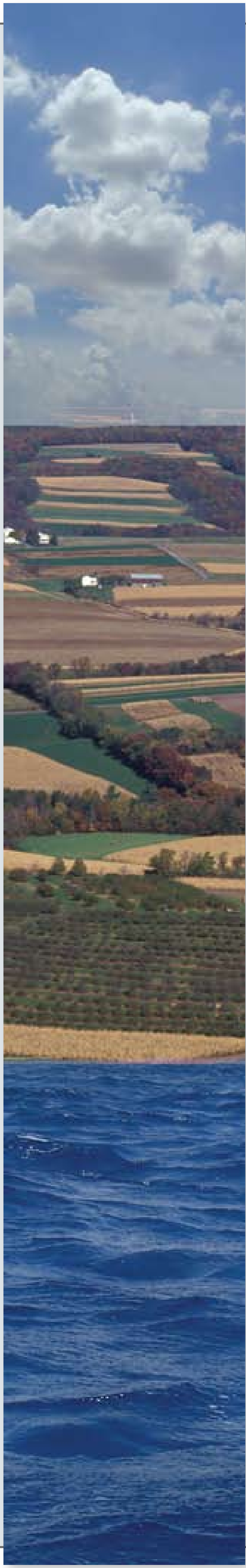

Hypoxia in the Gulf: An Analytical White Paper

Executive Summary

In recent years, there has been great uncertainty regarding the cause of the hypoxic zone (low oxygen) in the northern Gulf of Mexico. This has often been the result of a lack of data to support many of the prevailing theories regarding the size, duration and source of the problem. This paper looks at the available information and draws the following conclusions.

First, the hypoxic zone is seasonal. While localized effects can be severe, vast "dead zones" with widespread negative effects on the fishing industry may be overstated. On the contrary, it is possible that the water flow from the Mississippi-Atchafalaya River Basin (MARB) delivers the basic nutrients required for the very existence of the northern Gulf fishing industry.

Second, fishing data since 1985 shows no negative impact nor any clear relationship between the fish catch, the flow of water through the MARB or the size of the seasonal hypoxic zone.

Third, there is also no clear evidence of a relationship between nitrogen and the size of the seasonal hypoxic zone. In recent years, as corn production has become more efficient and yields have increased, the nitrogen removed from corn fields in the grain may equal or exceed the amount of nitrogen applied in the fertilizer.

NCGA
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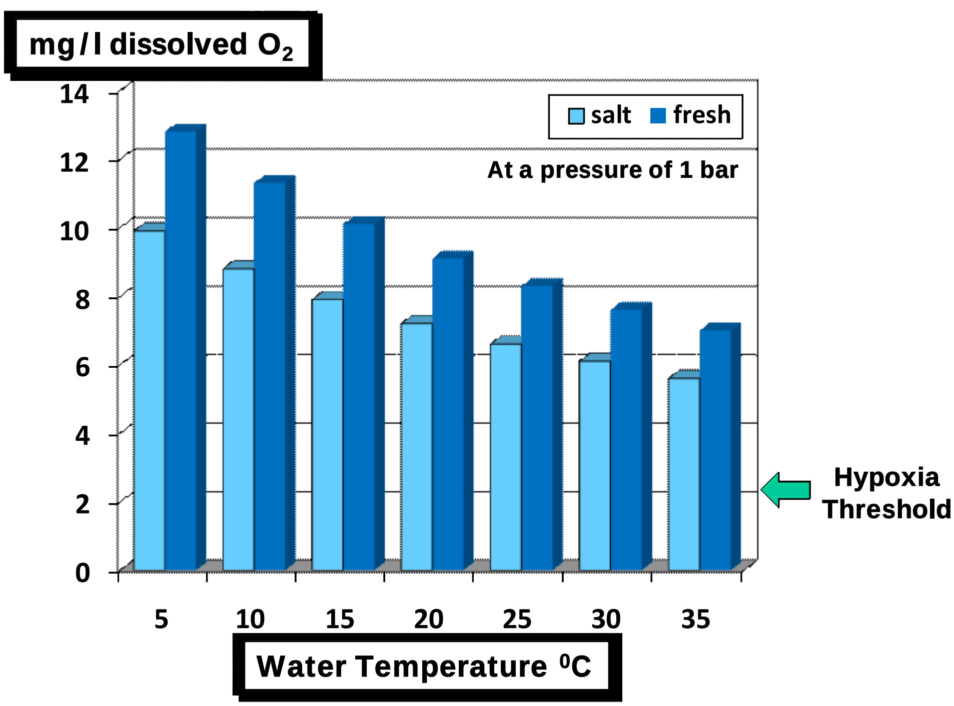
Hypoxia in the Gulf: An Analytical White Paper

For NCGA by StrathKirn Inc. April 2009.

CONTENT

1. What is "Hypoxia"?

Hypoxia literally means low oxygen which, in aquatic situations, is typically less than 2 parts per million (2 ppm O_2), or 2 milligrams per liter (2 mg O_2/l)(USGS, 2009). The normal concentration of O_2 in water is primarily a function of the partial pressure of oxygen over the water, the temperature of the water, and the salinity of the water. Saltier water and warmer water hold less O_2 but usually have sufficient O_2 to be above the hypoxia level. The relationship for dissolved O_2 is:



When hypoxia occurs, fish and other aquatic animals become stressed and will attempt to move out of the zone. Mass death occurs at O_2 levels of 0.5 – 1.0 mg/l.

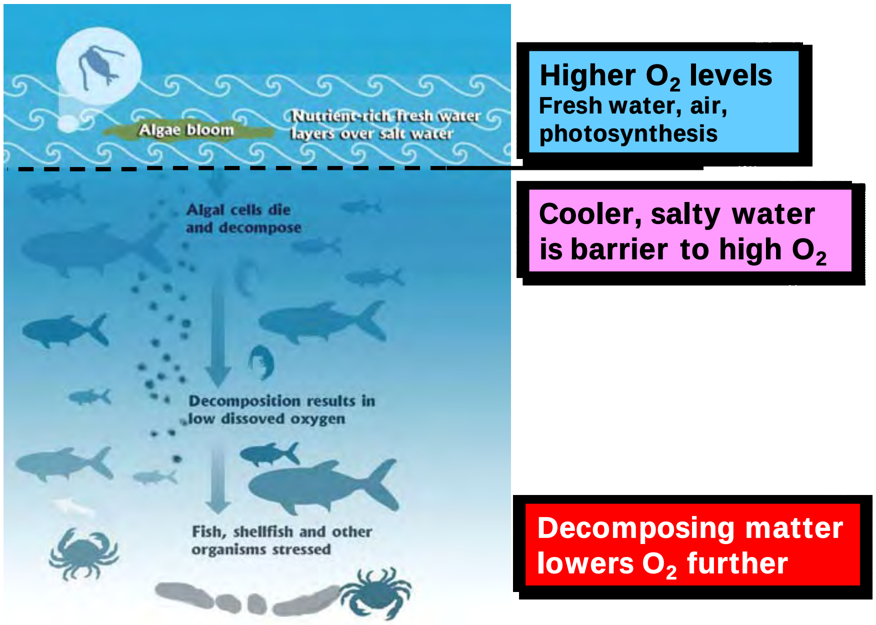
Hypoxic zones are often misnamed as "dead zones": truly dead zones are anoxic with almost zero O_2 and may cause less seasonal death since fish and animals avoid these areas. Hypoxic zones that are problematical are typically highly fertile areas with hypoxic development on a seasonal basis. The occurrence of such hypoxic zones is dependent on two major natural processes occurring simultaneously, eutrophication and stratification in the water body.

Eutrophication is a process whereby incoming water flows carry nutrients that stimulate considerable growth of algae (although in lakes water plants may also be stimulated into atypical growth). Such areas are highly fertile and can support higher fish populations due to photosynthetic production of food (carbohydrates, proteins, lipids, etc.). Higher photosynthesis also produces more O_2 which may dissolve in the water, dependent on the temperature, salinity, and existing O_2 content. In cases where the growth is greater than the capability for immediate utilization in the natural food-chain then an “algal bloom” occurs.

One of the factors that can initiate an algal bloom is the sudden inflow of a larger than normal concentration of nutrients, or other algal growth promoting substances (e.g. diatoms require silica). Nutrient inflows can arise from many sources, such as erosion of soil containing nutrients, or from sewage treatment plant discharges, or from fertilizers applied to agricultural fields, golf courses, and suburban lawns, or even as nitrogen from the atmosphere or subsurface leakage. Irrespective of the causal source, eutrophication can turn into a hypoxia problem if the eutrophication process occurs in combination with stratification.

Stratification is a process that occurs naturally due to water having different characteristics such as salinity or temperature, in an area where mixing is not occurring (e.g. static water, lack of storms, can encourage stratification). For example, where a river with warmer fresh water enters the ocean (cooler salt water) it is typical for stratification to occur. Such stratification tends to inhibit movement of O_2 into the lower salty zone due to density differentials, plus fresh water “holds” more O_2. In addition, the movement of carbon from above – as large amounts of dead algae and fish feces sink – results in utilization of lower level dissolved O_2 by the microbes that decompose the sinking carbonaceous matter. The net result is a lowering of the O_2 in the lower strata and the consequent development of hypoxia.

The combined effect of eutrophication with stratification is depicted in the following diagram:



Adapted from "Hypoxia", NCGA report 2008

Gulf of Mexico Hypoxia

The zone on the continental shelf along the Louisiana-Texas coast shows seasonal hypoxia to a varying degree each year. During most of the year, the oxygen-rich water reaches the bottom and hypoxia is not present. However, during early summer, the surface and bottom waters of the Gulf stratify into two layers. Basically, fresh, warm, and less dense water from the Mississippi and Atchafalaya river basin (MARB) spreads out on the surface of the deeper and colder Gulf water. Calm winds and warm sunshine prevent the layers from mixing thoroughly. With less mixing, the incoming nutrient concentration increases and the algae grow rapidly, feeding a large zooplankton and fish population.

