Presence and Reduction of Eutrophication in aquatic systems

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Abstract

Eutrophication is prominent through many parts of the world. The addition of nutrients into the water fuels primary production, which leads to consumption of oxygen beyond regeneration rates. Eventually, oxygen can be depleted to hypoxic conditions (no dissolved oxygen in the system). Eutrophication through agricultural runoff has given way to the Mississippi River estuary being termed the "dead zone." Many external factors and source types have led to the increase in nutrient flows over the years. Controlling agricultural runoff will be a key component in improving the Mississippi River. Many internal factors must also be reviewed when considering the best approach for limiting nutrient loads and preventing the eutrophication process.

Keywords

Algae blooms, eutrophication, nutrients, water quality

Introduction

A major problem associated with water quality, both in America and around the world is eutrophication. As described by Nixon (1995), eutrophication is the increase in organic matter leading to the over enrichment of an aquatic ecosystem. Primary production is a result of organisms which can create organic matter from inorganic compounds like sunlight, CO_2, or nutrients (Nester, 2004). In aquatic systems, phytoplankton or algae is a large contributor to primary production. Organic matter in moderation can increase the stability of a system (Paerl, 2005). Too much organic matter has extremely negative effects, one of which is eutrophication. Additional nutrients added to the system further fuels primary production (or algae) which, sequentially, feeds additional organic matter into the system (Nixon, 1995). Since nutrients inputs are easier to control than organic matter directly, eutrophication is often considered a result of nutrient addition (nitrogen and phosphorus) (Pinckney et al., 2001).

Eutrophication is no more apparent than in the Mississippi River Basin. The Gulf of Mexico's connection with the Mississippi River is the second largest zone of hypoxia in the world (Rabalais, 2002). Hypoxia is the condition in which waters having no dissolved oxygen concentration. For this reason, the area is known as the "dead zone." The low dissolved oxygen area of the Gulf of Mexico consists of more than 20,000 km^2 and home to about 25 percent of the United States' fishing industry (Turner and Rabalais, 2003).

A number of aspects have given rise to the increase of eutrophication in waters. Some include urbanization (especially near coastal areas) from the overall increase in population, agricultural activities, and industrial development; all of which being human activities. Seventy five percent of the world's population is located in estuaries and costal waters with increasing rates (Paerl, 2005). Of the total estuary surface area in the United States, 65 percent are experiencing moderate to high levels of eutrophication (Bricker et al., 1999).

The biotic diversity and productivity of an estuary makes for one of the most interesting ecosystems in existence. It is important preserve estuary systems for their aesthetic beauty, recreational opportunity, and significance to the economy.

Causes

A few components add to the eutrophication of aquatic systems; although, two nutrients are considered limiting factors which are nitrogen and phosphorus. A limiting factor will considered one that increases primary production among the system (Pinckney et al., 2001). Therefore, eutrophication can be ultimately controlled by limiting nutrients.

Nitrogen, after many years of research and debate, is considered the limiting nutrient in estuaries (Nixon, 1995). Nitrogen inputs have been on the rise over the past century at a 10 fold increase (Howarth et al., 1996). In contrast to nitrogen, phosphorus is the limiting agent in lake systems although it still has a role in estuary eutrophication (Nixon, 1995). Sources of these nutrients will be discussed later.

Other elements affecting the aquatic community structure and its response to the nurreints mentioned above are silicon and iron. Silicon, which is introduced to the system via eroding soil and sediment, effects the structural composition of phytoplankton. As the silicon content of the system decreases, the production of harmful algae blooms increases (with nitrogen addition) (Rabalais et al., 1996). Harmful algae blooms no longer have to compete with phytoplankton requiring silicon as they have decreased in population. Another element that encourages harmful algae blooms is iron. Similar to silicon, iron also effects the composition of phytoplankton in the system (Rabalais et al., 1996). As discussed later, changes in the phytoplankton community is a major factor in eutrophication.

