Reviving the Dead Zone

Solutions to Benefit Both Gulf Coast Fishers and Midwest Farmers

Union of Concerned Scientists

On the surface, nothing seems amiss in the waters of the Gulf of Mexico, just off the Louisiana coastline. Deep below, however, an invisible phenomenon threatens aquatic life forms for months on end, year after year.

For more than 30 years, scientists have investigated an area of deep water in the Gulf known as a "dead zone," which contains so little oxygen that fish and other marine life flee from it or die (Hazen et al. 2009). In the summer of 2017, it swelled to the size of New Jersey. The size of this area experiencing often fatally low levels of oxygen—what scientists call hypoxia—varies depending upon spring rains and snow melt. These carry large quantities of excess soil nutrients, largely nitrogen, down the Mississippi and Atchafalaya rivers to the Gulf. There, this polluted water sets off a chain reaction of ecological and economic consequences straining the resilience of diverse fishing operations and local communities that depend upon a healthy Gulf for their livelihoods.

EXCESS NITROGEN FUELS THE DEAD ZONE

Most of the nitrogen that contributes to the dead zone—between 60 and 80 percent—originates on farms and livestock operations in the Midwest, largely in the form of synthetic fertilizers that run off fields of corn and other crops. The significant expansion of agricultural production in some parts of the Midwest over the last many decades (Fausti 2015; Lin and Huang 2019) adds to this concern. The excess nitrogen in rivers can cause algae overgrowth and deplete the oxygen supply available to healthy marine life, creating vast dead zones that make it harder for the region's fishers to make a living. The challenge of the dead zone is made worse by other closely intertwined environmental stressors. Climate change is increasing the frequency of heavy rains and floods in the Midwest, which could wash even more nitrogen off farms and into rivers feeding the Gulf (Altieri and Gedan 2015). Ocean temperature changes are expected to exacerbate Gulf pollution effects, which will make shrinking the dead zone even more challenging in the years ahead (Laurent et al. 2018; Reidmiller et al. 2018). What is more, oil drilling in the Gulf of Mexico and the potential for oil spills—such as the 2010 British Petroleum Deepwater Horizon disaster—threaten the Gulf fishing industry as long as our economy stubbornly relies on fossil fuels.

> ***Climate change is increasing the frequency of heavy rains and floods in the Midwest, which could wash even more nitrogen off farms and into rivers feeding the Gulf.***

With all these challenges bearing down on the Gulf and the people who fish in it, straightforward solutions are needed. Reducing nitrogen losses from farms is such a solution—with the added bonus of many co-benefits for farmers and rural communities upstream—that could head off much more serious damage to Gulf ecosystems and fishing industries in the future. While many studies have estimated how much it would cost to reduce nitrogen losses from Midwest farms in order to meaningfully shrink the dead zone (Kling et al. 2014; Rabotyagov et al. 2014a), the potential economic *benefits* of such action have not yet been quantified. Gulf fisheries and marine habitat are the foundation for fishing and coastal industries. These industries in turn are important economic engines for the region. In 2016 alone, commercial fishing industries generated between $17 billion and $57 billion in economic impacts and 200,000 jobs for the region (NMFS 2016). Reducing nitrogen losses from farms could generate a large return on investment through healthier, more productive fisheries in the Gulf.

REDUCING NITROGEN FOR THE BENEFIT OF FARMERS AND FISHERS ALIKE

Fortunately, there are already ways to make this return on investment a reality. Farmers and scientists have developed a suite of agricultural practices that reduce synthetic nitrogen fertilizer use and keep what is applied to fields out of

Cover image: Billy Metcalf Photography/Creative Commons/Flickr waterways. The resulting soils contain more living organic matter and are kept covered year-round to resist erosion and hold more water and nutrients. These practices can simultaneously reduce farmers' costs and make farmland more resilient to floods and droughts, while improving the long-term fertility of soil (Basche 2017; Basche and DeLonge 2019; Hunt, Hill, and Leibman 2019; Mulik 2017; Myers, Weber, and Tellatin 2019; Stillerman and DeLonge 2019). Thus, these two important food production and economic forces in our country—the Midwest farming industry and the Gulf Coast fishing industry—can jointly benefit from one set of practices.

To show how improved agricultural practices in the Midwest can offer economic benefits to the Gulf fishing industry, we used publicly available data to estimate how much avoidable nitrogen pollution has made its way from farm fields and into the two main rivers that feed the Gulf of Mexico. We next estimated in economic terms the damage that nitrogen pollution from farms, which fuels the dead zone, causes to the ecosystem services that fisheries and marine habitat provide for the Gulf of Mexico. We further explored the value of the damage costs that could be averted if nitrogen pollution and the dead zone were reduced through changes in agricultural practices upstream. Our analysis found that on average the equivalent of 3,100 standard-sized shipping containers per year of excess nitrogen has washed off Midwest cropland into the Mississippi and Atchafalaya rivers, and ultimately into the Gulf of Mexico. This nitrogen has contributed up to $2.4 billion in damages to ecosystem services generated by fisheries and marine habitat every year since 1980. We also found that significant economic benefits could be realized by reducing these damages through changes in agriculture upstream.

These benefits cannot be realized without policy support. We recommend policy actions that can help Gulf Coast fishing industries and communities while supporting a thriving, sustainable agricultural economy in the Midwest through science-based solutions that provide farmers with tools to build healthy, living soil.

Healthy Fisheries Are Economically Important to Diverse Gulf Coast Communities

Commercial fisheries, recreational fishing, and coastal tourism along the Gulf Coast play an important role in the region's economy. Gulf of Mexico fisheries have the second highest commercial landings—the quantity of fish caught and unloaded on shore—in the United States, just behind Alaska (NMFS 2018). In 2016, commercial fishing along the Gulf Coast generated at least $17 billion in economic impacts (Box 1, p. 4) and nearly 200,000 jobs (NMFS 2016). Recreational fishing together with coastal tourism along the Gulf Coast (which includes non-fishing recreational boating excursions) generated an additional $57 billion in economic impacts in sales and nearly 500,000 jobs in 2016 (Kosaka and Steinback 2018; NMFS 2018).[1]

Grant Heilman Photography/Alamy Stock Photo

Midwestern farmers rely heavily on nitrogen fertilizer, much of which escapes and flows downstream every year. While pairing fertilizer application with conservation tillage (as shown here) can help, US agriculture must do much more overall to reduce applications of nitrogen and keep more of it in the soil.

Yet some reporting indicates that commercial fish landings have declined in the Gulf (Karnauskas et al. 2017), and economic impact data show that commercial and recreational fishing industries in the Gulf have experienced little growth over the past decade (Figure 1, p. 5; Figure 2, p. 6). Additional challenges to the commercial fishing industries in the Gulf Coast region stem from both human-caused and environmental stressors (Chen 2017; Johnson 2019), such as competition from imported seafood (Karnauskas et al. 2017). While imports are affected by a variety of drivers, cleaning up the dead zone could make the region's fishing operations more competitive and present potential economic benefits.

The recreational fishing industry is also put at risk by the dead zone, as some tourists may be turned off by the thought of a "dead" ocean ruining a fishing trip, even if those concerns may be overstated or misunderstood (Felsher 2013). Consequently, reducing nitrogen loadings and hypoxia in the Gulf could be a way to boost the economic impact of both commercial and recreational fishing industries (see Box 1), bringing additional jobs and tax revenue to the region and making the commercial industry more competitive against imports.

The shrimp industry—which is particularly vulnerable to the formation of the dead zone—is an important economic and cultural feature of life along the Gulf Coast. In 2016, the total value of shrimp caught in the Gulf was estimated at $412 million, and shrimp is arguably the most valuable fishery in the region, bringing in nearly half the revenue of the top 10 commercial fishery catches in that year (NMFS 2018). Commercial shrimp operations in the Gulf have caught nearly 200 million pounds of shrimp every year since the late 1990s. However, annual total catch has been decreasing steadily over this time period, partly due to increased pressure from inexpensive imported shrimp but also due to other human and environmental stressors (Tabarestani, Keithly, and Marzoughi-Ardakani 2017; Asche et al. 2012).

These challenges have made it increasingly difficult for Gulf shrimpers to remain profitable, and many are going out of business (Box 2, p. 7). In Texas, two-thirds of shrimper licenses have been repurchased by the state since the mid-1990s, and the number of shrimp boats going farther offshore in search of a viable catch has declined by one-fourth since 2010 (Subramanian 2018). Our analysis of commercial fishing and shrimping licenses issued by the Louisiana Department of Fish and Wildlife indicates a significant decline over a similar time period (LDWF 2019; see Appendix 1, online at www.ucsusa.org/resources/reviving-dead-zone).