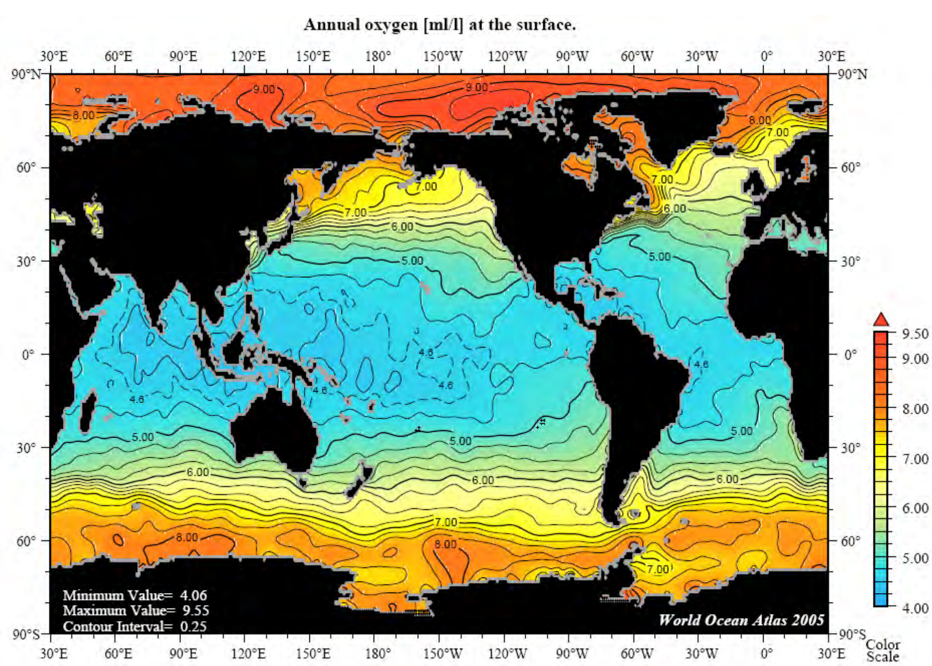
As the cycle progresses, the organic matter, such as dead algal cells, zooplankton and fish feces, sinks to the lower layer where it decomposes, consuming available oxygen and initiating hypoxia. In some years, the hypoxia has been claimed to reach the surface although it is not clear how this occurs from the natural process. In the Fall, the Gulf storms mix the water, stratification is lost, and hypoxia disappears till the next Spring cycle.

2. The Occurrence of Hypoxia.

Reports of hypoxia have increased over the past 30 years, and now cover many locations across the world with several causal factors being involved (Diaz and Rosenberg, 2008). Clearly the ability to detect hypoxic zones has increased and there is a growing understanding of the complex factors involved in generating the hypoxic condition. Ecosystem processes are driven by several factors and observed changes are usually the result of a combination of factors working together. For example, some hypoxic areas, in the Black Sea, have arisen from the combination of eutrophication plus stratification, plus overfishing plus invasive species. In some cases, it is believed that anthropogenic impact has occurred: for example, increased eutrophication due to nitrogen entering a marine ecosystem from an adjacent river (Goolsby *et al*, 2001). In other cases, the currents and natural upwelling of nutrients results in massive and continuous hypoxic zones, such as in the Eastern tropical Pacific Ocean.

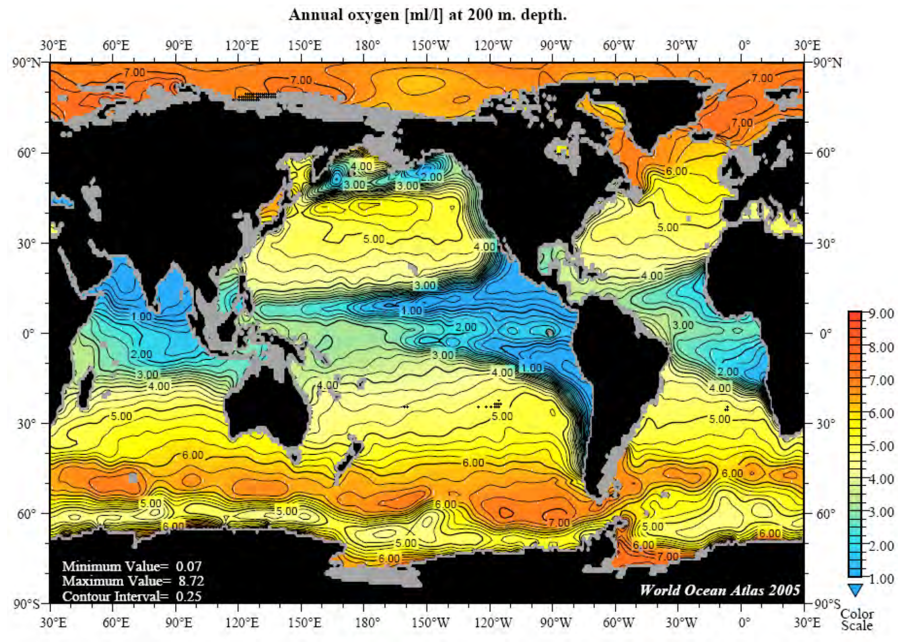
In the following charts, the global oceans are shown with data, having been extracted from the National Oceanographic Data Center, for oxygen and nitrate situations (NODC, 2009). Hypoxia would occur at 1 - 1.5 ml/l (~2 mg/l) O_2. It should be noted that while hypoxia conditions can be observed in various locations, the Gulf of Mexico does not show up as having hypoxia when viewed relative to the global situations.

While nitrogen (N) and phosphorous (P) contribute to eutrophication the relative sources of these nutrients are not always well understood. Some believe that the MARB delivers a massive amount of N and P that arises from agricultural fertilizer use. If this were the case then the Gulf should show up quite clearly as having high concentrations of N and P relative to the natural concentrations in other regions of the ocean. These charts provide a comparative observation of the relative concentrations.

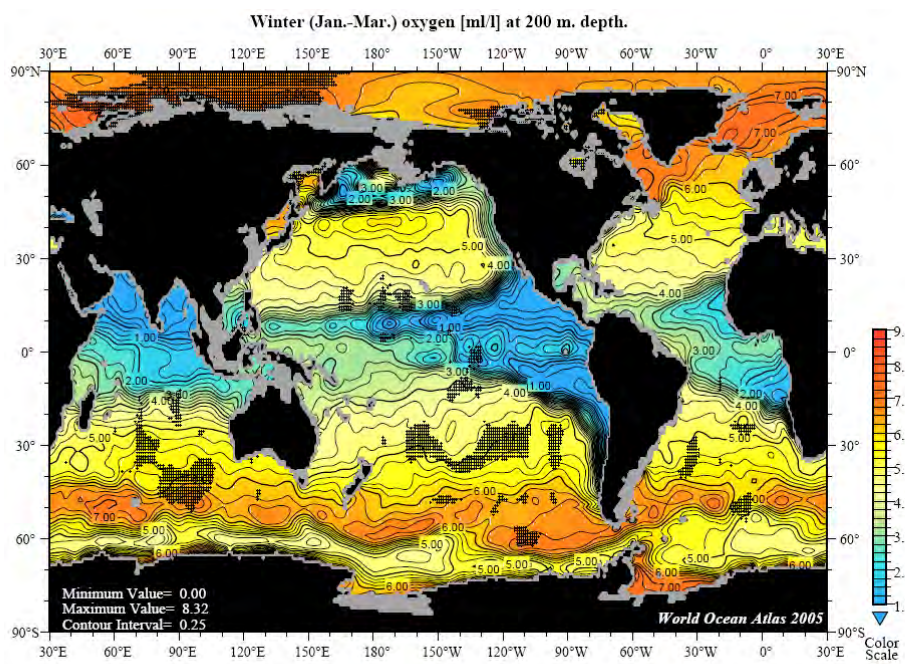


Annual oxygen in the oceans of the world at the surface – no hypoxic conditions are observed.

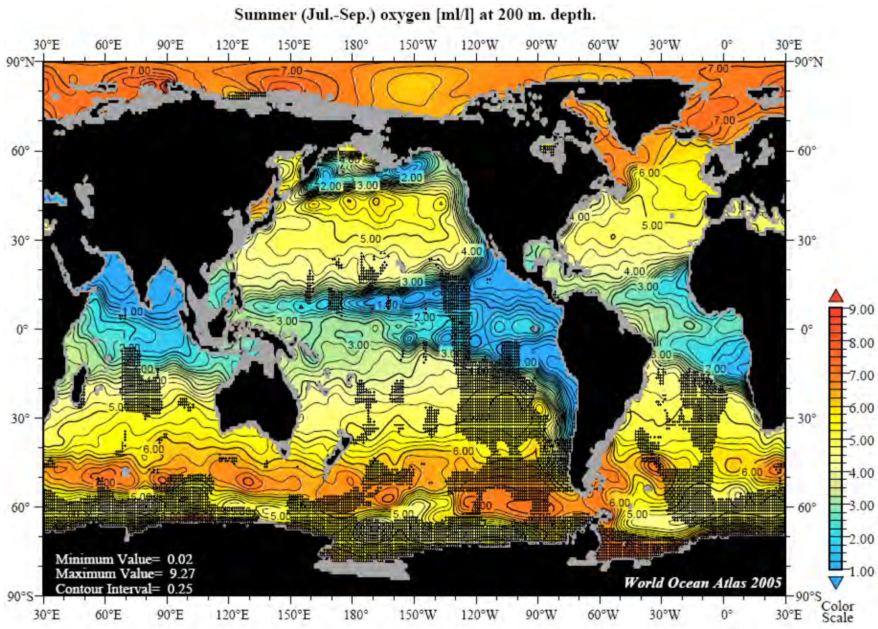
At 200m depth (equivalent to the continental shelf in the northern Gulf) there are natural hypoxic conditions in the Pacific and Indian Oceans, but no hypoxic conditions visible in the Gulf.



The local hypoxia reported in the Gulf is seasonal and, when present, it shows up only in the summer. Therefore, the annual global data on a

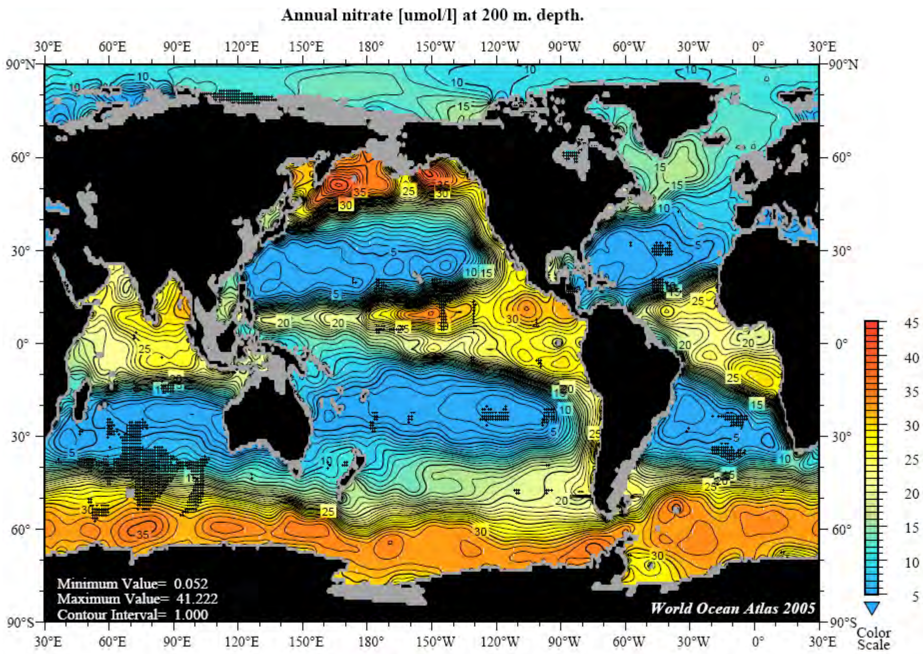


scale (above) may have missed this. The following charts are for ocean oxygen data in winter and in summer, for comparison. Again, the Gulf does not show up relative to the global presence of hypoxic conditions:

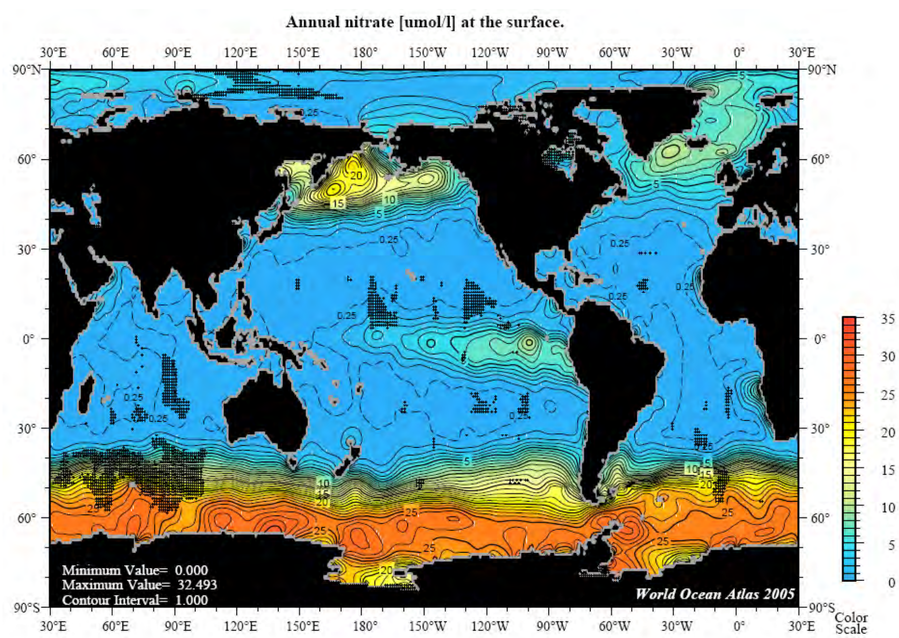


And for the summer months, at 200m depth, the Gulf does not show-up as being hypoxic, on an ocean-wide scale even although several other regions clearly show natural hypoxia.

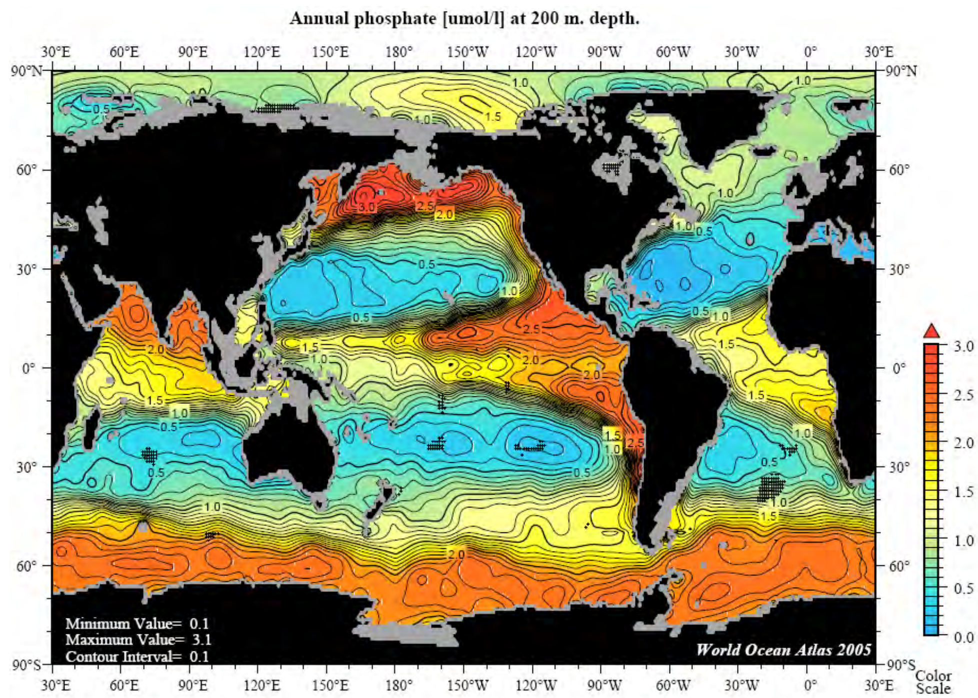
Annual nitrate concentration in the oceans of the world, showing that in some locations nitrate

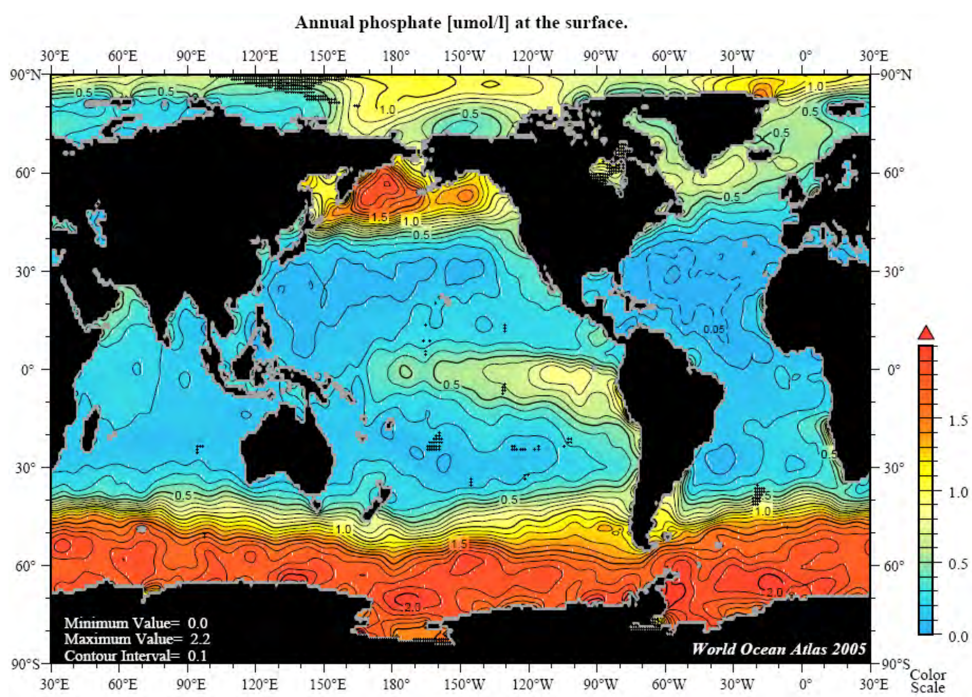


concentration can be relatively high. In the Gulf region, nitrate does not show up as being high compared with many other areas of the oceans.



Annual phosphate concentration in the oceans of the world, showing that in some locations phosphate concentration can be relatively high. In the Gulf region, phosphate does not show up as being high compared with many other areas of the oceans.





Occurrence of the Hypoxic Zone in the Gulf.

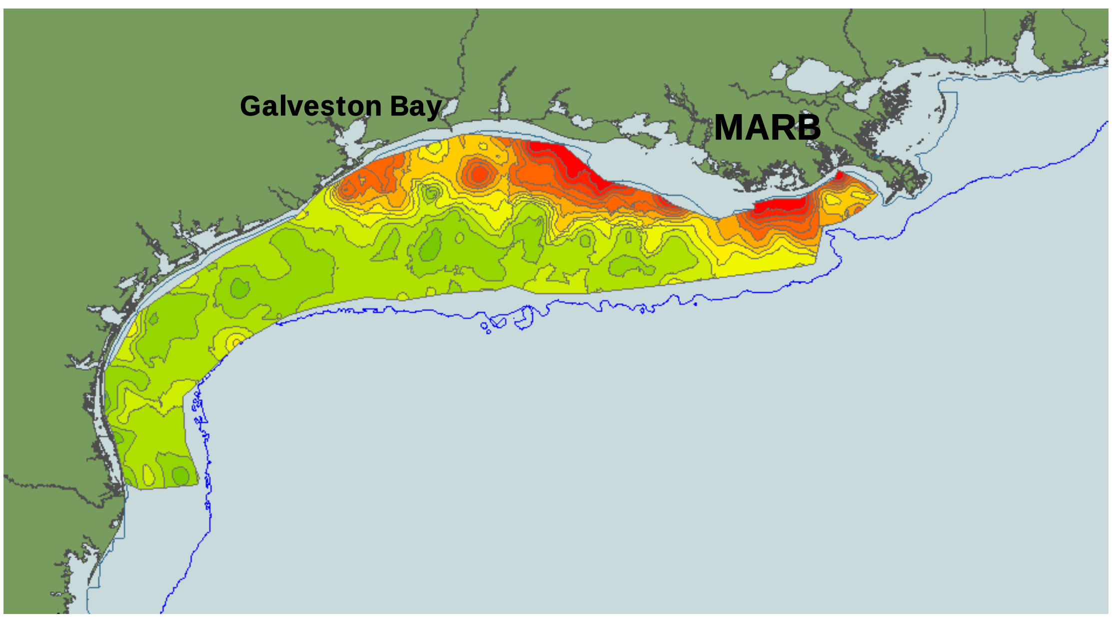
Local observations indicate that a seasonal hypoxic zone occurs in the vicinity of, and to the west of, the MARB outflow, and that the area of the zone varies on an annual basis from 2,000 – 8,000 square miles. This area is not sufficient to show-up compared to the large areas of natural hypoxia on a global scale, but has become of sufficient concern to have multiple federal and local government agencies be involved in research to better understand the phenomena and to monitor for annual changes.

In 1997, the U.S. Environmental Protection Agency (EPA) formed the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force and asked the White House Office of Science and Technology Policy to conduct a scientific assessment of the causes and consequences of Gulf hypoxia through its Committee on Environment and Natural Resources (CENR). A Hypoxia Working Group was assembled from federal agency representatives, and the group developed a plan to conduct the scientific assessment. The National Oceanic and Atmospheric Administration (NOAA) has led the CENR assessment, although oversight is spread among several federal agencies. Initially, 6 reports were developed – see Rabalais *et al* (1999). The objectives remain to provide scientific information that can be used to evaluate management strategies, and to identify gaps in our understanding of this complex problem.

