional efforts made to combat ocean acidification issue).

83. *See* Hull, *supra* note 10, at 364 (discussing purpose of FOARAM).

84. *See id.* at 364-65 (discussing additional efforts required by FOARAM). NOAA is an organization that "seeks to better prepare society to respond to changing ocean conditions and resources by expanding understanding of ocean acidification . . . ." *NOAA Ocean Acidification Program*, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., http://oceanacidification.noaa.gov/ (last visited Feb. 24, 2018) (stating purpose of NOAA's ocean acidification program).

any other president.[85] Coinciding with FOARAM, President Obama issued a memorandum that established the Interagency Ocean Policy Task Force.[86] The Task Force gave President Obama recommendations about the state of ocean acidification, and in 2010, he issued an executive order "with the goal of 'protect[ing], maintain[ing], and restor[ing]' the health and biological diversity of 'ocean, coastal, and Great Lakes ecosystems and resources.'"[87]

The Environmental Protection Agency (EPA) has taken substantial measures to help combat ocean acidification.[88] The Clean Water Act (CWA) is "the primary mechanism available to states and the federal government to regulate and control the direct deposition of pollutants into marine and fresh waters."[89] Its purpose is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[90] The CWA requires states to set water quality standards for bodies of water in their jurisdictions.[91] The standards, however, are only thresholds, as states may implement more protective criteria to help maintain appropriate pH levels.[92] If states decide not to adopt the baseline required under the CWA,

85. Yong, *supra* note 73 (discussing impact former President Obama made on ocean acidification measures).

86. Cogan, *supra* note 3, at 907 (explaining efforts made by executive branch). The Task Force was designed to develop "recommendation[s] for a national policy that ensures protection" and maintenance of the United States' oceans and lakes. *Interagency Ocean Policy Task Force*, COUNCIL ON ENVTL. QUALITY, https://obamawhitehouse.archives.gov/administration/eop/ceq/whats_new/Interagency-Ocean-Policy-Task-Force (last visited Feb. 20, 2018) (outlining purpose of Interagency Ocean Policy Task Force).

87. Cogan, *supra* note 3, at 907 (discussing additional efforts made by President Obama regarding ocean acidification). The changing in Earth's waters' pH also threatens marine life and the chemical makeup of lakes and rivers, which is part of the NOAA's mission to explore. *See* Deirdre Lockwood, *Could acidification threaten Great Lakes?*, CHICAGO TRIBUNE (Aug. 16, 2010) http://articles.chicagotribune.com/2010-08-16/news/ct-met-great-lakes-acidification-20100816_1_carbon-dioxide-zebra-and-quagga-mussels-acidification (discussing acidification effects on rivers and lakes in United States).

88. *See* Carr, *supra* note 13, at 200-01 (stating statutes passed to combat ocean acidification).

89. *Id.* at 201 (explaining current way to directly combat ocean acidification). *See also* Miyoko Sakashita, *Using the Clean Water Act to Tackle Ocean Acidification: When Carbon Dioxide Pollutes the Oceans*, 6 WASH. J. ENVTL. L. & POL'Y 600, 603 (2016) (stating CWA "is the nation's strongest law protecting water quality.")

90. 33 U.S.C.A. § 1251 (stating congressional goals of enacting CWA).

91. *See* Carr, *supra* note 13, at 200-01 (discussing use of CWA for maintaining appropriate acidic levels). *See also* 33 U.S.C.A. § 1251(a) (listing national objectives for CWA). "Water quality standards designate specific uses for each water body and set narrative or numeric criteria for the water that will support those designated uses." *See* Sakashita, *supra* note 89, at 604 (stating what water criteria standards are).

92. *See* Carr, *supra* note 13, at 201 (explaining CWA as limitation and that additional measures may be taken).

it must "provide a science-based explanation for their alternate criteria."[93] The CWA also incorporates other controls and preventative measures to assist in regulating bodies of water.[94] The CWA requires those who want to construct any building or structure to obtain state certification to ensure it will comply with state water quality standards before builders can submit a federal application.[95] Furthermore, every two years the CWA requires that states create a list of impaired bodies of water that do not meet existing pollution controls within their jurisdiction.[96] This, in turn, gives the state the "authority and duty to control pollutants from all sources that are causing the impairment."[97]

The Clean Air Act (CAA), also created by the EPA, is another option available to states for combatting the "drivers of ocean acidification."[98] Similar to the CWA, the CAA "sets thresholds for environmental protection while states are invited to enact more stringent regulations."[99] The CAA, however, directly controls and regulates atmospheric pollutants such as CO_2.[100] The CAA's National Ambient Air Quality Standards (NAAQS) program "regulates stationary and mobile sources of air pollutants and sets regional air quality goals."[101] Under the NAAQS program, the federal government establishes a list of "criteria pollutants," while states are delegated the authority to regulate polluters' compliance with those standards.[102] It was not until 2007 that the Supreme Court determined greenhouse gases fell within CAA's definition of "air pollu-

93. *See* Sakashita, *supra* note 89, at 605-06 (explaining specific criteria is required by each state).

