



Hypoxia in the Gulf

Executive Summary

- Excess nutrients in freshwater from the Mississippi and Atchafalaya River Basin have been suggested as the primary cause of annual summer hypoxia in the Gulf of Mexico and the crucial factor for its control. Floods, erosion and the overtaking of Mississippi River by the Atchafalaya River continue to contribute to the occurrence and extent of hypoxia in the Gulf.
- Nitrogen and phosphorus from nonpoint agricultural sources, such as fertilizers applied to Midwestern corn fields, are cited as the primary source of nutrients. The contribution of urban nonpoint and point sources, such as lawns and industrial discharges, has been underestimated and remains overlooked as another source from controlling hypoxia.
- Since the 2001 Environmental Protection Agency (EPA) Hypoxia Action plan, nitrogen flux to the Gulf through the Mississippi River system has decreased by 21 percent, but phosphorous flux to the Gulf has increased by 12 percent. Since 2001, however, the size of the hypoxic zone has not decreased, indicating that there may be other, as yet unidentified point sources that are also contributing to hypoxia. The 2008 EPA Hypoxia Action Plan draft calls for a 45 percent reduction of both nutrients to reduce the size of the hypoxic zone.
- Midwestern farmers have continued to conserve land, restore and enhance wetlands, practice better nutrient management and apply conservation farming techniques to more acreage. They have reduced the amount of nitrogen required for corn production.

Introduction

The largest area of oxygen depleted water in the Western Hemisphere lies off the coast of the Gulf of Mexico between the Mississippi and Atchafalaya Rivers (Fig. 1). It has suffered from severe oxygen depletion, or hypoxia, since the great flood of 1973 (1). The size of the hypoxic zone increased after the devastating flood of 1993. The area averaged from 3089 to 3475 miles² during 1985-1992, but doubled during 1993-1997 ranging 6178 to 7722 miles² (1). The current five year-average during 2003-2007 is 5654 miles², which is more than twice the size of the EPA Action Plan established goal (2).

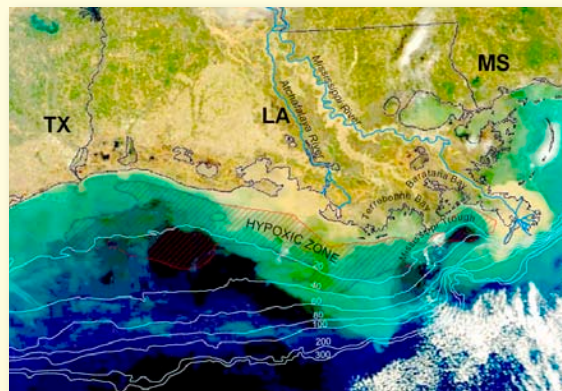


Figure 1: The measured hypoxic zone in 2002 showing the Mississippi and Atchafalaya Rivers that drains into the Northern Gulf of Mexico (1).

The hypoxic zone in the Gulf is said to be, "...absent most marine life and threatening to inexorably change the biology of the region..." (2). Hypoxic stress can disrupt or destroy aquatic ecosystems when dissolved oxygen drops below 2mg/L. Potential economic and ecological consequences of hypoxia have been suggested, but have not been quantified. The role hypoxia plays in fishery productivity in the Gulf of Mexico is not well defined. A negative correlation exists between hypoxic zone size and shrimp catching for Texas and Louisiana (3). In spite of the seasonal hypoxia, both states remain national leaders in shrimping, netting 64 percent of the U.S. total haul in 2004 (3). It is important not to forget that nutrient-enriched river waters, the hypothesized cause of hypoxia in the Gulf, enhance fishery productivity in the Gulf, with 70-80 percent of the fishery landings coming from waters surrounding the Mississippi Delta (4). The evidence for damage by hypoxia to commercial and recreational fishing resources in the Gulf is not strong, but hypoxia can encourage over-fishing by making commercial fishing easier, "...as shellfish congregate at the edges of the oxygen-depleted waters and become easier targets for fishing vessels" (5).