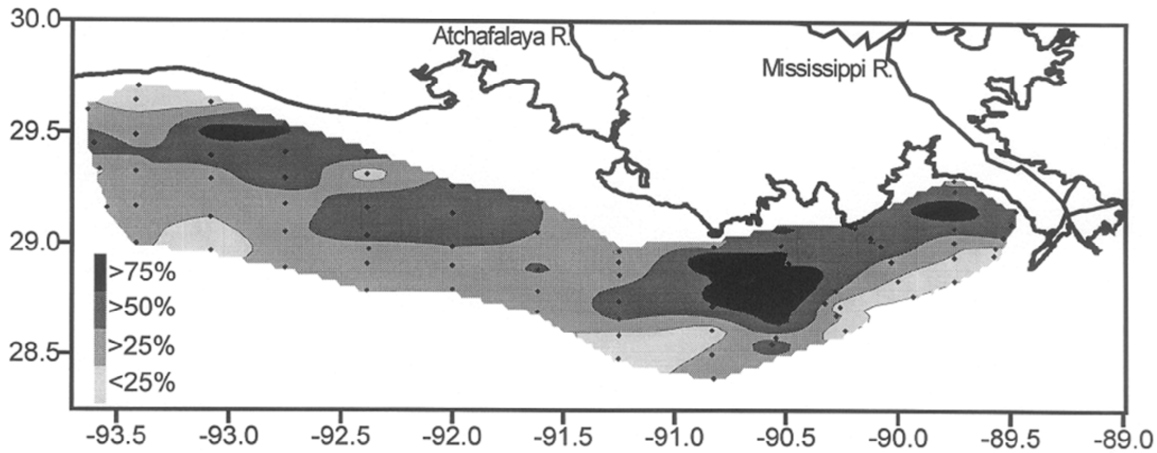
A monitoring grid across the Northern Gulf on the coastal Louisiana continental shelf is used to monitor for seasonal hypoxia every year. There appears to have been an increase in hypoxia area and/or occurrence from the 1960's up to the early 1990's, but the area impacted has not increased since then, and is much smaller in some years.

The region of the Gulf impact by seasonal hypoxia is relatively small and is confined to the northern coastal Gulf, just west and down-current from the MARB discharge:

On a higher resolution scale the seasonal hypoxic region appears to be non-uniform across the impacted area, and seems to occur more in location closer to the shore:

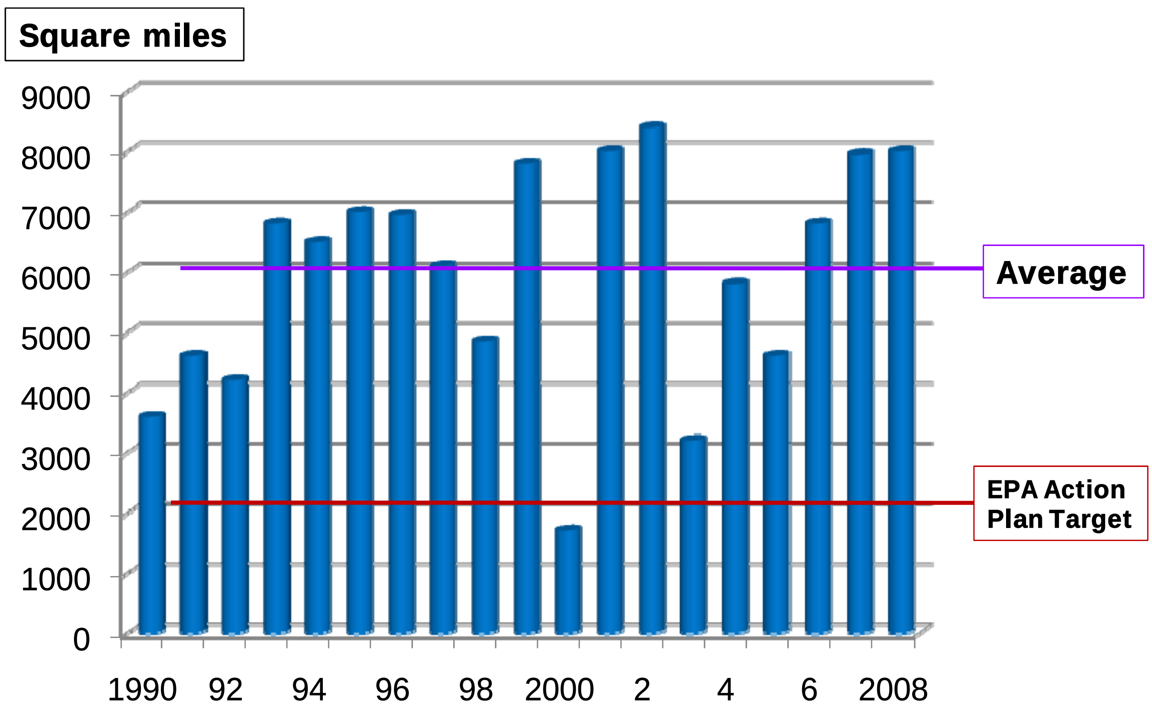


The existence of hypoxia at any one location within this area also varies from year-to-year, as is show in the following frequency diagram from Rabalais *et al*, 1999:



Distribution of frequency of occurrence of mid-summer hypoxia over the 60- to 80-station grid from 1985 to 1997.

The total estimated area impacted by seasonal hypoxia also varies from year to year:



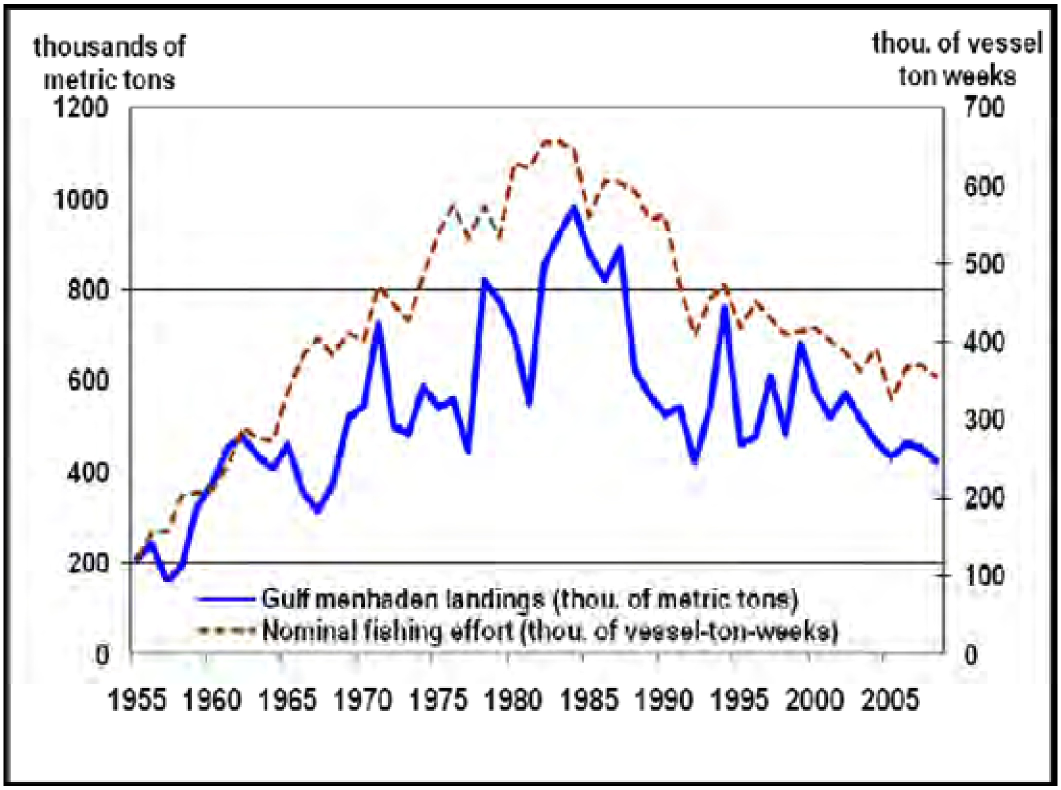
Note that while the severity and area impacted vary considerably on an annual basis, there is no evidence of a continuing increase in the hypoxic zone since 1993. The EPA Action Plan has a target goal of reducing the observed hypoxia zone to less than 5K sq km (~2,000 sq miles): this target is severe since the zone has seldom been at this level since measurement began, and the long-term natural baseline area is unknown.

3. Fish Catch in the Northern Gulf Region

A) Menhaden

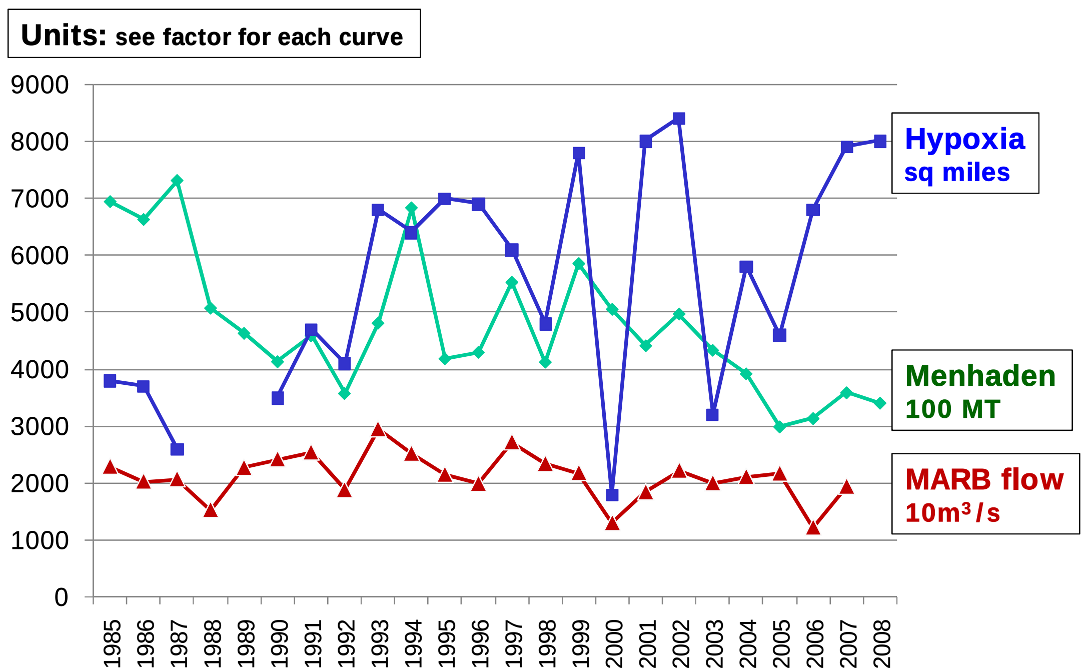
Gulf menhaden (*Brevoortia patronus*) is an estuarine-dependent marine species of fish that inhabits the northern Gulf of Mexico. Juvenile and adult gulf menhaden inhabit estuaries throughout the year but most gulf menhaden migrate from estuaries into offshore marine waters in late fall and winter. Adult menhaden are filter feeders, eating vast quantities of phytoplankton (algae). Menhaden are a major food source for predatory food fishes that are caught in the Gulf, and are also caught themselves for processing into fish meal.

