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Dead Zones: A Global Threat To Marine Ecosystems

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Dead Zones: A Global Threat to Marine Ecosystems

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I. Introduction

Oceans cover two thirds of the Earth’s surface and support the majority of sustainable life on this planet. When the oceans are threatened, global livelihoods are threatened. Hundreds of coastal areas around the globe are home to “dead zones” which pose an environmental threat because the oxygen levels in the water can no longer sustain life. Dead zones currently exist along the coasts of almost all major continents in the world and are increasing in size and number. Dead zones are caused by a variety of factors such as fertilizer runoff enriched with nitrogen and phosphorus, pollution and sewage runoff, water stratification, destruction of wetlands, burning of fossil fuels, and climate change. However, there is evidence that dead zones may be able to recover if steps are taken to reduce or eliminate these direct causes. But in the absence of restorative measures, the many harmful effects of dead zones will result in drastic
changes to marine ecosystems, reduction in commercial fishing jobs around the world, and loss of marine species providing much needed food.

Currently, the Gulf of Mexico hosts the second largest anthropogenic dead zone caused by excessive fertilizer runoff from agriculture in the Mississippi River Basin. Although strategies have been implemented in the Gulf, and around the world to combat dead zones, many do not directly address the issue of fertilizer runoff. Dead zones are a global threat to our oceans and marine ecosystems and will continue to increase in size and number unless immediate action is taken to curb the human impact on our marine environment.

Part II of this paper defines dead zones, and describes the scientific processes involved in their formation. Part III identifies both the primary factors causing dead zones and their harmful effects. Part IV examines the most significant of the world’s dead zones, focusing on the Gulf of Mexico, Baltic Sea, Black Sea, and the Pacific Northwest Coast. Part V evaluates the current strategies being used to address dead zones. Lastly, Part VI presents five possible proposed actions to reduce the causes of dead zones.

II. The History And Formation of Dead Zones

Dead zones are so named because the deeper waters near the sea floor are hypoxic\(^1\) (low oxygen levels), or anoxic (no oxygen), and very few organisms can survive in such hostile conditions.\(^2\) Dead zones occur where sediments from rivers mix with ocean waters, particularly where natural water flow is restricted.\(^3\) Specifically, hypoxic conditions are caused by

\(^1\) Hypoxia occurs where oxygen levels fall below two parts per million dissolved oxygen. Normal oxygen levels fall in the range of five parts per million. Suzie Greenhalgh & Amanda Sauer, *AWAKENING THE DEAD ZONE: AN INVESTMENT FOR AGRICULTURE, WATER QUALITY, AND CLIMATE CHANGE*, WRI Issue Brief, Feb. 2003.


\(^3\) *Id.*
phytoplankton algal blooms on the surface of the water which occur when the water is nutrient enriched due to fertilizer and pollution runoff. Zooplankton and fish eat the phytoplankton and the organic waste falls to the ocean floor. Bacteria then decompose the organic waste through bacterial respiration which releases carbon dioxide into the water and consumes large amounts of oxygen in the coastal water, eventually rendering the water hypoxic.

Scientists estimate there are over 400 dead zones in existence worldwide. This is a dramatic increase from 149 dead zones recorded by the United Nations Environment Programme (UNEP) in 2004, and forty-nine in the 1960s. Hypoxic zones have been charted as early as 1911 in the northern Adriatic Sea. Core samples taken from ocean sediments in the Gulf of Mexico indicate hypoxic conditions existed in the 1940s and 1950s and increased significantly with each passing decade. Some of the earliest recognized dead zones include those in the Chesapeake Bay in the United States, the Baltic Sea, the Black Sea, and northern Adriatic Sea. Currently, the largest dead zone is located in the Baltic Sea, followed closely by the one in the Gulf of Mexico. Depending on the severity of the dead zone, the effects can be permanent or seasonal. Seasonal dead zones may recover, while permanent dead zones cannot, and thus create a detrimental shift in ecosystem structure and function. During the summer months, seasonal dead zones increase in size due to warmer water temperatures and calmer seas, which

4 Id.
5 Id.
6 Id.
10 Id. at 174.
11 See Nuttall & Solomon, supra note 8.
12 Id.
13 See Greenhalgh & Sauer, supra note 1.
14 See Rabalais, supra note 9.
prevent the mixing of the salt and fresh waters. This creates a water stratification effect which prevents the oxygen from being replenished in the deeper waters. However, autumn months generally show a decrease in the size of dead zones due to stronger winds and cooler water temperatures.

III. Contributing Factors And The Harmful Effects of Dead Zones

A number of factors contribute to the growth of dead zones, including, nitrogen and phosphorus from fertilizer runoff, destruction of wetlands, water stratification, the burning of fossil fuels, and pollution and sewage runoff. Each of these factors, whether individually or in unison, have proven to be primary causes of dead zones. Many of these contributors are anthropogenic and can be reduced or eliminated if action is taken in each dead zone basin.

Nitrogen and phosphorus are found in most fertilizers as essential nutrients that are absorbed through the soil which enable agricultural crops to grow. Fertilizer runoff is the primary cause of most dead zones worldwide. These chemical fertilizers are carried by surface water runoff into nearby rivers and streams, and ultimately flow into coastal waters. Typically, nitrogen is removed from the water through the process of “denitrification,” in which bacteria convert nitrates into nitrogen gas which is released into the atmosphere. However, with the destruction of wetlands, this denitrification process has been significantly reduced and therefore more nitrates are distributed into coastal waters. Over-enrichment of nutrients in the water – referred to as nutrient loading – causes increased productivity of phytoplankton, which are

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15 See Greenhalgh & Sauer, supra note 1, at 3.
16 Id.
17 See generally Biello, supra note 7.
19 Id.
20 See generally Biello, supra note 7.
21 Id.
known as harmful algae blooms (HABs), and an increased production of organic matter.\textsuperscript{22} This process, commonly referred to as “eutrophication,”\textsuperscript{23} creates hypoxic conditions in the water and is a primary influence on the growth of dead zones.\textsuperscript{24}