From Big Rivers to Open Oceans: Excess Nitrogen Causes Great Harm

Nitrogen occurs naturally in waterways and is essential to healthy aquatic ecosystems (Gruber and Galloway 2008). However, large infusions of excess nitrogen from agriculture runoff alter an aquatic system's natural ecological balance and harms various species. In particular, excess nitrogen causes eutrophication—in which nutrient-rich waters cause excessive

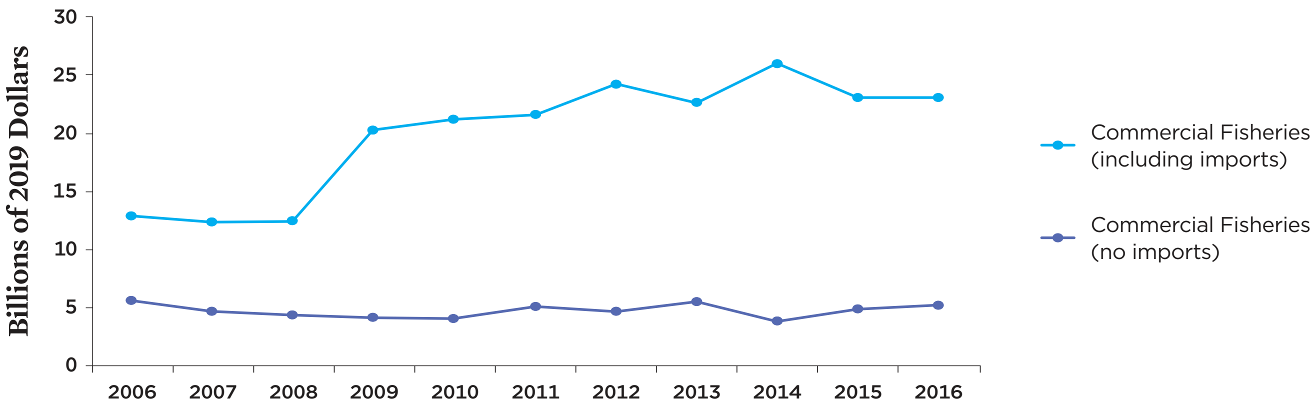
BOX 1.

From Sea to Plate: Economic Ripple Effects of the Gulf Fishing Industry

A healthy Gulf ecosystem benefits many people, beyond just those who fish. Economic value generated by commercial fishing accrues to many other people and businesses in the Gulf region. Commercial fishers buy fuel, gear, and other supplies, and then they sell their catch to various buyers: wholesalers, seafood processors, restaurants, and retail stores. These transactions trigger additional economic activity, resulting in a wide network of business opportunities and jobs for local residents. The wages and income generated from these businesses multiply throughout the Gulf economy, as seafood restaurant owners and workers, for example, spend their paychecks on goods and services, and restaurants purchase equipment and supplies from other businesses in the region. Together, the economic transactions that originate from commercial fisheries sales generate direct, indirect, and induced economic impacts, illustrated in Figure 1.

Economic impacts from recreational fishing and coastal tourism flow through the region in a similar way. For-hire and private boating operations, as well as shore-fishing operations, purchase tackle and fuel from other businesses, which provides jobs and wages for residents. When tourists pay boat and shore-fishing operators for their services, they spend their income on rent, food, and other goods and services. Again, this spending ripples through the economy. The combined economic impacts (direct, indirect, and induced) of the recreational fishing industry are illustrated in Figure 2.

FIGURE 1. Total Economic Impacts of Gulf Coast Commercial Fishing Industries, with and without Seafood Imports, 2006–2016



Imported seafood is responsible for an increasing amount of the economic impact of commercial fishing industries in the Gulf. Shrinking the dead zone could increase the economic impact of domestically caught commercial fish industries for the Gulf region.

Notes: Economic impacts include the dollar value of each industry's sales, the indirect economic effects of those sales on related business-to-business transactions, and the induced impacts resulting from consumer-to-business transactions. Impacts in the figure are for Alabama, Louisiana, Mississippi, Texas, and West Florida. Nominal dollar values were adjusted to 2019 dollars using the Consumer Price Index for all urban consumers residing in the South (BLS Consumer Price Index 2020).

SOURCES: ANNUAL EDITIONS OF "FISHERIES ECONOMICS OF THE UNITED STATES" FROM 2006 TO 2016 (SEE NMFS 2006–2016).

growth of algae—which when severe enough can cause hypoxia (Turner and Rabalais 1994). In freshwater environments such as the Mississippi River, excess nitrogen has been reported to reduce aquatic species diversity, cause skeletal deformities in fish and amphibians, and delay the hatching of fish and amphibian eggs (Camargo and Alonso 2006; Alabaster and Lloyd 1982; Morris, Taylor, and Brown 1989). Up and down the Mississippi River, concentrations of nitrate (a water-soluble nitrogen compound) have risen by as much as fivefold since the early 1900s (Box 3, p. 8) (Goolsby et al. 2000).

THE DEVELOPMENT OF HYPOXIA

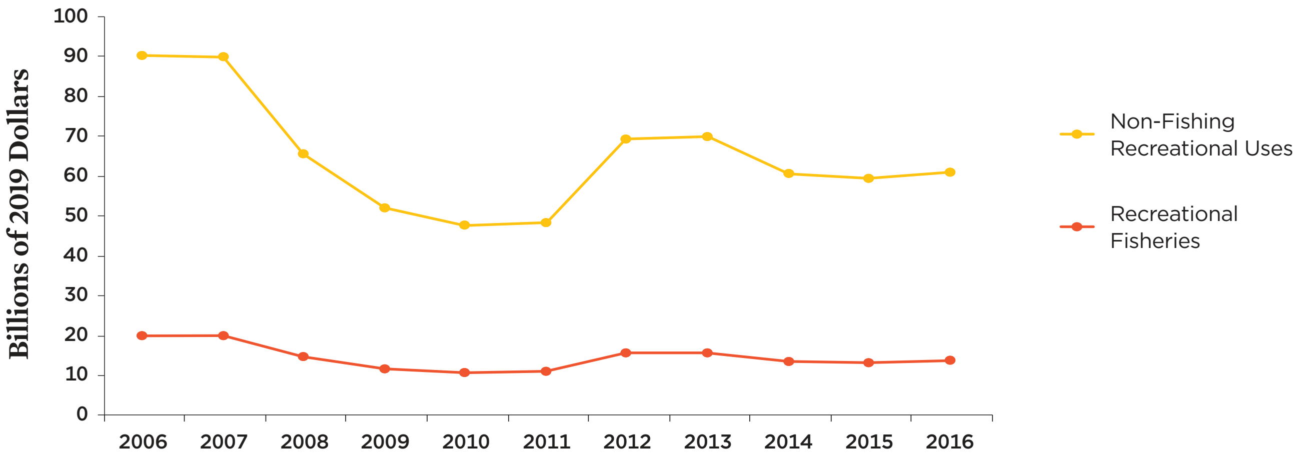
Far beyond the ecosystems and communities in the Mississippi and Atchafalaya watersheds, the damage continues. Just beyond the shoreline and wetlands at the mouth of these river basins, excess nitrogen is flushed out into the shallow waters of the Louisiana continental shelf, causing a cascade of changes in these ecologically sensitive waters. Excess nitrogen ultimately leads to a proliferation of bacteria, which deplete the water's dissolved oxygen. The large amounts of nitrogen first increase the growth and reproduction of algae. Some of the algae die and sink to the ocean floor, where they are decomposed by bacteria. Other algae are consumed by microscopic aquatic animals known as zooplankton, whose fecal material also falls to the Gulf sea floor and is consumed by bacteria. Hypoxia is the result. In the Gulf, hypoxia has serious impacts on suitable habitat for commercially important fishes and crustaceans and on the abundance of small bottom-dwelling organisms that are the food for commercially important species (Coleman n.d.).