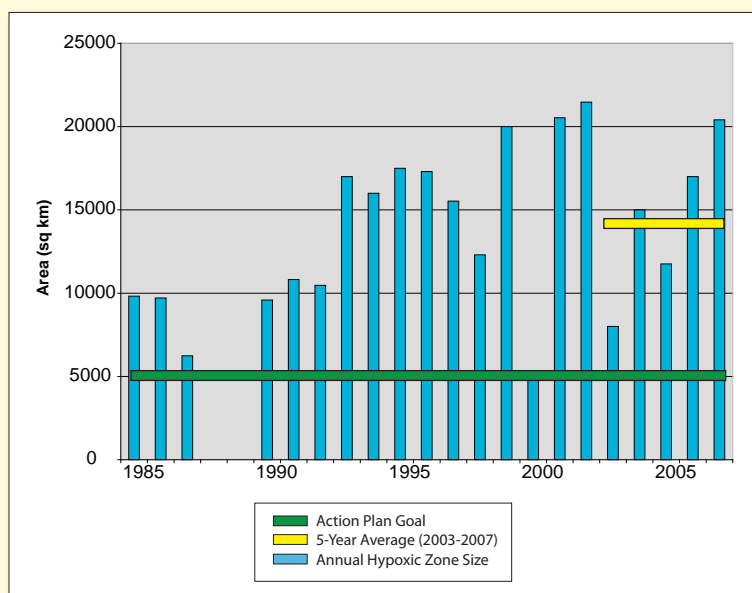


Figure 2: Size of Hypoxic Zone in the Gulf of Mexico from 1985 to 2007. Source: Draft Gulf Hypoxia Action Plan 2008; Web site: http://www.epa.gov/msbasin/taskforce/pdf/2008draft_actionplan.pdf

Over-fishing preceded all other human disturbances to coastal waters and is the most important human disturbance that impacts coastal communities (6). Hypoxia, climate change and disease are cited as some of the causes of recent collapses of U.S. coastal communities, when they may actually be a consequence of historic over-fishing. Over-fishing may often be a necessary precondition for eutrophication, outbreaks of disease or species introduction to occur (6). Jackson notes that oceans and coastal waters were not "mythical untouched wilderness" that has only recently deteriorated (7).

Fertilizers and Gulf Hypoxia

In any estuarine system, where fresh river water flows into coastal sea tides, hypoxia has the potential to occur. Two simultaneous processes contribute to hypoxia in the Gulf, *stratification* and *eutrophication*. Water stratification happens when warm fresh water does not adequately mix with cold, salty sea water and eutrophication occurs when water bodies receive nutrients. Estuarine waters are some of the most productive aquatic ecosystems because river inflow provides them with nutrients from drainage of urban and rural areas (8). An increase in nutrients is beneficial to a point. However, when nutrients reach an excess they can cause an algal bloom which can be detrimental to fish and other aquatic species (Fig. 3).

Like all estuarine environments, the Gulf of Mexico is naturally prone to bouts of hypoxia because of stratification. Marine sediments deposited in the eastern half of the hypoxic zone over the last 4600 years indicate periodic swaps between anoxic (absence or near absence of oxygen) and oxic (presence of oxygen) coastal waters in the Mississippi River delta long before the current hypoxia (1).

The assessment that eutrophication is causing hypoxia in the Gulf and that fertilizers are the source of the nutrients come from analyzing bottom sedimentary and nitrogen loadings (see 9, 10 for summary of research). Sediment provides a snapshot of the productivity of algae in the waters. Higher algal production overlapped with elevated nitrogen loadings to the Mississippi River, suggesting excess nutrients are altering ecosystems in the Gulf. This hypothesis was demonstrated over a 6 year period time from 1988 to 1994 (10). These authors noted the relationship between nutrient loading and production is likely not linear and difficult to predict, because a complete understanding of intermediate processes between organic matter production and oxygen depletion is lacking (11).