Gulf menhaden are taken in purse seines from off Mobile Bay, Alabama, to Galveston Bay, Texas. The catch is taken primarily from estuarine waters of Mississippi and eastern Louisiana and near-shore marine waters of southwest Louisiana and some from the Texas coast. In 2007, 45% of Louisiana menhaden landings by weight came from a distance of 0-3 miles from shore (NMFS, 2009). Menhaden represent the largest fishing enterprise by weight in Louisiana, and for the Gulf of Mexico: in 2008, landings totaled 425,442 metric tonnes from a fishing effort of 355,800 vessel ton weeks. The menhaden landings are closely related to fishing effort, as shown in the 1955-2008 statistics (NOAA, 2009):



It is notable that the fishing effort for menhaden expanded from the mid-1950's until around the mid-1980's. During this time we have no good data for the extent of the natural hypoxia zone in the area, or any trend, since hypoxia was measured only from 1985 onwards. We can see that, since around 1985, there has been less weight of menhaden landed. Whether or not the menhaden landings are a function of the available fish, or of the fishing effort being adjusted due to economic factors is not clear.

We have explored data from 1985 onwards for other possible relationships and have not found anything that is striking. The following chart shows the comparison of the measured hypoxia area, the menhaden landings by weight, and the flow of water from the MARB to the Gulf (NMFS, 2009; NOAA, 2009). The units have been adjusted to place the three curves on the same chart:



In the year 2000, the MARB flow was lower and the hypoxia zone was much lower yet in 2006 the MARB flow was also lowered but the hypoxia zone was not corresponding lower. Likewise there are years when the menhaden landings are high and the hypoxia zone is larger but the reverse is also true. While there does not appear to be a clear simple relationship among these three variables, there is perhaps a general view that the lower menhaden landings have occurred during a timeframe when the hypoxia zone seems to have reached a higher plateau.

Interestingly, several Atlantic states have prohibited purse-seine fishing of Atlantic menhaden due to over-fishing, and the fact that lower menhaden levels can have a detrimental effect. For example, according to Franklin (2007), menhaden are important “grazers” and accumulate nutrients (via feeding on the algae): he indicates that there is a connection between diminishing menhaden and increasing hypoxic dead zones, in particular in the Chesapeake Bay.

What is known is that menhaden eat algae and are in turn the food source for other fish. The MARB flow brings nutrients to the Gulf, algae are fertilized by these nutrients, and the food chain realizes a benefit – that has perhaps not been well accounted for in the overall picture. The menhaden catch is valued at $35-40MM/year in recent years and has been as high at $68MM/year, and a considerable amount of the nitrogen entering the Gulf in the water stream is removed again in the fish landings.

B) Shrimp

The N. Gulf shrimp catch is second in weight (~82K MT), behind menhaden, but is the highest in value at ~$280MM. Louisiana represents over 6o% (by weight) of the total shrimp and remainder is caught in Texas, or further out in federal waters. The state waters reach out to 3 miles off-shore and over 50% of the shrimp are caught within this limit.

Harvesting of shrimp is controlled by the Gulf of Mexico Fishery Management Council's Shrimp FMP. A moratorium on new shrimp fishing in federal Waters was established in March 2007 and all existing shrimp vessels had to obtain new permits. Shrimp is harvested with trawlers. According to Fishwatch (2009), trawling can affect the seabed in a variety of ways. Individual impacts may be relatively minor, but the cumulative effect and intensity of trawling may have long-term effects on bottom communities. Trawling for shrimp is annually prohibited in state and federal waters off Texas from mid-May to mid-July. In addition, commercial fishing for shrimp involves a large by-catch of non-target species, including red snapper.

There are two types of shrimp taken in Gulf fishing, with the weight of each being about equal:

1. Brown Shrimp (*Farfantepenaeus aztecus*)

   Population levels of brown shrimp are high. The condition of the brown shrimp stock is monitored annually and has not been classified as being overfished for over 40 years. The typical habitat is shallow water on soft bottoms of mud, sand, and shell: most abundant at less than 180 feet but occur as deep as 360 feet.

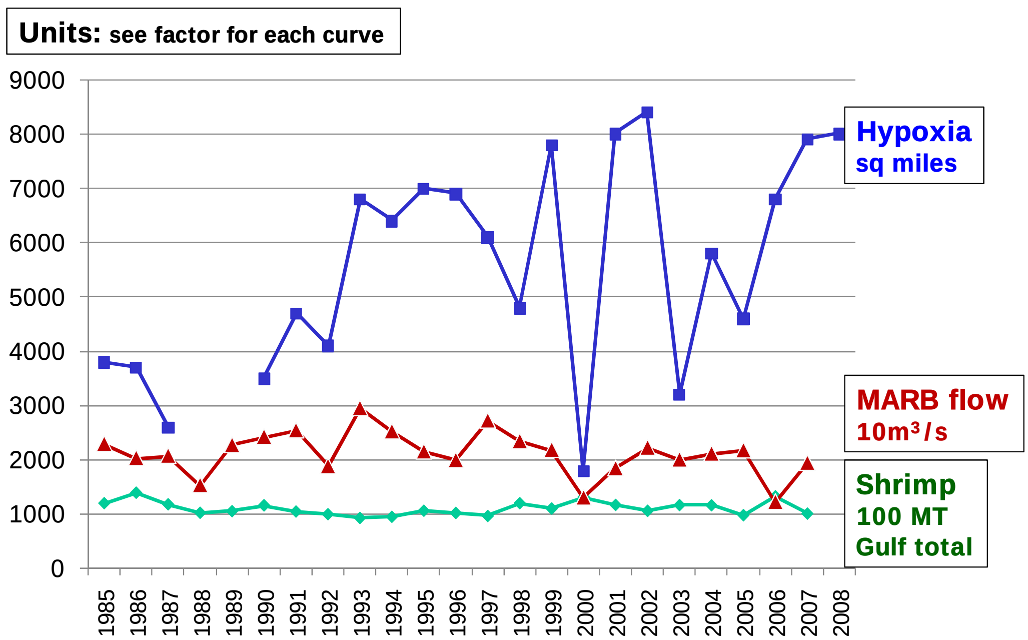
2. White Shrimp (*Litopenaeus setiferus*)

   Population levels of white shrimp are high, and overfishing is not considered to occur. The typical habitat is shallow water with a preference for muddy or peaty bottoms rich in organic matter and decaying vegetation in inshore waters, and soft muddy bottoms offshore. Usually in waters of less than 90 feet although occasionally found up to 270 feet. White shrimp enter the estuaries in April and early May and begin emigrating out to commercial fishing areas in August through December.

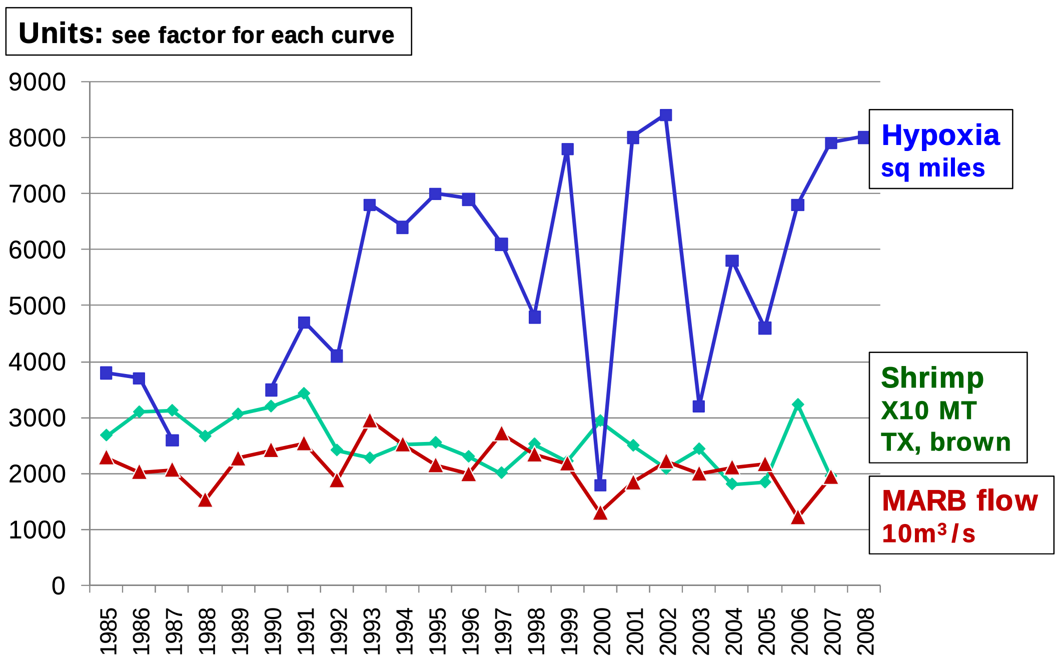
In previous studies and subsequent reports, it has been stated that:

> "Previous analyses have shown a negative relationship between hypoxic area and brown shrimp (*Farfantepenaeus aztecus*) catch for the Texas and Louisiana coasts combined from 1985 to 1997. Extending these analyses with data through 2004, we found that the correlation between hypoxic area and landings holds ($r = -0.52$), plus there was a significant negative relationship ($r = -0.59$) between hypoxia and shrimp landings for the Texas coast alone. "
> Excerpt from O'Connor and Whitall, 2007.

The problem here is that statements like these are heavily propagated and believed by those who have not studied the original data. We contend that there is no real meaningful relationship here. First, to have a correlation of r= -0.52 is meaningless in causal relationships. The variance unaccounted for in this relationship is $1-r^2$, which in this case is 1-0.27 = 73. Thus, 73% of the variance in the data is unaccounted for by the hypothesis that hypoxia and shrimp landings are negatively correlated. Secondly, the data support that there is no clear relationship, as in demonstrated in the following charts:



Clearly, there is no relationship between the total landings of N. Gulf shrimp, and the MARB flow rate, or the hypoxia zone size. However, the relationship claim was made more strongly concerning the Texas coast and brown shrimp. That specific data is shown in the following chart:



The data indicates possible association trend between Texas brown shrimp and the MARB flow between 1987-1992, but then subsequent years do not show any relationship. There is no relationship between Texas brown shrimp landings and the hypoxic zone area.

It seems that the negative portrayal of relationships between the hypoxic zone and fish landings do not hold when the data is scrutinized. Perhaps the EPS Hypoxia Zone Task Force should be asked to re-analyze the fish data, publish accurate findings, base future actions and goals on realistic numbers rather than emotional statements, and take into account the value of the nutrients delivered to the Gulf fishing industry by the MARB.