94. *See id.* at 604 (noting sections 401 and 303(d) of CWA).

95. *See id.* (explaining section 401 of CWA's hurdle to obtain permit for building).

96. *See id.* (discussing section 303(d) of CWA's control over pollution in state's bodies of water).

97. *Id.* at 605 (explaining what happens after body of water is listed on impaired list).

98. Carr, *supra* note 13, at 200 (stating CAA use to combat acidifying oceans). *See also U.S. Agency Programs Involved in Ocean Acidification Research*, INTERAGENCY WORKING GROUP ON OCEAN ACIDIFICATION, https://www.st.nmfs.noaa.gov/iwgoa/pages/activities.html (last visited Feb. 22, 2018) (summarizing how CWA and CAA work together to combat acidifying oceans).

99. Carr, *supra* note 13, at 200-01 (stating what CAA does). *See also* 33 U.S.C.A. § 1370 (2017) (designating state authority to adopt stricter standards).

100. *See Carr*, *supra* note 13 at 203 (explaining why CAA is one important tool for combatting ocean acidification).

101. *Id.* (discussing how CAA controls air pollutants).

102. *See id.* (explaining divide of power under CAA).

tant" and could be regulated under the CAA.[103] Since this decision, the EPA has discovered other types of gases and created additional standards to regulate its emissions.[104] Moreover, new major emitting facilities and polluters must comply with certain thresholds before development.[105] New emitters "must comply with the EPA's lower achievable emissions rate technology standards" and "employ best available control technology" that helps limit the amount of pollution that is released into the atmosphere.[106] Under both the CWA and the CAA, if a state government is not complying with threshold standards, the federal government has the authority to intervene and remedy the diversion.[107]

In 2013, the National Ocean Council (NOC), designed to restore and maintain the health of the ocean, released its final implementation describing actions the federal government planned to take to improve the state of the oceans.[108] The plan was focused on the health of the oceans and adaption strategies to reduce vulnerabilities of coastal communities and ocean environments.[109] This approach is thus focused strongly on long-term research to provide answers on addressing the accelerating pH changes in Earth's oceans.[110]

This frightening crisis of ocean acidification has been considered a "national security issue."[111] In a 2015 National Security Strategy Report, the White House called attention to many areas of importance to national security.[112] The report, however, acknowledged that "[t]he national security risks of projected climate change are as serious as any challenges we have faced."[113] The re-

103. *See* Mass. v. Envtl. Prot. Agency, 549 U.S. 497, 533 (2007) (explaining that for greenhouse gases to be regulated under CAA, it must be considered "air pollutant" that contributes to climate change).

104. *See* Carr, *supra* note 13, at 204 (stating discovery of six other greenhouse gases that contributed to air pollution).

105. *See id.* at 203 (discussing polluters requirement to comply with Prevention of Serious Deterioration provisions under CAA).

106. *Id.* (explaining criteria that must be met before new emitters may develop).

107. *See id.* at 201 (explaining federal authority to take over state action when states are not complying with required standards).

108. *See* Hull, *supra* note 10, at 367 (detailing implementation plan recommendations and actions to be taken).

109. *See id.* at 368 (discussing final plan's procedure for combatting ocean acidification).

110. *See id.* (stating overall purpose of final implementation plan).

111. *See* Cogan, *supra* note 3, at 902 (stating severity of ocean acidification problem).

112. *Id.* at 904-05 (discussing White House's national security considerations).