The increase of fertilizer usage in the Midwest after the 1950s is readily documented, but the nutrient loadings on the Mississippi River around this time and for the start of the century have been modeled and estimated from only a few years of actual data. This makes predictions of decadal trends and relationships and historical changes difficult. It is hypothesized that nitrogen levels have increased 5 fold since the 1950s. For example, to quantify changes in nutrients in the Mississippi River between the 1960s and 1980s, Justić et al. estimated levels for the 1960s using data from only 1960-1962 (12). Annual nutrient fluxes in the Mississippi and Atchafalaya River Basins (MARB) have only been collected since 1985 and they show a decrease in total nitrogen delivery down the river and a slight increase in phosphorous (Fig. 4). Nutrient fluxes vary greatly from year to year because of differences in precipitation. Stream-flow and nutrient flux are strongly correlated suggesting that managing waterways instead of nutrients may be more important to mitigating hypoxia (Fig. 6 in 13).

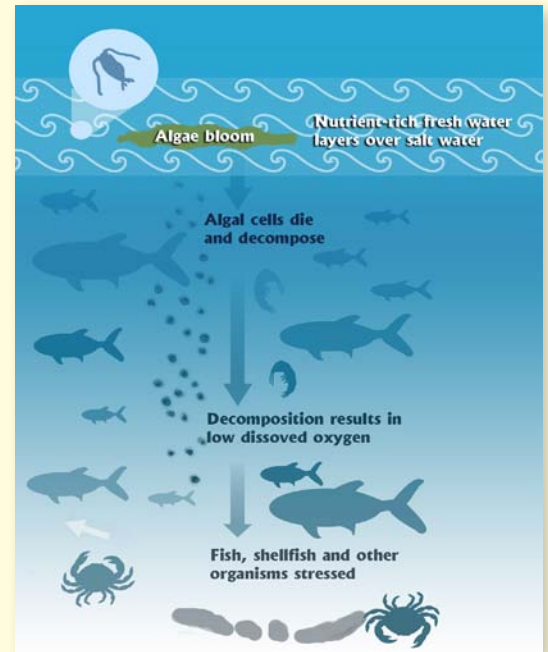


Figure 3: Stratification and run-off leads to nutrient-rich fresh water that sits on top of salt water, providing an environment for excessive algal growth. As algae cells die and decompose, dissolved oxygen in the water is depleted, creating a hypoxic stress for marine organisms. Source: LaCoast, <http://www.lacoast.gov/watermarks/2004-09/1hypoxia/index.htm>.

Changes to the Mississippi and Atchafalaya River Basins

Anthropogenic, man made changes to the watershed of the MARB have accelerated the flux of nutrients to the Gulf. According to the draft of the 2008 EPA Hypoxia Action report, “historic landscape changes in the drainage basin, primarily losses of freshwater wetlands, and increases in artificially drained areas...” have diminished the ability of the river basin to remove nutrients (2). Channelization and impoundments of the Mississippi River throughout the basin and delta have intensified stratification. Loss of coastal wetlands allows freshwater from the MARB to more directly flow into the Gulf. Erosion in the Mississippi River delta, during 1983 to 1990 was estimated to be 25.37 miles² per year (1). Erosion not only puts organic matter directly into the waters near the hypoxic zone, but it also intensifies summer stratification by increasing the volume of warm fresh water that is delivered to the hypoxic zone (1).

Construction along the Missouri River, which accounts for 45 percent of the total flow of the Mississippi River past St. Louis, Mo., has also put organic matter into the waters (14). At a river chute restoration project on the Missouri River near Jameson Island in Missouri, the Army Corp of Engineers sent approximately 5.4 million tons of soil, which consisted of an estimated 11.1 and 9.3 million pounds of nitrogen and phosphorous, respectively, into the river (15). Eight additional sites on the Missouri River are scheduled to dump soil directly into the water.