Sources

Sources contributing to eutrophication can be studied from the initial development of the America (Turner and Rabalais, 2003). Throughout the years, population growth has resulted in natural landscape alterations including forests and prairies being altered into agricultural lands. As these lands changed, the loss of nutrients from the soil became evident. Drainage systems were also developed along rivers. Alluvial soils, which would assist in removing nutrients before reaching estuaries through their natural processes, have been secluded from the river channel for flood control. Those same alluvial lands were changed to additional agricultural land. Clearly, the movement of nutrients is amplified by human land modifications.

A number of sources are associated with the addition of nutrients to aquatic systems. One category, which is more effectively monitored and enforced, is point sources. Point sources may include industrial and municipal wastewater treatment plants, storm water outfalls, and combined sewer overflows. The other category of nutrient loading is form nonpoint sources. Nonpoint sources include watershed runoff and atmospheric deposition. The true source of nutrients varies from one location to the next. For example, the Long Island Sound experiences 60 percent of its nitrogen inputs from wastewater treatment plants associated with New York City; wastewater treatment and other point sources are the cause of one quarter of the nitrogen and phosphorus inputs in the Chesapeake Bay (Pinckney et al., 2001). In the Mississippi River Basin, point sources only add 10 and 40 percent of nitrogen and phosphorus fluxes, respectively (Pinckney et al., 2001). So it can be determined that overall addition of both nitrogen and phosphorus is dominated by nonpoint sources in the Mississippi River Basin.

Point Sources and Wastewater Treatment Plants

Wastewater treatment plants have seen increased supervision of effluent quality over the years. The levels of nitrogen and phosphorus in effluent are no exception. New technologies in wastewater treatment have provided excellent approaches in nutrient removal. Tertiary treatment has provided plants with the ability to decrease nitrogen in effluent by 80 to 90 percent and phosphorus by 95 to 99 percent (NRC, 1993). Even without tertiary treatment, standard plants can decrease nitrogen and phosphorus by 20 to 25% (NRC, 1993).

Other point sources include combine sewer overflows. Many older cities have combined sewer systems in which both storm water and sewage flow through the same pipe. When a large rain event occurs, the system can no longer handle the additional flow. The overflow results in both sewage and storm water being released, untreated, into a water body. CSO are also continually monitored by state agencies and are slowly being phased out in smaller communities.

Storm water outfalls may also contain nutrients from local fertilizers and domestic animals. Outfalls may also carry nitrogen products from atmospheric deposition. These sources should not be overlooked yet, in many cases, they do not have the national dominance of nutrient delivery processed by nonpoint sources (Howarth et al., 1996).

Non-Point Sources

The increase in fertilizer (especially inorganic fertilizer) use after World War II has a direct correlation with the nitrate increases there after (Howarth et al., 1996). Absorption of nutrients is a function of the type of crop being grown, its growth rate, and the application method of the fertilizer (Howarth et al., 1996). Of course, the amount of time rainfall takes place after application as well as the amount of rain could also have an impact on nutrient runoff. With an increase in agriculture drainage (including drainage tiles) and elevated levels of precipitation, nutrients can easily be released into surface water. And with drainage tiles, nutrients (mainly dissolved nitrogen, nitrate) could run into groundwater supplies and, later, become part of surface water flows (Rabalais, 2002). As shown by Turner and Rabalais (1991) release of nitrogen has tripled and phosphorus doubled since the 1950's in the Mississippi River Basin. Of the total nitrogen discharged into the Gulf of Mexico, 35 percent is from Iowa and Illinois (Goolsby et al., 1999).