> ***[The shrimp industry is particularly vulnerable to the formation of the dead zone.]***

THE AGRICULTURAL ORIGINS OF NITROGEN LOADING IN THE GULF OF MEXICO

Between 60 and 80 percent of the nitrogen loading in the Gulf of Mexico has been traced back to farming and livestock production in the Mississippi and Atchafalaya watersheds (Figure 3, p. 9) (EPA 2017; Robertson and Saad 2013; White et al. 2014). Just over 40 percent of the total nitrogen loading comes from synthetic fertilizer used to grow crops, particularly corn. Ten percent comes from livestock manure produced by animal feeding operations, and 9 percent comes from legumes that fix nitrogen in the soil (Robertson and Saad 2013).[2]

FIGURE 2. Total Economic Impacts of Gulf Coast Recreational Fishing and Non-Fishing Recreational Industries, 2006–2016



Over time, the economic impacts of both recreational and non-recreational fishing industries have either remained flat or declined. Shrinking the dead zone could potentially help increase these economic impacts.

Notes: Economic impacts include the dollar value of each industry's sales, the indirect economic effects of those sales on related business-to-business transactions, and the induced impacts resulting from consumer-to-business transactions. Impacts in the figure are for Alabama, West Florida, Mississippi, Louisiana, and Texas. Nominal dollar values were adjusted to 2019 dollars using the Consumer Price Index for all urban consumers residing in the South (BLS Consumer Price Index 2020).

SOURCES: ANNUAL EDITIONS OF "FISHERIES ECONOMICS OF THE UNITED STATES" FROM 2006 TO 2016 (SEE NMFS 2006–2016); KOSAKA AND STEINBACK 2018.

Today, most farmers in the Corn Belt[3]—in the heart of the Mississippi and Atchafalaya watersheds—apply nitrogen fertilizer to ensure maximum plant growth and crop yields.[4] Farmers typically use fertilizer generously because it is relatively inexpensive, representing a small share of their operating budgets, and it can act as a form of crop insurance for farmers (Ribaudo et al. 2011). Synthetic nitrogen fertilizer use became increasingly popular in US agriculture following World War II (Cao, Lu, and Yu 2018; Zhang et al. 2015). Between 1960 and 1980, when prices for synthetic nitrogen began to fall significantly, its use on US farms increased more dramatically than at any other time in history and continued to rise at a decreasing rate thereafter until the present time (Cao, Lu, and Yu 2018). The Corn Belt has the highest rates of total nitrogen use in the United States, and while many crops are fertilized with nitrogen in this region, the per-acre application rate is highest for corn (Cao, Lu, and Yu 2018).

Annual measures indicate that the Gulf dead zone typically peaks in the summer months, a result of springtime fertilizer applications on farms and peak river water flows in the Mississippi and Atchafalaya rivers, which coincides with increasing ocean temperatures and a reduction in the mixing of natural layers of ocean water (Rabalais et al. 1991). The largest dead zone on record occurred in 2017, when it was the size of New Jersey (Hypoxia Research Team n.d.). Since the tracking of the dead zone began in the mid-1980s, its areal extent (its size as measured from the bottom area) has not been meaningfully reduced, nor have nitrogen levels upstream in the month of May, which are strongly linked to the size and volume of the dead zone (Boesch 2019; Scavia et al. 2017; Scavia et al. 2019; Turner, Rabalais, and Justić 2008).

THE IMPACTS OF GULF HYPOXIA ON MARINE LIFE

Numerous studies have found a largely negative association between Gulf hypoxia and indicators of the health of fish, crustaceans, and other marine species, including their abundance and spatial distribution. Moderate to severe seasonally recurring hypoxia in the Gulf has reduced the abundance of species such as crustaceans, mollusks, sponges, and other species that occupy the sea floor (Diaz and Rosenberg 1995). Other research found that Atlantic croaker populations could decline by up to 25 percent in the future if hypoxia in the Gulf is not reduced significantly (Rose et al. 2018a; Rose et al. 2018b). The abundance of jellyfish, which can harm competing fish species in the same area, increased substantially between 1987 and 1997 in the waters adjacent to the discharge of the Mississippi and Atchafalaya rivers, which overlaps with the dead zone (Graham 2001). Bottom-dwelling fish and crustaceans have been observed temporarily moving away from the dead zone during its summer peak and reoccupying the area in the fall (Craig et al. 2001; Rabalais, Harper, and Turner 2001; Rabalais and Turner 2001), and some species, such as flounder (a flatfish), avoid hypoxic areas in the Gulf even after the area recedes in the fall (Switzer, Chesney, and Baltz 2009). Fish that occupy waters closer to the surface have also been observed avoiding the area where the dead zone forms each year (Zhang et al. 2009). What is more, change in the spatial distribution of commercial species can increase the accidental catch of vulnerable species such as turtles and dolphins (Craig 2012; Craig and Bosman 2013; Purcell et al. 2017).

The Economic Impacts of Hypoxia on Gulf Fishing Operations

How the Gulf dead zone affects landings and catch rates, and other economic indicators of the fishing industry, is less clear. This is partly attributable to the fact that marine life can adapt by moving out of harm's way. One study found that shrimp catches increased despite the formation of the seasonal dead zone (Zimmerman, Nance, and Wiams 1996), although the same authors later found that that in years when hypoxia was extensive, some shrimp species could not migrate to offshore waters and instead came nearshore, which made them easier to catch (Zimmerman and Nance 2001). Other research has found that shrimp employ compensatory mechanisms in their respiratory capacity to survive hypoxia (Rosas et al. 1998). Newer research has found beneficial impacts on some fish catches from increased nitrogen loading in the Gulf, since relatively small amounts of additional nitrogen promotes growth of marine plants and species (de Mutsert et al. 2016; de Mutsert et al. 2017). But some studies have more definitively shown declines in fish catches due to Gulf hypoxia. In the early 1980s, shrimp and finfish catch rates were lower in the most severely hypoxic areas (Leming and Stuntz 1984; Renaud 1986). Later, an assessment by the National Oceanic and Atmospheric Administration found that brown shrimp catches declined significantly from 1992 to 1997, coinciding with a substantial decrease in dissolved oxygen concentrations in Gulf waters (Diaz and Solow

BOX 2.

Diverse Gulf Community Traditions and Livelihoods Are on the Line

Each May, some Cajun, Vietnamese, and other shrimpers in Plaquemines Parish, Louisiana, perform the "Blessing of the Fleet," a tradition to ensure a healthy brown shrimp season (Wist 2019). The importance of this annual celebration reflects just how heavily many communities rely on shrimp harvests for their incomes and way of life. For example, one-quarter of Louisiana's commercial shrimpers are Vietnamese refugees who brought a fishing tradition with them to this country and who still make their living from the sea (Fernandez Campbell, Whiteman, and *National Journal* 2014). But nitrogen pollution that fuels the dead zone, as well as climate change and other intertwined concerns, are putting these cultural traditions and the economic well-being of this and other communities at risk.

Kim Tran, a Vietnamese shrimper out of Texas and a leader of a local shrimper's association, told reporters in 2019 that increased water and pollution flowing into the Gulf caused by flooding in the Midwest forced shrimp and other marine life farther out to sea. Tran described how this in turn made some shrimp smaller and harder to catch, increasing fuel and other costs for many boats and causing many shrimper families to go hungry (Dick 2019). A shrimp processing business owner in the area, Trey Pearson, worried last year about the dead zone because of the risks it poses to his bottom line (Lee 2019). Dean Blanchard, who has been shrimping in the Gulf for nearly 40 years and is one of the nation's largest shrimp suppliers, explained in 2019 that "when the dead zone comes, it just kills everything." Even new equipment and technology, which few shrimpers can afford, have not sufficiently helped them overcome the challenge (Johnson 2019). Moreover, when shrimp harvests are bad, other regional businesses that process and sell shrimp also feel the impact (see Box 1).

Indigenous people who rely on Gulf waters for economic security and their cultural identity are also hurt by its degradation. For example, members of the United Houma Nation, which is composed of 17,000 tribal members along the southeastern Louisiana coast, have been catching and preparing shrimp and other seafood for generations (United Houma Nation 2019; Parker 2019). Shrimp file gumbo, a classic Cajun dish, originated from the Houma (McIntosh 2019). In the early 2010s, many Houma Nation and nearby Pointe-au-Chien Native American shrimpers were forced to shut down their operations due—in addition to competition from imported shrimp, the BP oil spill, and hurricane activity—to excess nitrogen in the Gulf that fuels the dead zone (Bayles 2011).

BOX 3.