A naturally occurring contributor to dead zones is water stratification. Salt water has a higher density than fresh water and this disparity in density creates a layered effect between fresh and salt water columns where rivers meet the ocean.\textsuperscript{25} Warmer waters tend to contribute to this stratification process by preventing the flow of oxygen in the fresh water from reaching the deeper hypoxic salt water.\textsuperscript{26} Generally strong winds and cooler water surface temperatures help alleviate this problem by enabling the waters to exchange more freely.\textsuperscript{27} This stratification process perpetually prevents the recovery of dead zones because the hypoxic salt water column is naturally restricted from being re-oxygenated by the surface fresh water.\textsuperscript{28}

The burning of fossil fuels is another primary cause of dead zones. When these fuels are burned, smog-forming nitrogen oxides are released into the atmosphere and are then washed out of the sky and into the ocean when it rains.\textsuperscript{29} Rain water also disburses pollutants and sewage into rivers and streams which are deposited in the ocean and contribute to the eutrophication process.\textsuperscript{30} An estimated one third of the carbon dioxide produced by humans through the

\textsuperscript{22} See Greenhalgh & Sauer, supra note 1, at 3.
\textsuperscript{23} Eutrophication is the production of organic matter that forms the basis of aquatic food webs. In the eutrophication process, nutrients are taken up by aquatic plants (phytoplankton, benthic microalgae, epiphytes, emergent vegetation, and submergent macrophytes) to form organic carbon. Robert Livingston, EUTROPHICATION PROCESSES IN COASTAL SYSTEMS, 1 (2001).
\textsuperscript{24} See generally Creeping Dead Zones, supra note 2.
\textsuperscript{25} Id.
\textsuperscript{26} See Greenhalgh & Sauer, supra note 1, at 3.
\textsuperscript{27} Id.
\textsuperscript{28} Id.
\textsuperscript{29} See generally Biello, supra note 7.
\textsuperscript{30} Id.
burning of fossil fuels is absorbed by the ocean.\textsuperscript{31} This process is known as “ocean acidification” because the seawater becomes more acidic through lowered pH levels.\textsuperscript{32} This acidification process removes calcium carbonate from the water which is an essential element for the sustainability of coral reefs.\textsuperscript{33} High concentrations of carbon dioxide make it difficult for marine life to respire, and when combined with hypoxic waters, the marine ecosystems suffer a “double whammy.”\textsuperscript{34}

The destruction of wetlands is a further contributor to the size and number of dead zones. Wetlands function as natural “filters” to remove the excess nutrients, sediments, and pollutants from land runoff.\textsuperscript{35} These estuaries provide habitat, food, and protection to a wide variety of animals, and specifically serve as fish nurseries.\textsuperscript{36} An estimated seventy-five percent of commercial fish and shellfish are dependent on estuaries, which means wetlands play a vital role in maintaining water quality and harboring fisheries which have both commercial and recreational value.\textsuperscript{37} Unfortunately, the construction of flood control structures, dredged canals, and recreational facilities along the coasts have significantly contributed to wetland loss.\textsuperscript{38}

However, over-enrichment of nutrients from fertilizer runoff in these estuaries is the main cause

\textsuperscript{32} Id.; \textit{Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide}, Royal Society, June 30, 2005.
\textsuperscript{34} See generally MBARI Press Release, supra note 31. (hereinafter MBARI Press Release)
\textsuperscript{36} Id.
\textsuperscript{37} Id.
of wetland habitat deterioration. Without wetlands to filter the nitrogen, more nitrogen is able to disperse into the oceans which results in eutrophication and algal blooms.

Crabs, shrimp, fish, and oysters are just a few of the bottom dwelling species affected by dead zones. When oxygen levels become hypoxic, animals living in the water column experience both behavioral and physiological impairments. The low levels of oxygen disrupt the endocrine system of fish, shrimp and crabs. Marine animals in hypoxic waters cannot respire which makes it harder to find food, avoid predators, and inhibits reproduction. One study, performed by researchers at the City University of Hong Kong, showed carp fish living in hypoxic waters had lower hormone levels and smaller sexual organs than fish in normal oxygen waters. A decrease in marine life reproduction will significantly impact the global fishing industry. Shrimping and fishing industries in the Gulf of Mexico are threatened economically by the loss of marine life which sustains their business. The Gulf of Mexico is a major source of recreational and commercial fishing. The commercial fishing industry alone generates over $2.8 billion annually, and provides over 200,000 jobs to Americans. These fisheries in the Gulf provide seventy-two percent of the shrimp in the U.S., sixty-six percent of the oysters in the U.S., and fifteen percent of commercial fish in the U.S. according to a 1995 report. This adverse impact on fishing industries from the dead zone will foreseeably affect the U.S. economy

39 See Livingston, supra note 23, at 44.
41 See generally Creeping Dead Zones, supra note 2.
42 See Rabalais, supra note 9, at 177.
43 Id.; see also MBARI Press Release, supra note 31.
44 See MBARI Press Release, supra note 31.
45 Sarah Graham, Dead Zone Waters Stymie Fish Reproduction, SCIENTIFIC AMERICAN, Mar. 11, 2003.
46 See Greenhalgh & Sauer, supra note 1, at 3.
47 Id.
48 Id.
49 Id.
50 See Belefski & Norton, supra note 40, at 333.
through a reduction in jobs. Moreover, communities along the coasts, which depend on marine life as a source of food, will also suffer harmful effects from the dead zones. It is estimated in the Gulf of Mexico alone, over 212,000 metric tons of food is lost to hypoxia.

Neurotoxic shellfish poisoning is a rare but harmful consequence of algal blooms which significantly affects both marine and human health. Shellfish are contaminated by the dinoflagellate *Gymnodinium breve* which is commonly found in “red tide” algae blooms in the Gulf of Mexico. When humans ingest the poison shellfish, the neurotoxin can cause respiratory problems, gastrointestinal problems, paralysis, and even death. Marine mammals and birds generally die from ingesting the neurotoxic shellfish. To prevent this danger, various federal agencies including the National Oceanic and Atmospheric Administration (NOAA), Environmental Protection Agency (EPA), and National Science Foundation (NSF) carefully monitor these algal blooms and conduct tests to determine toxicity levels.