Throughout the development of America, the landscape changes influenced sediment inputs in water systems. Existing vegetation was removed and soil surface disrupted resulting in a loose soil surface, more susceptible to erosion into streams. Livestock were also able to roam free and consume further vegetation, further disrupting soil surfaces. Many nutrients in the soil were lost through erosion into streams as sediment yields increased 50 fold in conversion of forests and prairies to cropland (Turner and Rabalais, 2003). The clearing of land elevate erosion rates from 100 to even 1000 times (Novotny, 1999 as referenced by Turner and Rabalais, 2003). The freedom of top soil to move into streams can add further to nutrient additions. A large amount of phosphorus is lost through weathering of soil and rock. Almost 193,000 mT/km^2 of soil was lost from prairie disruption in Iowa around 1935; 40 percent of Iowa lost 50 to 70 percent of its top soil (Prince, 1997 as referenced by Turner and Rabalais, 2003). Loses are clearly evident when comparing bluegrass cover to cropland in figure 1.

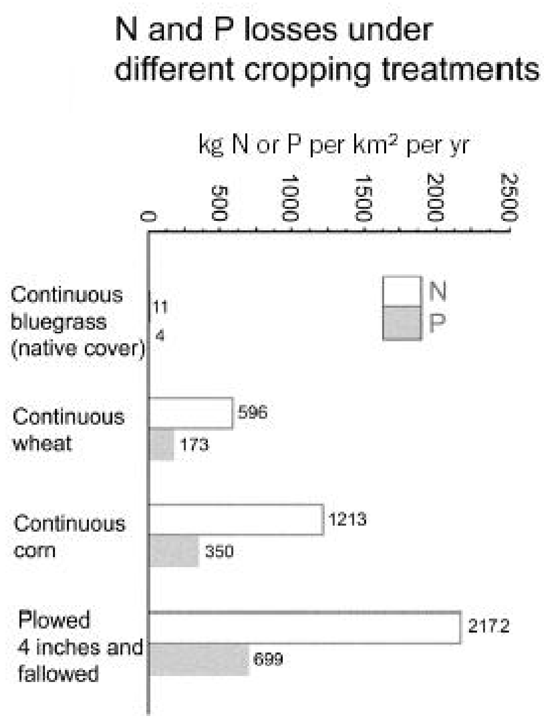

Figure 1 – Land use comparison between cropland to native cover (Turner and Rabalais 2003).

Another significant source of nutreint input into waterways includes atmospheric deposition of nitrogen. Nitrogen enters the atmosphere in three forms; nitrogen oxides (NO_x) mainly from combustion of fossil fuels, ammonia (NH_3) mainly from fertilizers and manures, and organic nitrogen which are not well understood (EPA, 2000). When these inputs are added to agricultural runoff, the results can be significant. The Chesapeake Bay receives 21 percent of its nitrogen from the atmosphere (EPA, 2000). Nitrogen returns to the ground in two forms: as wet deposition (rain or snow) and dry deposition (dust particles). When nitrogen lands on the surface, its fate is dictated by the type of land in which it landed on. Grasslands and forests tend to retain atmospheric nitrogen better than agricultural and urban lands (Carpenter et al., 1998).

Aquatic Ecology Interaction

Physical, chemical, biological parameters make each system very unique; however, the basic eutrophication characteristics exist. An increase in deposition of organic matter leads to the characteristics of eutrophication (Nixon 1995). The amount of organic material is altered through primary production. Primary production is influenced directly by nutrient inputs into the system and is the controlling factor of eutrophication (Pearl, 2005).

Nutrient loads enter the system form the sources mentioned above. They enter the nutrient cycle and phytoplankton begin to consume available nutrients. The phytoplankton populations are primary producers which, by definition, produce organic matter (the actual cause of eutrophication).

With increased phytoplankton development, comes the creation of dinoflagellate and cyanobacterial (both having toxic forms) algal blooms which are not consumed as readily (Paerl, 2005). As more and more phytoplankton develops and grows, zooplankton begins to consume algae. However, through the continued nutrient loading, some members of the phytoplankton community will not be consumed and they begin to settle to the low dissolved oxygen layers of the system. The lower layers are naturally somewhat oxygen depleted but eutrophication enhances this effect. The low mixing characteristics of the lower level also adds to further sedimentation. The alga is now part of the sediments below, which is already rich in organic material, to be consumed by microbes. Microbial breakdown of organic matter results in the creation of CO_2 and inorganic nitrogen, increasing nitrogen in sediment and adding to anoxic water conditions (Pearl, 2005). The structure of the phytoplankton community influences whether organic material is exported to the ocean or stays in the system. With additional nutrients from the watershed, the community continues to be altered into less desirable forms and grows. Organic matter input exceeds export from the system and less desirable and toxic algal blooms begin to control the process, increasing eutrophication (Paerl, 2005). Low dissolved oxygen levels, one major result of eutrophication, is now present. A visual representation of this phenomenon is available below in figure 2 and figure 3.