113. *Id.* at 905 (discussing severity of climate change as national security risk).

port recognized ocean acidification and the reduced survival ability of basic food chain organisms such as coral and shellfish, which will in turn affect the entire food chain.[114] Moreover, such a disruption "will cause food shortages around the world."[115]

III. CRITICAL ANALYSIS: WHAT'S NEXT?

A. State action

Today, with the change in administration, the federal government has decided to shift its focus to other areas of national security.[116] The 2018 federal budget hit NOAA with a dramatic budget cut of sixteen percent.[117] Currently, the Trump administration's reprioritization is resulting in a proposed plan to further cut NOAA's budget by twenty percent in 2019.[118] The budget cut will reduce the agency's climate research, which includes research designed to help understand ocean acidification implications, by thirty-seven percent.[119] In fact, the White House's 2019 NOAA budget aims to eliminate many programs assisting ocean acidification research, such as the Coastal Zone Management Grants Program, Regional Coastal Resilience Grants, and the Sea Grant Program.[120]

With the federal government taking a financial step back from efforts directed towards combatting ocean acidification, states are

114. *Id.* (stating ocean acidification issue in national security report).

115. *Id.* (discussing decrease in food supply which will affect human life).

116. *See* Alison Chase, *Trump's Budget Leaves States Holding the Bag*, NAT'L RES. DEF. COUNCIL (Feb. 16, 2018) https://www.nrdc.org/experts/alison-chase/trumps-budget-leaves-states-holding-bag (discussing Trump's administration's fiscal year 2019 proposed budget cuts). According to House Budget Director, Mick Mulvaney, the Trump administration plans to shift focus and allocate its environmental funds for climate change, or the long-term forecasts, to current weather research, which focuses on day-to-day weather trends. *Id.*

117. *See id.* (discussing continued slash in NOAA budget in 2018). The Trump administration has even taken measures for substantial cutback on numerous global warming efforts, including the EPA's funding. *See* Cogan, *supra* note 3, at 909 (discussing President Trump's efforts to direct federal funds elsewhere).

118. Chase, *supra* note 116 (explaining implications of Trump's administration budget cuts on our Nation's air, water, and environment).

119. *See id.* (stating how budget cut of NOAA will affect ocean acidification programs).

120. *Id.* (discussing federal government's plan to eliminate sea programs that assists ocean acidification research). The Coastal Zone Management Grants Program, Regional Coastal Resilience Grants, and the Sea Grant Program aimed to safeguard coastal communities, protect fish and wildlife, keep waters clean, prepare for threats that cross state lines, and work to reduce the nutrient pollution in the Nation's Great Lakes. *Id.*

essentially left "holding the bag."[121] Thirty-nine percent of the United States' population considers the oceans and Great Lakes their home, which means that millions of people are going to be relying on their state governments to ensure secure living conditions along the coasts, but also their oceans' well-being.[122]

Fortunately, states may be in a better position to handle the impact of ocean acidification.[123] Ocean acidification has global causative drivers, but it can be exacerbated or diminished at local scales.[124] Considering the Earth's oceans absorb approximately one-third of atmospheric CO_2, state governments are able to directly control and regulate water pollution by using the CWA and CAA to regulate atmospheric CO_2.[125] Under the CWA, states are already mandated to set water quality standards for bodies of water within their jurisdictions, and failure to meet those standards gives states the power to control the causative drivers.[126] Additionally, under the CAA, states are also required to regulate and enforce certain air quality standards, but may enforce stricter standards if they chose to do so.[127] By state governments further constraining water and air standards to meet more stringent CO_2 thresholds, it will put pressure on cities, companies, and other polluters to better regulate their CO_2 output.[128] This effort can also assist in decreasing other dangerous chemicals in the ocean, such as sulfur dioxide and nitrogen oxides, which contribute to higher acidity levels.[129]

Under the CAA, the EPA has struggled with including certain gases as a contribution to air pollution, and consequently, their

121. *Id.* (discussing pressure on states to make more efforts due to federal government's decision to allocate funds elsewhere).

122. *See id.* (explaining coastal communities' pressure to protect their homes).

123. *See* Carr, *supra* note 13, at 201 (outlining states' ability to use CWA to fight acidification).

124. *See* Terrie Klinger & Jan Newton, *Ocean Acidification as a Problem in Systems Thinking*, 6 WASH. J. ENVTL. L. & POL'Y 208, 209 (2016) (explaining state and local communities' ability to intensify ocean acidification problem).

125. Cogan, *supra* note 3, at 902 (stating amount of atmospheric CO_2 that is absorbed into oceans).

126. *See* 33 U.S.C.A. § 1314(a) (stating criteria state governments are required to adopt).

127. *See* Carr, *supra* note 13, at 200-01 (explaining how air quality effects ocean chemistry).

128. *See id.* at 201 (discussing CWA and CAA ability to reduce chemical output in atmosphere and oceans).