The harmful effects of dead zones are felt on a global level. The environment is deeply impacted when hypoxic and anoxic waters destroy marine habitats and marine life. Whenever a marine habitat is destroyed, there is an unexpected chain reaction which triggers drastic changes in the environment. These drastic changes in the environment are called “environmental cliffs” and exist where there are sudden disturbances to ecosystems. It is impossible to know in advance what the consequences will be due to the collapse of one

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51 See Greenhalgh & Sauer, supra note 1, at 3; see also Biello, supra note 7.
52 See Biello, supra note 7.
53 See Biello, supra note 7.
55 Id. at 1.
56 Id. at 1.
57 See generally Biello, supra note 7.
59 Id.
ecosystem, therefore it is crucial that the effects of dead zones be significantly reduced to prevent further destruction of marine life and habitats.\textsuperscript{60}

\textbf{IV. Major Dead Zones Of The World}

The most significant of the world’s dead zones exist in the Gulf of Mexico, the Baltic Sea, the Black Sea, and the Pacific Northwest Coast. The Baltic Sea and the Gulf of Mexico are currently two of the largest recognized dead zones on the planet. The Black Sea is one of the few dead zones in the world to have recovered due to measures taken to combat fertilizer and pollution runoff. Steps have been taken in the Gulf of Mexico and Baltic Sea to reduce the causes of dead zones, but restoration is a slow process. One of the most recently discovered dead zones exists along the Pacific Northwest Coast, and is believed to be caused by climate change and warmer water temperatures. If climate change is the cause of this new dead zone, it may suggest that the effects are not reversible and more dead zones may begin to appear globally.

\textbf{A. Gulf of Mexico}

The Gulf of Mexico is host to the second largest anthropogenic dead zone on earth.\textsuperscript{61} The dead zone exists where the Mississippi River and Atchafalaya River meet the Gulf.\textsuperscript{62} In 2002, the dead zone in the Gulf was measured at 8,484 square miles, which was double the size recorded in the 1980s.\textsuperscript{63} Current predictions for 2010 estimate the dead zone could range

\begin{thebibliography}{99}
\item Id.
\item Id.
\item See Greenhalgh & Sauer, supra note 1, at 3; Nancy N. Rabalais, Hypoxia in the Gulf of Mexico, 12 TUL. ENVTL. L.J. 321 (1999) (discussing the dimensions of Gulf of Mexico hypoxia).
\end{thebibliography}
between 6,500 and 7,800 square miles, equivalent to the size of New Jersey.64 This dead zone is most severe between the months of May and September and is affected by the circulation patterns of the Louisiana shelf and coastal currents in the Gulf.65 One of the primary causes of this dead zone is water stratification because the Louisiana coastal current prevents oxygen replenishment from the high influx of fresh water to the denser salt water below.66 Turbulent waters and strong winds from hurricanes have been known to reduce this stratification process. However hurricanes also have the adverse effect of flooding the rivers which increases nutrient and pollution runoff.67 The hypoxic waters in the Gulf extend from five meters below the surface to as deep as twenty meters.68 When the wind patterns change in the Gulf and come from the north, the hypoxic waters move closer to shore which trap crabs, shrimp, and fish along the beach.69 These conditions often result in what the locals along the coast who consume the fish and shellfish call a “massacre” of the marine life confined by the hypoxic waters.70 The harvesting of the marine life is one example of the many unforeseen consequences caused by the hypoxic waters of the dead zone.

The Mississippi River Basin is comprised of the Mississippi River, Ohio River, and Missouri River. The Basin contributes ninety percent of the freshwater inflow to the Gulf of Mexico and encompasses forty-one percent of the coterminous United States.71 The use of commercial fertilizers containing nitrogen and phosphorus in the basin increased drastically in the 1950s and

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64 Elizabeth Weise, *Gulf of Mexico Dead Zone Predicted to be the Size of New Jersey This Year*, USA TODAY, June 29, 2010.
65 See Rabalais, supra note 63, at 322.
66 See Rabalais, et. al., supra note 61.
67 See generally Creeping Dead Zones, supra note 2.
68 See Rabalais, supra note 9, at 175.
69 Id.
70 Id.
was the earliest primary cause of the dead zone in the Gulf.72 Today, ninety percent of the nitrogen flowing into the Gulf of Mexico is due to fertilizer runoff.73 More recently, fertilizer runoff into the Gulf of Mexico has increased because of planting of corn crops used for cellulosic biofuels.74 Biofuels primarily function as an alternative energy source to petroleum and may help reduce greenhouse gas emissions.75 In August 2005, Congress passed the Energy Policy Act which included a Renewable Fuel Standard (RFS) program which mandated the volume of renewable fuel required to be blended into gasoline to reach 7.5 billion gallons by 2012.76 These 7.5 billion gallons of fuel will be produced from domestically grown corn-based ethanol, which leads to an increased demand for corn crops.77 In 2007, farmers in the U.S. planted over ninety million acres of corn for biofuel and food.78 This federal mandate provides economic incentives for farmers who are able to sell their corn bushels for a higher price, and the government is able to reduce its commodity crop payment due to a stimulated market for corn.79 While biofuels have a positive effect in reducing greenhouse gas emissions (GHG), they simultaneously have an adverse effect on the dead zone in the Gulf. With the increased use of commercial fertilizers to enhance corn crop growth, excessive amounts of nitrogen are reaching the Gulf through the Mississippi River Basin.80 Scientists predict the dead zone will increase as much as thirty-four percent by 2022 if measures are not taken to reduce the nitrogen runoff into the Gulf.81