Increased phytoplankton populations can also block light from the seaweed beds in the lower water layers, important contributors to the benthic aquatic community. These plants would assist in reducing CO_2 presence; yet, without light, photosynthesis is not able to proceed and low O_2 levels still exist.

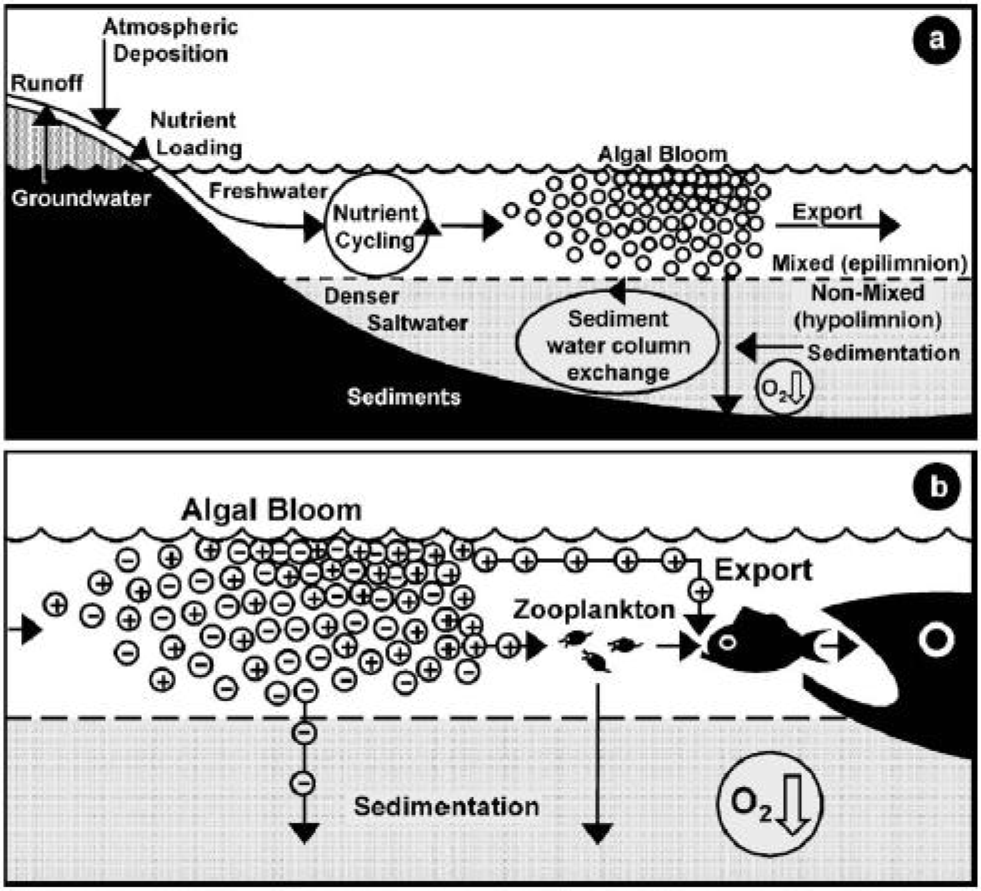

Figure 2 – A. Nutrient effects in estuary. B. Increased algae in system with (+) algae consumed and (–) algae not consumed, falling into sediments below (Paerl 2005).