Nitrogen Contaminates Drinking Water and Harms Health on Its Way Downstream

Up and down the Mississippi and Atchafalaya rivers, excess nitrogen has contaminated groundwater and drinking water supplies for many communities. Nitrogen in drinking water can cause acute health problems, such as blue baby syndrome in which oxygen is restricted in the blood supply of infants exposed to nitrate in water, leading to congenital heart defects and respiratory problems (Majumdar 2003). It can also cause chronic health conditions such as cancer and thyroid disease, as well as adverse pregnancy outcomes and birth defects (OWMB 2011; Ward et al. 2018). Remediating contaminated drinking water is very costly. In some Minnesota counties, for example, the cost to society due to nitrogen contamination in private domestic wells and public water supplies is estimated to be $5 million per year (Keeler et al. 2016). In Iowa, the Des Moines Water Works spent more than $500,000 to remove nitrates from drinking water in 2016 alone and is planning to expand its operation at a cost of $15 million (Cannon 2019).

1999). More recent studies have found that menhaden populations, for example, have shifted due to hypoxia, increasing the effort needed to catch them in the most severely hypoxic Gulf waters (Langseth et al. 2014; Langseth et al. 2016).

The biological complexity of the Gulf ocean ecosystem has made researching how the dead zone affects the fishing industry a major challenge for decades. Despite these challenges, the economic consequences of the dead zone for Gulf fisheries are beginning to emerge, largely due to increasingly interdisciplinary and sophisticated research efforts. Two studies stand out in this regard. In the first, Gulf hypoxia was found to be negatively correlated with the relative price of large and small brown shrimp catch (Smith et al. 2017). The study found that as the hypoxic zone reaches peak size, smaller shrimp migrate closer to shore to avoid it, making them easier to catch and, as a result, the price that shrimpers earn for them goes down and fewer shrimp are able to grow to larger and more valuable sizes. Another Gulf-based study found that shrimpers must exert more effort—defined as the amount and intensity of time spent catching shrimp—to catch shrimp when hypoxia occurs (Purcell et al. 2017).

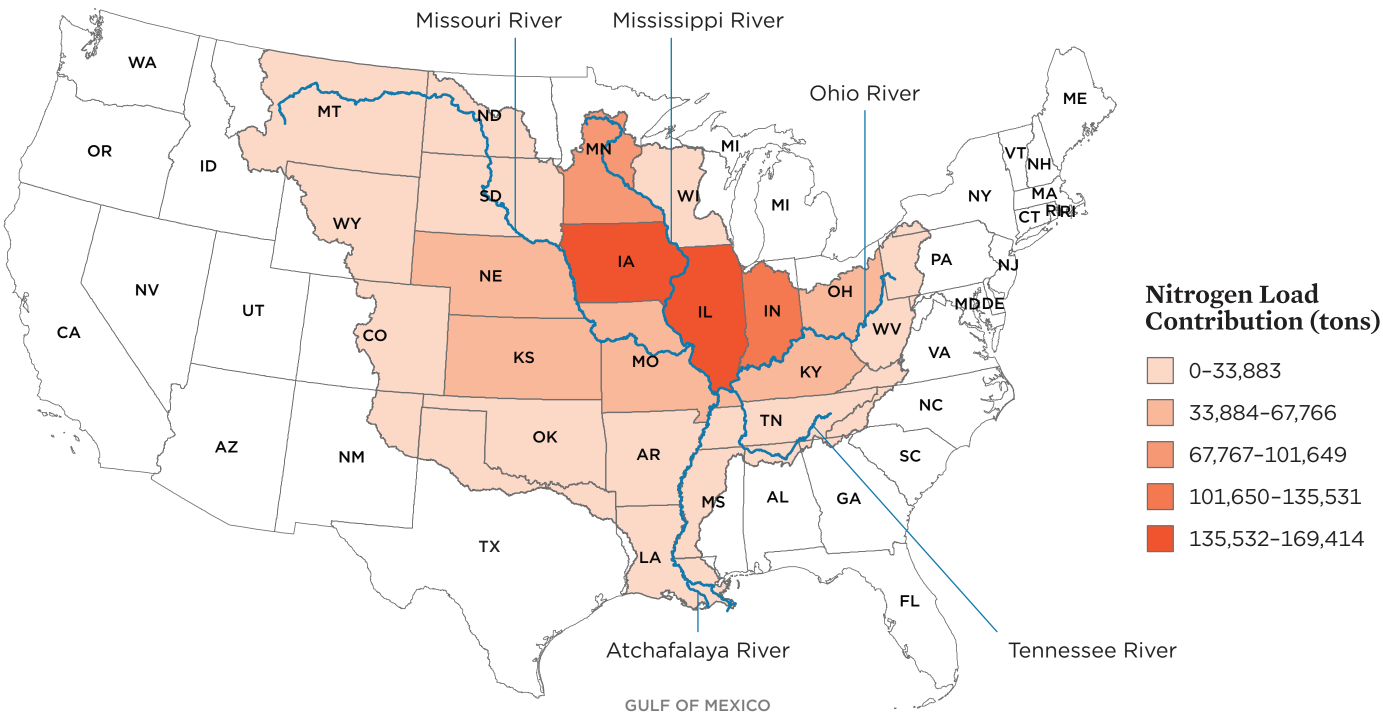
Without doubt, more research detailing the economic consequences of Gulf hypoxia on the fishing and shrimping industries is needed. Yet studies of other hypoxic waters in the United States and globally provide additional insights about the economic dangers of the Gulf dead zone. For example, in North Carolina, seasonal hypoxia—due in large part to agricultural nitrogen losses—in the Neuse River and Pamlico Sound has resulted in a 13 percent annual decrease in brown shrimp landings from 1999 to 2005, while shifting the optimal shrimp harvest season to much earlier in the year (Huang, Smith, and Craig 2010; Huang and Smith 2011), disrupting normal fleet operations. When shrimp landings are down, imported shrimp make up the shortfall, further hurting shrimper revenues (Huang et al. 2012; Keithly and Poudel 2008). For North Carolina's blue crab fishers, research indicates that reducing hypoxia there could result in millions of dollars in economic benefits to it, while bringing additional co-benefits to recreational fisheries (Smith et al. 2007).

Research has also documented the harm caused by hypoxia on commercially important fisheries elsewhere. This includes the Chesapeake Bay and one of its main tributaries, the Patuxent River. Summer flounder catch rates there have been reduced by as much as 20 percent due to hypoxia, while striped bass fisher and blue crabber revenues have been collectively reduced by hundreds of thousands of dollars in a single year due to this problem (Lipton and Hicks 2003; Massey, Newbold, and Gentner 2006; Mistiaen, Strand, and Lipton 2003). Hypoxia's economic consequences have also been extensively studied in the Baltic Sea (Compton 2020). Researchers there have found that reducing eutrophication and related water quality problems could bring as much as $10 billion (1999 dollars) more in economic benefits than the costs of reducing nitrogen loads (Gren 2001; Gren, Jannke, and Elofsson 1997; Rabotyagov et al. 2014b; Turner et al. 1999).

Dollars at Stake: Shrinking the Dead Zone Can Help Gulf Coast Fisheries

In the fall of 1997, the Environmental Protection Agency established the Mississippi River/Gulf Hypoxia Task Force to better understand the impacts of nutrient pollution and hypoxia in the Gulf. This group—and the passage of the landmark federal law the Harmful Algal Bloom Research and Hypoxia Research

FIGURE 3. Total Nitrogen Load in the Mississippi and Atchafalaya Rivers from Farm Fertilizer, by State



Fertilizer runoff flows to the Gulf via several major rivers (and smaller tributaries, not shown) that drain a vast expanse of the central United States. As this map shows, the highest concentrations of nitrogen loading come from states at the heart of the Corn Belt: Iowa, Illinois, and Indiana.

Note: State loading represents sum of incremental loads for each state and includes farm and non-farm sources of nitrogen. For more methodological details please see source. Loading data are based on nutrient inputs similar to 2002 and while dated Figure 4 in this report shows that inputs have not declined substantially since this time period.

SOURCE: DATA OBTAINED FROM USGS MISSISSIPPI-ATCHAFALAYA RIVER BASIN NUTRIENT LOADING MAP, USING THE SPARROW MODEL. AVAILABLE ONLINE AT HTTPS://SPARROW.WIM.USGS.GOV/MARB/.

and Control Act of 1998—stimulated research on the impacts of the Gulf dead zone, including many estimates of the costs of reducing its size through changes in agricultural practices across the Mississippi and Atchafalaya watersheds (Kling et al. 2014; NRCS 2012; Tallis et al. 2019). These studies have provided information that lawmakers need to implement policies and programs to cost-effectively reduce the dead zone by reducing nitrogen losses from agriculture upstream. Yet, to date, few studies have quantified economic benefits that Gulf Coast communities reliant on healthy oceans could realize if the dead zone were reduced. Quantifying these benefits in economic terms can help policymakers understand the potential return on investment from addressing this problem.