Significant changes to the MARB occurred in 1963 and 1973. In 1963, the Army Corp of Engineers constructed the Old River Control Structure at the divergence of the Mississippi and Atchafalaya Rivers. The Atchafalaya River, which has a shorter and steeper course to the Gulf of Mexico, had slowly been capturing flow from the Mississippi for centuries (1). The structure fixes the distribution between the two rivers at 70 percent and 30 percent for the Mississippi and Atchafalaya respectively. If the Corp of Engineers had not intervened, then the Atchafalaya River would have completely overtaken the flow of the Mississippi River by the 1970s and New Orleans would have been bypassed. Transportation and large-scale development would not have been possible and the city would have lost its economic importance (16).

The Atchafalaya River basin did not drain into the Mississippi River until the Great Flood of 1973. Now, it is the fifth largest ocean discharging river in North America, directly discharging freshwater and sediment to the center of the hypoxic zone (1). The occurrence of seasonal hypoxia since the breakthrough of the Atchafalaya is not a coincidence “...the massive increase of Atchafalaya River sediment starting in 1973 increased oxygen demand in the hypoxic zone through the influx of organic matter and nutrients,” (1).

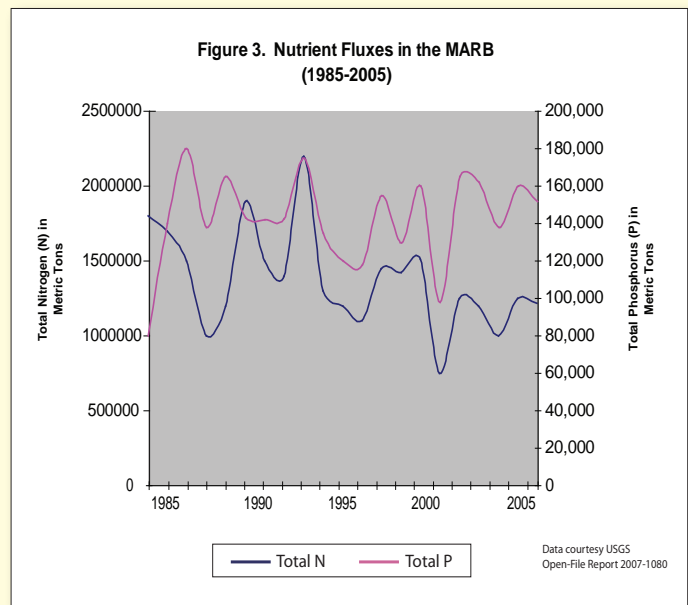


Figure 4: Nutrient Fluxes in the MARB from 1985-2007.

Other Sources of Nutrients

Nutrients may be transported as water moves across the land or through the soil from agricultural nonpoint sources. Other important nonpoint sources include residential fertilizers and detergents and storm water run-off. Point sources of pollution, such as industrial waste, are discharged or disposed of directly into waterways. The most recent estimates of the sources of total nitrogen and phosphorous flowing down the MARB suggest that agricultural sources, including livestock and crops, contributed more than 70 percent of the delivered nitrogen and phosphorus (17). Corn and soybean cultivation contributes 52 percent of the nitrogen; whereas, urban sources were estimated to contribute 9 percent of the nitrogen and 12 percent of the phosphorus.

The 2001 EPA Hypoxia Action report called for an investigation into point sources and the 2008 assessment notes, “additional analysis of detailed nutrient contributions from multiple sectors, including point sources and non-agricultural contributions needs to be undertaken” (2). The issues cities face managing sewage water must be considered. The city of Milwaukee unintentionally dumped 4.6 billion gallons of untreated sewage water in Lake Michigan after heavy rains in 2004, (18). Recently, the EPA and the Missouri Coalition for the Environment have filed lawsuits against the Metropolitan St. Louis Sewer District for illegally dumping millions of gallons of sewage into rivers and waterways below St. Louis (19, 20). The EPA estimates that about 860.5 billion gallons of sewage is dumped yearly into rivers and lakes nationwide (18).