72 Id.
73 See Greenhalgh & Sauer, supra note 1, at 4.
75 Id. at 2.
77 See Marshall & Greenhalgh, supra note 74.
79 See Marshall & Greenhalgh, supra note 74, at 5.
80 See generally Biello, supra note 78.
81 Id.
On April 20, 2010, the BP Deepwater Horizon oil rig exploded in the Gulf of Mexico, leaking over 70,000 barrels of oil per day.\textsuperscript{82} Tragically, this oil spill has occurred in the area of the current dead zone, and will undoubtedly result in increased hypoxia underneath the oil covered surface waters.\textsuperscript{83} When the surface waters are coated in oil, oxygen in the atmosphere cannot be absorbed by the seawater.\textsuperscript{84} In addition, the coastal wetlands along the coast will be destroyed by the oil washing up on shore, which will prevent the natural filtration process of the wetlands and result in more fertilizer and pollutant runoff reaching the Gulf.\textsuperscript{85} The BP oil spill is particularly harmful to the dead zone in the Gulf of Mexico because of the inability of the coastal currents to replenish the oxygen levels in the water, resulting in a perpetual water stratification effect.\textsuperscript{86} Moreover, microorganisms which are released into the water to breakdown the oil exacerbate the hypoxic condition because they consume oxygen in the process.\textsuperscript{87} Scientists predict marine life living in deeper waters will be forced to migrate to shallower depths to survive which will lead to habitat compression.\textsuperscript{88} Due to the recentness of this disaster, scientists are uncertain of the extent of harm from the spill however, the dead zone is estimated to be as large as 7,800 square miles as opposed to the recorded 6,000 square miles for the last six years.\textsuperscript{89}

\textsuperscript{83} David Biello, \textit{How Will the Oil Spill Impact the Gulf’s Dead Zone?}, \textsc{Scientific American}, June 3, 2010.
\textsuperscript{84} Id.
\textsuperscript{85} Id.
\textsuperscript{86} Id.
\textsuperscript{87} Id.
\textsuperscript{88} Id.
B. Baltic Sea

The Baltic Sea is home to the largest known dead zone in the world, extending from Sweden to the Gulf of Finland in northeast Europe. The bottom waters of the Baltic Sea are completely anoxic and cannot recover mainly due to natural characteristics of the Sea. The water flow in the Baltic Sea is particularly restricted due to the narrow channels and islands around Denmark. Geographically, the Baltic Sea is very shallow with a depth of fifty-four meters, and the water mass is brackish, having only one fifth the salinity of normal ocean waters. The Baltic Sea is unique because of land uplift which occurs seasonally when the bottom areas of the Sea rise after they are no longer suspended by glacial ice. Excess nitrogen and phosphorus in the water is ultimately buried in the sediment. Land uplift perpetuates the existence of the dead zone by releasing phosphorus and nitrogen in the sea floor back into the water, causing eutrophication. This problem is exacerbated by areas known as “zero solution” where water is not exchanged by any movement through the strait. In addition to land uplift, nitrogen and phosphorus in the sediment are released back into the water through a process called “internal loading” which is triggered by oxygen depletion in the water. This “internal loading” cycle prevents recovery of the dead zone, also perpetuating the problem.

The Baltic Sea is a primary source of fishing, shipping and recreation and there are currently over eighty-five million people living in the fourteen countries which comprise its drainage

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90 Fran Weaver, Baltic Sea Dead zone Spreading, HELSINKI TIMES, Sept 1, 2008.
92 See generally Creeping Dead Zones, supra note 2.
94 See Hakanson & Bryhn, supra note 91, at 4.
95 See generally Biello, supra note 7.
96 See Hakanson & Bryhn, supra note 91, at 53-54.
97 See Lepparanta & Myrberg, supra note 93, at 310.
98 Id. at 312.
99 See generally Biello, supra note 7.
basin.\textsuperscript{100} In 1986, when the hypoxic conditions were most severe, the Norway lobster fishery collapsed which forced the Danish government to draft an Action Plan to reduce wastewater emissions and fertilizer use.\textsuperscript{101} Finland, as well as many other countries in the Basin are primarily agrarian societies.\textsuperscript{102} Rural homes along the Basin are not connected to sewage systems, so fertilizer nutrients and untreated sewage are disbursed freely into the Baltic Sea.\textsuperscript{103} Agriculture alone contributes sixty percent of the nitrogen and fifty percent of the phosphorus nutrients entering the Baltic Sea from the drainage basin.\textsuperscript{104} Moreover, the Gulf of Finland which flows into the Baltic, receives a majority of its untreated sewage runoff from St. Petersburg, Russia where 4.7 million people reside.\textsuperscript{105} Thus, sewage and fertilizer runoff produce large algae blooms which thrive on nutrient enriched water and render the water hypoxic.\textsuperscript{106}

The Baltic Sea is one of the most heavily trafficked marine areas in the world.\textsuperscript{107} Shipping accidents occur frequently in the Baltic Sea due to the narrow straits, shallow waters, and extreme weather conditions.\textsuperscript{108} The discharge of sewage from the ships has greatly contributed to eutrophication in the Baltic Sea.\textsuperscript{109} Moreover, the burning of fossil fuels, specifically gasoline and diesel, releases nitrogen oxides into the atmosphere.\textsuperscript{110} The nitrogen oxides are then washed out of the sky and into the Sea through rainfall, causing the water to become more acidic.\textsuperscript{111}

\textsuperscript{100}See Lepparanta & Myrberg, supra note 93, at xi, 4.
\textsuperscript{102}See Weaver, supra note 90.
\textsuperscript{103}Id.
\textsuperscript{104}See Lepparanta & Myrberg, supra note 93, at 310.
\textsuperscript{105}See Weaver, supra note 90.
\textsuperscript{106}Id.
\textsuperscript{107}Id.; Summary of the Four Main Segments of the HELCOM Baltic Sea Action Plan: detailing goals, objectives, and actions, Helsinki Commission website http://www.helcom.fi/BSAP/ActionPlan/en_GB/SegmentSummary/.
\textsuperscript{108}See HELCOM Summary, supra note 107.
\textsuperscript{109}Id.
\textsuperscript{110}Id.
\textsuperscript{111}See generally Biello, supra note 7.
Natural and man-made causes collectively contribute to the dead zone in the Baltic Sea, however the unique geographical characteristics of the Sea have created this permanent dead zone which cannot recover.