> ***To date, few studies have quantified how Gulf Coast communities could benefit economically if the dead zone were reduced.***

ESTIMATES OF AVOIDABLE NITROGEN

We used state-level data from the US Department of Agriculture on the application of fertilizer nitrogen in states that drain partially or exclusively into the Mississippi and Atchafalaya watersheds (NASS 2020). Based on our analysis, we estimate that since 1990, corn and soybean farmers in the Mississippi and Atchafalaya River basins have applied approximately 114 million tons of fertilizer nitrogen to their fields, at a total cost of $37 billion in 2018 dollars (see Appendix 2). Even with recent improvements in available methods for farmers to fine tune nitrogen applications, the most recent estimates indicate that 34 percent of applied fertilizer nitrogen to crops in the United States is lost to the environment (Zhang et al. 2015). Some nitrogen loss is inevitable, including a small share that will be lost as nitrous oxide, a potent heat-trapping gas that contributes to climate change. On farms, however, a relatively large amount of nitrogen is easily carried away as water drains through and from agricultural fields (Rabotyagov et al. 2010; David, Drinkwater, and McIsaac 2010); nearly 75 percent of the nitrogen lost typically flows into surface water and groundwater (NRCS 2012).

Our analyses also reveal that over the same time period nearly 31 million tons of fertilizer nitrogen from corn and soybean farms flowed into surrounding rivers and streams that feed into the Gulf, fueling the dead zone (Figure 4). Based on historical nitrogen fertilizer prices over the last three decades (ERS 2019), we estimate that this lost nitrogen represents $12 billion (in 2018 dollars) in total nitrogen purchased for corn and soybean crops over three decades, an average of nearly $400 million per year (in 2018 dollars).

ESTIMATING COSTS TO FISHERIES AND MARINE HABITAT

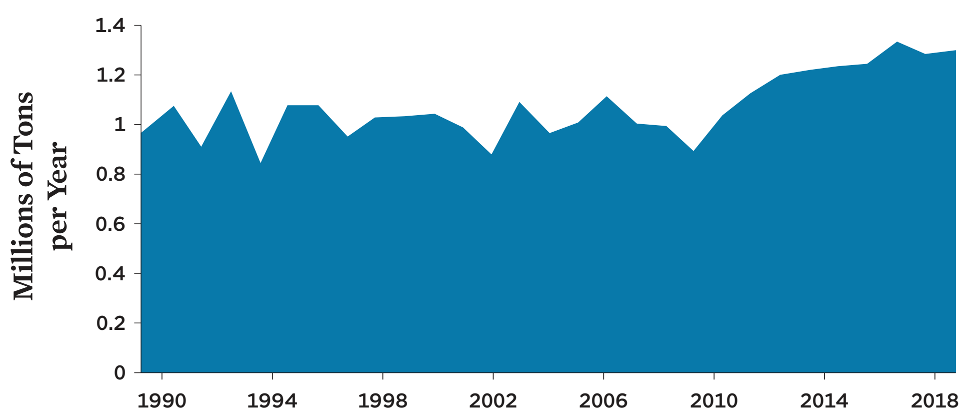
Much of this nitrogen ultimately makes its way into the Gulf and fuels the dead zone, causing harm to the natural ecosystem and marine life. This damage has an economic cost, which we estimate here. Due to data and methodological limitations, our estimates of the economic cost do not directly include impacts to fisheries' landings, revenues, or other economic indicators. Rather, we have quantified the damage to ecosystem services on which Gulf fisheries depend, thus shining light indirectly on the economic impacts of the dead zone on these fisheries.

> ***About 34 percent of applied fertilizer nitrogen to crops in the United States each year is lost to the environment.***

Ecosystem services are defined as the benefits that the environment and wildlife provide to people. Specifically, we evaluated the damage caused to ecosystem services provided by fisheries and marine habitat due to annual peak Gulf nitrogen loadings attributable to agricultural nitrogen losses upstream.[5]

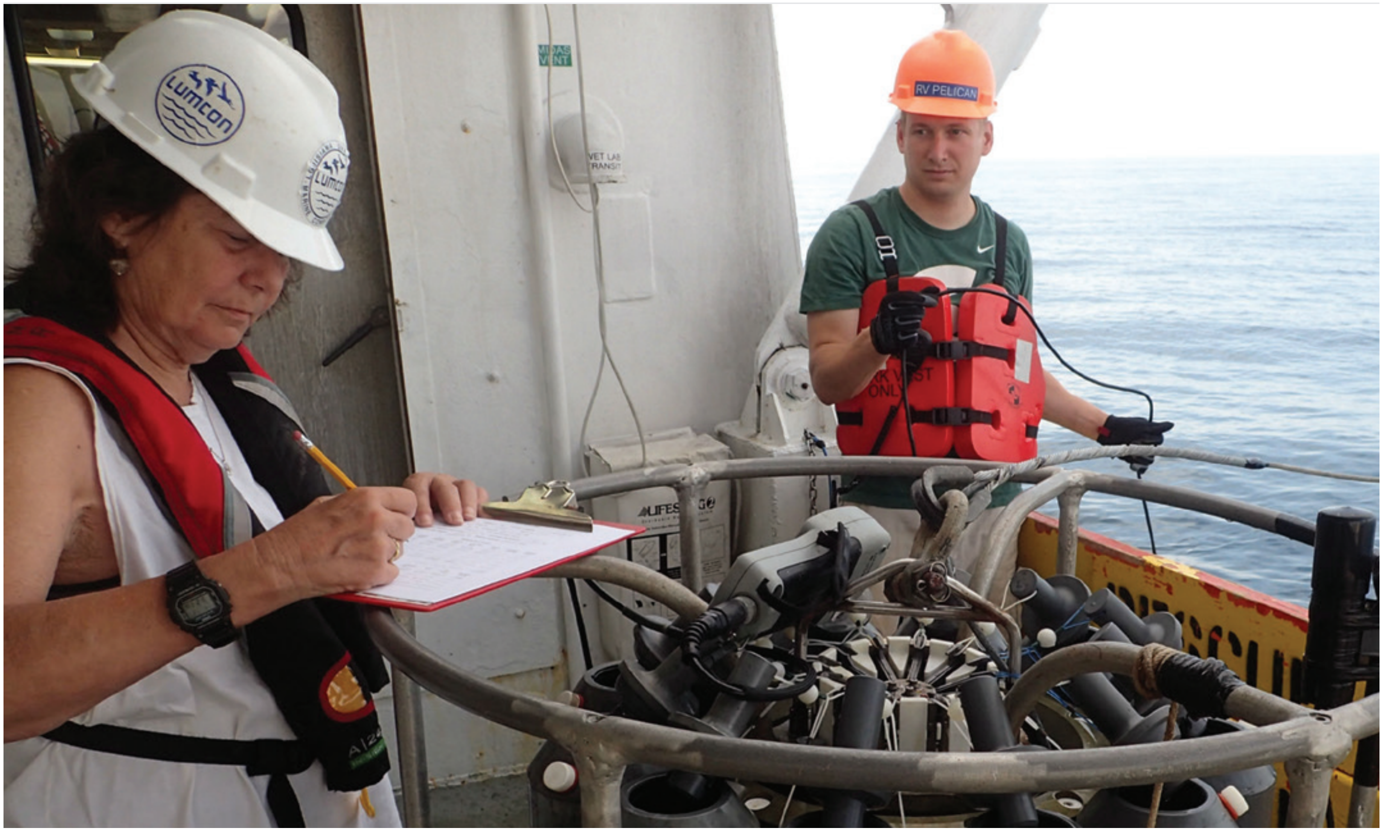
Quantifying the value of ecosystem services tells us how economically important they are to human populations. In turn, these economic values can be used by policymakers to make decisions about how to manage natural resources and other environmental amenities. In the case of the Gulf of Mexico, fisheries and marine habitat provide many ecosystem services.

FIGURE 4. Tons of Fertilizer Nitrogen Leaving Corn and Soybean Farms and Entering the Mississippi and Atchafalaya Watersheds, 1990–2018



Estimated total fertilizer nitrogen applications have only increased in the watershed since 1990. The sharp increase after 2009 has been linked to an expansion of corn and soybean acreage following the enactment of the federal Renewable Fuel Standard (Lark, Salmon, and Gibbs 2015). (See Appendix 2 for methodological details.).