Ironically, most point sources in the MARB, which would likely be easier to control than nonpoint sources, are not required to remove nitrogen or phosphorous from discharged waters from their operations (21). Additionally, managing point-sources has been shown to be cost effective and more predictive than implementing best management practices for nonpoint agricultural sources (21). Small changes in management to point sources of pollution in urban areas may have a large impact on nutrient loading. Unlike nonpoint agriculture sources, where the transport mechanism of nutrients from soils to waterways is being elucidated and best management practices to reduce run-off are being determined, biological nutrient removal and enhanced nutrient removal technologies are readily available and just need to be implemented.

Pollutants can also be deposited from the atmosphere. Nitrogen from the atmosphere comes from burning fossil fuel for transportation, generating electricity and from volatilization of agricultural sources like animal wastes (5). It has previously been suggested that 40 percent of all nitrogen pollution reaching U.S. coastal waters comes from atmospheric deposition (5). The Chesapeake Bay, which also suffers from hypoxia, was estimated to have equal contributions of atmospheric deposited nitrogen and nitrogen from agricultural sources (5). So far, atmospheric deposition has been estimated to contribute 16-18 percent of total nitrogen flux in the MARB (17).

Hypoxia Policy and Outcomes

Because research pointed to nutrients as the primary cause of hypoxia, a “no regrets’ approach to implementing fertilizer and land-use controls in the MARB,” was taken (1). To shrink the hypoxic zone to an annual average of 1931 miles², the 2001 Hypoxia Task Force Action Plan called for a 30 percent reduction of average total nitrogen flux from the MARB into the Gulf for 2001-2006 (22).

Since that report, nitrogen flux to the Gulf decreased by 21 percent for 2001-2006 in comparison to 1980-1996 baseline averages; while the average phosphorus flux to the Gulf increased by 12 percent from 2001-2006 in comparison to 1980-1996 averages (2). The draft of the 2008 Hypoxia Action Plan now calls for at least a 45 percent reduction of both total nitrogen and phosphorous flux to the Gulf.

Although nitrogen flux to the Gulf was reduced, the average size hypoxic zone for this period did not decrease. The current five year average (2003-2007) is 5654 miles² (2). For the summer of 2007, the zone stretched 7915 miles², the third largest area recorded (2). The draft of the 2008 report acknowledges that, “...uncertainties remain in the ability to characterize the spatial and temporal dynamics of hypoxia and the biological, chemical, and physical properties that contribute to it,” (2). Judging the success of the EPA’s strategy by the size of the hypoxic zone does not tell the actual nutrient reduction success story that has occurred.

Better Management Practices

Since the 2001 EPA Hypoxia Action Report, 42.8 million acres of land were put under conservation tillage and improved nutrient management or were used to restore, enhance or create wetlands (2). Conservation tillage provides agriculture a tool for clean water management because it protects the soil from water and wind erosion and reduces nutrient run-off. Conservation tillage reduces rainfall run-off by more than 60 percent and soil loss by more than 90 percent (23). The 2006 survey by the Conservation Tillage Information Council of farmers' management practices found that about 55 percent of farmers surveyed practiced conservation tillage and 77 percent are engaged in crop residue management (24).

Over the last decade, net nitrogen and net phosphorous inputs for the MARB have declined because of more efficient use of fertilizer, as evidenced by increasing corn yields and constant or declining fertilizer application rates (2). The use of enhanced efficiency fertilizers, such as slow- and controlled-release fertilizers and stabilized nitrogen fertilizers has reduced nitrogen loss and improved crop yields. Better nutrient management practices and conservation tillage have reduced the flux of nutrients to the Gulf; however, the hypoxic zone has not shrunk. Nitrogen use efficiency has increased over the past decades (Tab. 1). Nitrogen use efficiency will continue to improve with better land management, fertilizer application practices and improved genetics.