129. *See What is Ocean Acidification*, CONSERVE ENERGY FUTURE (Dec. 3, 2015) https://www.conserve-energy-future.com/causes-effects-solutions-of-ocean-acidification.php (explaining effects of industrialization on atmosphere).

control over those gases is limited.[130] Although Congress has attempted to create legislation outside of CAA's context to assist the EPA's efforts, many of those proposed bills have failed.[131] State and local governments, however, have the power to create greenhouse gas reduction legislation on their own.[132] The ability to regulate emissions at a local scale throughout the United States will drive down the CO_2 emissions in the atmosphere, thereby decreasing the amount of CO_2 absorbed by Earth's oceans from domestic drivers.[133]

There are other ways that state and local governments can utilize these statutes to combat acidifying oceans.[134] "In 2013, the Center for Biological Diversity petitioned the EPA to adopt new water quality criteria for ocean acidification."[135] Additional water quality criteria for chemical parameters that are linked to ocean acidification, such as aragonite saturation, will allow researchers to gather accurate and consistent measurements overtime.[136] These additional measurements will provide "a more accurate understanding of biologically relevant effects such as the rate at which shells and other hard parts dissolve in seawater."[137] Overall, "creating new criteria for and measuring these factors simultaneously with pH would generate a more complete picture of the chemistry underlying ocean acidification and its attendant biological effects."[138] This also allows government agencies to pinpoint the main sources

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130. *See* Carr, *supra* note 13, at 203-05 (explaining difficulty of EPA's authority to regulate certain air pollutants).

131. *Id.* at 204 (discussing additional attempts taken by Congress to combat CO_2 emissions rates).

132. *Id.* at 204-05 (explaining ability of state and local governments to assist federal government in combatting ocean acidification).

133. *See id.* (discussing how state and local governments possess power to enact their own legislation even if federal government cannot).

134. *See* Kelly & Caldwell, *supra* note 30, at 319-20 (discussing ability for EPA and states to create additional water quality standards).

135. *See* Sakashita, *supra* note 89, at 607 (discussing Center for Biological Diversity's push for better quality standards).

136. *See* Kelly & Caldwell, *supra* note 30, at 319-20 (discussing advantages of additional measurements taken through water quality criteria). Two additional measurements that will allow relevant datasets to compare with pH levels are Total Alkalinity and Dissolved Inorganic Carbon. *Id.*

137. *Id.* at 320 (listing ways additional water quality criteria will further ocean acidification research and understanding). By expanding the CWA to include information gathering and not only quality regulation, the Act will provide information necessary to effectively implement regulations that will reduce and eliminate pollution. *Id.*

138. *Id.* (explaining how comparing seawater's chemical trends can result in answers about ocean acidification's biological effects).

of acidification and appropriately implement regulations and standards that will most efficiently address the problem.[139]

An advantage of the CWA is that "water quality standards" are also used to determine whether a body of water is "impaired" for failing to meet an applicable standard.[140] Once a body of water is discovered to be impaired, the state develops an impaired waters list.[141] This list is then submitted and reviewed by the EPA to ensure that all waters that are impaired are listed.[142] Once a body of water is listed as impaired, "the state has the authority and duty to control pollutants from all sources that are causing the impairment."[143] One way the state will take over control is by developing more stringent total maximum daily loads.[144] This "puts in place a plan for reducing the pollution that is causing the water quality impairment."[145] A maximum load "defines the specified maximum amount of a pollutant which can be discharged or 'loaded' into the water at issue from all combined sources."[146] Moreover, states may make it more difficult for applicants to obtain discharge permits.[147]

Although this seems to be a sufficient way to address bodies of water that are threatened by acidification, some bodies of water are slipping through the list.[148] Some states fail to include numerous water quality criteria that are linked to ocean acidification when evaluating whether a body of water should be listed on the impaired list.[149] Although oceans cannot be listed on the impaired bodies of water list, a Washington federal district court "highlighted

139. *See id.* (summarizing how additional measurements can lead to agencies better regulating acidification issue).

140. *See* Sakashita, *supra* note 89, at 603-04 (discussing CWA's uses). Two ways states utilize the CWA is by permitting specific levels of pollution from individual point sources and setting tolerable pollutant loads to protect water quality. *See* Kelly & Caldwell, *supra* note 30, at 308 (explaining how bodies of water are listed on impaired waters list).

141. *See* Sakashita, *supra* note 89, at 603-04 (stating that states develop impaired waters list).