C. Black Sea

The Black Sea is one of the few dead zones in the world to have partially recovered – although not from actions intended to solve the problem. The Black Sea contains the world’s largest permanent anoxic basin which exists below a depth of 150 meters. The deep basin in the Black Sea reaches a maximum depth of 2200 meters which contributes to the stratification between the surface layers and deep waters. Fresh water leaves the Black Sea through the Bosporus Strait, and the salt water enters through the Mediterranean Sea and Sea of Marmara. Due to the landlocked location of the Black Sea, the anoxic basin is created naturally from restricted water flow much like the Baltic Sea. Over 160 million people live in the catchment area of the Black Sea, six million of which live along the coastal areas of the Sea. Nearly twenty-two countries in Europe and Asia Minor make up the Black Sea Basin.

The northwestern portion of the Black Sea experiences the highest levels of eutrophication due to the Danube River inflow. A majority of the nutrient inflow is due to fertilizer runoff from the surrounding agrarian countries. The countries of the Soviet Union relied heavily on nitrogen and phosphorus enriched fertilizers which dispersed into the Black Sea and contributed

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112 See generally Creeping Dead Zones, supra note 2.
115 See generally Biello, supra note 7.
117 Id.
118 Id.
119 See generally Biello, supra note 7.
to large algae blooms.\textsuperscript{120} In the early 1980s, the dead zone in the Black Sea reached a size of 20,000 square kilometers, which was the largest recorded dead zone at that time.\textsuperscript{121}

In the mid to late 1980s, the Soviet Union went through political and economic upheaval.\textsuperscript{122} The economy completely collapsed and fertilizer became too expensive for farmers to purchase, so the nitrogen runoff into the Black Sea was decreased by half.\textsuperscript{123} In addition, phosphorus applications were cut by sixty percent.\textsuperscript{124} This drastic reduction in the amount of nitrogen and phosphorus reaching the Black Sea allowed the dead zone to recover and enabled the natural reestablishment of coastal wetlands to occur.\textsuperscript{125} In 1996, the hypoxic areas of the dead zone disappeared for the first time in twenty-three years, demonstrating the effects of dead zones can indeed be reversed.\textsuperscript{126} However, such abatement measures may take a decade or more before the dead zone begins to show any improvement.\textsuperscript{127}

\section*{D. Pacific Northwest Coast}

This dead zone was first recognized in 2002 and is believed to be caused by changes in wind patterns and warmer water temperatures due to climate change.\textsuperscript{128} The National Science Foundation found that the warmer surface waters are perpetuating the stratification effect by inhibiting oxygen penetration to the deeper waters.\textsuperscript{129} The hypoxic waters off the Oregon coast have occurred every summer since 2002, and were the worst in 2006 when the waters were

\begin{flushleft}
\textsuperscript{120} \textit{Id.}
\textsuperscript{121} See Larsen, \textit{supra} note 101.
\textsuperscript{122} \textit{Id.}
\textsuperscript{123} \textit{Id.}
\textsuperscript{124} \textit{Id.}
\textsuperscript{125} \textit{Id.}
\textsuperscript{126} \textit{Id.}
\textsuperscript{128} \textit{Id.}
\textsuperscript{129} \textit{Id.}
\end{flushleft}
completely anoxic. Unfortunately, the effects of climate change cannot be immediately reversed, so there is a high probability more dead zones like the one off the Oregon coast will begin to appear.

The destruction of wetlands is one of the primary concerns for the Pacific Northwest coast. Currently, Canada does not have a wetland protection program enacted like the Clean Water Act in the United States. The Pacific Northwest alone contains twenty-three estuarine systems which receive freshwater inflow. These wetlands and riparian buffers are vital to the filtration of nutrients, silt, pathogens, and toxic contaminants which normally disperse into fresh water rivers, but are prevented from reaching the ocean. In addition, land uplift in the Pacific Northwest from tectonic plate movement also contributes to the dead zone. When the ocean floor shifts, the nutrients in the sediment are released back into the water which instigates eutrophication. Shifts in wind patterns due to climate change further exacerbate this effect through upwelling. Researchers examined records dating back to the 1950s and have not found any evidence of hypoxic conditions existing along the Pacific Northwest Coast prior to 2002 when the Oregon dead zone was identified. This means it is more probable the Oregon dead zone is a phenomenon caused by long term climate change that cannot be reversed.

\[ 130 \text{Id.} \]
\[ 132 \text{Id.} \]
\[ 133 \text{National Oceanic and Atmospheric Administration Estuarine Eutrophication Survey, Vol. 5: Pacific Coast Region, Apr. 1998.} \]
\[ 134 \text{See Schindler & Vallentyne, supra note 131.} \]
\[ 135 \text{See generally Eutrophication Survey, supra note 133, at 8.} \]
\[ 136 \text{Id.} \]
\[ 137 \text{Kim Murphy, Pacific Ocean Dead Zone in Northwest May Be Irreversible, L.A. TIMES, Oct. 9, 2009.} \]
\[ 138 \text{Id.} \]
As will be discussed in part V, while strategies are being implemented in the Gulf of Mexico, Baltic Sea and Black Sea to reduce the size of dead zones, the dead zone identified off the coast of Oregon in the Pacific Northwest may not be reversible.139

V. Current Strategies Implemented to Combat Growing Dead Zones

A. Gulf of Mexico

Several programs have been implemented in to reduce the size of the dead zone in the Gulf of Mexico. The Clean Water Act (CWA), passed by Congress in 1972, was one of the first programs to assess the impacts on water quality from pollution.140 Under the CWA, pollutants are categorized into point141 and nonpoint142 sources.143 Point and nonpoint sources are recognized as major contributors of eutrophication in the Mississippi River.144 Section 319 of the CWA requires states within the Mississippi River Basin to assess water quality impacts from nonpoint source pollution and to develop management programs.145 Many states have implemented programs that combine state, local, and federal resources to address nonpoint source pollution.146 Section 402 of the CWA requires a permit for any discharge of point source pollutants to ensure compliance with regulations and monitor the volume and character of the

139Id.
140 See Belefski & Norton, supra 40, at 348.
141 Point source pollution originates from a single identifiable source, and includes discrete conveyances such as pipes or manmade ditches that discharge pollutants into waters of the U.S. This includes discharges from municipal sewage plants and industrial facilities as well as storm drainage from large urban areas, some types of ships, tank trucks, and offshore oil platforms. EPA Clean Water Act Glossary available at www.epa.gov/waterrain/cwa/glossary.htm.
142 Nonpoint source pollution does not originate from a single source. Nonpoint source pollution comes from rainfall or snowmelt moving over and through the ground. As the runoff moves it picks up and carries away natural and manmade pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even underground drinking water. See Id.
144 See Belefski & Norton, supra note 40, at 348.
146 See Belefski & Norton, supra note 40, at 349.
pollutants. Failure to comply with the permit conditions set forth in a permit issued under the CWA results in civil or criminal penalties. However, the CWA exempts permits for discharges composed entirely of agricultural irrigation runoff, which is categorized as a nonpoint source of pollution.