In a study looking at nitrogen use from 1949 to 1997, the Upper Mississippi River Valley, which is considered the main contributor of nutrients to the Gulf, was shown to be the most efficient region (25). It reduced its amount of excess nitrogen available for run-off from 30 percent to 15 percent. All regions in the Midwestern Corn Belt had lower levels of excess nitrogen available for run-off in 1997 than 1949. The authors note that changes in nitrogen utilization in the Corn Belt seem like they would have the greatest effect on nitrogen loads in streams; however, these regions are already the most efficient and the changes needed to have an effect on the Gulf, "... may be so dramatic that they cannot be attained with existing technology, policies, and economics," (25). Technology that further reduces run-off and improves profitability is being developed. It remains uncertain if decreases in nutrient loadings will reduce the size hypoxic zone.

Production		1980	2005	Change (%)
Corn Acres Planted	(million)	84.0	81.8	-2.6
Corn Acres Harvested	(million)	73.0	75.1	+2.9
Corn Yield	(bu/acre)	91.0	148.0	+62.6
Total Production	(mil. bu.)	6,639	11,114	+67.4
Nutrient Use Per Bushel				
Nitrogen per bushel	(lbs./bu.)	1.567	0.972	-38.0
Phosphate per bushel	(lbs./bu.)	0.874	0.432	-50.6
Potash per bushel	(lbs./bu.)	0.874	0.396	-54.7
Aggregate Nutrient Use				
Total Fertilizer Used	(mil. tons)	10.6	9.6	-10.0

Table 1. Changes in corn production and nutrient use from 1980-2005, Sources: USDA, The Fertilizer Institute.

The greatest strides in nutrient management will continue to come through local private and public partnerships that determine best management practices of nutrient application and waterways. The Great Rivers Partnership Program of the Nature Conservancy shows successful examples of private and public partnerships that have helped farmers learn how to reduce nutrient run-off without compromising productivity. Currently there are integrated projects run by the Nature Conservancy that involve farmers, industry and the government along the following waterways: Boone River, IA; Mackinaw River, IL; Pecatonica River, WI; Root River, MN (26). In total, 850 agricultural producers are involved in these projects.

Managing water and not agricultural inputs will result in the largest reduction to nutrient loading, because fertilizer rates will generally stay the same or decrease. Moreover, in drought stricken years nitrate levels in waters drop dramatically even though nitrogen application rates were constant. It is hypothesized that a majority of nitrate leaving crop fields may leave through tile water. The Nature Conservancy has partnered with an agricultural drainage company, Agreeem, to investigate a closed loop drainage system that removes nitrates before over flow rain water is delivered to streams (26).