142. *See id.* at 604-05 (explaining what happens to impaired water list when EPA receives it).

143. *Id.* at 605 (stating what happens to bodies of water when listed impaired).

144. *See id.* at 610 (stating one-way states take control of bodies of water).

145. *See id.* (discussing how total maximum daily loads are used).

146. *See* Sakashita, *supra* note 89, at 610 (defining what maximum loads are).

147. *See* Kelly & Caldwell, *supra* note 30, at 308-09 (discussing what happens after bodies of water are listed on impaired waters list).

148. *See* Sakashita, *supra* note 89, at 607 (recognizing failure of impaired waters list).

149. *See id.* (explaining need to revise criteria in evaluating bodies of water).

the need for site-specific ocean acidification information and monitoring data."[150]

In 2009, the Center for Biological Diversity alleged that the EPA failed to identify seawaters as impaired.[151] In a response to the lawsuit, the EPA issued a memorandum in 2010 directed towards state governments.[152] The EPA stressed the need for states to include ocean acidification in their water quality assessments.[153] The EPA acknowledged that ocean acidification is a serious problem and the court held the Center for Biological Diversity had standing to bring the claim "based on concrete injuries to its members that harvest shellfish and use and enjoy areas affected by ocean acidification."[154] The court, however, ultimately deferred to the EPA's expertise and judgment.[155] As part of the memorandum, the EPA stated that the CWA "has the breadth to address ocean acidification".[156] Taken into consideration the accelerated rates of acidification and the ocean's daily intake of CO_2, seawater will violate the water quality standards under the CWA.[157] At some point, when seawater is undeniably in direct controversy with water quality standards, the EPA must consider listing oceans on the impaired waters list.[158] Such a listing will assist in monitoring chemical changes in coastal waters and provide data for continued research.[159] In turn, this research will allow states and the federal government to develop and implement improved standards that directly target and monitor ocean acidification.[160] Ultimately, such a listing will allow

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150. *See id.* at 609 (discussing importance of *Ctr. for Biological Diversity*).

151. *See id.* at 608 (explaining challenges to EPA's decisions). In 2008, government agencies were so slow to translate the ocean acidification research that Washington State failed to include any marine waters on its impaired waters list. *See* Kelly & Caldwell, *supra* note 30, at 314 (discussing Washington State's failure to efficiently interpret ocean acidification research).

152. *See* Sakashita, *supra* note 89, at 608 (explaining need to amend criteria to be listed on impaired waters list).

153. *See id.* (explaining why ocean acidification rates need to be part of water quality standards).

154. *Id.* at 609 (discussing court's decision in *Center for Biological Diversity* to find standing in bringing suit).

155. *See id.* (discussing court's decision in *Center for Biological Diversity* was to defer to EPA's expertise).

156. *Id.* at 608 (discussing EPA's memorandum as part of settlement agreement).

157. *See* Cogan, *supra* note 3, at 902 (stating accelerated acidity levels in oceans).

158. *See* Sakashita, *supra* note 89, at 609-10 (contemplating possibility of seawater being listed on impaired waters list).

159. *See id.* (explaining benefit of being on impaired waters list).

160. *See id.* (explaining oceans' need to be listed on impaired waters list).

states to establish stricter pollution controls to develop healthier oceans.[161]

By states aiding locally acidifying seawater through more stringent water quality criteria and implementing rigorous thresholds to obtain polluters' permits, local coastal communities will experience vast benefits.[162] Local benefits generated from these stricter standards will include "healthier state fisheries, shellfish operations, and other coastal activities dependent on water chemistry . . . ."[163] Moreover, lawsuits challenging the present water quality criteria as inadequate will be significantly reduced and states can spend more time revising the existing regulations rather than litigating them in court.[164]

The CWA provides many avenues for success when addressing ocean acidification.[165] As the EPA has acknowledged, the CWA already has the breadth to handle this emerging problem.[166] Therefore, there is no need to wait for new legislation to address ocean acidification.[167] Although CO_2 as a form of water pollution is a recent realization, the CWA already combines the appropriate expertise and structure to implement further stringent regulations to control how much CO_2 is absorbed by Earth's ocean from domestic-based polluters.[168]

B. Issue with Current Plan

Ocean acidification is known as global warming's "evil twin" and the "other CO_2 problem."[169] These references are not surprising because ocean acidification is a largely under-appreciated topic of concern.[170] "Climate change," ocean acidification's counterpart,

161. *See id.* at 605 (explaining how being on impaired bodies of waters list allows states to control direct pollutants effecting its water).