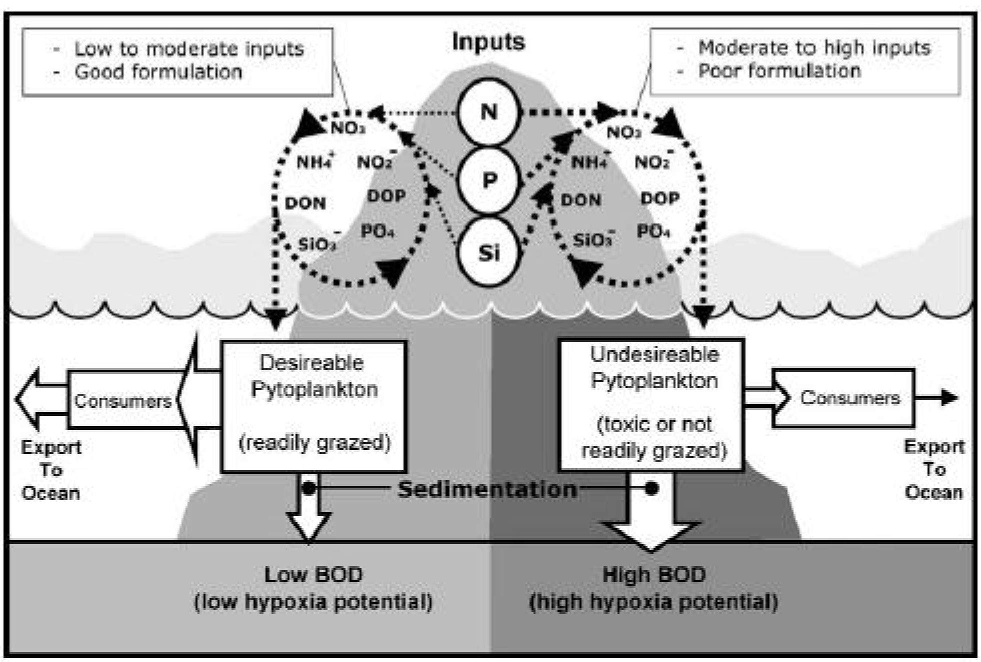

Figure 3 – Nutrient inputs in system (DON and DOP – Dissolved Organic Nitrogen and Phosphorus, respectively) (Paerl 2005).

One of the physical characteristics manipulating export form the system includes discharge rates. Discharge directly influences residence time and flushing. When the system has a longer residence time, organisms will utilize nutrients fully and increase oxygen use. With limited flushing, new oxygen gets little chance to enter the system. Flushing also helps break up stratification and turbidity that can add to eutrophication with increased sedimentation (Paerl, 2005). In addition to basic discharge, strong storms and hurricanes can mix the system and alter residence times and oxygen inputs; even floodwaters can increase nitrogen loading (Paerl, 2001). These parameters control the nutrient supply and the nutrient supply controls the makeup of the phytoplankton community (Paerl, 2005). Community structure is the primary parameter in exportation of organic material.

Results of Eutrophication

The increase in primary production and algal blooms results in elevated organic matter production within the system. These primary producers continue to consume dissolved oxygen. As oxygen consumption begins to exceed replenishment, anoxia and even hypoxia begin to develop. The bottom waters are the first area of the system to experience hypoxia, decreasing the population of the benthos community (Paerl, 2005).

Blooms begin to reduce light from entering the system. The light reduction affects photosynthetic organisms like sea grass at the bottom of the sea floor. The loss of aquatic vegetation loosens sediment on the sea floor as on land, adding to particulate suspension and turbidity, further blocking light penetration. The sea grass also provides habitat for smaller aquatic species (Paerl, 2005). Loosing habitat for smaller fish affects the entire food web with in the system

With loss of food and oxygen, species begin to migrate to better waters and species that are not mobile will die (Rabalais, 2002). As the habitat becomes less desirable, life cycles of smaller species are dominated by predators and food sources change (Rabalais, 2002). The shifted food webs begin to decrease the biodiversity of the system.