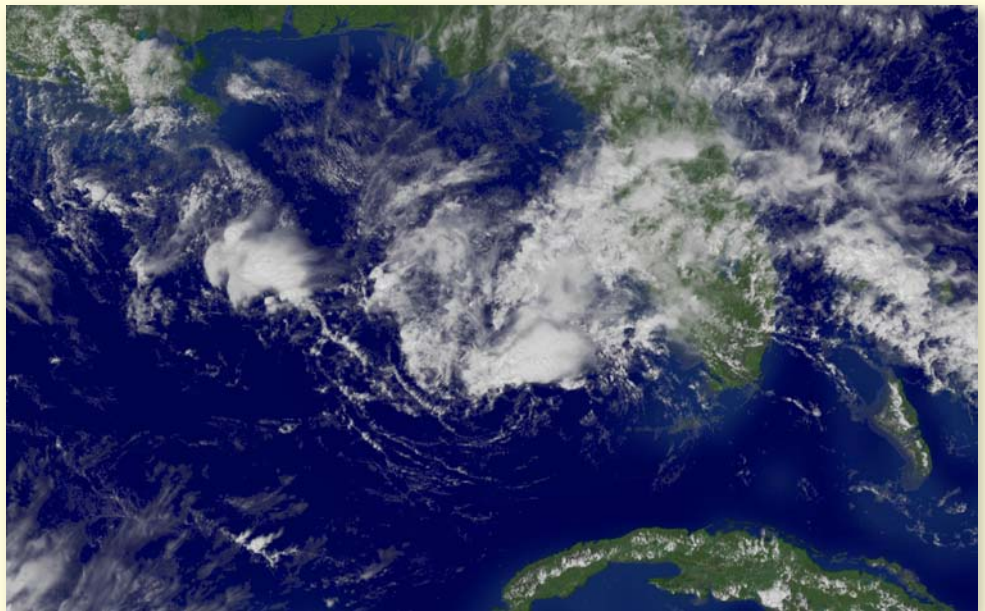
Conclusion

Hypoxia in the Gulf of Mexico remains a complex environmental issue resulting from natural and man-made events. Naturally occurring stratification, which has been intensified by man-made changes to the flow of the Mississippi River, plays an important role in summertime hypoxia formation in the Gulf. Nutrients moving from urban and rural landscape of the Midwest and ultimately to the river waters of the Mississippi and Atchafalaya rivers have led to eutrophication of the Gulf. Additionally, the great floods of 1973 and 1993, the massive amount of wetland loss in the MARB and the continuous river-changing event of the Atchafalaya River taking over the Mississippi River have all contributed to the occurrence and extent of hypoxia in the Gulf. While the contribution of such events is difficult to quantify, they have no doubt increased the efficiency of sediment transfer down the MARB to the Gulf. It is more important to remember that floods, erosion and the overtaking of the Mississippi River are still occurring and still contributing to seasonal hypoxia in the Gulf.

Agriculture may contribute to eutrophication of the Gulf of Mexico, but it is not alone in delivering nutrients to the MARB. Many contributors of nutrients to the Gulf have yet to be identified. The Science Advisory Board noted in their recent update of hypoxia, “Sewage treatment plants and industrial dischargers represent a more significant source of N and P in the MARB that was originally identified in the Integrated Assessment,” (21). Unlike many point sources

of nutrients in the MARB, which are not legally bound to remove nitrogen or phosphorus from their discharge into water systems, farmers and agricultural companies are voluntarily investigating and implementing ways to control run-off and working to deliver better nutrient management.

Policy, thus far, has focused on nutrients from agricultural sources and called for a reduction in nitrogen in the MARB, in order to reduce the size of the hypoxic zone. A decrease has occurred for total nitrogen in the MARB, but hypoxia in the Gulf has only grown. This result needs to be explained, for it calls into question the relationship between nitrogen in the MARB and the extent of hypoxia in the Gulf. Research and policy now include phosphorus as a nutrient that must be controlled to mitigate hypoxia. Now, to reduce the hypoxic zone, a 45 percent reduction of both nitrogen and phosphorus has been suggested (2).



Corn-based ethanol production is proposed to exacerbate hypoxia in the Gulf, because of increases in corn acreage (28). It takes less nitrogen to produce a bushel of corn today than in the past because of better hybrids and more efficient nutrient applications. Future studies should look at the changes in nitrogen loss per acre of corn over the past decades. It is possible that the amount of nitrogen that can potentially be lost from the 89 million acres of corn that will be planted in 2008 is no greater and likely less than amounts of nitrogen estimated to have been lost by past years' corn crops.

Whether or not the hypoxic zone in the Gulf of Mexico shrinks over the coming years, Midwestern farmers will continue to do their share, by meeting growing global demands for food, feed, and fuel in more sustainable ways. They will produce more with a smaller total footprint: less land, less inputs, and less run-off into the nation's critical water resources.

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