162. *See* Kelly & Caldwell, *supra* note 30, at 315 (explaining state incentives to act against ocean acidification).

163. *Id.* (listing state benefits from stricter water quality standards).

164. *See id.* at 315, 317 (stating reduced number of lawsuits if states implement stricter standards).

165. *See* Sakashita, *supra* note 89, at 611 (stating CWA's advantages to address acidifying oceans).

166. *See id.* at 611-12 (explaining CWA's strength to combat ocean acidification).

167. *See id.* at 611 (discussing direct control states have over ocean acidification problem through CWA).

168. *See id.* at 612 (summarizing CWA's ability to address ocean acidification).

169. *See* Hull, *supra* note 10, at 349 (stating ocean acidification as global warming's evil twin); Doney ET AL., *supra* note 41, at 213 (stating ocean acidification as other CO_2 problem).

170. *Ocean Acidification: NSF awards $11.4 million in new grants to study effects on marine ecosystems*, NAT'L SCI. FOUND. (Sept. 9, 2014) https://www.nsf.gov/news/

tends to be the sweeping term.[171] Ocean acidification tends to receive less attention in part because its effects are less apparent.[172] In order to start combatting the acidification problem, more people need to become aware of the issue.[173] A good place to start is to educate society on the existence of global warming and ocean acidification, how much CO_2 people are releasing into the atmosphere, and the adverse effect of CO_2 emissions on Earth's oceans.[174]

The effects of changes in the oceans' chemical makeup are still largely a mystery.[175] Although we know that ocean acidification is happening and that many marine organisms are being affected, the ultimate consequences are unknown.[176] Through funded research, scientists have been able to look back at the Earth's conditions fifty-five million years ago.[177] During that time, "changes in ocean chemistry resulted in massive changes in ocean ecology that led to the extinction of between [thirty-five] and [fifty] percent of deep-water marine species."[178] Today, with changes in ocean chemistry occurring at a much faster rate than they did fifty-five million years ago, we are only able to guess at the future state of Earth's oceans.[179] This unsettling realization has prompted scientists to urge the government to take action.[180] Scientists are concerned that, at these accelerated rates, "such action may come too late."[181]

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news_summ.jsp?cntn_id=132548 (explaining how ocean acidification goes unnoticed).

171. *See* Cogan, *supra* not 3, at 902 (explaining that ocean acidification is just one part of global warming issue).

172. *See id.* (explaining how under-appreciated ocean acidification is compared to global warming).

173. *See id.* at 903-04 (discussing impact of ocean acidification).

174. *See id.* at 902 (stating that "people still do not believe humans cause climate change"). The belief that climate change does not exist is completely contrary to the data and information that scientists have collected and studied for the last decade. *See* Carr, *supra* note 13, at 193. Scientists have proven that "the ocean chemistry is changing as a result of [ ] CO_2 being released into the [E]arth's atmosphere, and can [be] trace[d] . . . to the burning of fossil fuels." *Id.*

175. *See* Hull, *supra* note 10, at 365-66 (explaining unknown risks of ocean acidification).

176. *See id.* (explaining known effects of ocean acidification compared to unknown risks).

177. *See id.* at 362 (comparing Earth's current conditions to Earth's prior conditions).

178. *See id.* (explaining effects of prior change in Earth's ocean's chemical makeup).

179. *See id.* at 363 (explaining Earth's oceans unknown state).

180. *See* Hull, *supra* note 10, at 363 (explaining researchers' response to unknown state of Earth's oceans).

181. *Id.* (stating need for action now, rather than later).

As researchers and scientists have banded together to fight the ocean acidification issue, they have found current funding levels may be inadequate to achieve the goals envisioned under the national plan.[182] "The current response framework requires no direct action to stop the process of acidification."[183] Instead, the plan is to put its funding into long-term studies.[184] These studies are designed to understand ocean acidification harms, and the best "methods to adapt to those harms."[185] The program envisioned requires funding of about fifty to one-hundred million dollars per year, however, with funding under thirty million dollars and expected future budget cuts, such plans will be impossible to accomplish.[186]

This plan, although important for understanding ocean acidification and the best ways to combat it, has its issues.[187] The plan pursues efforts towards understanding and generating data about what we already know the problem is, and does not affirmatively take steps to fix the acidification problem.[188] Researchers have already discovered the "rate at which ocean pH is declining is accelerating."[189] If immediate action is not taken, devastating consequences are anticipated to occur in the near future.[190] With the current approach focused on "long-term, comprehensive ocean acidification research," by the time we learn how to handle these accelerating changes it may be too late, and the data may be inadequate.[191] The unknown future of acidification effects on Earth's oceans makes it immensely important to fund research exploring what is to be expected and how we, as a society, can fight the negative impacts.[192] Taking into consideration the mass extinction from millions of years ago, and the unknown future state of the Earth's

182. *See id.* at 369 (discussing current plans to battle ocean acidification).