Protein extraction

An approximate calculation for the Louisiana fishing industry is:

400K MT menhaden @ 60% protein

100K MT shrimp @25% protein

50K MT other (crab, crawfish, snapper, drum, etc) @25% protein

Which means that 610 MM lb protein is removed each year, just from Louisiana area waters. Using the typical ratio of 6.25 for protein nitrogen, means that 98 MM lb N are removed from the Louisiana waters each year.

Estimates from USGS (2009B) indicate that the total inflow of nitrogen, from MARB to the Gulf, is ~2820 MM lb N (all forms plus organic matter N converted to N). The corresponding amount of $[NO_2 + NO_3]$ expressed as N is ~1890 MM lb N. We have no way of knowing how much of the Gulf is fed by MARB (extent of dilution of the inflow N) but we can make some assumptions for a rough calculation:

Gulf total area = 500K sq miles
MARB feeds the northern 50% of the Gulf = 250K sq miles: means 11,280 lb N/sq mile

Louisiana area for fishing (landed in LA) = 300 X 60 miles = 18K sq miles
This area would have an average input of 203MM lbs N from the MARB flow

This area removes 98 MM lb N in fish each year, which is equal to almost 50% of the incoming N.

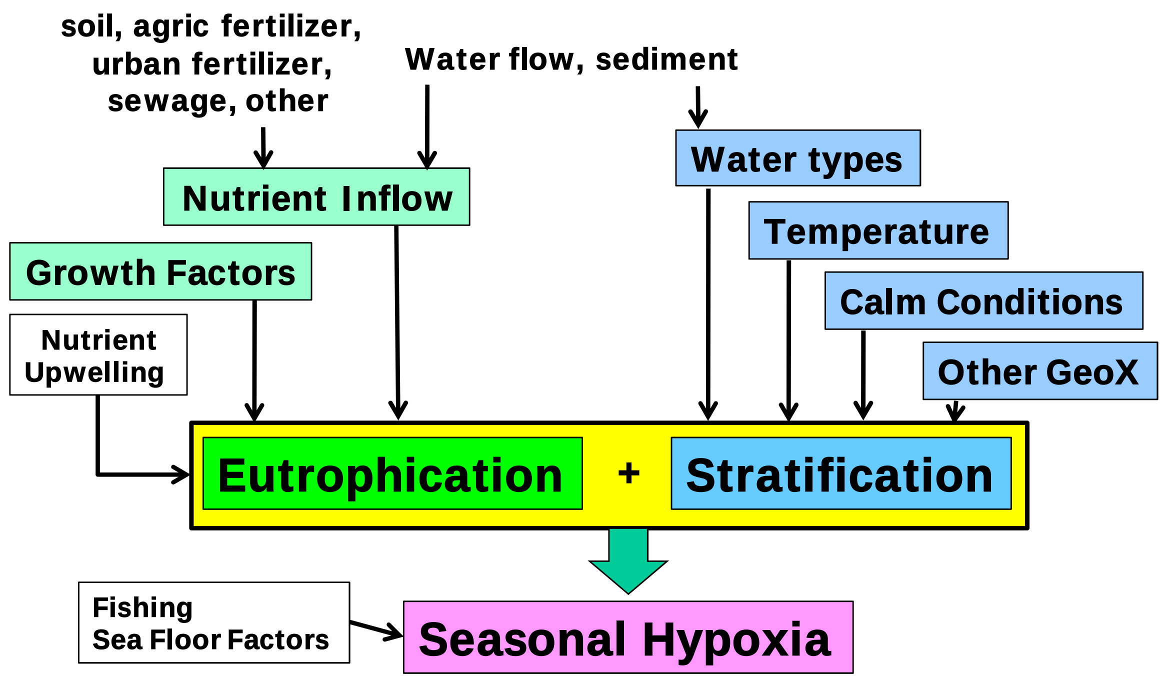
While these numbers are likely not exact, the calculation shows that altering the inflow of N would probably have a noticeable effect on the fishing industry in the northern Gulf.

4. Analysis of Factors Thought to Influence Hypoxia in the N. Gulf of Mexico.

In recent years, it has become unnervingly common to read misleading press reports and even overdone headlines in scientific magazines, such as:

> *Fertilizer Runoff Overwhelms Streams and Rivers--Creating Vast "Dead Zones"* (Biello, 2008)**.**

Despite such emotional claims, there is a large body of scientific and technical knowledge that underlies the occurrence of hypoxia in the Gulf. The main factors involved are many and complex including some anthropogenic, some geological, and some natural biology. The overall process may be described as:



For those who are involved in the detailed study of the hypoxic zone in the Gulf, each of these factors should be analyzed and taken into account. Hypoxia is complex natural phenomena and is impacted by multiple interacting factors.

For this particular study, we will focus on the nitrogen entering the Gulf via the MARB since that has been a focal point of criticism by several groups.

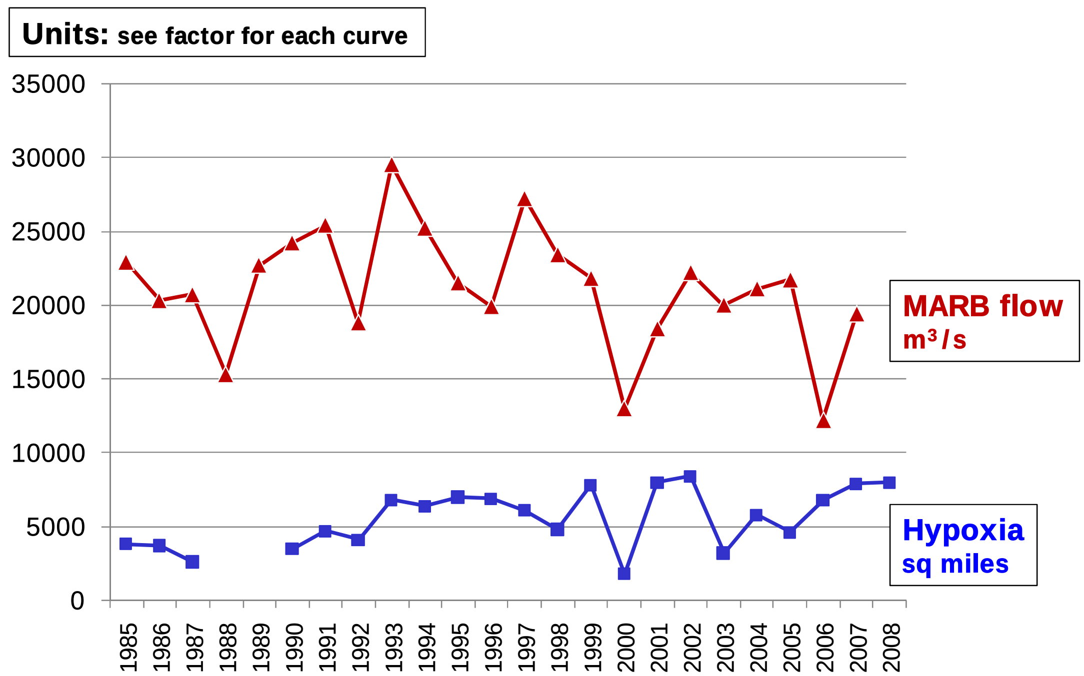
Water flow

The volume of water entering the Gulf via the MARB fluctuates around an average of 21,000 m^3/s (Stdev = 4,000). The annual variation reflects the water status in a huge collection area of Mississippi watershed which encompasses 42 river sub-basins, 20 major cities, and ~40% of the area of the U.S.

Several reports indicate that the stream flow is related to the hypoxic zone area. For example:

"U.S. Geological Survey (USGS) scientists have published a new analysis of streamflow and nutrient (nitrogen, phosphorus, and silica) delivery from the Mississippi River Basin to the northern Gulf of Mexico. Scientists have linked the delivery of nutrients and streamflow from the Basin to the formation and extent of a "hypoxic zone"".
Excerpt from USGS website at http://toxics.usgs.gov/highlights/of-2007-1080.html

We have explored the data from USGS (2009B) from the MARB flow, and compared this to the size of the hypoxic zone from 1985 to 2008 and can find no clear relationship between the two factors:



Prior to 1997, there may be a slight trend of association and in 2000 both show a marked trough. However, the lowest MARB flow rate in 2006 does not correspond to a low value in the hypoxic zone. Overall, it is difficult to see why there are statements about a relationship with annual stream flow.

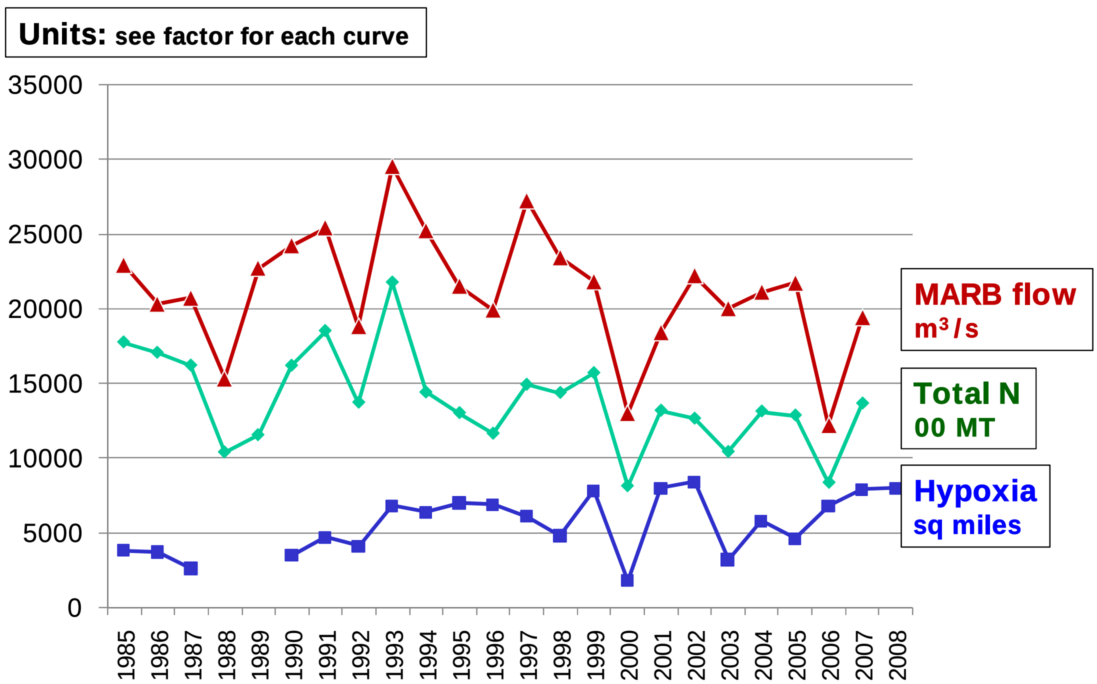
Nitrogen

The above statement, by USGS, also implicates the amount of nutrients reaching the Gulf in the MARB flow. Additional statements include:

"Nitrogen is introduced to streams from diverse point and nonpoint sources, and the influx of nitrogen to stream waters has increased as a result of human activities. An additional factor is wetland loss in the Mississippi River watershed, which has reduced the watershed's natural ability to consume nutrients, such as nitrogen. As a result of both of these factors, nitrogen discharge to the Gulf has increased."