Due to the fact many U.S. waters were still degraded more than twenty years after the enactment of the CWA in 1998, President Bill Clinton adopted the Clean Water Action Plan (CWAP). The CWAP contains specific strategies to deal with the hypoxia issue in the Gulf and prevent nutrient over-enrichment. The CWA failed to reduce nonpoint pollution runoff from farms, which was a primary factor in the formation of the Gulf’s dead zone. Under the CWAP, farmers and landowners are given incentives to adopt practices to protect water quality. President Clinton proposed a $568 million budget for the CWAP to protect the public health and restore contaminated waterways. The CWAP initiated over 100 new action plans with a program specifically addressing nitrogen and phosphorus runoff by the year 2000, and the goal of implementing enforcement standards. Moreover, there is a focus on restoring wetlands by fifty percent, and creating two million miles of buffer zones next to waterways to reduce polluted runoff. The CWAP appears to have remedied some of the problems which were not addressed by the CWA twenty years prior, and the CWAP encouraged the Department of Agriculture to
announce a new agreement to promote buffer strips and conservation measures on agricultural lands.\textsuperscript{155}

The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force was created by the Environmental Protection Agency (EPA) in fall 1997 to assess the condition of the hypoxic waters in the Gulf of Mexico.\textsuperscript{156} This Task Force studied the causes and effects of nutrient runoff in the Mississippi River Basin, and established a new Action Plan in January 2001 to combat hypoxia specifically.\textsuperscript{157} The Action Plan had three primary goals: (1) Coastal Goal, (2) Within Basin Goal, and (3) Quality of Life Goal.\textsuperscript{158} The “Coastal Goal” planned to reduce the size of the dead zone to less than 5,000 kilometers squared by 2015 through a reduction in nitrogen runoff.\textsuperscript{159} The report estimated a twenty to thirty percent reduction in nitrogen runoff would allow the dead zone to begin to recover by slowly increasing oxygen levels.\textsuperscript{160} The Action Plan suggested reducing nitrogen loads into the Gulf by improving farming practices, restoring wetlands, establishing riparian buffers, and placing tighter controls on wastewater treatment plants.\textsuperscript{161} The “Within Basin Goal” attempted to restore and protect the waters within the Mississippi River Basin through a reduction in nutrients and sediments, while the “Quality of Life Goal” sought to improve the economic conditions of the Mississippi River Basin through agriculture, fisheries, and recreation.\textsuperscript{162} The success of this Action Plan has yet to be assessed, but it appears to focus on reducing agricultural runoff which will mitigate the effects of the dead zone and hopefully achieve their goal by 2015.

\textsuperscript{155} Id.
\textsuperscript{156} See Greenhalgh & Sauer, supra note 1, at 4.
\textsuperscript{157} Id.
\textsuperscript{158} Id.
\textsuperscript{159} Id.
\textsuperscript{160} Id.
\textsuperscript{161} Id.
\textsuperscript{162} Id.
In October 1998, the U.S. Congress passed the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) to assess the characteristics, causes, and effects of hypoxia in the Gulf.\(^{163}\) HABHRCA was proposed to formulate alternative ways to reduce, mitigate and control harmful algal blooms in the Gulf, and examine the societal and economic impacts of those alternatives.\(^{164}\) Under the Act, the President was required to submit a plan for controlling hypoxia in the Gulf of Mexico by March 30, 2000.\(^{165}\) In 2004, the National Oceanic and Atmospheric Administration (NOAA) initiated a forecast operation for harmful algae blooms (HABs) in the Gulf through satellite imaging, wind data and transport models.\(^{166}\) The NOAA extensively studied the dead zone in the Gulf and has developed the capability to forecast the size of the dead zone each year based on the HABs.\(^{167}\) The HABHRCA was reauthorized in 2004 as the Harmful Algal Bloom and Hypoxia Amendments Act which required five reports to assess and recommend research programs on HABs.\(^{168}\) The HABHRCA has made considerable progress in assessing long term and short term effects of hypoxia, and has identified the research need to assess the impacts of the dead zone on commercially important species.\(^{169}\)

The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) has developed the Mississippi River Basin Healthy Watersheds Initiative (MRBI) to implement conservation practices in selected watersheds.\(^{170}\) MRBI, announced in September 2009 under President Obama’s administration, focuses specifically on avoiding,


\(^{164}\) Id.

\(^{165}\) *See Belefski & Norton, supra* note 40, at 344.

\(^{166}\) *Harmful Algae Blooms and Hypoxia in the Gulf of Mexico*, NOAA website http://www.cop.noaa.gov/stressors/extremeevents/hab/habhrca/GoMEX-fact_04-08.pdf.