183. *Id.* (explaining framework for future plans to fight ocean acidification).

184. *Id.* (stating plan to understand ocean acidification effects and ways to combat them).

185. *See* Hull, *supra* note 10, at 369 (explaining plan for research on ocean acidification).

186. *See id.* at 368-69 (stating budget issues for plan to combat ocean acidification).

187. *See id.* 368 (explaining framework for studies on ocean acidification).

188. *See id.* (stating focus of plan is for researching and understanding ocean acidification).

189. *See id.* at 352 (stating accelerated rate of acidification).

190. *See* Hull, *supra* note 10, at 352 (explaining immediate need for action against ocean acidification).

191. *See id.* at 368-69 (discussing future plan to conduct studies on ocean acidification).

192. *See id.* at 365-66 (discussing unknown risks to ecosystem changes by higher acidic levels).

oceans, it is important to direct some of the ocean acidification's funding into efforts directed at mitigating the current acidification issues.[193] A more balanced approach through funding both research and immediate efforts may be a better option for the limited resources such programs receive.[194]

IV. IMPACT

In 2015, atmospheric CO_2 exceeded four hundred parts per million, and under current emissions scenarios, one estimation predicts the acidity of the oceans will double before the end of the century.[195] Although acidifying harms are currently happening, "the worst consequences are predicted for the future."[196] The Earth's oceans are already more acidic today than "they have been at any point in the last 20 million years," and it is expected to become 150 percent more acidic by 2100.[197] The most troubling detail is the "rate at which the ocean pH is declining is accelerating."[198]

While CO_2 emission rates can be predicted by looking at past levels and measuring current rates, all the actual causes of ocean acidification are still largely unknown.[199] The unknown potential causes of an acidifying ocean are why the current federal plan pursues researching to understand the problem.[200] This lack of knowledge poses the possibility that "the projected decline in pH could be greater than predicted."[201]

The effects of ocean acidification on marine species are also mysterious.[202] Due to the ability of scientists to observe what Earth was like fifty-five million years ago, where current CO_2 rates were comparable to today's levels, researchers expect massive future ef-

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193. *See id.* at 369 (stating that today's framework does not implement measures to stop acidification process).

194. *See id.* (discussing framework of funding research and not direct action).

195. *See* Sakashita, *supra* note 89, at 602-03 (stating one estimation of rise in CO_2 levels).

196. *See id.* at 603 (stating that future consequences are expected to be worse than in past experiences).

197. Hull, *supra* note 10, at 351 (explaining that such decline in pH will cause immense impacts on marine ecosystems).

198. *See id.* at 352 (stating accelerating decline of pH in seawater).

199. *See id.* at 351 (discussing unknowns of acidifying oceans).

200. For a discussion about the current federal plan, see *supra* notes 108-110 and accompanying text.

201. Hull, *supra* note 10, at 351 (noting how unknown causes creates murky current measurements).

202. *See id.* at 355 (explaining marine species future survival).

fects on marine species.[203] Researchers, however, estimate more serious consequences for the marine environment as acceleration rates continue to rise.[204]

This rapid decline in pH threatens the survival of marine organisms that undergo the calcification process.[205] The ocean's pH has already declined to the point where it has become corrosive to marine organisms' shells and skeletons, which are dependent on carbonate ions.[206] As pH continues to decline, however, the availability of carbonate ions needed by these marine organisms to survive is also expected to decline.[207] The impact of declining pH will be "species-specific, with some organisms benefiting from the change and others negatively impacted, based on their differential vulnerability."[208] Basic food chain species such as reef-building corals, mollusks, shellfish, and plankton will become increasingly vulnerable.[209] In order to survive with weaker shells and skeletons, these marine organisms will need to expend a significant amount of their limited energy to find and acquire the carbonate ions available to become stronger.[210] This type of exertion "will reduce the energy available to carry out other essential life functions, which makes them more vulnerable to other stressors in the environment."[211] Ultimately, without strong shells and skeletons, these marine species will not have enough energy to survive the next stage of development.[212] At the rate of declining pH, these calci-

203. *See id.* at 362-63 (discussing historical revelations about ocean acidification).