Another problem associated with eutrophication is harmful algae blooms (HAB) which differ form other blooms because of their toxic nature. The toxins of these blooms continue to work their way through food webs. HAB can result in kills of fish species, illness and even death of humans that ingest species affected by HAB, and death of seabirds and aquatic mammals (Paerl, 2005). Certain fish diseases have also been linked to HAB (Paerl, 2001). The function and structure of the community continues to change with the addition of HAB to regular blooms and limit dissolved oxygen concentrations.

Figure 4 is a flow chart for the effects of eutrophication described above. With increased algal blooms, comes reduction in light to the benthic community; therefore, loss to vegetation results. With a change in phytoplankton community composition, comes the increase in nuisance (poorly consumed) and toxic algal blooms. Finally, with increased organic matter being created by primary producers (consuming nutrient loads), comes the increased demand for oxygen and dissolved oxygen levels decrease. The resulting effects are loss of habitat, increase in toxic algae blooms, fish kills, and bad odors.

The obvious economical impact of eutrophication is the commercial fishing industry’s part in patrolling effected waters for healthy fish populations. Eutrophication would either kill or drive away the fish desired by these organizations. It becomes worse when considering 25 percent of the commercial fishing industry is located in the dead zone of the Mississippi River Basin (Turner and Rabalais, 2003). Other concerns (figure 4) are recreational fishing and the consumption of sea creatures affected by toxic algae blooms. The loss of aesthetic values could also lead to a reduction in tourism to these areas; not to mention, swimming in eutrophic waters may not be recommended.