\(^{167}\) Id.


controlling, and trapping nutrient runoff, improving wildlife habitats, and maintaining agricultural productivity.\textsuperscript{171} The twelve participating states in the initiative include Arkansas, Kentucky, Illinois, Indiana, Iowa, Louisiana, Minnesota, Mississippi, Missouri, Ohio, Tennessee, and Wisconsin, all of which contribute to nutrient loading in the Gulf of Mexico.\textsuperscript{172} MRBI will provide around $320 million dollars over the next four years to these projects, and will focus on implementing screening and ranking systems for agricultural producers in regards to water quality concerns.\textsuperscript{173} The USDA will work with farmers to encourage new land stewardship practices like conservation tillage and nutrient management.\textsuperscript{174} NRCS agreed to contribute eighty million dollars between 2009 and 2012 through the Cooperative Conservation Partnership Initiative (CCPI), Conservation Innovation Grants, and the Wetlands Reserve Enhancement Program to assist projects in the participating states.\textsuperscript{175} If these programs are successful, the initiative will reduce the nutrient footprint on the primary watersheds and reduce the environmental impact on the dead zone through more efficient uses of nutrients in crop production.\textsuperscript{176}

\textbf{B. Baltic Sea}

The Helsinki Commission, also known as HELCOM, is responsible for the protection of the Baltic Sea.\textsuperscript{177} HELCOM introduced the Baltic Sea Action Plan in 2005 hopes of restoring the marine life in the Baltic Sea by 2021.\textsuperscript{178} This Action Plan was targeted to combat eutrophication, curb inputs of hazardous substances, ensure maritime safety and response capacity for accidents

\begin{footnotes}
\item[171] Id.
\item[172] Id.
\item[173] Id.
\item[174] Id.
\item[175] Id.
\item[176] Id.
\end{footnotes}
at sea, and halting habitat destruction.\textsuperscript{179} The purpose of the Plan is to include all major stakeholders in the area who can implement the changes proposed through government, private sectors, and industry.\textsuperscript{180} In March 2007 at the Second Helsinki Commission Stakeholder Conference, the Baltic Sea Action Plan was subject to an extensive review of the actions proposed in the Plan, and many changes were made.\textsuperscript{181} In November 2007, the Plan was officially adopted at the HELCOM Ministerial Meeting in Krakow, Poland.\textsuperscript{182} In order to achieve the “clear water” objective in the Baltic Sea Action Plan, it is estimated that annual phosphorus inflow into the Baltic would have to be reduced by 15,000 tons, and nitrogen inflow would have to be reduced by 135,000 tons.\textsuperscript{183} In order to achieve these results, the Plan detailed the development of national programs to achieve the reductions by 2010, called for improvement of wastewater treatment filtering systems, and sought to alter manure and fertilization practices.\textsuperscript{184} The Baltic Sea Action Plan also targets individual pollution “hot spots,” like major animal farms, where more stringent fertilizer requirements will be enacted.\textsuperscript{185} In recent years, the countries in the Baltic Sea basin have begun to use their satellite surveillance system to detect illegal discharges through the HELCOM Automatic Identification System, which facilitates the exchange of information between ships and shore stations.\textsuperscript{186} The Baltic Sea Action Plan incorporates both innovative technology and the latest scientific information to combat the problem of the dead zone, and has already begun to show promising results.\textsuperscript{187}

\textsuperscript{179} Id.  
\textsuperscript{180} Id.  
\textsuperscript{181} Id.  
\textsuperscript{182} Id.  
\textsuperscript{183} See HELCOM Summary, supra note 107.  
\textsuperscript{184} Id.  
\textsuperscript{185} Id.  
\textsuperscript{186} Id.  
\textsuperscript{187} Id.
C. Black Sea

In 1992, the United Nations held the Convention on the Protection of the Black Sea Against Pollution in Bucharest. The purpose of this Convention was to protect the marine environment of the Black Sea through preventing, controlling, and reducing pollution entering the Black Sea. The countries involved in this Convention include Bulgaria, Georgia, Romania, Russian Federation, Turkey and Ukraine. In 1996, the Convention enacted the Strategic Action Plan for the Rehabilitation and Protection of the Black Sea to encourage the countries in the Basin to reduce land based sources of pollution, reduce illegal discharges from marine vessels, and implement waste management policies. This Action Plan was replaced in 2009 with the Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea. This revised Action Plan sought to resolve the trans-boundary environmental problems including eutrophication, changes in marine living resources, chemical pollution, habitat changes, and alien species introduction. Under this 2009 Plan, three primary environmental management approaches were proposed such as integrated coastal zone management, the ecosystem approach, and the integrated river basin management. Integrated coastal zone management involves the collection of information by stakeholder countries to find a balance between environmental, economic, social and cultural objectives. The ecosystem approach focuses on management of land and water resources to promote sustainability.

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189 Id.
190 Id.
191 Id.
192 Id.
193 Id.
194 Id.
195 Id.
196 Id.
Lastly, the integrated river basin management approach primarily addresses the quality of rivers, lakes and coastal waters and attempts to alleviate the pressures on these water sources.\textsuperscript{197}

The International Commission for the Protection of the Danube River (ICPDR), established in 1998 by the eleven Danube countries, aimed to limit nutrient discharge into the Black Sea through the river basins.\textsuperscript{198} This program specifically focuses on “adaptive environmental assessment and management” which offers a practical means on integrating knowledge toward long term management decisions.\textsuperscript{199} ICPDR was aided by the Global Environment Facility (GEF), United Nations Development Programme (UNDP), and the European Commission, and has successfully improved the water quality and ecosystems in the Black Sea’s northwest shelf.\textsuperscript{200} Moreover, nitrogen and phosphorus emissions have decreased significantly over the last fifteen years partly due to ICPDR efforts.\textsuperscript{201}

\textbf{VI. Proposed Actions to Address the Causes of Dead Zones}

As discussed in part V, various strategies have been implemented internationally to attempt to reduce the impact of pollutants on dead zones. Many of these initiatives focus on research and long term goals which will take years, if not decades to produce results. Unfortunately, dead zones continue to increase in size and number despite these efforts, signaling a stronger need for drastic action.

Agricultural and pollutant runoff has been determined to be the primary cause of dead zones around the world. Only the MRBI, CWAP, and Baltic Sea Action Plan programs appear to focus

\begin{flushleft}
\textsuperscript{197} Id.
\textsuperscript{199} Id.
\textsuperscript{201} Id.
\end{flushleft}
primarily on preventing nonpoint source pollution from agricultural runoff. The Black Sea dead zone is one of the few in the world to have partially recovered once nitrogen and phosphorus inflow was reduced by half. This fact alone should demonstrate a greater need to focus on agriculture runoff in order to reduce the size of the dead zone and prevent future dead zones by implementing preventative strategies. There are a number of proposed actions to accomplish these goals including nutrient trading, enacting a nitrogen fertilizer tax, providing subsidies to farmers for altering their tillage practices, and genetically engineering low nitrogen consuming corn plants.