204. *See id.* (explaining future prediction of consequences to marine life under current emission scenarios).

205. *See id.* at 355 (discussing marine life's survival is dependent on their ability to form shells).

206. For a discussion about ocean acidification effects on shell forming organisms, see *supra* notes 54-57 and accompanying text.

207. Hull, *supra* note 10, at 355 (stating need for carbonate ions by certain marine life).

208. *See id.* at 357 (stating that some marine life will benefit from declining pH). Although many species will suffer an adverse effect from declining pH, other species such as sea grasses and algae will benefit because they require CO_2 to survive. *Id.*

209. *See id.* at 358 (explaining how marine organisms at base of food chain will become increasingly vulnerable).

210. *See id.* (noting how marine species who are dependent on carbonate ions survive).

211. *Id.* (explaining need for certain marine organisms to retain energy for other life functions).

212. *See* Hull, *supra* note 10, at 358 (discussing need for energy to survive next stages of development for shell forming species).

fying species will begin to disappear altogether.[213] Some researchers predict that "declining ocean pH may actually reverse the process of calcification and cause existing shells and skeletons to dissolve."[214] Though the level of under-saturation needed to reverse calcification is unknown, it is expected to reach that point within the next few decades.[215] Some marine species' shells may even completely dissolve.[216]

In 2010, NOAA "announced that there is 'substantial' scientific information to support listing eighty-two species of coral found in [Unites States] waters as either threatened or endangered under the Endangered Species Act."[217] With the accelerated pH decline happening, a vast number of additional species of coral and other calcifying organisms will likely find its way on the Endangered Species Act as well.[218] Even more concerning, one study has predicted that under predicted emissions rates, "reef-development could cease entirely."[219] Ultimately, the "loss of coral reefs could cause the collapse of the entire marine system."[220]

The total shift in the marine predator-prey framework could be catastrophic.[221] "The ability to adapt to higher acidity will vary from fish species to fish species, and what qualities will help or hurt a given fish species is unknown."[222] Those marine species threatened by the decrease of pH will either need to adapt to the changing seawater chemistry or relocate to carbonate ion-rich regions in order to have any chance at survival.[223] Failure to adapt or

213. *See id.* at 359 (explaining predicted disappearance of calcifying organisms).

214. *Id.* (stating possibility of marine organisms' shells and skeletons dissolving).

215. *See id.* (explaining when dissolution of shells and skeletons are expected to occur).

216. *Id.* at 360 (discussing possibility of how far reverse calcification can extend). For instance, when pteropods, which are found in polar regions, "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." *Id.*

217. Hull, *supra* note 10, at 362 (discussing current coral conditions).

218. *See id.* (explaining possibility of additional species being put on endangered list).

219. *Id.* (stating possibility of end to coral reefs).

220. *Id.* at 363 (explaining impact of coral reefs failure to survive).

221. *Id.* at 352 (explaining effect on human life concerning collapse of marine ecosystem).

222. *Ocean Acidification*, SMITHSONIAN INST., http://ocean.si.edu/ocean-acidification (last visited Jan. 30, 2018) (explaining acidification effects on food chain).

223. *See* Doney ET AL., *supra* note 41, at 229 (explaining survival options for calcifying species as pH continues to decrease).

relocate will mean the end of that marine organism.[224] A shift in dominant fish species, however, can have major impacts all the way up the food chain and on fisheries.[225] When some marine species die-off, their predators are also threatened because they have nothing to feed on.[226] This rippling effect has the power to change the predator-prey relationship drastically.[227] Within decades, such a change "will likely impact more than half of the world's population that depends on the ocean for its primary source of food."[228]

*Kimberly N. Smith**

224. *See id.* at 229-30 (discussing long term effects of acidifying oceans).

225. *See Ocean Acidification*, SMITHSONIAN INST., http://ocean.si.edu/ocean-acidification (last visited Jan. 30, 2018) (discussing food chain issues due to ocean acidification).

226. *See* Cogan, *supra* note 3, at 904 (discussing predator-prey impact due to ocean acidification).

227. *See id.* (explaining rippling effect of extinction of some marine species).

228. Hull, *supra* note 10, at 352 (stating effect of marine life on human life).

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