From USGS website summary: http://toxics.usgs.gov/highlights/nitrogen_isotope.html

Using USGS (2009B) data we generated the following chart, where total N is the measured keldahl nitrogen plus the nitrite plus the nitrate amount (all expressed as N) and the unit adjusted to hundred metric tonnes to fit the scale:

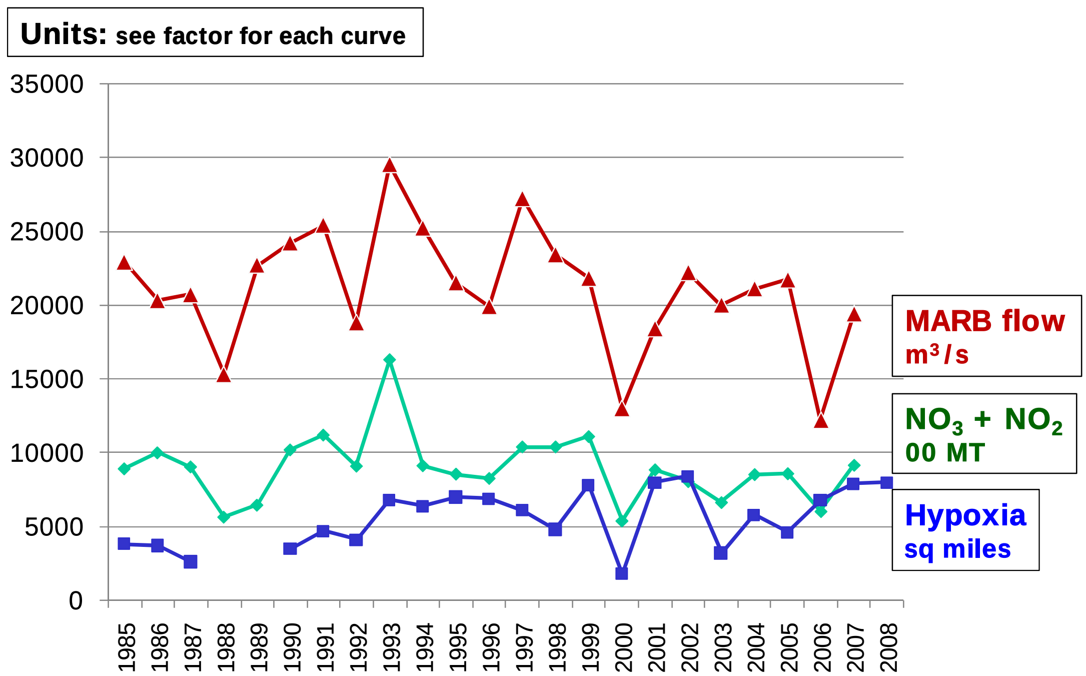


What we see is a general trend for an association between the MARB flow and the total N delivered, although this is more a case of low water flow delivers a lower N load rather than also being that a high water flow delivered a high N load (perhaps, a one-sided relationship).

However, irrespective of the relationship between the MARB flow and N amount, there is no clear relationship between water flow, or total nitrogen load, and the size of the hypoxic zone. All are low in the year 2000, but water flow and total N are low in 2006 with no corresponding low in the zone size. Similarly, 1993 had a high water flow and N load but not a noticeably higher hypoxic zone size.

Some may say that total N is not related to available N deliver since the Keldahl N is mostly organic and not immediately available as a nutrient in the Gulf waters. USGA also records the amount of nitrite (NO_2) and nitrate (NO_3) that enters the Gulf via the MARB, and this may better reflect the immediately available N.

Consequently, we have taken the data for nitrite (NO_2) plus nitrate (NO_3), and plotted that out to see if there is a relationship:



Again, there appears to be an association between water flow and the amount of nitrite (NO_2) plus nitrate (NO_3), but these do not relate well to the size of the hypoxic zone (except that they are all low in the year 2000).

Thus, many of the statements about the relationship between water flow, nitrogen, and the size of the hypoxic zone are inaccurate.

Sources of Nitrogen

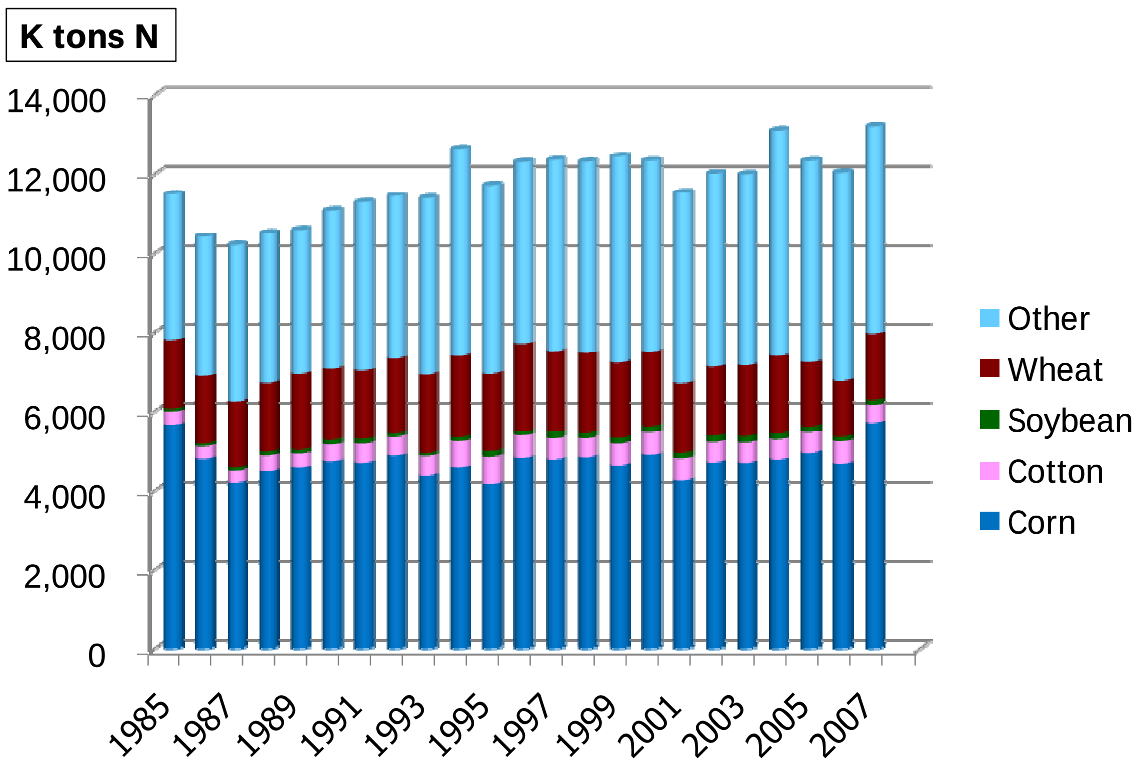
While we have raised valid concerns about the data showing any clear relationship between the size of the hypoxic zone and nitrogen delivered via the MARB, there is a considerable baseline level of N delivered to the Gulf. It is of interest to better understand where this nitrogen originates from.

There are a number of potential sources of N that contribute to the N load entering the Gulf via the MARB. These include:

- Natural sources such as fixation, soil, etc
- Agricultural sources such as fertilizer application
- Industrial sources such as waste water treatment
- Municipal sources such as sewage, golf courses, and run-off from lawns, etc.

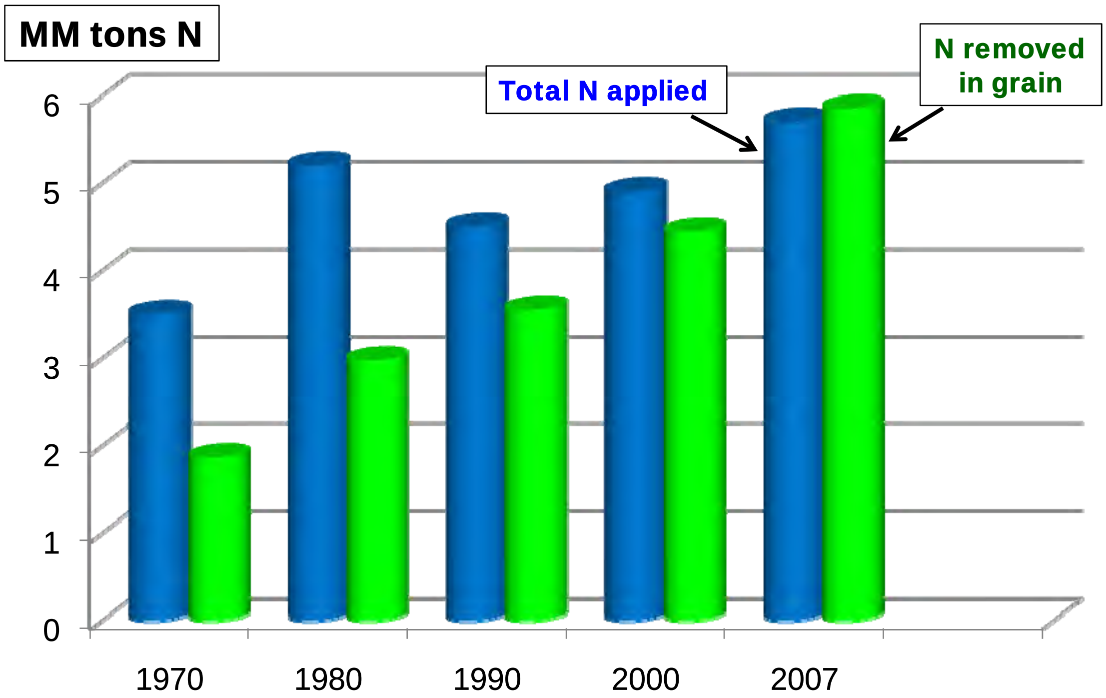
There has been considerable finger-pointing at agriculture as the source of N and, in particular, at corn because the total N application is relatively high.

The USDA data on N application shows that corn does indeed account for a high portion of applied N in the U.S. (*We use total U.S. data here to demonstrate the calculated relationship and key points: the actual amounts going out via the MARB will be a portion of the total but the ratio will be similar*). The overall application for the 4 major crops is assessed from acres and application rates. The “other” in the following chart arises from the difference between total N used in the U.S and the amount applied to the 4 major crops in the U.S. Thus, “other” will be for rangeland, vegetables, lawns, etc., and it can be seen that the volume in this category is about the same as for corn.