Nutrient trading is a market approach which allows agricultural cropping enterprises (nonpoint source pollutant) who reduce their nutrient contributions, to sell reduction credits to waste water treatment plants (point source pollutant).202 Essentially nutrient discharge is “capped” and the waste water treatment plants are prevented from discharging more nutrients than permitted.203 Nutrient trading is based on individual waste water treatment plant compliance costs based on size, scale, age, and overall efficiency of the plant.204 Basically, nonpoint source pollutants are encouraged to trade with point source pollutants in a joint effort to reduce nutrient loads.205 Currently, agricultural farmers are not limited by a “cap,” meaning they are not penalized like the waste water treatment plants for excess runoff, but can receive payments if they choose to reduce their nutrient runoff.206

However, nutrient trading may not be the best possible solution. Agricultural farmers are left “uncapped” which does not alleviate the threat to the dead zones from fertilizer runoff. Although waste water treatment plants contribute to part of the problem in the Gulf of Mexico, nitrogen

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202 See Greenhalgh & Sauer, supra note 1, at 9.
203 Id.
204 Id.
205 Id.
206 Id.
fertilizers are determined to be the primary contributor to the dead zone. The Black Sea has proven by example that a substantial reduction in the amount of nitrogen and phosphorus runoff from fertilizers enabled the dead zone to recover. If the United States cannot curb fertilizer runoff into the Gulf, it is unlikely the dead zone will be able to recover. Nutrient trading appears to be only a minor solution to the problem which is highly unlikely to be implemented given the extensive amount of time it take Congress to enact such legislation.

Placing a tax on nitrogen fertilizer may help limit the use of excessive amounts of fertilizer and reduce fertilizer runoff. 207 Unfortunately, taxes on nitrogen fertilizers are likely to have a negative economic impact on agricultural farmers. The overall U.S. agricultural income will foreseeably be significantly reduced, and farmers will be forced to raise the price of their crops to counteract the tax.208 Moreover, farmers will plant fewer acres of crops which will lead to a decreased farm income. While a tax on nitrogen fertilizers may reduce the amount of nitrogen runoff into the Gulf, the economic consequences on the farmers could far outweigh the results.

Tillage subsidies are used to encourage farmers to convert from conventional tillage practices to conservation tillage practices.209 Conservation tillage210 involves strategies and techniques to improve water conservation and reduce soil erosion.211 In one study, a subsidy payment of twenty-five dollars per acre was given to farmers for changing from conventional tillage to

207 Id. at 11.
208 Id. at 12.
209 Id.
210 Conservation tillage is any of several farming methods that provide for seed germination, plant growth, and weed control yet maintain effective ground cover throughout the year and disturb the soil as little as possible. The aim is to reduce soil loss and energy use while maintaining crop yields and quality. No-till is the most restrictive (soil-conserving) form of conservation tillage. Other practices include ridge-till, strip-till, and mulch-till. USDA Glossary, USDA National Agricultural Library available at http://ageclass.nal.usda.gov/mtwdk.exe?k=glossary&l=60&w=1248&n=1&s=5&t=2
conservation tillage practices.\textsuperscript{212} This study estimated a twenty-five dollar per acre subsidy would provide sufficient incentive to farmers to switch to conservation tillage practices.\textsuperscript{213}

The tillage subsidies approach appears to be a viable solution to the dead zone problem because it directly addresses the issue of nitrogen runoff. By providing an economic incentive to switch to tillage practices which conserve water and prevent runoff, it is more likely farmers will take action. Money is a powerful motivator, hence subsidies for farmers may be the best possible solution to combat nutrient loading into the Gulf.

With the recent federal mandates for increases in biofuels, corn crops appear to be a leading concern for the dead zones, particularly in the Gulf of Mexico. One possible solution involves manufacturing genetically engineered strains of corn plants which absorb less nitrogen from the soil.\textsuperscript{214} At the Okayama University in Japan, scientists engineered a strain of \textit{Arabidopsis} plants which contained more carbon, more amino acids, and thirty percent more nitrogen.\textsuperscript{215} These genetically engineered plants were able to grow in soil with one tenth the amount of nitrogen contained in commercial fertilizers.\textsuperscript{216} It is foreseeable that large acres of crops which require less nitrogen will help alleviate the excessive use of fertilizers, and thus reduce the amount of nitrogen runoff into the Gulf. This solution is still in the early stages of research and development, so the potential negative effect of replacing natural crops with genetically engineered strands remains undiscovered. It is also a possibility that genetically manufactured crops may have harmful effects on humans, or on the natural crop yields, and these uncertainties create many unanswered questions. Furthermore the cost of manufacturing acres of these

\textsuperscript{212} See Greenhalgh & Sauer, supra note 1, at 11.
\textsuperscript{213} Id.
\textsuperscript{215} Id.
\textsuperscript{216} Id.
genetically engineered strands of crops may be so expensive that this solution is not even a possibility.

VII. Conclusion

Dead zones pose a threat to oceans and ecosystems worldwide. Although steps have been taken to combat the contributing factors to the dead zones, it does not appear to be enough because the dead zones are not getting smaller. Major steps must be taken internationally to reduce the amount of fertilizer runoff into the ocean if there is any hope of recovery for these dead zones. The Black Sea dead zone only recovered when the cost of fertilizer was too expensive for farmers to buy, not because of steps taken to reduce the size of the dead zone. Fertilizer and pollution runoff are both anthropogenic causes, meaning humans alone have the ability to reduce or eliminate these causes.

Although many causes of the dead zones are naturally occurring factors, the newest threat to dead zones is climate change which does not have an immediate or even near-term solution. It is essential for the world to work together to reduce the human impact on the environment, and raise awareness of the threat posed by dead zones. If we do not revolutionize the agricultural industry, dead zones will inevitably continue to grow in size and number, and the harmful effects will be felt globally. The oceans are the elemental source of life on our planet, and if we fail to protect this valuable resource, we are failing to protect ourselves.