SOURCES: NITROGEN APPLICATION DATA WERE OBTAINED FROM THE US DEPARTMENT OF AGRICULTURE'S NATIONAL AGRICULTURAL STATISTICS SERVICE AGRICULTURAL RESOURCE MANAGEMENT CHEMICAL USE SURVEY PROGRAM FOR ANNUAL DATA FROM 1990 TO 2018.



gulfhypoxia.net

Scientists have studied the Gulf of Mexico dead zone for more than 30 years. Here, researchers from the Louisiana Universities Marine Consortium and the National Oceanic and Atmospheric Administration collect data on an annual expedition to map the dead zone's location and measure its size. In 2017, it was the size of New Jersey, the largest measurement on record.

For example, they help maintain the natural balance of nutrients and species and they produce food for human consumption (Barbier, 2017; Constanza et al. 1997). Economists have developed ways to calculate the value of these ecosystem goods and services even though they are not easily priced like regular goods and services that we typically buy. Our analysis relies on estimates of how much people are willing to pay for restoring ecosystem services derived from fisheries and marine habitats that have been lost due to excess nitrogen loading. We refer to the value of these lost ecosystem services as damage costs.

First, we estimated the damage to the ecosystem services that could be averted by reducing annual peak nitrogen loadings to levels that substantially shrink the Gulf dead zone. We then compared (1) the costs of achieving these nitrogen-loading reductions through changes in agricultural practices upstream, to (2) the economic benefits resulting from reduced damages to the ecosystem services provided by fisheries and marine habitat in the Gulf. This reflects our assumption that May nitrogen loading levels cause the greatest harm in the Gulf and that reducing this month's loadings would be the most effective way to reduce the dead zone and, consequently, damage to Gulf fisheries and marine habitat. To calculate damage costs, we compiled total Gulf of Mexico nitrogen loading data from the US Geological Survey from the month of May from 1980 to 2017 (Lee, Norman, and Reutter 2018). May nitrogen loading values are strongly correlated with annual peak river water flow, which naturally delivers the largest amounts of nitrogen to the Gulf over the course of a year (Scavia et al. 2017; Lee, Norman, and Reutter 2018). May nitrogen loadings are also highly correlated with the peak area and volume of the dead zone (Scavia et al. 2017; Turner, Rabalais, and Justić 2008). To estimate the amount attributable to fertilizer lost from croplands upstream, we multiplied the May nitrogen loading values by 41 percent (EPA 2015; Robertson and Saad 2013).

To estimate the damage costs to Gulf fisheries and marine habitat attributable to upstream fertilizer losses, we multiplied May nitrogen loading attributable to upstream crop production by nitrogen damage factors (Sobota et al. 2015). The nitrogen damage factors are obtained through previous surveys of people that ask them to quantify the amount they would be willing to pay to protect certain ecosystem services.[6] In the context of excess nitrogen loading in waterways, willingness to pay studies are a standard economic methodology used to assess how much people would pay to resolve a particular environmental concern. In this case, increases in ecosystem services were assumed to be achieved by reductions in excess nitrogen loading, eutrophication, and hypoxia in ocean systems (Van Grinsven et al. 2013), and the estimated low, medium and high values were $6,236, $16,190, and $27,016 (2018 dollars) per ton of nitrogen, respectively. This range of values accounts for the variability and uncertainty inherent in estimating people's willingness to pay to protect ecosystem services.

We then estimated the proportion of these damage costs that could be averted by decreasing agricultural nitrogen losses upstream. Here we used a series of nitrogen loss reduction scenarios achieved through changes in agricultural practices, derived from four previously published studies. These studies all examined how widespread shifts in practices on cropland in the Mississippi and Atchafalaya watersheds influenced nitrogen loadings in the Gulf (Kling et al. 2014; NRCS 2012; Rabotyagov et al. 2014a; Tallis et al. 2019). The scenarios assumed different scales and scopes of changes to current agricultural practices, such as increased adoption of cover cropping, nutrient management, conservation tillage, riparian buffers, planting of perennials, and improved subsurface tile management to achieve reductions in nitrogen losses. In these scenarios, reductions in the May Gulf nitrogen loading due to shifts in agricultural practices upstream ranged from just over 5 percent to 45 percent.

Southern Foodways Alliance/Creative Commons (Flickr)

Nitrogen pollution from upstream farms imposes significant costs on Gulf coast industries and communities—we estimated annual costs between $552 million and $2.4 billion. Damage to fish habitat and stocks can make fishing less profitable, helping to drive some small fishers out of business.

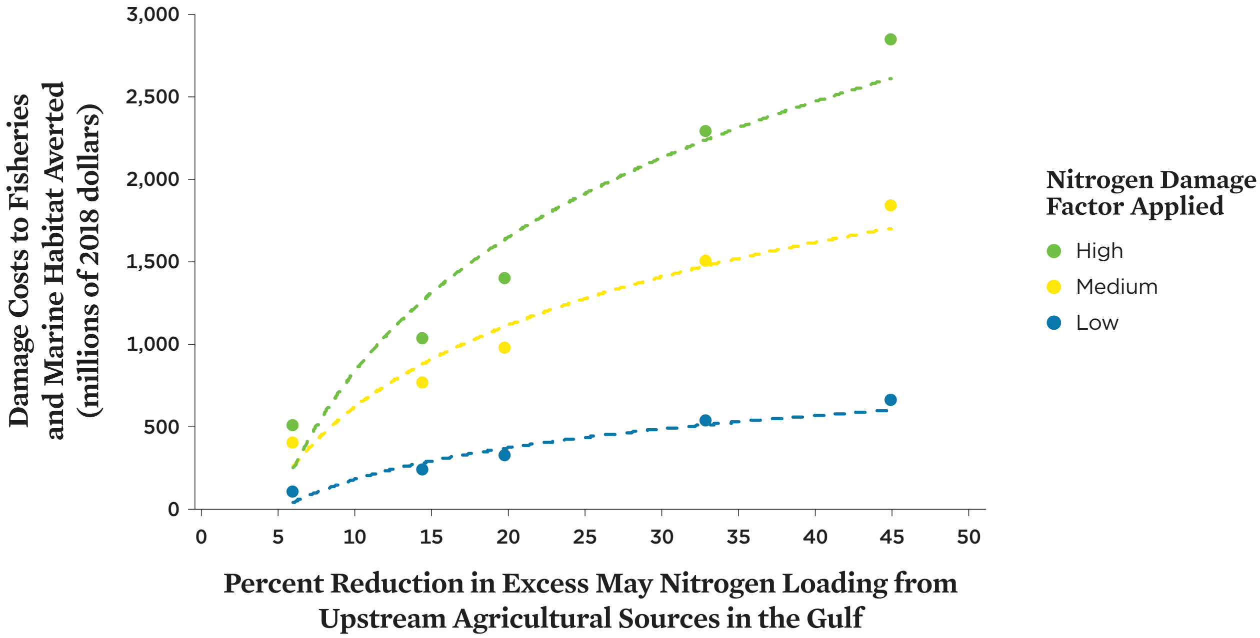
We then calculated damage costs averted for each scenario by multiplying the percentage reduction in nitrogen loading by total damage costs to fisheries and marine habitat under current May nitrogen loading levels. (Additional methodological details and information about these scenarios can be found in Appendix 3.)

A SUBSTANTIAL RETURN ON INVESTMENT

Our results showed that, on average, May nitrogen loading in the Gulf attributable to agricultural losses upstream is estimated to be nearly 87,000 tons annually. To put this number in perspective, this amount of nitrogen would fit, measured in weight only, into approximately 3,100 standard 40-foot-long shipping containers.[7] Our findings show that nitrogen loading in the Gulf that is attributable to agricultural losses upstream caused between $552 million and $2.4 billion (2018 dollars) in damage to Gulf fisheries and marine habitat annually from 1980 to 2017. Based on the scenarios described above, we estimate that between $98 million and $2.8 billion (2018 dollars) in damage costs to Gulf fisheries and marine habitat could have been averted every year from 1980 to 2017 through shifts in agricultural practices (see Appendix 3 for full scenarios) (Figure 5). Further, we found that scenarios that decreased May nitrogen loading by 20 percent or more could reduce the average size of the dead zone to levels recommended by the Environmental Protection Agency's Hypoxia Task Force.