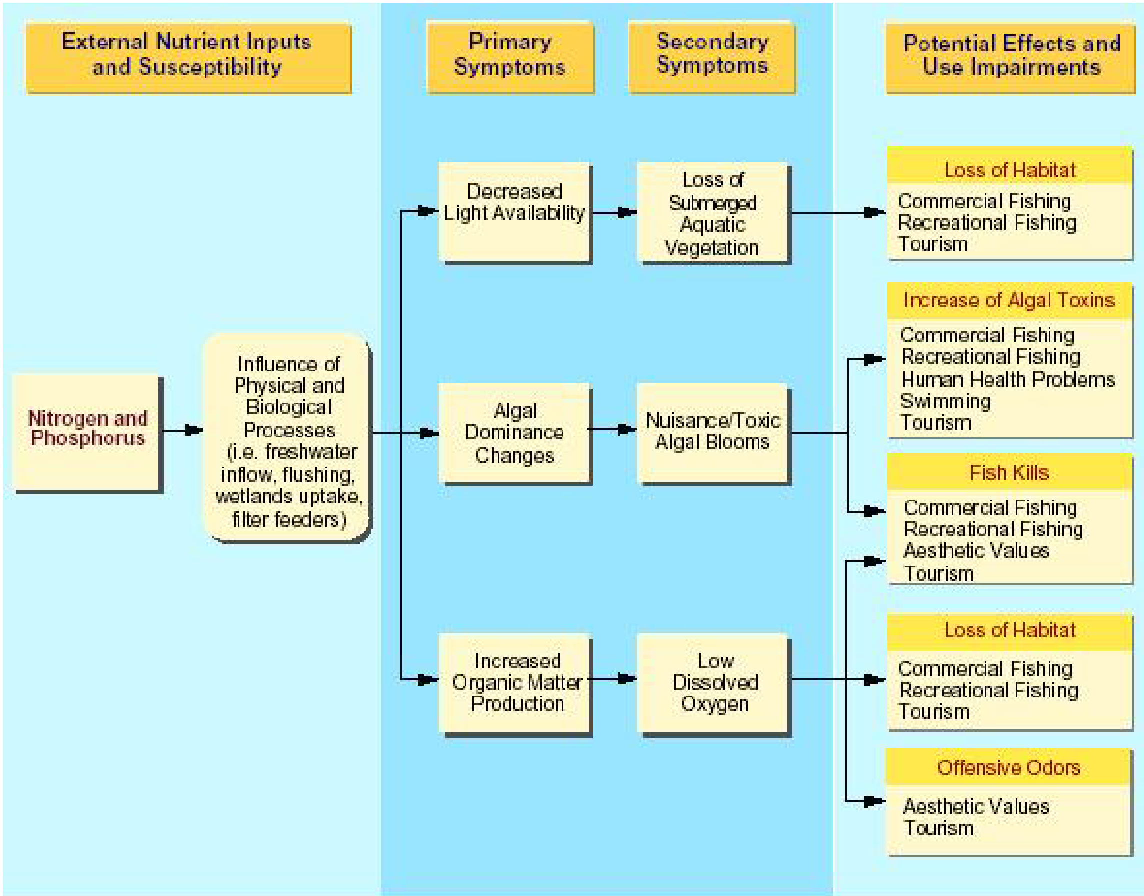

Figure 4 – The effects of eutrophication (Bricker et al. 1999).

Conclusion

Point sources are not the dominant source of nutrients, nationally. Agricultural runoff and other nonpoint sources are the preferred approach in reducing nutrient additions into our streams (Howarth et al., 1996). Point sources, although important in many parts of the world, are also under more stringent standards and regulation in the US. In areas like the Long Island Sound (wastewater effluent), point sources should be considered a strong contributor to nutrient loading.

The most effective and cheapest way to limit nutrient loads from none point source is the use of wetlands or buffer strips (Bricker et al., 1999; Pinckney et al., 2001; Turner and Rabalais, 2003). Starting with wetland development at the beginning of a large watershed will help conditions down stream. With a small increase in the percentage of land utilized as marsh land, nitrogen loads dropped considerably as seen in figure 5 (Jones et al., 1976 as referenced by Turner and Rabalais, 2003). Wetland creation will also help in controlling atmospheric deposition of nitrogen that falls on land and storm water nutrients from urban runoff which may include lawn care products, domestic animal waste, etc.

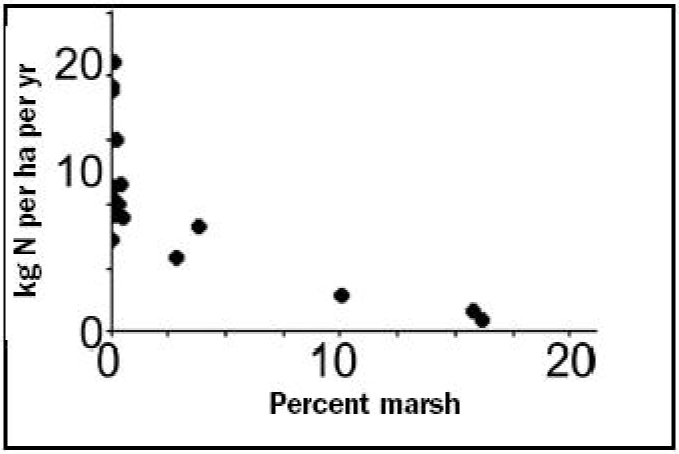

Figure 5 – Nitrogen relief through marsh lands (Jones et al. as referenced by Turner and Rabalais 2003).

Another aspect to consider is land management practice for agricultural lands could be improved. Erosion control is important for stopping nutrients and particulates entering the stream. Developing Best Management Practices (BMP) for agricultural lands would be a nice addition in controlling nutrient loads (Rabalais, 2002). Including wetlands in nearby watersheds of large agricultural areas will also help nutrient control.

If nutrients are controlled, then primary production is controlled; therefore, achieving reduction in organic matter. From the definition of eutrophication, if organic matter is reduced so is eutrophication. The biodiversity of the estuary depends on the reduced delivery of nitrogen and phosphorus. It is important to conserve the aesthetic beauty as well as the recreational and economical opportunities of these unique ecosystems. Although it is repetitive for most environmental issues, eutrophication will not be eliminated in one day. It is important to control and monitor this problem before any additional damage occurs.

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