The “other” category has increased slightly in recent years, while corn varies on an annual basis and tends to be related to the area planted. What we can see is that the total N applied to corn does not show any relationship to the N arriving in the Gulf via the MARB: e.g. the previous nitrite (NO_2) plus nitrate (NO_3) chart shows a peak in 1993 and a low in 2000 – there is no corresponding high and low in the N applied to corn.

We explored this further to determine the net N balance in relation to corn: our hypothesis was that since corn yield has increased considerably over the years then the nitrogen removed in the grain will have increased, thereby, resulting in a large increase in nitrogen use efficiency in corn. For the calculations we assumed that grain protein content has been approximately the same, at 10% on a bushel weight basis, and that N content in protein is a factor of 6.25. Using the USDA data on yield and acres harvested, we calculated the N removed in the grain and compared this to the published weight of N applied to corn. The following chart shows that in 1970 and 1980 the N removed was just over 50% of the applied N. However, as yields corn increased without a corresponding increase in applied N, the ratio gradually improved until, for 2007, the N amount removed in the grain is about equal to the N amount applied. This change over time is clearly shown in the following chart:



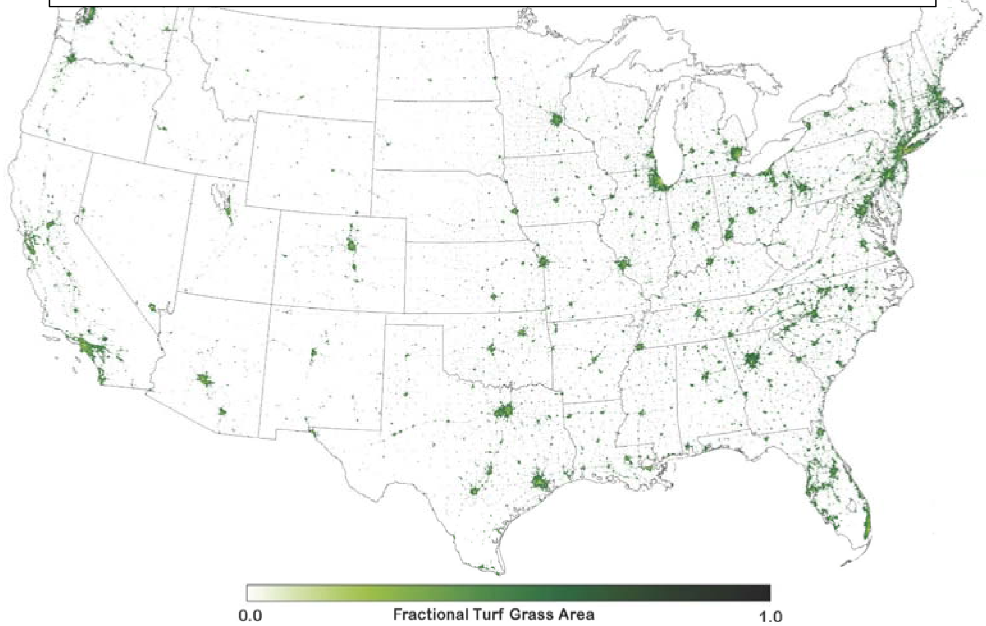
Therefore, under present day cultural practices, the net balance for N applied and N removed in corn is such that there is no excess N available due to fertilizer use. The conclusion then is that any change in N entering the Gulf via the MARB, over time, is probably not related to the use of fertilizer N for corn.

Other possible sources

The amount of N flowing through the MARB that originates from sewage has likely increased by a considerable amount. While difficult to calculate the exact number, we can assume that N output per person is relatively constant, while the population within the Mississippi watershed increased by 22% between 1970 and 2000. Based on the U.S. Census Data, the population numbers are:

Year	Total Mississippi Watershed	% Change
1970	65102090	0%
1980	70840151	109%
1990	72193256	111%
2000	79205511	122%

Another source that is linked to population and the expansion of homes is that from the N applied to lawns. We don't have a time series for the area of lawns but the following charts shows a large area of lawns in the Mississippi watershed:



Color-coded map shows satellite-derived estimates of the fractional turf grass (lawn) area across the United States in shades of green. Areas where a large fraction of the land surface is lawn-covered are deepest green. NASA, 2005

The estimated area for lawns, which includes golf courses and other commercial grass areas, in 2005, was ~64K sq miles = 41 MM acres across the U.S. We estimate that 60% of the area falls within the Mississippi watershed, which would be 24.6 MM acres of lawns.

The typical recommendation for lawns works out to be 130 lb N/acre/season. Some people over-fertilize and some people forget to fertilize: we use the recommended rate as the possible average use-rate. Therefore, the amount of N applied to lawns within the Mississippi watershed is 3.2 billion lbs, or 1.6 MM tons N per year.

Since most lawns are cut and mulched there is relatively little removal of N, unlike the grain in corn. Consequently, a major portion of the N applied to lawns may be available for leaching.

While the total amount of N applied to lawns is approx 25% of the total N applied to corn, the net N available for leaching per acre is almost infinitely higher for lawns than from corn.

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6. APPENDIX

Oxygen in water is impacted by pressure, temperature, and salinity as shown in the following tables:

Oxygen Solubility in Fresh Water - *Salinity ~ 0*

Solubility of Oxygen in Fresh Water - ***Salinity ~ 0***										
Pressure abs	*mm Hg*	760			1520			3040		
	psi	14.7			29.3			58.7		
	bar	1			2			4		
	Pa	101.1			202.2			404.3		
Temperature		Solubility								
^oC	^oF	*µMol*	*mg/l*	*ml/l*	*µMol*	*mg/l*	*ml/l*	*µMol*	*mg/l*	*ml/l*
0	32	457	14.6	10.2	913	29.2	20.5	1823	58.4	40.9
5	41	399	12.8	9.1	798	25.5	18.2	1595	51.1	36.4
10	50	353	11.3	8.2	705	22.6	16.4	1411	45.1	32.8
15	59	315	10.1	7.5	630	20.2	14.9	1260	40.3	29.8
20	68	284	9.1	6.8	568	18.2	13.7	1137	36.4	27.3
25	77	258	8.3	6.3	517	16.5	12.6	1034	33.1	25.3
30	86	236	7.6	5.9	473	15.2	11.8	947	30.3	23.6
35	95	218	7	5.5	436	14	11	872	27.9	22.1
40	104	202	6.5	5.2	404	12.9	10.4	808	25.9	20.8

Oxygen Solubility in Sea Water - *Salinity ~ 35,000 ppm (3.5% salt)*

Solubility of Oxygen in Sea Water - ***Salinity ~ 35***										
Pressure abs	*mm Hg*	760			1520			3040		
	psi	14.7			29.3			58.7		
	bar	1			2			4		
	Pa	101.1			202.2			404.3		
Temperature		Solubility								
°C	*°F*	*μMol*	*mg/l*	*ml/l*	*μMol*	*mg/l*	*ml/l*	*μMol*	*mg/l*	*ml/l*
0	32	349	11.2	7.8	699	22.4	15.7	1399	44.8	31.3
5	41	308	9.9	7	616	19.7	14.1	1233	39	28
10	50	275	8.8	6.4	550	17.6	12.8	1099	35.2	25.6
15	59	248	7.9	5.9	495	15.9	11.7	991	31.7	23.4
20	68	225	7.2	5.4	450	14.4	10.8	901	28.8	21.7
25	77	206	6.6	5	413	13.2	10.1	826	26.4	20.2
30	86	190	6.1	4.7	381	12.2	9.5	761	24.4	18.9
35	95	176	5.6	4.5	353	11.3	8.9	706	22.6	17.9
40	104	165	5.3	4.2	329	10.5	8.5	658	21.1	16.9

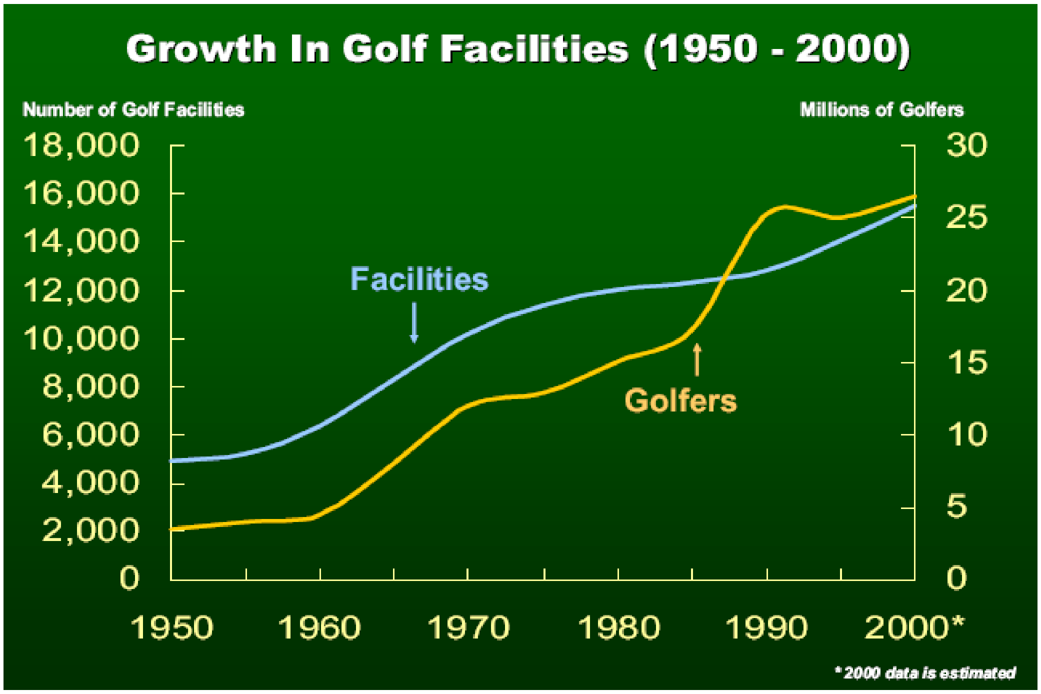
Population in the Mississippi Watershed

Population by River basin

Year	Upper Mississippi Basin	Lower Mississippi Basin	Missouri River Basin	Ohio River Basin	Tennessee River basin	Arkanasas - White-Red Region	**Total Mississippi Watershed**
1970	19,605,744	6,288,638	8,623,661	20,565,791	3,188,642	6,829,614	**65,102,090**
1980	20,564,922	7,093,824	9,629,551	21,880,114	3,749,913	7,921,827	**70,840,151**
1990	21,020,445	7,099,866	10,043,497	21,801,561	3,925,273	8,302,614	**72,193,256**
2000	23,100,101	7,629,423	11,387,652	23,233,388	4,505,623	9,349,324	**79,205,511**

Source: CBS3 Clean Water Project, http://kyw.envirocast.net (Based on 1970-2000 US Census Data)

Golf Courses



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