The ways in which our estimates may under- or overestimate the actual value of damage costs due to May nitrogen loading in the Gulf are important to note. Our analysis could overstate the potential to avert damage costs based on our assumption that immediate reductions in Gulf nitrogen loading would result in immediate reductions in dead zone areal extent. Recent research has indicated that so much nitrogen has accumulated in the Mississippi River basin that it may take 30 years or more to reduce loads enough to meaningfully reduce the size of the Gulf dead zone (Ballard et al. 2019; Van Meter, Cappellen, and Basu 2018). And in several ways our analysis underestimates damage costs. First, our damage cost estimates only reflect harm to ecosystem services derived from fisheries and marine habitats most affected by the dead zone; other impacts of nitrogen loading in the Gulf have also been documented (Ren, Rabalais, and Turner 2020). Second, we did not evaluate how reduced damage costs to the ecosystem services provided by healthier fisheries and marine habitat would ripple through the many industries connected to Gulf fishing (see Box 1). Third, nitrogen pollution from agriculture upstream causes harm to waterways and the climate as it makes its way to the Gulf of Mexico (see Box 2). However, our damage cost estimates do not take into account the costs of this impaired groundwater, surface water, and drinking water. Nor do we

FIGURE 5. Potential Reductions in Damage Costs to Gulf Fisheries and Marine Habitat Made Possible from Reductions in Nitrogen Loading



Estimated damage to fisheries and marine habitat ecosystem services caused by the nitrogen pollution that forms the dead zone ranges from $98 million to $2.8 billion (2018 dollars).

Note: Damage costs averted under three scenarios are based on high, medium, and low nitrogen damage factors applied and the percent reduction in nitrogen. Point estimates are fitted with logarithmic best fit lines to show trends in damage costs averted for each of the damage factors applied. Appendix 3 provides additional methodological details and data sources.

account for the economic value of decreased emission of nitrous oxide, a global warming gas. If these factors were able to be taken into consideration, estimates of damage costs would likely be much higher.

Of course, financial investments are needed to achieve these benefits. In the scenarios analyzed from previously published work, researchers estimated the increased adoption of agricultural practices that reduce nitrogen losses to the Gulf to cost between $705 million and $3.1 billion annually in 2018 dollars (Kling et al. 2014; NRCS 2012; Rabotyagov et al. 2014a; Tallis et al. 2019). By comparison, our analysis estimated benefits of a similar magnitude for the medium and high damage factor scenarios. Given that the costs and benefits in the medium and high scenarios are of similar magnitude, we conclude that there could be a major return on investment in adopting improved agricultural practices that can reduce nitrogen losses to the Gulf.

It is important to note that our analysis and comparisons here are not intended to be a complete accounting of all the costs and benefits associated with improvements to agriculture upstream and returns to the Gulf fishing industry. The costs associated with implementing improved agricultural practices to reduce nitrogen losses reflect only policy and program costs. The widespread shifts in agricultural practices in these scenarios could change production costs, individual farmer yields in the short term, or total land devoted to agricultural production. In turn, these shifts could affect crop prices and farmer incomes, with broader effects and unintended economic consequences for the agricultural industry (Marshall et al. 2018). Likewise, the present analysis does not fully account for all of the potential economic benefits from the adoption of the recommended practices that would accrue to the Gulf.

Policy Recommendations

Millions of tons of nitrogen continue to wash off Midwestern farmland each year, fueling the annual Gulf dead zone. This excess nitrogen, as we documented in this report, causes a range of serious problems for the fishing industry and people along the Gulf Coast who rely on healthy ocean waters for their livelihoods and cultural traditions. However, our analysis reveals that significant economic benefits could be realized through reducing Gulf nitrogen loading attributable to agricultural losses upstream. The fishing industry stands to benefit from increased ecosystem services provided by healthier waters in the Gulf.

Hypoxia is being addressed successfully elsewhere in the United States. For example, efforts to reduce total daily loads of nitrogen in the Chesapeake Bay and thus reduce hypoxia have had a positive impact, providing up to an estimated $88 million in annual benefits to the commercial and recreational fishing industries in the region (Massey et al. 2017). However, for these benefits to materialize for the Gulf of Mexico, farmers in the Midwest need to adopt agricultural practices that reduce nitrogen losses. Such practices also benefit farmers, preserving agricultural soils and protecting the water supplies for countless communities. To achieve these benefits, we offer several policy recommendations that focus on expanding the adoption of these practices in Midwest agriculture and that bring greater awareness and understanding to the Gulf Coast fishing industry's need for healthy ocean waters.

INCREASE ADOPTION OF HEALTHY SOIL PRACTICES

We recommend increased funding to expand the adoption of agricultural practices that improve soil health and keep nutrients such as nitrogen out of our waterways. Large quantities of nitrogen have accumulated in the Mississippi River basin over the past three decades, and, as our analysis has shown, nitrogen continues to flow to the Gulf in large quantities. Consequently, action to reduce nitrogen levels in the Gulf are urgently needed. We stress that additional funding must be spent in ways that cause the largest and most immediate reductions to nitrogen flowing to the Gulf. The following federal policy changes are crucial:

- **Establish performance-based standards or discounts within the federal crop insurance program to incentivize large-scale reduction in nitrogen losses from farming through improved soil management.** As this report has demonstrated, crop agriculture in the Midwest is the primary source of the nitrogen pollution that makes its way into the Gulf, fueling the dead zone. Conservation compliance programs have worked in the past to incentivize crop farmers to adopt practices that benefit soil and water quality (Claassen et al. 2017). As a result, we recommend that crop insurance programs incentivize the adoption of soil health–building practices that have proven to significantly reduce nitrogen losses. The US Department of Agriculture's Risk Management Agency should give a premium discount to farmers who use the following agricultural management practices: cover cropping, conservation tillage, riparian buffers, and perennial plantings.
- **Expand and speed up the reductions in nitrogen loss by increasing funding for and strengthening the Conservation Stewardship Program's (CSP) focus on soil health improvements.** This popular working-lands conservation program takes a holistic approach and incentivizes conservation practices based on national, state, and local priority resource concerns. However, participation in CSP is competitive, as farmer demand continues to outpace available funding (NSAC 2015). We recommend that CSP funding be expanded significantly to meet this demand. Further, to more effectively target its funding toward management practices that build soil health and reduce nitrogen losses, soil health improvement should be added to the list of criteria under which CSP contract offers are evaluated.

[*Funding must be spent in ways that cause the largest and most immediate reductions to nitrogen flowing to the Gulf.*]

Lynn Betts/NRCS/SWCS

Planting perennial prairie plants in and around crop fields is one practice shown to cost-effectively reduce nitrogen runoff. When planted on just 10 percent of crop acres, prairie strips like those shown here can reduce nitrogen loss by 80 percent.

- **Further reduce nitrogen losses to the Gulf by expanding the number of focus area watersheds in the Mississippi River Basin Healthy Watersheds Initiative and increase overall funding.** Established in 2009, the Mississippi River Basin Healthy Watersheds Initiative draws funding from multiple farm bill conservation programs, focusing on individual watersheds within the Mississippi River basin to reduce nitrogen losses. Approximately 61 percent of these watersheds are in the Upper Mississippi and Ohio River basins, which have been identified as the basins which contribute the most nutrients to the Gulf (Marshall et al. 2018). However, the initiative fails to target all of the watersheds that have high levels of nitrogen losses (Rabotyagov et al. 2014a). The watersheds selected for inclusion in this program should be evaluated to ensure maximum reductions in nitrogen flowing to the Gulf.

ENSURE PROTECTION FOR GULF FISHING INDUSTRIES AFFECTED BY NITROGEN LOADING AND THE DEAD ZONE, AND ENSURE THEIR REPRESENTATION ON THE HYPOXIA TASK FORCE

As this report has shown, diverse fishing operations, including those operated by refugee, immigrant, and indigenous people, are harmed by nitrogen pollution and the Gulf dead zone. It is critical for them to be represented in efforts to address this problem. The following actions can accomplish this:

- **Investigate the feasibility of creating a new program to compensate Gulf fishing industries for losses they incur from the chronic occurrence of nitrogen pollution and the dead zone.** Under the Magnuson-Stevens Act, fishing operations and related coastal businesses can receive payments when natural or other disasters occur in US ocean waters. Just as hurricanes and oil spills cause acute damage, nitrogen pollution causes chronic, long-term damage to the Gulf ocean ecosystem and harms the fishing and shrimping industries. Policymakers should explore amending the Magnuson-Stevens Act to create a new program to compensate Gulf fishing or shrimping operations for losses they incur from the chronically recurring dead zone. Payments could be determined based on May nitrogen loadings in the Gulf measured by the US Geological Survey or the size of the dead zone as measured by the National Oceanic and Atmospheric Administration.
- **Instruct the Environmental Protection Agency's Office of the Inspector General to conduct an audit or investigation of the effectiveness of the Mississippi River/Gulf Hypoxia Task Force.** Established in 1997, this task force was charged with evaluating the causes and effects of eutrophication in the Gulf and coordinating efforts to reduce the size and severity of the dead zone (EPA 2015).

Eric Gay/AP Photo

The dead zone particularly affects the lucrative Gulf shrimp industry—valued at more than $400 million annually—and the people who work in it. This has particular equity implications, as many Gulf shrimpers are immigrants or people of color.

  As this report has documented (see Figure 4), there has been little to no progress reducing the size of the dead zone or nutrient loads in the Gulf over this time. The audit or investigation should analyze why the task force is not making progress in reducing hypoxia in the Gulf and offer concrete recommendations on how its efficacy can be improved. Those concrete recommendations should include which actions, including regulatory action, could help achieve nitrogen reductions in the Gulf.
- **Update and amend the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force Charter to ensure that diverse voices and perspectives are in positions of power on the task force, including voices of those involved in the Gulf fishing industry.** The Hypoxia Task Force currently lacks representation from diverse voices within leadership positions, despite its most recent report to Congress stating that it would expand and build new partnerships (EPA 2017). There is only one nongovernmental

> ***Policymakers, researchers, and advocates need to act with immediacy to shrink the Gulf dead zone.***

member of the Hypoxia Task Force (a member of the National Tribal Water Council), and most of the members represent agricultural interests. While these voices are essential for addressing Gulf hypoxia, people who are affected by the dead zone must have greater representation on the task force. The charter should be amended to allow for increased representation of tribal communities, community-based businesses, and organizations in the Gulf that are most vulnerable to the impacts of the dead zone (see Box 2). For example, groups such as Coastal Communities Consulting in Gretna, Louisiana, provide assistance to underserved fishing communities and businesses, and should be considered for membership on the Hypoxia Task Force given their expertise and knowledge (Coastal Communities Consulting n.d.; Fernandez Campbell, Whiteman, and *National Journal* 2014).

INVEST IN INTEGRATED RESEARCH ON THE IMPACTS OF NITROGEN AND OTHER NUTRIENT POLLUTION IN THE GULF OF MEXICO ON INDUSTRIES RELIANT ON HEALTHY OCEAN WATERS

As this report shows, there needs to be additional research to understand the economic impacts of this problem on fishing industries and related businesses, especially those that rely on or operate in the waters that become hypoxic each year. For example, federal lawmakers can provide:

- **Support and additional funding for research by the Environmental Protection Agency, US Department of Agriculture, Department of Energy, National Science Foundation, and universities on the damage costs caused by nitrogen pollution to the environment and trends in farmer nitrogen applications and loss, and how such trends affect nitrogen loadings in the Gulf.** For our analysis of damage costs from nitrogen loading in the Gulf, we applied the nitrogen damage factors from Sobota et al. (2015); however, much more work is needed to better evaluate the environmental and social costs of nitrogen pollution in the Gulf. Further, the US Department of Agriculture's tracking of nitrogen applications only occurs every five years for select states and crops, and losses are not tracked in a systematic way at the federal level. While models exist to evaluate the linkages between nitrogen applications on farms and loadings in the Gulf of Mexico (e.g., Kling et al. 2014), there is a need to improve the data and accuracy of such modeling approaches. Interdisciplinary collaborations within and between these agencies will help improve nitrogen application monitoring and losses, while improving our understanding of how nitrogen applied on farms affects the Gulf of Mexico ecosystem.
- **Increased federal funding and prioritized integrated research on how nitrogen pollution and the dead zone in the Gulf of Mexico affects the economic vitality of commercial and recreational fishing industries.** The Gulf of Mexico is a complex biological system, and disturbances to its natural state cause dynamic human and socioeconomic responses and feedbacks. This has made research on the impacts of the dead zone on the fishing industries very challenging, as this report has demonstrated. Further, many environmental and economic stressors affect the region's fisheries. How these other stressors interact with nitrogen pollution and the dead zone impacts is not fully known, yet together they could have serious consequences for the viability of the region's coastal economy. Consequently, a top priority should be to substantially increase and guarantee funding for integrated and systems-oriented economic research through the National Oceanic and Atmospheric Administration, National Science Foundation, Environmental Protection Agency, and US Department of Agriculture. This type of research will provide information on interconnected economic, social, and environmental costs and benefits that policymakers need to consider when they develop solutions to address nitrogen pollution and the Gulf dead zone.

Conclusion

Policymakers, researchers, and advocates need to act with immediacy to shrink the Gulf dead zone. Fisheries face multiple environmental and economic stressors in addition to nitrogen pollution, from climate change and ocean acidification to overfishing and increased competition from imported seafood. Of this set of challenges, nitrogen pollution may be the most straightforward to address. The origins of excess nitrogen are known and, importantly, agricultural practices to reduce the downstream nitrogen pollution bring significant benefits to farmers, as well as to the many communities that rely on healthy rivers and streams for their drinking water.

This analysis reveals that addressing nitrogen pollution and the Gulf dead zone would reduce the damage to fisheries and marine habitat that provide ecological and economic benefits for Gulf fishing and coastal industries. These benefits would likely have positive ripple effects for the region's wider economy. What is more, prior research has shown that farmers also stand to benefit in the short and long term when they adopt practices that reduce nitrogen losses and protect waterways, all while preserving and building up healthy soils. By adopting these practices, they can grow the food, fuel, and fiber that power our nation's economy while protecting fishing operations' revenue, regional jobs, and the diverse cultural traditions of Gulf Coast communities for generations to come.

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ENDNOTES

1 The National Oceanic and Atmospheric Administration defines commercial fishing as operations selling their catch for profit and recreational fishing operations as fishing for pleasure rather than for selling fish for profit or subsistence (NMFS 2018). Non-fishing recreational activities are defined as viewing or photographing the ocean, beachcombing, water sports, and other outdoor activities (Kosaka and Steinback 2018).

2 Another 14 percent of the nitrogen in the Gulf originates from urban runoff; discharges from wastewater treatment plants; and natural, agricultural, and urban atmospheric deposition (Robertson and Saad 2013). Atmospheric deposition is a process by which nitrogen gas in the air is transformed so that it can dissolve in water or penetrate soil (Paerl, Dennis, and Whitall 2002). Some of the nitrogen reaching the Gulf via atmospheric deposition originates from agricultural sources, but the exact amount is unknown.

3 States generally considered part of the Corn Belt include Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, South Dakota, and Ohio (Green et al. 2018).

4 A report by the US Department of Agriculture indicated that 97 percent of corn acres receive nitrogen, either synthetic fertilizer or nitrogen in animal manure used to fertilize farm fields (Ribaudo 2012).

5 We did not evaluate the damage costs associated with Gulf peak phosphorus loading because nitrogen loading has been found to be the primary driver of the dead zone (Scavia et al. 2017).

6 The European Nitrogen Assessment estimated willingness to pay to clean up eutrophication and other water quality concerns among European citizens living near oceans and other water bodies to calculate the damage costs of nitrogen in these ecosystems (Sutton et al. 2011). Because no US-based estimates of willingness to pay to reduce eutrophication or hypoxia exist, to our knowledge, we assumed for this analysis that the willingness to pay of US and European citizens would be similar. Additional US-focused studies are needed. A recent working paper has evaluated this topic, but it has not been published in a peer-reviewed journal, nor is the study focused on people living along the US Gulf Coast (Parthum and Ando 2019).

7 A standard 40-foot-long shipping container commonly transported by ships, trucks, or trains can hold approximately 28 tons. For simplicity, we did not convert fertilizer nitrogen for this analysis into a volume measurement.

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Reviving the Dead Zone

Solutions to Benefit Both Gulf Coast Fishers and Midwest Farmers

Gulf fisheries and marine habitat have incurred up to $2.4 billion in damage since 1980 from nitrogen pollution from farms upstream.

People who fish in the Gulf of Mexico have a persistent problem. A large "dead zone" appears in the water every summer, formed in large part by nitrogen fertilizer that runs downriver from Midwestern farms. This pollution harms marine life in the Gulf, which is the foundation of the region's economically and culturally important fishing industries. According to our analysis, nitrogen losses from farms upstream have caused up to $2.4 billion in damages to fisheries and marine habitat every year since 1980. Fortunately, this damage can be reduced through science-based farming practices that build up soils and keep nitrogen on farm fields. Policymakers should invest in technical and financial assistance to help farmers adopt such practices, to simultaneously improve the health of soil and local waterways; grow the food, fuel, and fiber that power our nation's economy; and protect farming and fishing industries, jobs, and communities for generations to come.

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